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Social vulnerability and spatial inequality in access to healthcare facilities: The case of the Santiago Metropolitan Region (RMS), Chile

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ABSTRACT

In Chile, the Metropolitan Region of Santiago (RMS) is exposed to several natural and anthropogenic hazards. This means that not only is there a constant need for healthcare, but also a significant increase whenever its inhabitants are affected by disasters. The RMS problem is not the lack of healthcare infrastructure; rather, the inequality in its spatial distribution, which does not consider the location of the most vulnerable population, who may have greater healthcare needs. In this paper, we have performed Pearson's correlation and multicollinearity analysis to select variables to include in the multiple regression analysis to identify the predictors of the number of healthcare facilities per commune in the RMS. Our research found that public healthcare facilities, average monthly income per person per commune, and population density predicts in a 74.1% the number of the total healthcare facilities per commune in the RMS. Network analysis allowed us to integrate distance-based and area-based approaches to spatially visualise the service area of the healthcare facilities in all the districts in the communes of the RMS according to three walking distances. Total coverage of service areas is observed only in 4% of the districts, while high and medium coverage is identified in 30%, low coverage is observed in 28% and 7% of districts are not covered at all. Those districts with low or non-coverage are mainly low-income and/or rural districts in the RMS communes.

1. Introduction

1.1. Case study area location

Chile is a country in the Global South located in the Pacific Ring of Fire in the extreme south of South America, as it is depicted in Fig. 1. This location results in a high seismic hazard [1] and besides this hazard that includes tsunamis, Chile is exposed to volcanic eruptions, floods [2], landslides, droughts, and pandemics, such as COVID-19. The country has 19 million inhabitants. It is divided into 16 regions, one of which is the Metropolitan Region of Santiago (Spanish acronym: RMS). This region has seven million inhabitants and is divided into 52 communes (see Fig. 2): 34 (65%) are urban, and 18 (35%) are rural. Each commune, in turn, is divided into districts according to size. There are 451 RMS districts (see Fig. 2), of which 316 (70%) are classified as urban, 52 (12%) are classified as rural and 83 (18%) are classified as mixed. The city of Santiago, located in this region, is the political-administrative centre of the country.

1.2. Natural and anthropogenic hazards in the RMS

The RMS is exposed to earthquakes [1], landslides [3], forest fires [4], floods [2], air pollution [5], traffic accidents [6], heat waves [7,8], terrorist attacks [9–11], social unrest (A. I. J. [12,13]) and pandemics such as COVID-19 [14,15]. After the *Maule* earthquake on 27 February 2010, also known as the 27F [16], the Chilean government declared six regions to be zones of catastrophe [17]. One was the RMS, our case study area, where several medical facilities were damaged [7], including two highly complex hospitals: the Psychiatric Hospital and the National Institute of Cancerology.

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1.3. Healthcare systems in the world and Chile, and healthcare facilities in the RMS

A healthcare system is composed of a combination of an integrated and adaptive set of people, processes and products. Behaviours, values, and knowledge, define people; processes, imply collaboration, customisation, etc., and products are represented by software, hardware, infrastructure, etc. All these components are integrated over the physical, temporal, functional and organisational dimensions, while adaptation occurs as a result of monitoring, feedback, cybernetics and learning dimensions [18]. Modern definition of infrastructure includes healthcare facilities, which is a component in the physical integration, defined by the degree of system co-location in the natural, constructed or virtual environment [18]. The degree of systems co-timing from the strategic, tactical and operational perspectives defines temporal integration. The degree of co-functionality concerned with inputs, processes, and outputs represents functional integration. The degree of systems co-management of resources, economics and management defines the organisational integration. A schematic representation of the concept of healtcare system according to Tien & Goldschmidt-Clermont is depicted in Fig. 3.

After defining the term: healthcare system, this section explains the structure of the healthcare system in Chile in the functional and organisational dimensions to focus on the temporal and physical dimensions of the healthcare system in the RMS. There are 805 healthcare facilities distributed around the RMS: 501 (62.2%) are public healthcare facilities, and 304 (37.8%) are private. Of this total, 669 (83.1%) are located in urban communes, and 136 (16.8%) are rural [7]. The public agency that manages the state resources for healthcare in Chile, the National Health Fund (Spanish acronym: FONASA) covers 80% of the population. Another 17% of the population is enrolled in private health insurance companies (Spanish acronym: ISAPRES). The health system of the armed forces covers the remaining 3% of the Chilean population. However, 50% of health disbursements are distributed to 50% of public health insurers and providers. The remaining 50% is allocated to private health insurers, without considering the 80% (i.e. 63% more) of the Chilean population is enrolled in the public healthcare insurance, thereby generating systemic inequality [19,20]. Although substantial underfinancing occurred during the Pinochet dictatorship, the public body is still the backbone of the Chilean healthcare system. Therefore, it is mainly responsible for the healthcare of the Chilean population [21].

In public and private healthcare insurance, the applicant signs a contract and pays a monthly subscription corresponding to a minimum of 7% of their gross salary [19]. The public healthcare insurance divides their enrolled population into four groups according to their income: group A, the population without income and immigrants; group B, the population with a monthly income less or equal to USD 448; Group C, the population with a monthly income above to USD 448 and less than USD 654; and group D, the population with a monthly income above USD 654; however, a person with three or more dependants will be classified into group C. This classification determines the need to purchase a bond to access healthcare and the possibility of access to healthcare in private centres [22,23]. In 2018, the average monthly salary of a person enrolled in the public system was USD 542; while in the private system, it was almost four times more: USD 1,978 [24]. The spatial distribution of the public healthcare insurance groups according to income in the RMS and in Santiago is plotted in Figs. 4 and 5, respectively.

In public healthcare insurance, the monthly contribution is less than 7% if the person is unemployed or a refugee and fully subsidised for those without any income or those officially certified as 'indigent' [25]. However, the population insured by the public healthcare system usually faces long waiting times (often extending into years) for medical appointments and/or surgeries [19,26]. These patients visit insufficiently equipped and outdated healthcare facilities and have fewer available appointments with specialist physicians [21].

Vásquez, Paraje, and Estay [27] demonstrated pro-rich inequity for appointments with general practitioners, dental, and specialised services in Chile. Unger et al. [21] established that the frequency of laboratory tests and surgeries positively correlated with Chile's income. In cases where the insured person's monthly salary exceeds USD 250, the person must pay a bonus (around USD 4) any time they attend a medical appointment, visit a hospital, or take medical tests. The final cost is determined by the service or medical speciality requested. The obligation to pay these bonuses is only waived when the insured has three dependants. In private healthcare insurance, the initial payment is

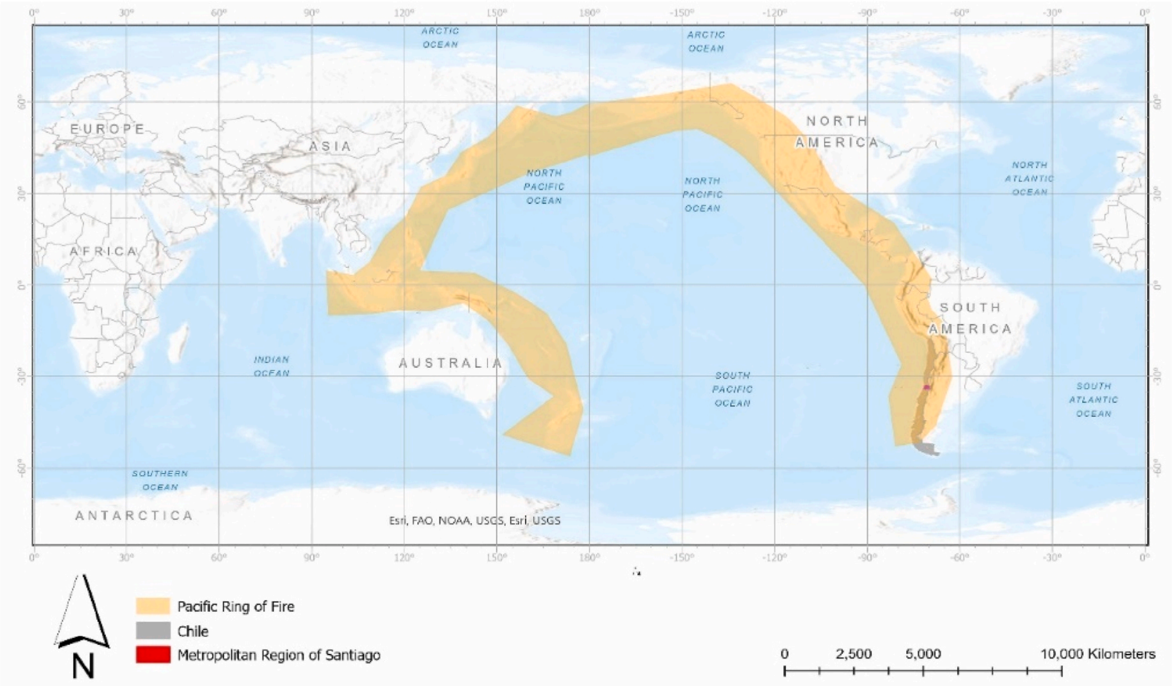

Fig. 1. Location of the RMS and Chile with respect to the Pacific Ring of Fire.

approximately 7% of the gross salary estimates the initial payment. According to the *unidades de fomento (*index inflation-linked Chilean peso) Ufs (USD 34), healthcare insurance contributions will increase monthly. Women of reproductive age pay up to four times more than men [28,29], while those over 60 years may pay up to eight times more [30]. Thus, the elderly are forced to move to the public healthcare system at this age [21]. Physically and/or mentally challenged people also pay more according to their disability status. Hence, they have worse access to healthcare because, given the high cost of private insurance, only 3.4% of adults with disabilities are affiliated with private insurance companies. The rest of this population has to opt for public insurance [29]. Additionally, physically and/or mentally challenged people face more difficulties reaching a healthcare facility, obtaining a doctor's appointment and attention, and paying for the medicine for their treatment [29]. Another prohibitive aspect is the price of medicine price in Chile, which is particularly expensive compared to other Latin American and European countries. This differential contribution based on gender, age, and disability conditions generates a structural disadvantage for these population groups, who paradoxically require more healthcare. No catastrophic illness can be declared on the application form for private healthcare insurance; otherwise, the application is likely to be rejected. One of the reasons for the social unrest in 2019 was a proposed 5% increase in healthcare insurance monthly contributions. Private health insurers have decreased solidarity between the sick and healthy, young and old, rich and poor, and rural and urban areas [21]. This mechanism of affiliation based on income has stratified access to healthcare.

Consequently, on the one hand, the higher socio-economic classes are affiliated with private insurance and choose other premiums to improve their healthcare plans. On the other hand, middle and lower income classes remain with public insurance without any other choice [25]. We developed a schematic representation of the healthcare insurance system in Chile, as described above, with an explanation of the differences between the public and private sectors in Fig. 6.

1.4. Socio-economic context of healthcare policy in Chile

In the case of Chile, universal healthcare coverage does not mean universal access. The neoliberal policies implemented in the Chilean healthcare system during the Pinochet regime were intended to guarantee equal access to healthcare. Instead, the policies turned healthcare into a commercial enterprise, thereby generating a structural disadvantage for vulnerable groups. These groups can not afford private health providers and become more exposed to health risks while increasing the urban-rural divide [7,25,31]. Medical equipment costs have pushed considerations of economies of scale to the forefront of healthcare planning. Therefore, large populations catchment are necessary to ensure the maximum return on investment in equipment and personnel. In geographic terms, this represents the centralisation of services into larger healthcare facilities, aggravating existing problems of physical access to services in rural areas [31]. In addition, there is a widespread lack of knowledge among the population about the location of the nearest healthcare facility and their healthcare insurance plan coverage. People in Chile going to a medical facility for the first time do so with the uncertainty of whether they will receive healthcare or not. On one side, these policies have made Chile the country with the highest gross domestic product (GDP) in Latin America, according to the International Monetary Fund (IMF), the World Bank (WB), and the Organisation for Economic Co-operation and Development (OECD) [32]. On the other side, the same model has turned Chile into one of the countries with the highest levels of inequality in the region, with a high concentration of wealth reflected in a GINI index of 44.9% in 2020 [33], insufficient public spending on health (only 4.2% GDP) and high out-of-pocket expense (33%) [34]. Evidence at the international level from De Maio [35] and in Chile presented by Subramanian, Delgado, Jadue, Vega, and Kawachi [36] has highlighted a connection between

Fig. 2. Spatial distribution of communes and districts at the RMS, Chile.

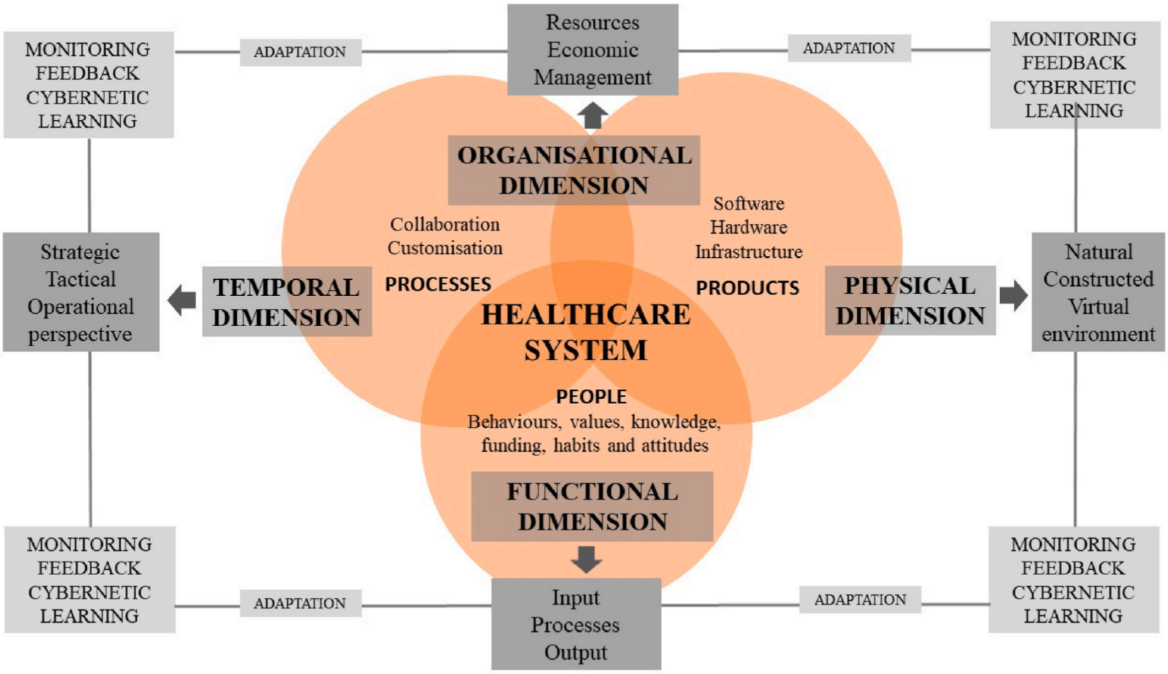

Fig. 3. Schematic representation of the concept of the healthcare system formulated by Tien & Goldschmidt-Clermont [18].

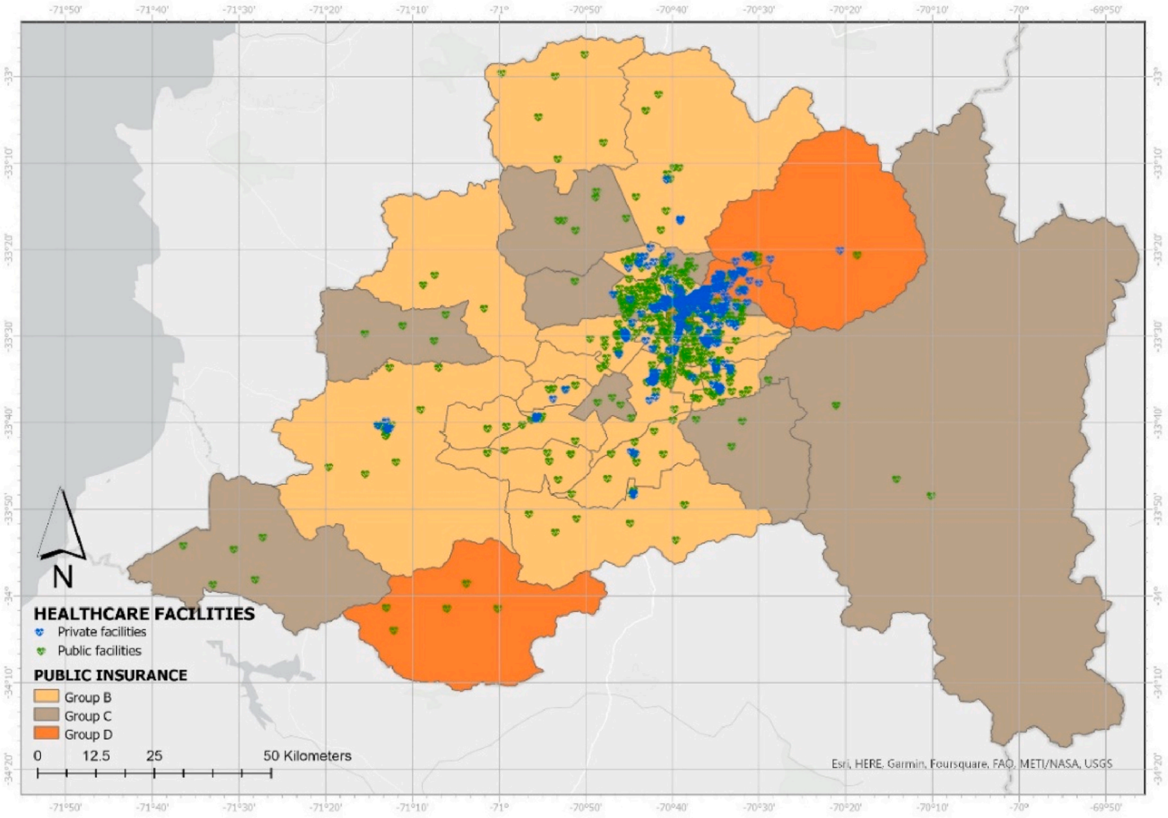

Fig. 4. Spatial distribution of healthcare facilities and public healthcare insurance groups according to income in the RMS, Chile.

health and income inequality.

Along with education and social welfare, healthcare is considered one of the main pillars of social policy [25]. Healthcare policy involves the decisions made by a government concerning the costs, quality, delivery, accessibility, and evaluation of programmes and initiatives to secure the population's well-being, particularly of vulnerable groups. Neoliberal healthcare reforms denote targets aiming to satisfy a free-market system, as occurred in Chile. Ayo [37] found links between neoliberalism and the generation of layers of disadvantage and exclusion for the population's poorer segments. This relationship turns the

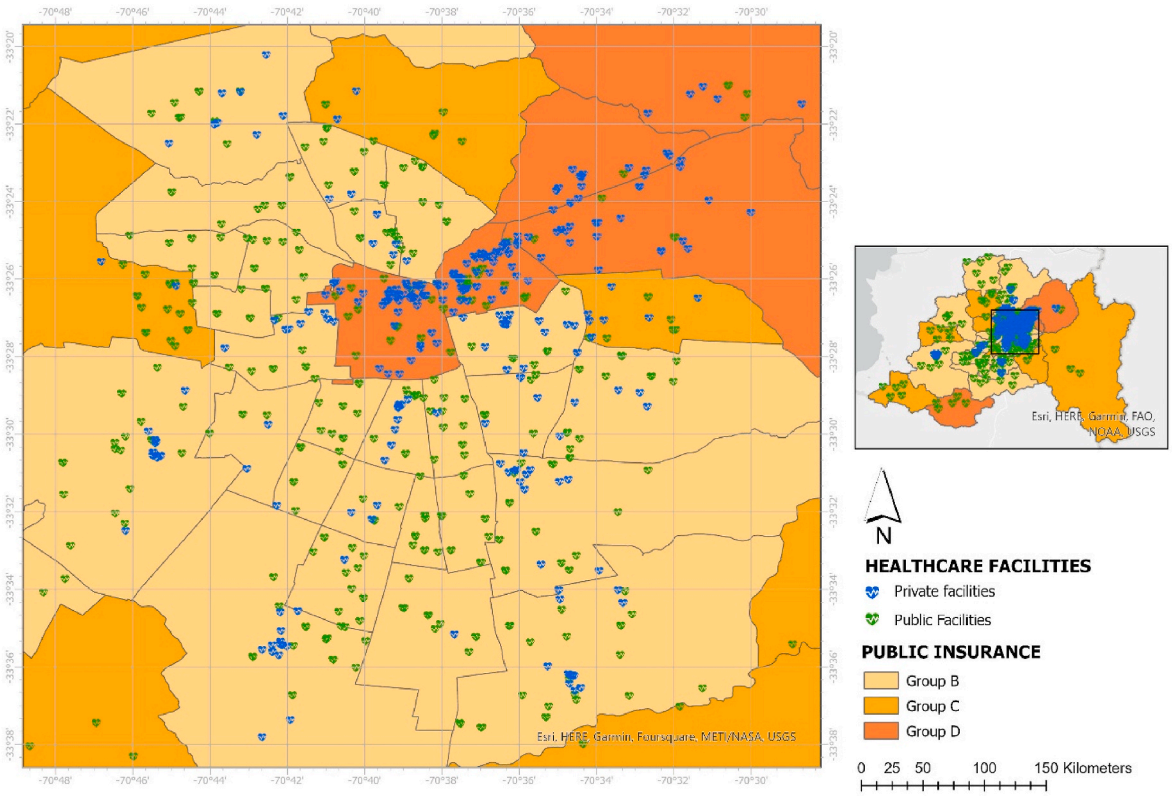

Fig. 5. Spatial distribution of the healthcare facilities and public healthcare insurance groups according to income in Santiago, Chile (urban area).

concept of health into a choice and an issue of personal responsibility. Through the commodification fostered by the neoliberal reforms implemented by the military dictatorship of Augusto Pinochet (1973–1990), which began in 1980, a dual healthcare system was implemented in Chile. Public and private healthcare insurance and correspondant facilities were created. According to neoliberal principles, this reform established competition between public and private health insurers and fostered private health services [21]. This reform turned healthcare into a product managed by the private sector rather than a human right [25,30].

1.5. *Resilience of critical infrastructure and social vulnerability*

The resilience of critical infrastructure (CI) has been gaining scholarly attention concerning disasters, unlike the assessment and mitigation of social vulnerability (SV) following the failure of CI, which has gained little attention [38]. The European Commission (EC) defined CI as all the assets, systems or parts essential for maintaining societal functions such as health, safety, security, and economic or social well-being. The authors identify more than 30 critical systems, but the most important highlighted by them are water, energy, communication technology, health, emergency services, food, transport, information technology, finance, banking, government and defence [39]. The present research will focus on health and healthcare facilities as part of emergency services. The differential impact of CI failure on vulnerable groups in society is not yet fully understood. This group includes elderly over 65, children under 5, physically and/or mentally challenged individuals [40], pregnant women, women in general, low-income populations, rural communities, and public transport captives [41–45]. Another unresolved aspect is how the aforementioned differential impacts are related to different scenarios and hazards (e.g. a power blackout after an earthquake) [38]. Social vulnerability studies allow an understanding of differential impacts and aspects of different scenarios and hazards. Social vulnerability is defined as the inability of people, organisations, and societies to cope with the negative impacts of the stressors they are exposed to. There are also spatial indicators of SV; the most common are population density, housing density and hospital beds per 100 people [41].

The vulnerability perspective raises key questions related to the linkages between CI failure, SV, and minimum supply: what levels of minimum supply are acceptable to avoid the disastrous effects caused by natural-hazard-induced CI failure? How do those minimum supply requirements affect different social groups and other infrastructure elements (e.g. housing, schools, business, green infrastructure) [38]. According to Doorn, Gardoni, & Murphy [46], health depends on the infrastructure's capacity to provide clean water and remove or sanitise wastewater. The Federal Ministry of the Interior and the Federal Office of Civil Protection and Disaster Assistance in Germany recommend the private stocking of medical equipment and preparation for short-term power outages [47]. The scientific literature has identified three population groups who are highly vulnerable to long-term CI disruptions: the elderly [40,48], individuals in need of healthcare and low-income households [38,49–52].

1.6. *Spatial access to healthcare and social vulnerability*

Access to healthcare comprises five dimensions: accessibility (travel time and distance), availability (health services in demand), affordability (cost), accommodation (accepting patients) and acceptability (patients' and providers' satisfaction) [53]. Spatial accessibility involves the first two dimensions considering that both define the spatial components of access to healthcare services [54,55]. The accessibility to healthcare from the socio-economic and behavioural perspectives is represented by the last three dimensions [56]. One requirement for human well-being is access to healthcare, which is limited by the allocation of healthcare resources relative to the geographically dispersed population [57], and one of the characteristics of a well-functioning health system is equitable access to care [25]. Measuring spatial

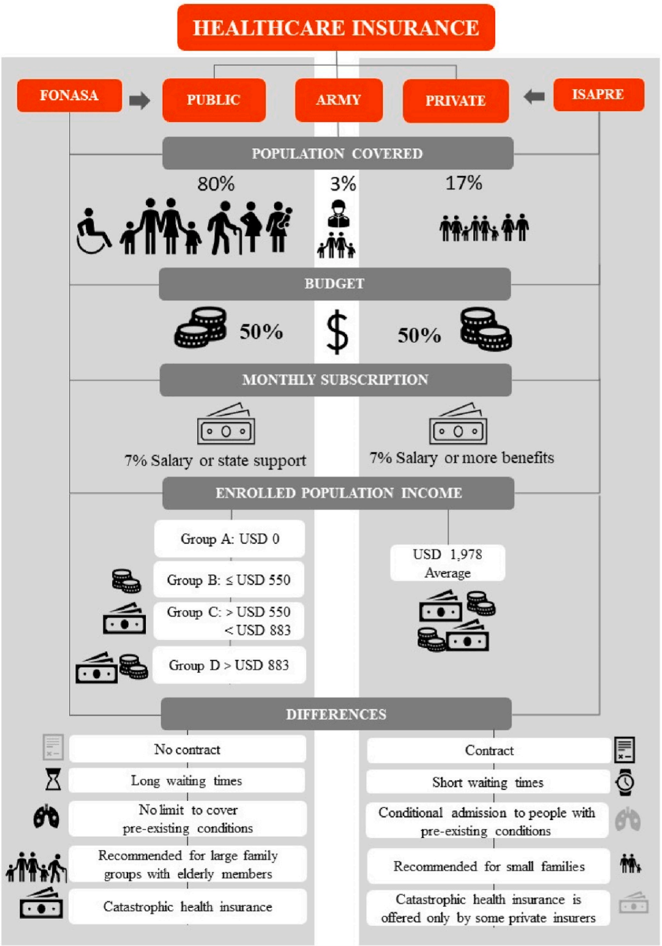

Fig. 6. Schematic representation of the public and private healthcare insurance system in Chile.

accessibility is essential for the evaluation of inequities in access to health care [58,59]. Walker et al. [60] consider travel distance metrics to hospitals and trauma centres to be a conceptual and practical aspect of earthquake vulnerability. In their multi-criteria evaluation model, these authors included access to trauma and other support services as a vulnerability component. Access to medical care is usually defined as a function of the distance, time, and travel barriers to reaching healthcare facilities [61]. According to medical geography research, travel distance to trauma centres is highly negatively correlated with the probability of patient survival [56,62]. Long travel times to healthcare facilities constrain seeking care when needed [57].

There are two approaches to measuring access: distance-based and area-based or container-based. The former focuses on the time required to reach a healthcare facility, while the latter identifies the ratio of the population to be covered in an area [61]. The area-based approach depends on administrative borders and it is mainly applied in the case of primary healthcare provision [63] and confronts a phenomenon known as the modifiable areal unit problem (MAUP) or ecological fallacy [[41], 64]. The distance-based approach does not have the MAUP, making it more accurate than the area-based approach [60]. The integration of census and road network data to measure the population's access to hospitals and physicians using geographic information systems (GIS) have been previously performed by Brabyn and Skelly, Luo and Wang [65], and Schuurman, Bérubé, and Crooks [66]. Walker et al. (2020) calculated driving distances by considering speed limits, travel time, walking time, and the number of road lanes per kilometre from the trauma centre and the nearest hospital to each census dissemination area and entered this information into an additive model. Subsequently, they standardised the resulting accessibility value for each dimension area to produce a systemic vulnerability score. Weiss et al. [57], found that if everyone in the world had access to motorised transport only 8.9% (646 million people) of the global population would be able to reach a healthcare facility within 1 hour, but this percentage increases to 43.3% (3.16 billion) based on those unable to reach a healthcare facility on foot within the same period.

Poor health is widespread in places with higher income inequality [67–70]. Similarly, significantly unequal environments usually have many materially deprived individuals, and poverty harmfully affects health. Additionally, psycho-social mechanisms may affect health, given inequality [67,71]. This explanation is that social distances are increased by more significant income differences [69]. These distances make people feel their lives are somehow less valuable, which erodes social trust [67] and causes social disruptions such as the 2019–2020 protests in Chile. Then the perception of macro-level inequality becomes frustrating at an individual level through the aforementioned psycho-social mechanism leading to 'Status Syndrome' [67,72]. However, the association between income inequality and physical health is stronger than between inequality and self-reported health [73]. Gugushvili et al. [67] observed negative associations between rural residency; widowhood; never married marital status; low education; unemployment; low socioeconomic status; the inability to afford fish, chicken, or meat; unavailability of heating, distrust of strangers; and self-reported health on the other hand. These authors found that income inequality was correlated with poorer health. However, it is still unclear whether the psychological effects of inequality are rooted in the subjective dimensions of inequality (perceptual basis) or the objective ones (material distribution of income and health). They discovered that self-reported health was correlated with subjective assessments. Consequently, when women and men believe the gap between poor and rich has grown, they tend to report poor health.

The healthcare system, as with any other kind of CI, not just consist of physical structures but also includes the population it serves. Healthcare as a service system is complex, mainly due to uncertainties linked to the human-centred aspect of this system [18]. Those uncertainties are related to the large variety of individual characteristics such as being frail and elderly or healthy and young, being a child or an adult, being a woman or man or being disabled, and living in a rural or an urban area. These characteristics make different demands on the healthcare system. There are population-based systems that focus on particular subgroups of the population with common needs and are those needs that define the optimum population size to cover without considering the administrative divisions [74], or the population income.

Our research hypothesis states that the coverage of the healthcare facilities in the RMS is shaped by the incomes rather than the population's healthcare needs, increasing the overall vulnerability of the population. While previous studies have demonstrated the inequality in access to the healthcare system in Chile in the socio-economic dimension, we also demonstrate it in the spatial dimension by plotting the service areas of healthcare facilities considering walking distances from vulnerable populations in each district of the RMS (local level) integrating the distance-based and the area-based approaches. This is the opposite approach of Pu, Yoo, Rothstein, Cairo, & Malemo [56] who focused exclusively on the spatial accessibility in North Kivu (regional level), Democratic Republic of Congo, without addressing the accessibility to healthcare from the socio-economic and behavioural perspective. We want to test the spatial accessibility to healthcare for vulnerable groups based on the coverage within walking distance of the healthcare facilities available in the RMS. Other authors such as Langford, Higgs, & Fry [75] have tried to measure potential geographical accessibility to healthcare services using two-step floating catchment area (2SFCA) techniques but considering public and private transport modes not walking distance.

Walking distance is a valid indicator during a disaster when debris could block roads, impeding the passage of ambulances and increasing the times the population requires to reach healthcare facilities. Disaster is defined by the United Nations of Disaster Risk Reduction (UNDRR) [76] as 'a serious disruption of the functioning of a community or society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources'. Our aim in identifying the districts that are insufficiently covered by the service areas with no healthcare facilities within walking distance is to present a method to spatially visualise the inequality in access to the healthcare infrastructure at the local level. Although this research focuses mainly on access to healthcare in the physical dimension, we consider that problems in the spatial distribution of healthcare facilities result from economic inequality in the RMS.

This paper investigates this level of access and is divided into four sections: Introduction, methods, results, and conclusions. The introductory section presented the location of the case study area. It explains RMS administrative divisions, the natural and anthropogenic hazards it is exposed to, the type of healthcare facilities available, the inequality in Chile's healthcare system and the socio-economic context of the healthcare policy in the country. The introduction also included a literature review regarding the components of the healthcare systems, the socio-economic context of healthcare policy in Chile, CI, SV and spatial access to healthcare. The methods section describes all the steps required to conduct the research. The results section presents the outcomes of the application of the methodology. The conclusions section highlights our findings and some recommended actions considering the results we obtained.

2. Methods

The methodology was divided into five steps. The first step was to identify the location and visualising the spatial distribution of public and private healthcare facilities in the RMS. As Pu et al. [56], we assume that in the case of a disaster, the injured population will go or will be taken to the nearest healthcare facility regardless of their insurance provider, healthcare plan or income, but for long-term medical treatment, population will go to the healthcare facility allocated by their insurance provider. The second step is to plot vulnerable population's spatial distribution in the RMS and compare it with the location of the healthcare facilities. The spatial distribution of the population is associated with the potential demands for healthcare, which is fundamental for the accurate assessment of spatial accessibility [56]. The third step was to assess the SV level of the RMS per commune to compare it with the location of the private and public healthcare facilities. The fourth step was to perform statistical analyses to identify the predictors of the number of healthcare facilities per commune in the RMS. The fifth and final step was to identify gaps in healthcare facilities' service areas, according to walking distance from the population's place of residence. In coverage analyses, transit planners assume certain walking-distance limits as the threshold that people willing to walk to access public transport [77]. In this research, we use this walking distance limit as the threshold that people are willing to walk to receive medical care and, based on this indicator, plot the inequality in the access to healthcare infrastructure in the RMS. The willingness to walk to a destination decreases with distance, known as 'distance decay'. Walking distances for accessing urban facilities vary among the different population groups [77]. Weiss et al. [57] plotted a worldwide walking-only map of travel time to healthcare facilities showing longer travel times for rural areas because healthcare facilities are located in densely populated zones, supplying only the local demand for healthcare. The methodology is depicted in Fig. 7.

In the second step, we managed to identify the vulnerable population using population data obtained by the 2017 census and the area per commune and the average monthly income in the RMS in 2019 [78]. In this research, we consider the vulnerable population to be women, the elderly (people aged 65 years), children aged 4 years and below, the low-income population, and those who live in high-density communes [41]. We would like to have used more updated population data, this is not possible as Chile, censuses are done every ten years. To solve the need for updated data, the National Institute of Statistics (Spanish acronym: INE) in Chile undertook a simplified census in 2017 that, according to this institution, will meet the needs for decision-making in terms of public policy until 2025, time for which they will be ready for the results of the complete census to be done in 2024 [79]. In the third step, we integrated these socio-economic variables and the indicator, summing them to equal weight and normalising the resulting values using Equation (1) to determine the level of SV per commune in the RMS.

$$\text{Normalisation } Z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)} \qquad \text{Equation 1}$$

The fourth step was to establish the correlation between the vulnerable population's location and the location of healthcare facilities per commune using a two-tailed Pearson correlation in SPSS 27. Additional multiple regression analysis was performed to identify the predictors for the number of healthcare facilities per commune in the RMS. The fifth step was the analysis of the coverage of the service area of healthcare facilities using network analysis. We planned to combine the area [61] and the distance-based approaches [60]. On the one hand, with the distance-based approach, we wanted to demonstrate the inequity in the spatial dimension of healthcare access based on walking speed, because walking is a common transportation mode for all socio-economic strata and available even when roads are blocked. On the other hand, with the area approach, we considered the administrative division in the service area analysis at the district level into the commune because corrective actions must be taken at this administrative level. Although the standard human walking speed is 5 km per hour, the Traffic Control Operational Unit (Spanish acronym: UOCT) from the Ministry of Transport and Telecommunications in Chile estimated a walking speed of 3.2 km per hour for children, elderly, people, and people with low mobility [80], who are considered vulnerable population and based in this speed we defined the service areas for healthcare facilities in this research.

Walking distance was considered because in an earthquake, tsunami, volcanic eruption, or landslide, streets will be blocked, and ambulances' circulation will be limited by debris. Another reason to consider walking distance was the uncertainty regarding transport media in the rural communes. Weiss et al. [57] found that on the one hand, with access to motorised transport, 60.3% of the worldwide population lives within 10 min of a healthcare facility, while 82.6% and 91.1% live within 30 and 60 min, respectively. On the other hand, when the trip is by foot, only 14.2%, 39.8%, and 56% of the worldwide population live within 10, 30 and 60 min of a healthcare facility.

Considering the walking speed (3.2 km per hour) estimated by the UOCT [80] for children, elderly people, and people with low mobility in Chile, and the time periods used by Weiss et al. [57] in their study we estimated a maximum walking time of 1620 m/30 min for one trip; this means a 1-h round way trip because we considered that no-one in the vulnerable group would be able to walk for more than 1 h to reach a healthcare facility and come back to their home. The walking distance will determine the service area covered by the healthcare facilities and therefore their accessibility. The periods and the estimated distance are listed in Table 1.

Using the ArcGIS Network Analyst extension [81], we combined the location of each healthcare facility located in the RMS and the road network of this region to identify their service areas. We created three service areas for each healthcare facility according to the walking speed assumed for this research paper. These were delineated based on all the accessible streets within the 10, 20, and 30 min. Once the service areas were created, we added 75% transparency to the service area analysis layer [82] to check the coverage and identify uncovered areas at a

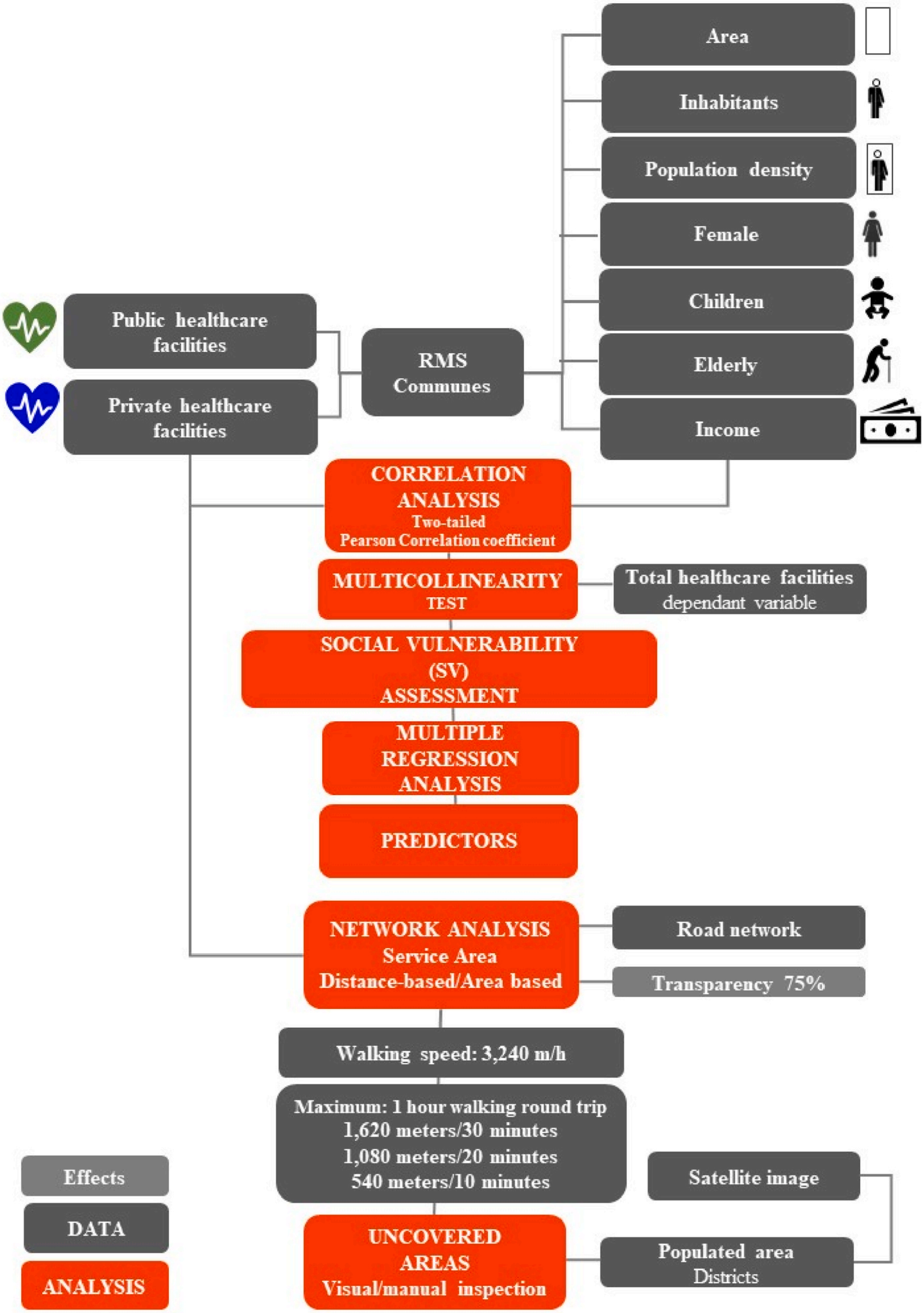

Fig. 7. Methodology.

Table 1
Walking distances estimated based on walking speed of 3.2 km per hour.

Time	Distance	Time	Distance
Minutes One-trip	Metres One-trip	Minutes Round-trip	Metres Round-trip
10	540	20	1080
20	1080	40	2160
30	1620	60	3240

district level. The coverage of the healthcare facilities per district is classified as total, high, medium, partial, and none according to the service areas, including inhabited districts observed in satellite images.

3. Results

A high concentration of private healthcare facilities is observed in Figs. 4 and 5 in urban communes where the population classified into group D of FONASA (highest income) is living. The vulnerable population groups and the availability of healthcare facilities per commune at the RMS are listed in Table 2. According to the 2017 Chilean census, Puente Alto is the commune with the highest number of women (292,959), children (40,586), and inhabitants in the RMS. We found the largest elderly population in *Maipú* (49,010). The commune with the largest area is San José de Maipo (4,994.8 km^2), and the one with the highest population density is Santiago (18,057.81 inhabitants/km^2). The highest average monthly income per person per commune in 2019

Table 2
Vulnerable population groups and the availability of healthcare facilities per commune at the RMS, Chile. Source [83,84]

Commune	Inhabitants	Area	Density	Female	Children	Elderly	Income	Public Healthcare Facilities	Private Healthcare Facilities	Total Healthcare Facilities
Name	Nr	Km^2	Nr inh/ km2	Nr	Nr	Nr	USD	Nr	Nr	Nr
Alhué	6,444	845	7.63	2,928	423	712	1,316.73	5	0	5
Buin	96,614	214.1	451.46	49,039	7,343	8,453	230.84	11	2	13
Calera de Tango	25,392	73.3	346.41	12,674	1,643	2,392	389.01	3	0	3
Cerrillos	80,832	21	3849.14	41,201	5,537	9,609	374.15	6	2	8
Cerro Navia	132,622	11 .1	12056.54	67,184	8,880	16,397	200.39	9	0	9
Colina	146,207	971.2	150.54	71,572	13,206	8,721	385.49	10	3	13
Conchalí	126,955	70.7	1795.69	65,078	7,989	17,452	247.77	11	2	13
Curacavi	32,579	693.2	47	16,357	2,240	3,869	277.41	4	0	4
El Bosque	162,505	14.1	11525.18	83,133	10,673	19,870	224.96	12	1	13
El Monte	35,923	118.1	304.17	18,130	2,825	3,654	249.09	3	0	3
Estación Central	147,041	15	9802.73	73,583	8,746	17,404	288.83	7	10	17
Huechuraba	98,671	44.8	2202.48	50,549	7,389	9,413	510.72	8	3	11
Independencia	100,281	7	14325.86	51,095	6,607	11,005	277.76	14	5	19
Isla de Maipo	36,219	188.7	191.94	18,168	2,610	3,697	244.81	8	0	8
La Cisterna	90,119	10	9011.9	46,972	5,382	12,945	234.11	4	3	7
La Florida	366,916	70.8	5182.43	191,223	22,262	47,090	250.5	21	14	35
La Granja	116,571	10.1	11657.1	59,546	7,646	13,910	220.09	10	0	10
La Pintana	177,335	30.6	5795.26	90,291	13,981	16,208	229.13	13	1	14
La Reina	92,787	23.4	4034.22	49,188	5,150	13,824	516.36	6	8	14
Lampa	102,034	451.9	225.79	50,489	9,268	5,951	421.29	7	0	7
Las Condes	294,838	99.4	2966.18	158,921	16,198	46,011	1,579.18	4	29	33
Lo Barnechea	105,833	1023.7	103.38	55,333	6,995	8,026	1,226.19	6	7	13
Lo Espejo	98,804	7.2	12.35	49,658	6,545	11,566	237.05	9	1	10
Lo Prado	96,249	6.7	14365.52	49,450	5,810	14,008	245.8	9	0	9
Macul	116,534	12.9	9033.64	61,373	6,739	17,128	263.55	6	6	12
Maipú	521,627	133	3849.65	270,835	32,203	49,010	319.81	21	10	31
María Pinto	13,590	395	34.41	6,760	926	1,559	457.14	5	0	5
Melipilla	123,627	1344.8	91.93	62,217	8,538	14,263	233.03	15	5	20
Ñuñoa	208,237	16.9	12321.72	112,828	12,165	30,409	372.39	7	16	23
Padre Hurtado	63,250	80.8	782.8	31,798	5,017	5,596	218.79	2	0	2
Paine	72,759	820	88.73	36,238	5,100	7,084	240.37	8	2	10
Pedro Aguirre Cerda	101,174	9.7	10430.31	51,661	6,034	14,380	204.35	10	0	10
Peñaflor	90,201	69.2	1303.5	46,257	6,555	8,952	226.86	6	2	8
Peñalolén	241,599	54.2	4474.06	124,717	15,270	24,922	326.69	15	5	20
Pirque	26,521	445.3	59.56	13,092	1,824	2,677	462.79	6	0	6
Providencia	142,079	14.4	9866.6	76,369	7,694	22,263	1,230.45	17	49	66
Pudahuel	230,293	197.4	1166.631	117,881	16,009	19,538	401.38	19	2	21
Puente Alto	568,106	88.2	6441.1	292,959	40,586	43,488	210.13	27	13	40
Quilicura	210,410	57.5	3659.3	106,954	15,051	11,444	307.37	10	7	17
Quinta Normal	110,026	13	8463.54	56,357	6,601	14,278	257.88	10	2	12
Recoleta	157,851	16.2	9743.89	80,142	9,780	19,815	314.16	10	1	11
Renca	147,151	24.2	6080.62	74,470	10,837	14,736	247.55	8	0	8
San Bernardo	301,313	155.1	1942.7	153,513	22,720	26,123	241.88	21	13	34
San Joaquín	94,492	9.7	9741.44	48,661	5,594	13,986	300.99	12	1	13
San José de Maipo	18,189	4994.8	3.64	8,328	1,052	2,003	457.27	5	0	5
San Miguel	107,954	9.5	11363.58	57,216	6,739	13,791	290.14	10	12	22
San Pedro	9,726	787.5	12.35	4,594	696	1,390	452.19	5	0	5
San Ramón	82,900	6.5	12753.85	42,027	5,457	12,112	258.08	10	0	10
Santiago	404,495	22.4	18057.81	197,817	20,617	30,019	564.72	18	50	68
Talagante	74,237	321.7	230.76	37,468	5,351	7,182	252.92	8	3	11
Tiltil	19,312	653	29.57	9,265	1,408	2,009	289.22	8	0	8
Vitacura	85,384	28.3	3017.1	46,982	5,732	15,033	1,588.31	2	14	16

was identified in the community of Vitacura (USD $1,588.31), while the lowest was observed in Cerro Navia (USD $200.38) [78].

The commune with the highest number of healthcare facilities in the RMS is Santiago (68). The highest number of public healthcare facilities in the RMS is in Puente Alto's commune (27), while the lowest is in Padre Hurtado (two). The highest number of private healthcare facilities in the RMS is found in the commune of Santiago (50) and Providencia (49), while Cerro Navia, La Granja, Lo Prado, Pedro Aguirre Cerda (PAC), Renca, San Ramón, Pirque, San José de Maipo, Lampa, Tiltil, Calera de Tango, Alhué, Curacaví, María Pinto, San Pedro, El Monte, Isla de Maipo, and Padre Hurtado do not have any private facilities.

The resulst of the correlation analysisis presented on Table 3. We found a significant positive correlation between the number of inhabitants per commune and the number of public ($r = 0.793$**), private ($r = 0.512$**) and total healthcare facilities ($r = 0.718$**). There is no correlation between area per commune and the number of healthcare facilities. There is correlation between the population density per commune and the number of public ($r = 0.282$**), private ($r = 0.362$**) and total healthcare facilities ($r = 0.395$**). There was a significant positive correlation between the number of women per commune and the public ($r = 0.786$**), private ($r = 0.513$**), and total healthcare facilities ($r = 0.716$**). The same result was observed for the number of children per commune and the number of public ($r = 0.808$**), private ($r = 0.408$**) and total healthcare facilities ($r = 0.643$**) and the number of elderly per commune and the number of public ($r = 0.671$**), private ($r = 0.558$**) and total healthcare facilities ($r = 0.704$**). There was a positive correlation between the average monthly income per commune in 2019, the number of private healthcare facilities ($r = 0.478$**) and total healthcare facilities ($r = 0.279$*).

Considering that several variables involved in this analysis are highly correlated between them (r=>0.800**), we need to run a multicollinearity analysis to select and discard the variables finally included in the SV assessment and later in the multiple regression analysis. Initially, ten variables were considered for the analysis, but after testing for multicollinearity, looking at variance inflation factors (VIF) > 2 [85,86], through three linear regression analyses having total healthcare facilities (Nr) as the dependent value we dropped five variables: number of inhabitants, females, children and elderly and private healthcare facilities. These variables were excluded to avoid collinearity that creates difficulties to interpret coefficients and reduce the power of the model to

Table 3
Pearson's two-tailed bivariate correlation between vulnerable population groups and the availability of healthcare facilities at the RMS, Chile.

Variables		Inhabitants	Area	Density	Female	Children	Elderly	Income	Public healthcare facilities	Private healthcare facilities	Total healthcare facilities
Inhabitants	Pearson Correlation	1	−0.237	.286*	.999**	.981**	.912**	−0.023	.793**	.512**	.718**
	Sig. (2-tailed)		0.091	0.040	0.000	0.000	0.000	0.874	0.000	0.000	0.000
	N	52	52	52	52	52	52	52	52	52	52
Area	Pearson Correlation	−0.237	1	−.369**	−0.241	−0.221	−.294*	0.095	−0.163	−0.150	−0.183
	Sig. (2-tailed)	0.091		0.007	0.085	0.115	0.034	0.503	0.248	0.287	0.195
	N	52	52	52	52	52	52	52	52	52	52
Density	Pearson Correlation	.286*	−.369**	1	.283*	0.203	.379**	−0.144	.282*	.362**	.395**
	Sig. (2-tailed)	0.040	0.007		0.042	0.149	0.006	0.308	0.043	0.008	0.004
	N	52	52	52	52	52	52	52	52	52	52
Female	Pearson Correlation	.999**	−0.241	.283*	1	.980**	.923**	−0.008	.786**	.513**	.716**
	Sig. (2-tailed)	0.000	0.085	0.042		0.000	0.000	0.955	0.000	0.000	0.000
	N	52	52	52	52	52	52	52	52	52	52
Children	Pearson Correlation	.981**	−0.221	0.203	.980**	1	.856**	−0.077	.808**	.408**	.643**
	Sig. (2-tailed)	0.000	0.115	0.149	0.000		0.000	0.588	0.000	0.003	0.000
	N	52	52	52	52	52	52	52	52	52	52
Elderly	Pearson Correlation	.912**	−.294*	.379**	.923**	.856**	1	0.099	.671**	.558**	.704**
	Sig. (2-tailed)	0.000	0.034	0.006	0.000	0.000		0.485	0.000	0.000	0.000
	N	52	52	52	52	52	52	52	52	52	52
Income	Pearson Correlation	−0.023	0.095	−0.144	−0.008	−0.077	0.099	1	−0.229	.478**	.279*
	Sig. (2-tailed)	0.874	0.503	0.308	0.955	0.588	0.485		0.102	0.000	0.045
	N	52	52	52	52	52	52	52	52	52	52
Public healthcare facilities	Pearson Correlation	.793**	−0.163	.282*	.786**	.808**	.671**	−0.229	1	.371**	.691**
	Sig. (2-tailed)	0.000	0.248	0.043	0.000	0.000	0.000	0.102		0.007	0.000
	N	52	52	52	52	52	52	52	52	52	52
Private healthcare facilities	Pearson Correlation	.512**	−0.150	.362**	.513**	.408**	.558**	.478**	.371**	1	.928**
	Sig. (2-tailed)	0.000	0.287	0.008	0.000	0.003	0.000	0.000	0.007		0.000
	N	52	52	52	52	52	52	52	52	52	52
Total healthcare facilities	Pearson Correlation	.718**	−0.183	.395**	.716**	.643**	.704**	.279*	.691**	.928**	1
	Sig. (2-tailed)	0.000	0.195	0.004	0.000	0.000	0.000	0.045	0.000	0.000	
	N	52	52	52	52	52	52	52	52	52	52

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

identify independent variables that are statistically significant. Eventually, a subset of five variables with a VIF >2 (see Table 4), which means they are unrelated to each other, were considered for the SV assessment and useful predictors for the multiple regression analysis: area, density, income and public healthcare facilities.

Considering these variables, the commune with the highest vulnerability in the RMS is San José de Maipo, followed by Melipilla. The commune with the lowest vulnerability in RMS is Vitacura. The other communes are classified into medium and low vulnerability. The spatial distribution of the SV levels and the location of healthcare facilities in the RMS are depicted in Fig. 8.

To determine the predictors of the number of the healthcare facilities per comune among the selected variables for the SV assessment, we performed a multiple regression analysis. Results listed in Table 5 show that total healthcare facilities had a large positive correlation with public healthcare facilities ($r = 0.691$), and this correlation is significant but not enough to consider a collinearity (r=>0.800**), between those variables.

The summary model in Table 6 indicates a $R^2 = 0.478$ in Model 1, meaning that the number of public healthcare facilities accounts for 47.8% of the variation in the total healthcare facilities per communed. However, when the other predictor: Income per commune, is included in Model 2, this value increases to 68%, and when population density is included in Model 3, this value increases to 74.1%. Then, including the two new predictors explains quite a large amount of the variation in healthcare facilities per commune.

At each stage of the regression analysis, SPSS provides a summary of any variables that have not yet been entered into the model [87]. The variable of the area of the commune was excluded in all the three models as it is presented in Table 7.

Moving from the predictors to the coverage of existing facilities. The coverage of healthcare facilities per district is classified according to the distance to reach healthcare facilities: total (within 540 m), high (within 1080 m), medium (within 1620 m), low (beyond 1620 m) and none. To avoid the MAUP, only inhabited areas per district will be considered for determining the coverage, not the total area. The coverage of the healthcare facilities' service areas per district based on the vulnerable population's walking speed and capacity can be observed in Fig. 9. A total coverage of service area of healthcare facilities considering walking distance was observed in 4% (20) of the districts in the communes of Cerro Navia (3), *Conchalí* (4), El Bosque (2), Independencia (1), Providencia (4), San Bernardo (1) and Santiago (5). Examples of districts with total coverage considering walking distance are 1, 2 and 6 in the commune of Providencia, as depicted in Fig. 10. High coverage of service area was identified in 10% of the districts (136) in the communes of Cerro Navia (3), *Conchalí* (3), Estación Central (7), El Bosque (2), Huechuraba (3), Independencia (4), La Cisterna (1), La Florida (8), La Granja (5), La Pintana (1), La Reina (1), Las Condes (4), Lo Espejo (2), Lo Prado (7), Macul (1), *Maipú* (2), Ñuñoa (10), Pedro Aguirre Cerda (5), Peñalolén (6), Providencia (4), Pudahuel (5), Puente Alto (2), Quinta Normal (3), Recoleta (4), Renca (2), San Bernardo (4), San Joaquin (6), San Miguel (7), San Ramón (4), Santiago (17), Tiltil (2) and Vitacura (1). Examples of a district with high coverage of service area of healthcare facilities considering the walking distance are districts 4, 5, 7, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24 and 26 in the commune of Santiago, as it is shown in Fig. 11. Medium coverage of the healthcare facilities' service areas was obeserved in 30% (136) of the districts in Alhué (2), Cerro Navia (2), *Conchalí* (3), El Bosque (5), Estación Central (5), Huechuraba (1), Independencia (2), La Cisterna (5), La Florida (9), La Granja (3), La Pintana (6), La Reina (4), Las Condes (8), Lo Espejo (5), Macul (4), *Maipú* (13), Melipilla (1), Ñuñoa (1), Padre Hurtado (1), Pedro Aguirre Cerda (2), Peñalolén (3), Pudahuel (2), Puente Alto (6), Quilicura (2), Quinta Normal (6), Recoleta (7), Renca (5), San Bernardo (5), San Joaquín (1), San Ramón (3), Santiago (7), Talagante (2), Tiltil (2) and Vitacura (3). Examples of a district with a medium coverage of service area of healthcare facilities considering the walking distance are districts 1, 2, 3, 6, 8, 9, 12, 15, 16, 18, 20, 21, 22 and 14 in the commune of Maipú, as it is presented in Fig. 12. RMS communes contain 127 (28%) districts with low coverage: Alhué (3), Buin (6), Calera de Tango (4), Cerrillos (4), Cerro Navia (1), Colina (5), Curacaví (2), El Bosque (1), El Monte (1), Estación Central (2), Huechuraba (2), Isla de Maipo (4), La Florida (4), La Reina (2), Lampa (3), Las Condes (4), Lo Barnechea (4), Macul (1), *Maipú* (7), María Pinto (4), Melipilla (8), Padre Hurtado (1), Paine (9), Pedro Aguirre Cerda (1), Peñaflor (3), Peñalolén (2), Pirque (3), Pudahuel (2), Puente Alto (11), Quilicura (2), Recoleta (2), Renca (3), San Bernardo (4), San José de Maipo (4), San Pedro (4), Talagante (2), Tiltil (1), Vitacura (1). Districts with low coverage of service areas of healthcare facilities considering the walking distance are districts 1, 2, 3, 4, 5, 6, 7, 14, 16, 18, 19 in Puente Alto commune, as shown in Fig. 13. In the RMS, 7% (32) of the districts at the communes Calera de Tango (1), Colina (1), Curacaví (6), El Monte (2), Isla de Maipo (1), La Pintana (1), Lampa (2), *Maipú* (1), María Pinto (1), Melipilla (8), Padre Hurtado (3), Pudahuel (1), San José de Maipo (2), San Pedro (2) are not covered by the service area of any healthcare facility. Examples of districts not covered by any service area are districts 4, 5, 6, 7, 8, 9, 11, and 13 in the commune of Melipilla, presented in Fig. 14. Not all districts in the RMS are inhabited, i.e. district 4 in Colina, district 2 in Curacaví, district 2 in Lampa, district 5 in Maria Pinto, district 6 and 8 in Melipilla, districts 2 and 5 in San Jose de Maipo, districts 2 and 3 in San Pedro. Other districts host industrial facilities, such as district 7 in Lo Espejo, district 15 in Maipu, district 2 in Quilicura, district 7 in Renca and districts 11 and 12 in San Bernardo.

4. Discussion

Although public insurance covers everyone born and/or lives in Chile regardless of age, gender, income, dependents or pre-existing conditions, nationality or immigration status, the access to medical attention for people enrolled in this system is limited to the care capacity of public healthcare centres. Suppose the person decides to seek

Table 4
Predictors of the total number of healthcare facilities per commune at the RMS, Chile.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	−13.113	2.843		−4.612	0.000		
	Area	0.000	0.001	−0.016	−0.206	0.838	0.859	1.164
	Density	0.001	0.000	0.253	3.073	0.004	0.809	1.236
	Income	0.019	0.003	0.484	6.333	0.000	0.940	1.064
	Public Healthcare Facilities	1.809	0.196	0.728	9.220	0.000	0.881	1.135

[a] Dependent Variable: Total healthcare facilities.

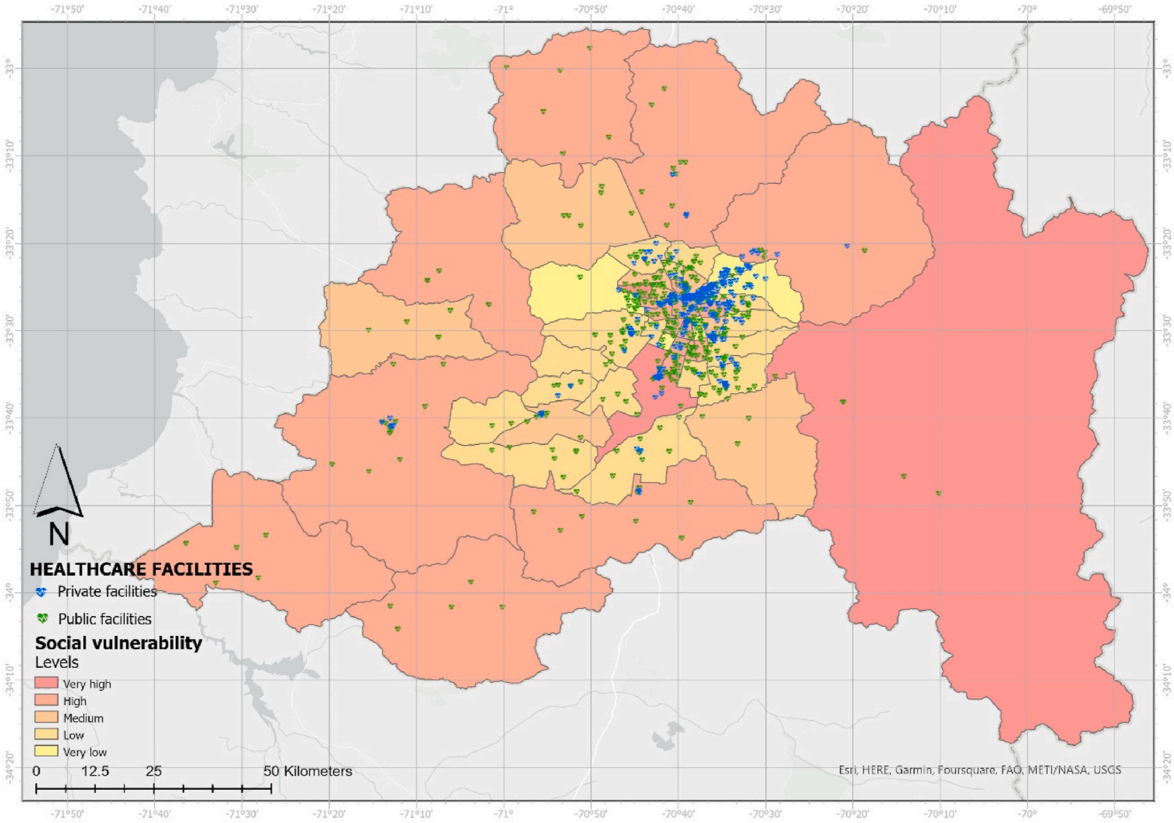

Fig. 8. Social vulnerability assessment and location of healthcare facilities in the RMS.

Table 5
Correlations.

		Total healthcare facilities	Area	Density	Income	Public healthcare facilities
Pearson Correlation	Total healthcare facilities	1.000	−0.183	0.395	0.279	0.691
	Area	−0.183	1.000	−0.369	0.095	−0.163
	Density	0.395	−0.369	1.000	−0.144	0.282
	Income	0.279	0.095	−0.144	1.000	−0.229
	Public healthcare facilities	0.691	−0.163	0.282	−0.229	1.000
Sig. (1-tailed)	Total healthcare facilities		0.097	0.002	0.022	0.000
	Area	0.097		0.004	0.251	0.124
	Density	0.002	0.004		0.154	0.021
	Income	0.022	0.251	0.154		0.051
	Public healthcare facilities	0.000	0.124	0.021	0.051	
N	Total healthcare facilities	52	52	52	52	52
	Area	52	52	52	52	52
	Density	52	52	52	52	52
	Income	52	52	52	52	52
	Public healthcare facilities	52	52	52	52	52

Table 6
Model summary.

Model	R	R Square	Adjusted R Square	Std.Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.691[a]	0.478	0.467	9.859	0.478	45.765	1	50	0.000	
2	.825[b]	0.680	0.667	7.795	0.202	30.996	1	49	0.000	
3	.861[c]	0.741	0.725	7.081	0.061	11.374	1	48	0.001	2.238

d. Dependent Variable: Total healthcare facilities.

[a] Predictors: (Constant), Public healthcare facilities.

[b] Predictors: (Constant), Public healthcare facilities, Income.

[c] Predictors: (Constant), Public healthcare facilities, Income, Density.

Table 7
Excluded variables.

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
						Tolerance	VIF	Minimum Tolerance
1	Area	−.072[b]	−0.689	0.494	−0.098	0.973	1.027	0.973
	Density	.217[b]	2.108	0.040	0.288	0.920	1.086	0.920
	Income	.462[b]	5.567	0.000	0.622	0.948	1.055	0.948
2	Area	−.100[c]	−1.219	0.229	−0.173	0.970	1.031	0.927
	Density	.259[c]	3.373	0.001	0.438	0.914	1.094	0.884
3	Area	−.016[d]	−0.206	0.838	−0.030	0.859	1.164	0.809

[a] Dependent Variable: Total healthcare facilities.
[b] Predictors in the Model: (Constant), Public healthcare facilities.
[c] Predictors in the Model: (Constant), Public healthcare facilities, Income.
[d] Predictors in the Model: (Constant), Public healthcare facilities, Income, Density.

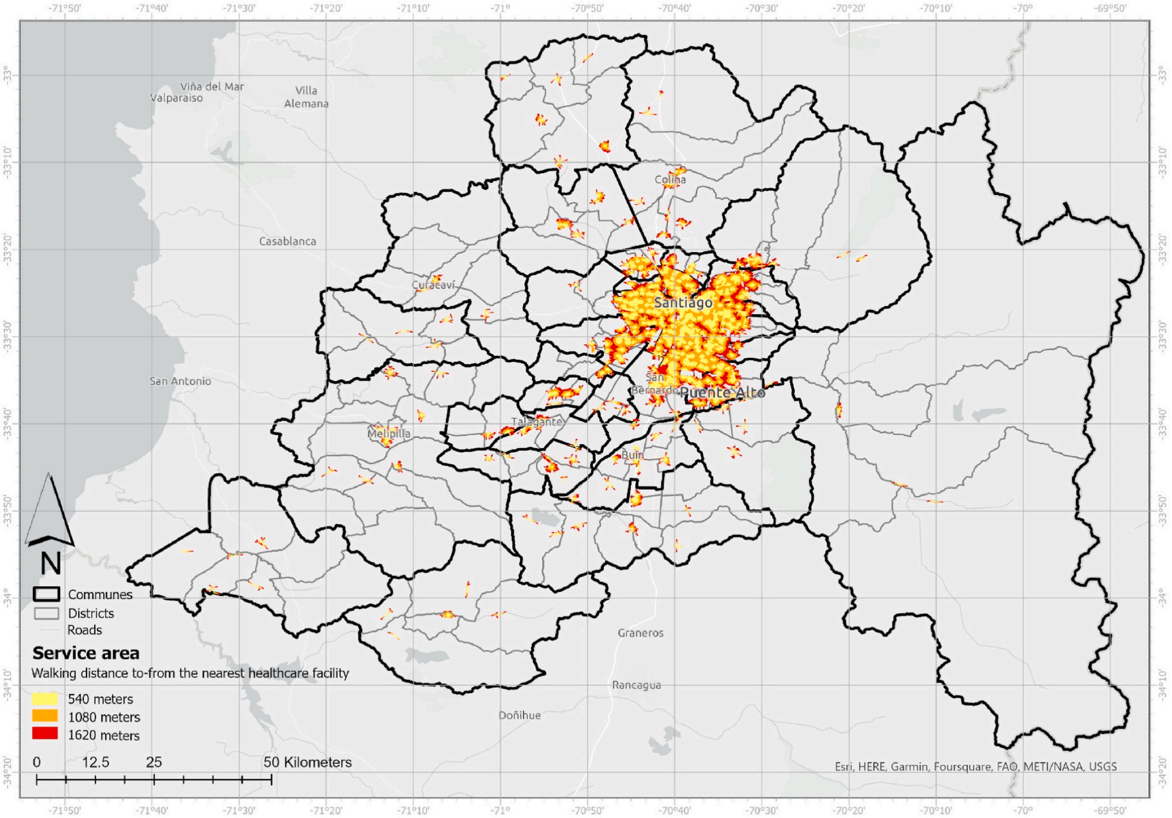

Fig. 9. Service area of healthcare facilities in the RMS, Chile.

attention in a private healthcare facility; in that case, this person will need to purchase bonuses, and the copayment will be higher than for a person already enrolled in a private health insurance company. Another reason to join a private health insurance company is the possibility of deciding the health coverage plan, while public insurance offers only one health coverage plan with two modalities of care provision: institutional care (public healthcare facilities) or free choice (public or private healthcare facilities); however, the last modality option is only available for people with an income above USD 550. Private health insurance companies offer discounts on medicines, dentistry plans, and refunds of money after the care service is provided with a bond purchase [26].

One of the limitations of our research is the lack of data availability for the same years for all the variables considered in the analysis. The average income per commune is from 2019 [78], the population data were extracted from the census done in 2017, the database with the location of healthcare facilities and network roads in the RMS is from 2020. We considered the average monthly income (USD) per commune in the RMS in 2019 [78] because it was the social uprising year and the only year available with information at this level of data disaggregation. In the case of the census, this data is valid to formulate public policy until 2025 [79]; therefore, we assume we can consider it also valid for our research which covers a period between 2017 and 2020 before the COVID-19 pandemic. Our research did not cover the pandemic period because despite the economic impact, Chile was the first country in Latin America to apply the fourth dose COVID-19 vaccine for its population and the second after Israel [88], therefore the mortality rate did not trigger any change in the long term in public healthcare policy.

The significant correlation between the number of inhabitants per commune and the number of public, private and total healthcare

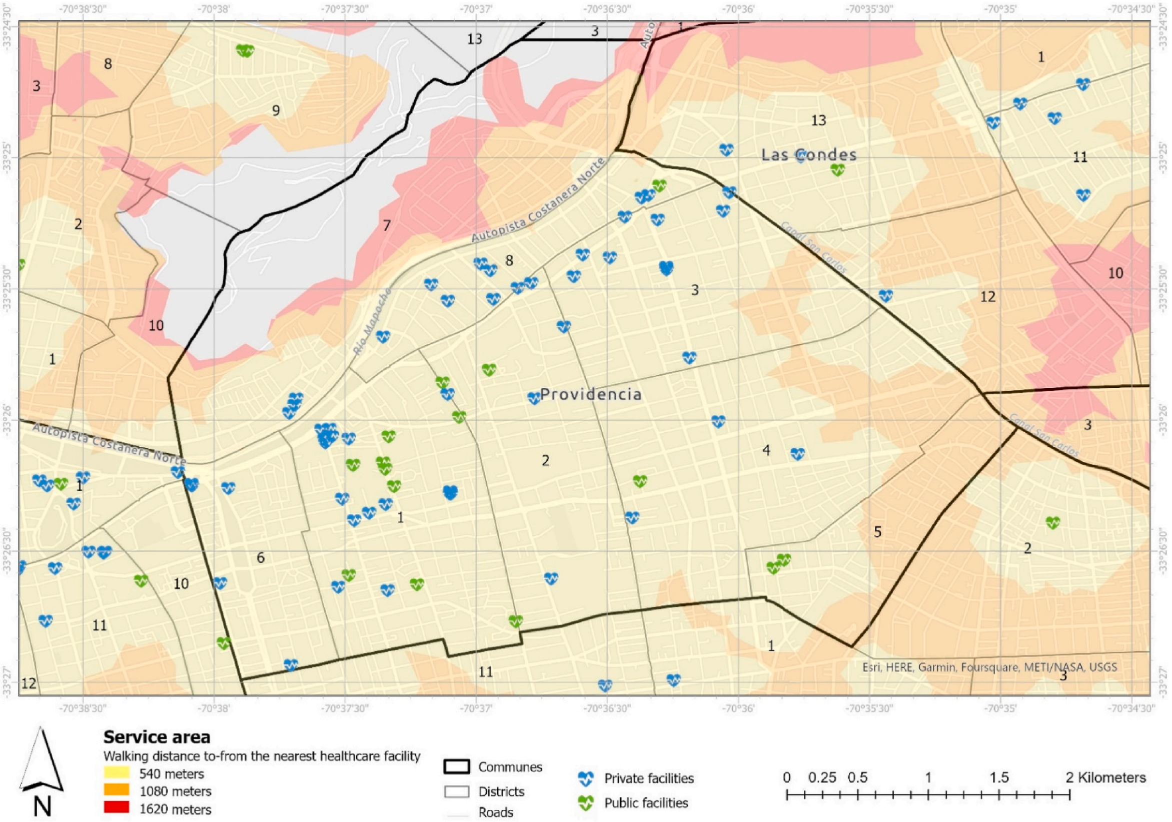

Fig. 10. Districts 1, 2 and 6 at the commune of Providencia in the RMS, Chile with healthcare facilities in service areas within 540 m, considering walking distance: total coverage at the district level.

facilities lead us reject our initial hypothesis. However, the lack of correlation between the area per commune and the number of healthcare facilities and the low correlation between density and the number of healthcare facilities could indicate coverage problems. The significant correlation between the number of women, children and elderly and healthcare facilities could be interpreted as evidence of a population-based system [18], but as we did not consider in the analysis, the different categories of healthcare facilities existing in the RMS with their medical specialities, we can not prove this statement, and it rather could be topic for further research. The correlation between the average monthly income per person, the number of private healthcare facilities, and the total healthcare facilities per commune can be interpreted as evidence to accept our initial hypothesis: the coverage of the healthcare facilities in Chile is shaped by the income rather than the population's healthcare needs. However, correlation coefficients do not necessarily indicate causality because other unmeasured or measured variables could affect the results. This factor is known as the *tertium quid* or the third-variable problem [87].

We consider SV as a proxy to introduce the social determinants of health (SDH) [89,90] into the analysis rather than using the distributional justice paradigm. In assessing SV, more variables could have been considered, such as the number of disabled people per commune, but unfortunately, we did not have access to that data. The highest levels of vulnerability in the RMS are observed in rural communes located around the urban communes with lower levels of vulnerability. It is also noted that public facilities mainly cover the healthcare of those rural communes except for the communes of Melipilla, Colina and Lo Barnechea, which are communes classified in the rurality index as medium rurality the first two and low the last one [91]. Spatial inequality in the supply of medical services in rural areas has long been regarded as a critical healthcare delivery problem [31].

The area of the commune was a variable excluded as a predictor of the location of healthcare facilities per commune in the multiple regression model. That exclusion can be explained by the fact that the area per commune was already integrated into the population density predictor and that not the total area of the communes is inhabited, mainly in rural communes. However, we can also take it as evidence of a lack of coverage in big communes, mainly those classified into the categories of high and medium rurality index (S. [91]), such as San Jose de Maipo, Melipilla, Colina, Alhué, San Pedro, Curacaví, Lampa and Pirque.

The fact that the main predictor of the location of healthcare facilities per comune is the number of public healthcare facilities can be explained because most of the healthcare facilities in the RMS are public (62%) and that it is possible that one commune has only public healthcare facilities and none private such in the cases of Alhue, Curacavi, Lampa, Maria Pinto, San Jose de Maipo, San Pedro and Tiltil, but not the opposite. A spatial pattern is observed that private healthcare facilities tend to locate around public facilities; this is mainly visible in the commune of Melipilla (districts 1,2, and 14). We also assume that FONASA must build at least a certain number of public healthcare facilities per commune, considering population density, as public service provided by the government for the citizens of each commune, but private healthcare insurers do not have that obligation, that is why the number of private healthcare facilities were discarded as predictor of the total number of healthcare facilities per commune.

Continuing with the spatial analysis of the accessibility, the network analysis to plot the service areas considered only main roads, not secondary ones that could also be taken by walking to reach healthcare facilities. This decision to use this spatial dataset was taken given the lack of availability of the complete road network of the RMS. Another limitation is not using data disaggregated at the district level. It would have been ideal to have surveyed in the RMS the parents of children under 5 years old, the elderly and people with low mobility to determine the maximum time they were willing to walk to reach a healthcare

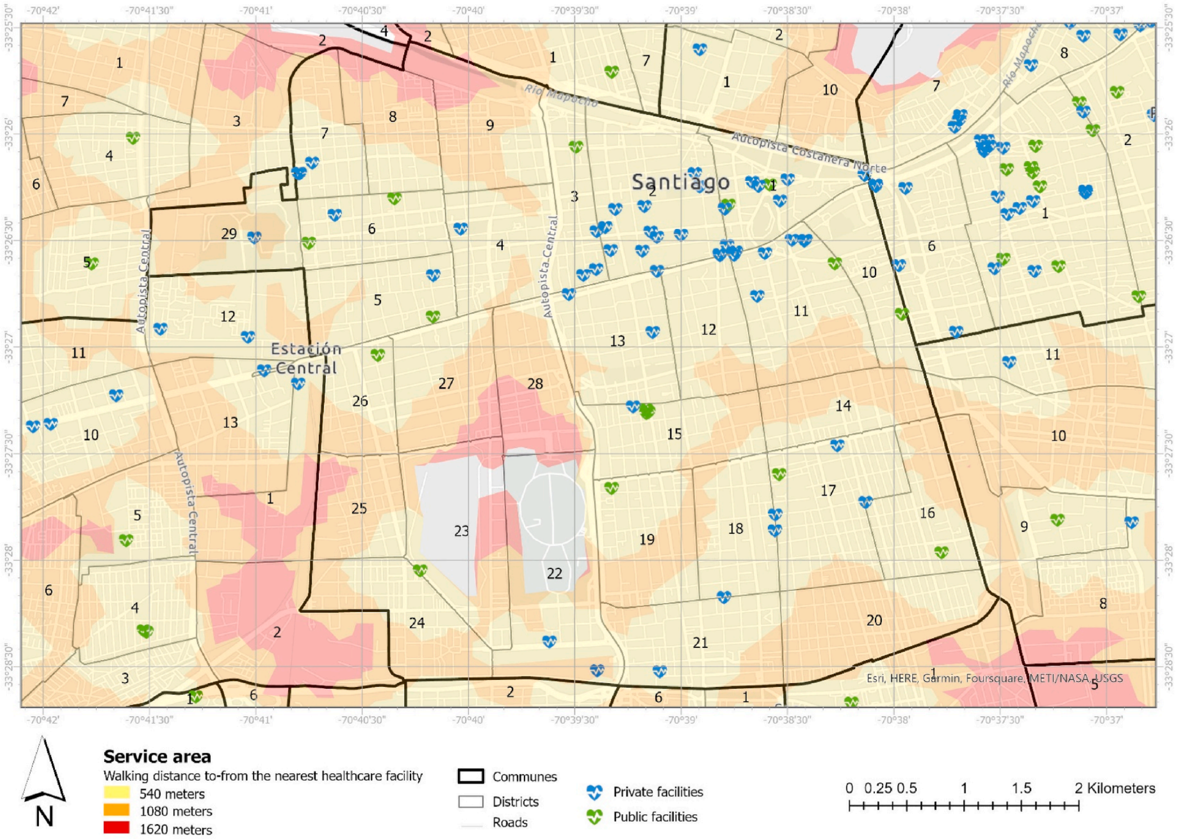

Fig. 11. Districts 4, 5, 7, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24 and 26 at the commune of Santiago in the RMS, Chile, with healthcare facilities in service areas within 1080 m, considering the walking distance: high coverage at the district level.

facility instead of relying on studies at the worldwide level to determine the walking times; however, a survey at the regional level is out of the scope of this research. Nevertheless, checking the literature, we found some proxy information: adults aged 65 and older need 30 min a day of moderate-intensity activity, such as brisk walking [92], and the continuous walking distance, defined as a person's maximum walking distance without resting, of the elderly population in Japan ranges from 50 to 500 m [93]. Toddlers and pre-schoolers should spend at least 180 min (3 hours) doing physical activities spread throughout the day, including outdoor play, and the pre-schoolers group should include at least 60 min of moderate-to-vigorous intensity [94]. These estimations and indications are aligned with the periods to travel by foot to a healthcare facility used by Weiss et al. [57] in their study and by us in this research. For people with low mobility, the maximum time they were willing to walk would depend on individual conditions.

Although we did our best to combine the distance and the area-based approach, considering administrative boundaries and walking distance, we acknowledge that results per commune are mainly the area-based approach but adding walking-distance to the analysis and considering the concentration of population observed in satellite images we did consider the particular spatial details inside each commune of the RMS. Another limitation in our research is that we are only referring to healthcare facilities near the population's place of residence, which is why we consider the number of inhabitants per commune in the RMS and not the number of the floating population during the day, which is more relevant in communes with urban facilities such as offices, factories, schools, universities that attract large crowds of population during the day but not during the night. In the spatial analysis with the availability of a real-world road network (shapefile), we considered real distances rather than Manhattan distance, which is more appropriate for grid-shaped road networks.

It is paradoxical that the commune with the highest number of public healthcare facilities (40), women, children and inhabitants: Puente Alto is also the commune with the highest number of districts with low coverage of the service areas. Maipú, the commune with the largest elderly population has a medium coverage of the service areas of healthcare facilities in 13 of its districts, followed by low in 7, with only one district with no coverage but two with total coverage. San José de Maipo is not only the commune with the largest area in the RMS but also the highest level of vulnerability, according to our analysis. Its four inhabited districts have low coverage of the healthcare facilities located in the commune. In Vitacura, the commune with the highest income and, therefore, lowest SV, three of the five districts have healthcare facilities with medium coverage, one with high and the other with low. Although Cerro Navia is the commune with the lowest income in the RMS, three of its districts have total coverage of the service area by healthcare facilities; in the other three, the coverage is high; in two is medium, and in only one, the coverage is low. As expected, Padre Hurtado, the commune with the lowest number of public healthcare facilities, has three districts with no coverage, only one with low coverage and another district with a healthcare facility with medium coverage. In the commune with the highest number of healthcare facilities and private healthcare facilities: Santiago, 18 of the 29 districts have high coverage, seven have medium coverage, and five have total coverage. It was more complicated to determine the service area coverage in communes with a high and medium rurality index, such as Alhué, given that the coverage was determined using the road network considering the inhabited areas into their districts, and in these rural communes, houses are scattered. Those districts are 1,2 and 3 in Alhue, and all the districts in Buin, Calera de Tango, Colina, Curacavi, El Monte, Isla de Maipo, Lampa, Maria Pinto, Melipilla, Paine, Pirque, San Jose de Maipo, San Pedro, district 1 and 2 in Talagante and district 2 in Tiltil.

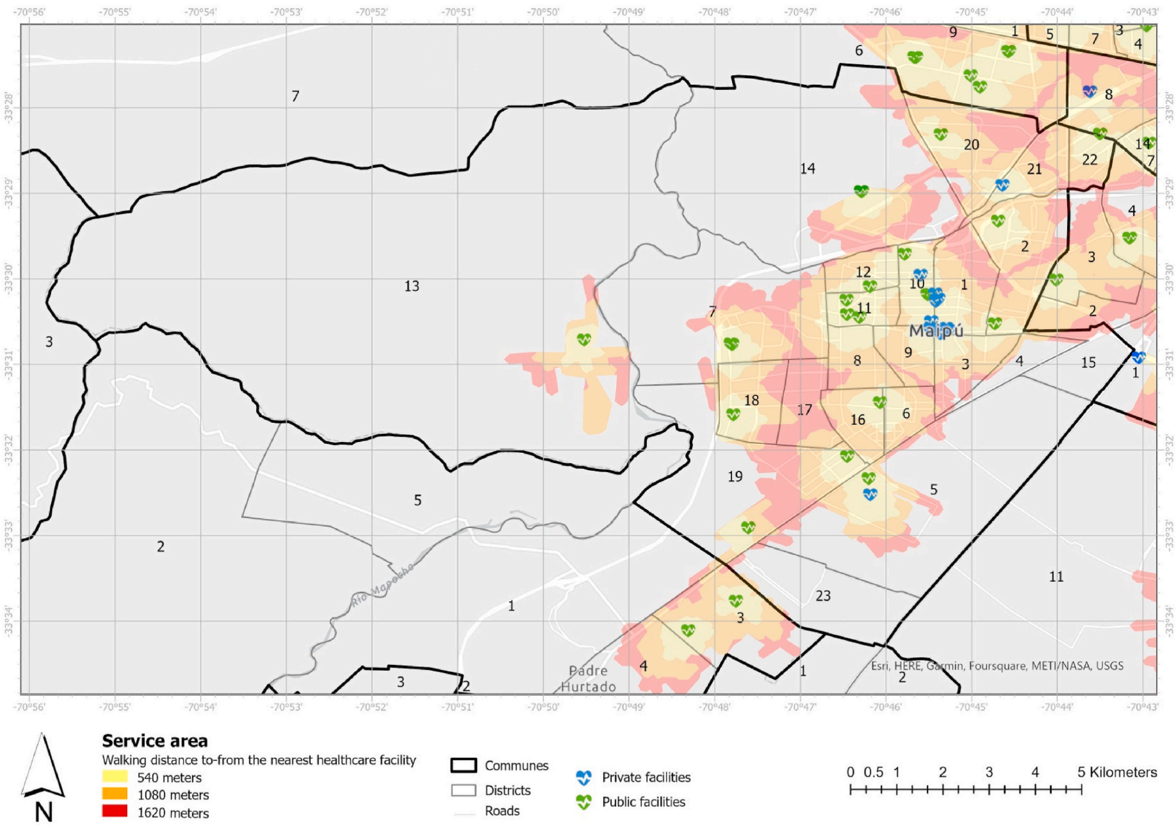

Fig. 12. Districts 1, 2, 3, 6, 8, 9, 12, 15, 16, 18, 20, 21, 22 and 14 at the commune of *Maipú* in the RMS, Chile, with healthcare facilities in service areas within 1620 m and beyond, considering the walking distance: medium coverage at the district level.

Although there are urban districts without healthcare facilities, they still can have high or medium coverage from facilities in the neighbouring districts i.e. district 7 in Conchali, district 2 and 3 in La Cisterna, district 7 in La Granja, district 2 and 7 in La Pintana, district 3 in Las Condes, district 3 in Lo Espejo, district 3 Pudahuel, district 3 Quilicura, district 5 and 8 Recoleta, district 3, 6 and 9 in Renca, district 3 and 13 in San Bernardo, district 5 and 7 San Miguel, district 2 and 6 in San Ramon, District 8, 9 and 14 in Santiago and district 1 in Vitacura. Other districts with no healthcare facilities can have low coverage but still have some coverage, such as districts 3 and 10 in Recoleta, districts 4 and 5 in Renca, district 7 in San Bernardo, and district 3 in Vitacura. Considering coverage of the service areas from neighbouring district we avoid the proven weakness of assuming that not interactions occurs across borders [63]. Districts 4, 5 and 8 in La Pintana and district 5 in Peñalolén have empty parcels, therefore the service area of the healthcare facilities is considered medium even if it could be considered low comparing with the administrative borders of the districts. The same happens with districts that host industrial facilities.

5. Conclusions

Private healthcare insurance offers more benefits for those enrolled but is mainly accessible to high-income populations. The inhabitants in the communes in the RMS relying only on the service provided by public healthcare facilities will typically have less quality care. Vulnerable population groups usually requires more visits to the doctor and more complex treatments given their gender, age and/or physical or mental condition, which is why they need a healthcare facility within walking distance. This inequity is mainly visible in the outer districts of Santiago and in the communes with high or medium rurality [91] in the RMS, which are barely covered by the public system and not covered by private facilities at all, such as San Pedro, Alhué and María Pinto. Instead, in the urban areas, one of the communes with the lowest levels of SV is also the comune with the highest number of healthcare facilities: Santiago. The highest number of healthcare facilities tends to be found in communes with the lowest SV and highest average income such as Providencia.

A healthcare system is composed of a combination of people, processes and products [18], represented in this research by the SV level of the population in the RMS, public and private healthcare insurance and healthcare facilities. However, the location of the total healthcare facilities in the RMS is predicted neither by the demographic characteristics of the population (age and gender) nor the SV level of their population, which we consider a proxy for the SDH, but rather by the location of the public healthcare facilities, population's income and density. Therefore we can state that our hypothesis is partially accepted: the coverage of the healthcare facilities in the RMS is shaped by the incomes rather than the population's healthcare needs. The area of a communes does not predict the number of healthcare facilities per commune at the RSM, given that rural communes tend to have inhabited districts with empty parcels and others host industrial facilities where healthcare facilities are less important. Hence the spatial distribution of healthcare facilities cannot be prioritized on the basis of locating at least one healthcare facility per district. That is why population density is considered a good predictor of the number of healthcare facilities per commune in the multiple regression model.

Network analysis has allowed us to integrate distance-based and area-based approaches to spatially visualise the service area of the healthcare facilities in all the districts in the communes of the RMS according to different walking distances. The coverage of the service areas of healthcare facilities in districts with communes with high or medium rurality is low or none and is mainly covered by public healthcare facilities, which is the opposite situation in urban districts, mainly in those with low vulnerability and high income, thus confirming the initial

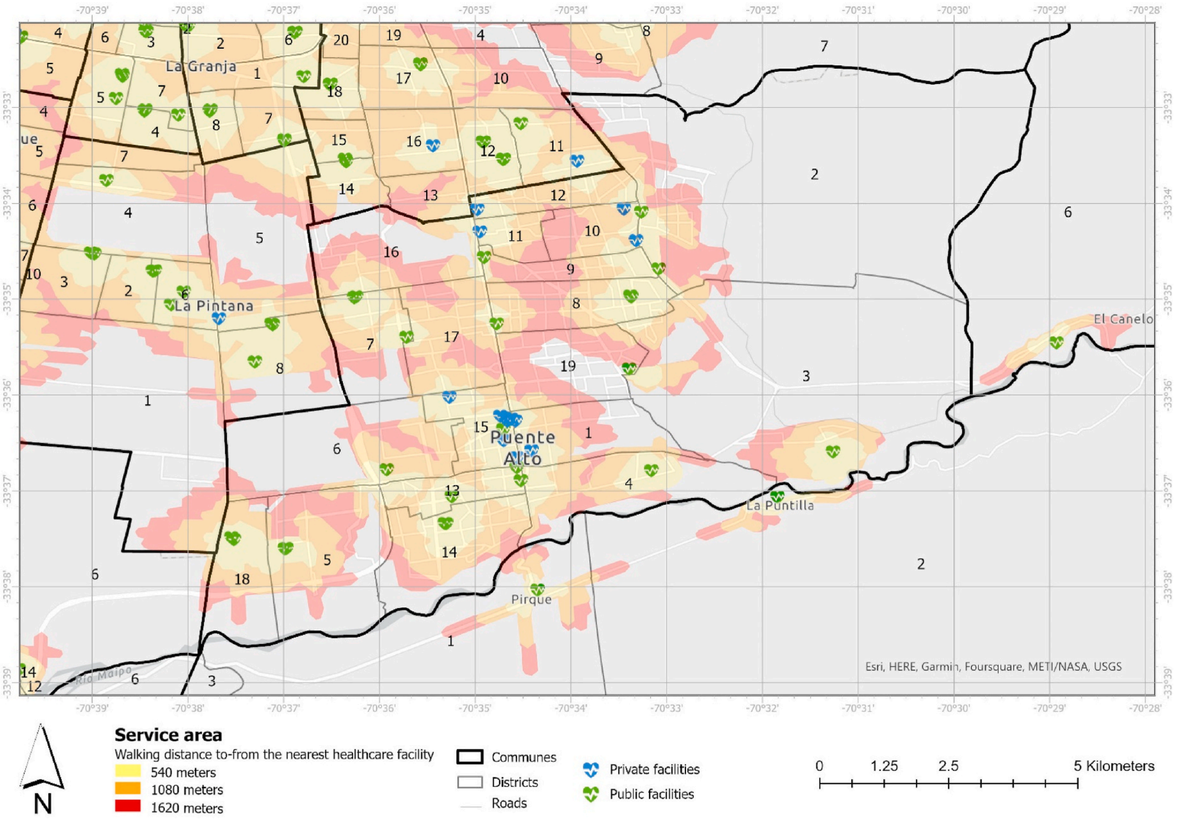

Fig. 13. Districts 1, 2, 3, 4, 5, 6, 7, 14, 16, 18 and 19 at the commune of Puente Alto in the RMS, Chile, with healthcare facilities in service areas beyond 1620 m considering the walking distance: low coverage at the district level.

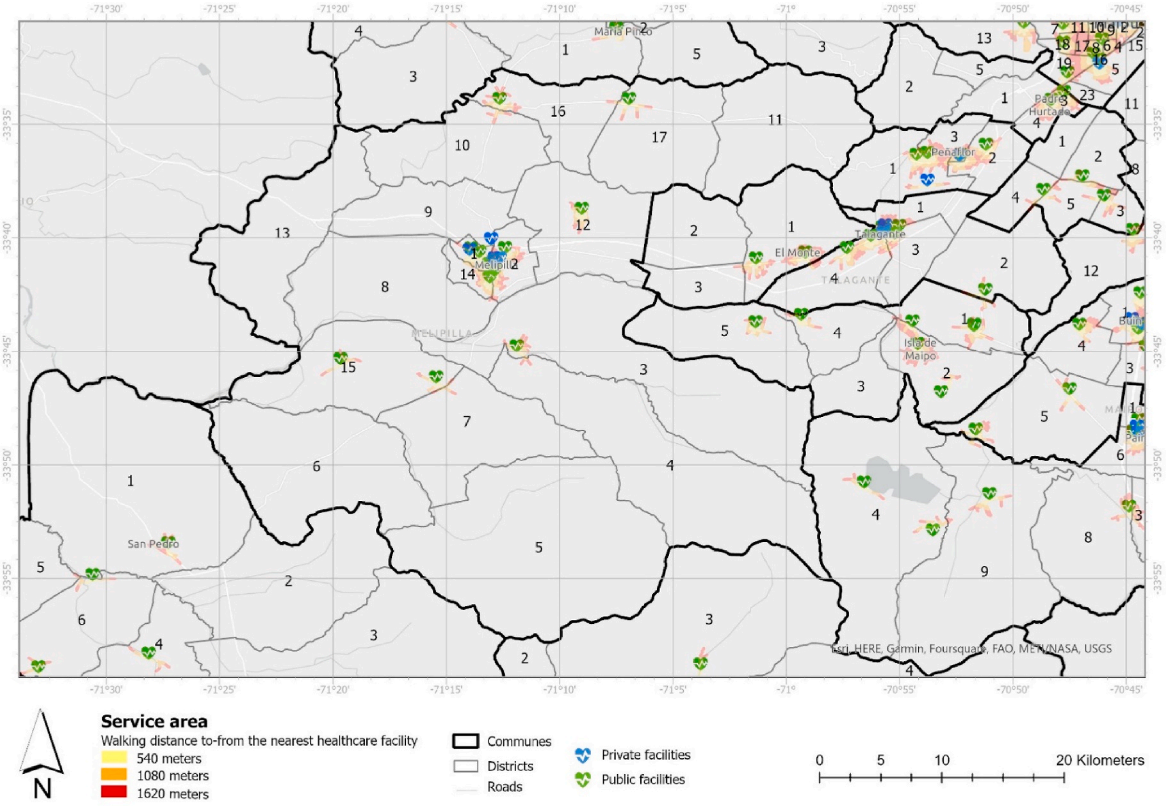

Fig. 14. Districts 4, 5, 6, 7, 8, 9, 11 and 13 at the commune of Melipilla in the RMS, Chile, with no coverage of service area of healthcare facilities considering the walking distance at the district level.

hypothesis.

6. Recommendations

Measuring spatial accessibility is fundamental for developing effective public health intervention strategies [58,59]. One important research area is to identify optimal locations for new facilities or to relocate existing facilities to improve the spatial planning of these facilities [95].

Consequently, our research shows that when additional healthcare facilities are being planned, the planner should consider locating at least basic healthcare facilities in those inhabited districts currently not covered by any or at least build capacity among their inhabitants as emergency first respondents. This capacity can be built based on first aid training and the provision of kits for this task. Our research suggest that the Index of Social Priority (ISP) developed by the Regional Ministerial Secretariat (SEREMI: Spanish acronym) in Chile [96] should be considered to prioritize the communes at the RMS either the capacity building in first-aid among its inhabitants or locate new healthcare facilities. This research indicates that it would be ideal including medical specialities in healthcare facilities according to the characteristics of the population in each RMS commune. More geriatricians and occupational therapists will be needed for Maipú, the commune with the highest number of elderly in the RMS, with walking distance not larger than 540 m around according to their walking speed [80], time for moderate-intensity activity [92] and maximum walking distance without resting [93]. The number of gynaecologists, obstetricians and paediatricians should be increased in Puente Alto, the commune with the highest number of women and children; in Estacion Central, the commune with the highest percentage of children under six-years-old suffering from malnutrition, and in La Pintana, the commune with the highest number or percentage of women between 15 and 19 years [96] with service areas not higher than 1620 m around according to the walking speed [80] of children and ideal time for moderate to vigorous physical activity in their age [94]. This approach to the allocation of medical care is known as a population-based healthcare system [18,74,97,98] that is rather an exception than a norm, despite policy-makers promoting it [97]. Considering that low-income households are particularly susceptible to CI's failures, our research demonstrate that it is necessary to increase the number of healthcare facilities in the communes of Cerro Navia, Pedro Aguirre Cerda, and Padre Hurtado.

After the service area analysis of healthcare facilities at the district level, our research indicates the need to add at least a second healthcare facility in the northeast of district 1 in Curacaví and the south-west of district 14 in San Bernardo. It is also recommended to add at least one healthcare facility in districts 4 and 3 in Curacaví, districts 2 and 3 in El Monte, districts 2, 6 and 9 in Estacion Central, district 5 in Huechuraba, district 4 in La Florida and La Granja, in district 1 in La Pintana, in districs 6 and 15 in Las Condes, in districts 2 and 5 in Lampa, in districts 23 in Maipu, in districts 5, 7 and 9 in Melipilla, in districts 3 in Maria Pinto, in districts 1, 2, 3 and 5 in Padre Hurtado, in districts 3 and 7 in Paine, in districts 8 in Pudahuel, in districts 4, 5 and 8 in Renca and in districts 10 in San Bernardo. The possibility of counting with the complete road network of the RMS, including secondary roads and integrating biking and pedestrians ways, will contribute to defining more accurate service areas for healthcare facilities.

Given the findings of Kondo et al. [73] and Gugushvili [67], it would be interesting for further research to survey self-reported health in the communes with higher levels of SV and low levels of healthcare facilities coverage. In the future, it would also be valuable to consider the service areas of other urban facilities that contribute to physical and mental wellness. These facilities include community and/or cultural centres, libraries, museums, parks, gyms, sports centres, churches, and swimming pools. Providing these urban facilities for more deprived communes will contribute to reducing the burden to healthcare facilities and reducing the current social inequality in the RMS.

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Author statement

Declarations of interest: 'none'.

Data availability

Data will be made available on request.

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