

Exploring the Influence of Urban Quality on Frailty, Nutritional Status, and Hematological/Biochemical Profile in Older Adults: Insights from Geospatial Approach

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Exploring the Influence of Urban Quality on Frailty, Nutritional Status, and Hematological/Biochemical Profile in Older Adults: Insights from Geospatial Approach

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Abstract

Background: Urban environments influence frailty through factors related to infrastructure for physical activity, social and medical support, and access to quality nutrition. Given the increasing aging population, understanding the link between urban quality, frailty, and metabolic health is crucial for effective public health and urban planning interventions.

Objective: To investigate the impact of urban quality on frailty and its correlation with nutritional status and hematological/biochemical parameters using geospatial analysis.

Methods: A cohort of 251 older adults (aged 65+) was studied. Frailty was assessed using the Frailty Trait Scale 5 (FTS-5), and nutritional status was determined using the Controlling Nutritional Status (CONUT) score. Hematological and biochemical parameters were evaluated in a subset of 70 participants by MINDRAY automatic equipment. A spatial analysis of frailty was conducted by incorporating GIS layers that mapped the distribution of urban facilities, including fruit and vegetable shops, senior centers, pharmacies, emergency health centers, parks and squares, community centers, and sports fields. Statistical analyses included t-tests, Mann-Whitney, ANOVA, and correlation analyses.

Results: The prevalence of frailty was 17.5%. Frail individuals exhibited significantly higher BMI (31.57 ± 4.4 vs. 28.57 ± 4.5 kg/m²; $p=0.0001$). When comparing the upper (Q4) and lower (Q1) quartiles of urban quality, Q4 participants had higher FTS-5 scores (15.27 ± 7.4 vs. 11.87 ± 6.4 ; $p=0.0334$) and lower handgrip strength (19.17 ± 4.4 vs. 22.87 ± 7.3 kg; $p=0.0059$). Frail individuals resided significantly closer to emergency health centers ($p<0.0001$), family health centers ($p<0.05$), and sports fields ($p<0.05$). Additionally, bilirubin (Spearman $R=0.3325$, $p=0.0049$), serum iron (Spearman $R=0.272$, $p=0.0272$), transferrin saturation (Spearman $R=0.2478$, $p=0.0386$), RBC (Spearman $R=0.2629$, $p=0.0303$), and RDW (Spearman $R=0.2391$, $p=0.0462$) were positively correlated with urban quality. Frail participants also had higher CONUT scores ($p=0.0323$), which were positive correlated with urban quality (Spearman $R=0.2513$, $p=0.0359$).

Conclusions: Urban quality significantly influences hematological parameters, nutritional status, and frailty. Frail individuals in areas with better urban quality exhibit lower handgrip strength, higher frailty scores, and greater proximity to emergency rooms, community health centers, and sports fields. This suggests compensatory behaviour to address increased healthcare needs. Urban planning and public health strategies should focus on creating age-friendly environments to prevent frailty and improve health outcomes.

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Conclusions: Urban quality significantly influences hematological parameters, nutritional status, and frailty. Frail individuals in areas with better urban quality exhibit lower handgrip strength, higher frailty scores, and greater proximity to emergency rooms, community health centers, and sports fields. This suggests compensatory behaviour to address increased healthcare needs. Urban planning and public health strategies should focus on creating age-friendly environments to prevent frailty and improve health outcomes.

Keywords: *Aging; Frailty; Geospatial analysis; Urban quality; Hematological parameters, Biochemical parameters, Nutritional status.*

INTRODUCTION

Global demographic changes have indicated an accelerated increase in the aging population, along with a rise in the prevalence of older adults [1]. This demographic transition has prompted the analysis of various key factors associated with the aging process, with frailty being one of the primary focuses in geriatric medicine [2]. This multisystemic syndrome is characterized by a decline in physiological reserves and intrinsic capacity, which leads to an increased vulnerability to stressors and a higher risk of adverse outcomes such as falls, hospitalization, disability, and mortality [3, 4]. The global prevalence of frailty varies between 12% and 24%, depending on the diagnostic tool used, and it is one of the key factors to prevent and reverse according to the World Health Organization (WHO) recommendations [5]. The increase in the frailty prevalence among older adults poses significant challenges for healthcare systems, highlighting the need for comprehensive strategies to address its underlying determinants [2, 3, 6]. Recent studies have highlighted the significant role of the urban environment in frailty, influencing both its development and improvement, independent of individual factors [7]. The built environment, characterized by access to green spaces, health services, community resources, places for physical activity, diet, and social interactions, plays a key role in frailty [7, 8, 9]. This is reflected in various studies indicating that older adults living in areas with lower land-use diversity and more social incivilities may be at risk of developing mobility limitations. In contrast, those residing in urban areas with limited resources and higher pollution levels tend to exhibit higher mortality rates associated with frailty [10, 11]. In this context, frailty and mobility limitations have been associated with the neighborhood physical characteristics, including land-use mix diversity, land-use mix access, street connectivity, walking infrastructure, aesthetics, crime safety, and social incivilities [11, 12]. Due to the relevance of frailty in older adults, the WHO has recognized the need to create age-friendly environments to promote healthy aging and reduce the risk of frailty [5]. In Latin America, urban inequalities are particularly pronounced, with limited access to critical services and significant variation in urban quality across neighborhoods and cities [13]. In Chile, rapid urbanization, the high prevalence of rural zones, and socioeconomic variability highlight the importance of understanding how urban quality affects the development, prevention and reversal of frailty in older adults. Despite these challenges, few studies have explored the spatial distribution of frailty in Chilean cities, indicating a significant research gap. Geospatial analysis has emerged as a powerful tool to assessing the spatial distribution of health outcomes such as frailty and their association with environmental factors [14]. By integrating Geographic Information System (GIS) data with health and sociodemographic variables, researchers can identify spatial clusters of frailty, assess the impact of urban quality, and suggest that urban

planning and policy interventions could play a crucial role in mitigating frailty risks [8, 9, 15]. In addition to environmental factors, nutritional and hematological status significantly influence frailty. Environmental conditions such as urban quality, have also been described as factors capable of modifying blood-level health profiles [16, 17]. Hematological abnormalities, such as variations in red blood cell (RBC) count and iron status, are correlated with frailty, potentially due to their impact on muscle function, oxygen transport, and fatigue. Additionally, various biochemical biomarkers have been associated with frailty, both at the hepatic and renal functional levels [18]. Therefore, understanding how urban quality influences these parameters could provide novel insights into frailty prevention strategies [17]. With this background, the aim of this study was to investigate the impact of urban quality on frailty status and its correlation with nutritional status and hematological/biochemical parameters using geospatial analysis.

MATERIALS AND METHODS

Participants and Study Design

A representative sample of 300 older adults (≥ 65 years; men and women) from Talca, Chile's Family Health Centers, and community groups participated in this cross-sectional case-control study. The inclusion criterion was adults aged 65 years and older. Participants with self-reported or medically documented cancer, Parkinson's disease, or vascular accidents were excluded, as well as older individuals unable to walk or speak, and those currently on statin therapy [18]. The study was approved by the University of Talca Ethics Committee, and all participants provided written informed consent. The sample size calculation (for adults aged ≥ 65 years, both men and women) considered a frailty prevalence of 24.6% in older adults, with a confidence level of 95%, statistical power of 80%, and a loss percentage of 20%. The sample's gender ratio mirrored the distribution of the over-65 adult population, as per National Socioeconomic Characterization Survey data.

Frailty Diagnosis

Frailty was measured using the FTS-5 scale, which assesses frailty across five key domains: nutrition, physical activity, nervous system, strength, and gait speed. Nutrition was evaluated using Body Mass Index (BMI). Physical activity was assessed with the Physical Activity Scale for Elderly (PASE). Nervous system function was evaluated using the Progressive Romberg Test. Strength was determined by handgrip strength in the dominant hand. Gait speed was measured by time taken to complete a 3-meters walk at a usual pace. Each domain is scored on a scale from 0 to 10 points. Frailty was determined by summing the scores across all five domains, resulting in a total range of 0 to 50 points. A score above 25 was considered indicative of frailty.

Nutritional Status

Nutritional status was assessed using the Controlling Nutritional Status (CONUT) score, a validated tool based on three biochemical parameters: serum albumin, total lymphocyte count, and total cholesterol levels. Each parameter is assigned a score based on predefined thresholds, and the sum of these scores provides the overall CONUT score. Higher scores indicate a greater degree of malnutrition, with classifications ranging from normal (0-1) to severe malnutrition (≥ 9).

Hematological and Biochemical Profile

Seventy plasma and serum samples were randomly obtained from cohort participants. Blood samples were collected using Ethylenediaminetetraacetic Acid (EDTA, 4.5 mL) and without anticoagulant (5 mL), by phlebotomy. The EDTA blood sample was used to determine hematological profile (BC-3600 MINDRAY, China) using automated equipment. The blood sample without anticoagulant was centrifuged at 240g for 15 min to obtain serum, which was used to determine the biochemical profile (BC300 MINDRAY, China) using automated equipment. The sample size was calculated using the GRANMO calculator with a 95% confidence level, 80% statistical power, and an expected loss rate of 20%.

Geospatial Data Base

A georeferenced database was created using Geographic Information System (GIS) technology to represent the physical environment of the study area and the locations of the older adults participating in the study (Figure 1). Each participant was geographically located as a point object based on the residence data provided during the medical evaluation. All data were organized into a point feature layer, accompanied by a corresponding thematic table. The database included relevant factors related to urban physical infrastructure within the city, such as fruit and vegetable shops, senior centers or communities, pharmacies, emergency health centers, main squares and parks, family or community health centers, and sports facilities like stadiums and fields. Each component was represented as a GIS layer, either in point or polygon form, at the neighborhood level, using geographical information from OSM (OpenStreetMap), Google Maps, and IDE Chile (Geospatial Infrastructure of Chile). The city of Talca (Maule Region, Chile) was further divided into six main clusters based on sociodemographic characteristics: Cluster 1 represents the northeastern sector with a high socioeconomic status; Cluster 2 covers the southeastern sector with a low socioeconomic status; Cluster 3 includes the northern sector with a lower-middle socioeconomic class; Cluster 4 corresponds to the historic center; Cluster 5 encompasses the southern sector with a medium-high socioeconomic level; and Cluster 6 refers to the industrial center area.

Urban Quality Level

Each GIS layer was analyzed using the Euclidean distance method to assess the proximity of each location within the city to various urban facilities. The resulting distance layers were then classified into three distinct zones: close, medium, and distant. Following this classification, each proximity category was assigned a score on a scale from 1 to 3, with the closest proximity receiving a score of 3 and the more distant areas being assigned a score of 1. The distance ranges and corresponding scores for each urban facility were defined based on the local context, as shown in Table 1. The general evaluation criterion was that closer proximity to a facility resulted in a higher score. A raster calculator was used to aggregate all layers into a Summary Index, with higher numerical values indicating better urban quality in the corresponding area. Finally, the values from the distance analyses and the resulting Summary Index for each participant were incorporated into the point feature layer. Data management, processing, and analysis were performed using ArcGIS software, version 10 (ESRI, Redlands, CA, USA).

Statistical Analysis

Statistical analyses were conducted using GraphPad Prism 9. Continuous variables were expressed as mean $\pm$ SD or median with 95% CI. Categorical variables were expressed as percentages with a 95% CI. Group differences were assessed using the Chi-Squared test with Yate's correction for proportions. For differences in means or medians, the t-test, Mann-Whitney test, or ANOVA were applied, depending on the context. Correlation analysis was performed using Spearman's correlation coefficient (R). Statistical significance was considered at p-values < 0.05 .

RESULTS

Sociodemographic Characteristics and Spatial Cluster Distribution by Frailty Status

Table 2 presents the sociodemographic characteristics of the study cohort, as well as the geospatial distribution by frailty group. The cohort consists of 17.5% (n=44) frail older adults and 82.5% (n=207) non-frail older adults. No significant differences were observed in the prevalence of women between groups ($p=0.6424$). The frail group had a higher mean age (75.6 ± 7.4 years) compared to the non-frail group (73.8 ± 5.2 years); however, this difference was not statistically significant ($p=0.0583$). Conversely, the frail group exhibited a significantly higher mean BMI (31.5 ± 4.4 kg/m²) compared to the non-frail group (28.5 ± 4.5 kg/m²) ($p=0.0001$). Regarding geospatial distribution, no significant differences were observed between the groups.

Frailty Characterization According to Quartile Distribution of Summatory Index

Figure 2 illustrates the different levels of urban quality [3], derived from the cumulative assessment of physical environmental factors considered in this study. These factors primarily include essential urban services and infrastructure critical to the older adult cohort under investigation. The quality level is closely linked to the accessibility of various facilities from each location within the city. Additionally, Figure 2 shows the individual distribution of older adults, with each participant identified by their frailty status. Table 3 presents the prevalence of frailty, frailty score, handgrip strength, gait speed, and BMI according to the quartile distribution of the summatory index associated with urban quality. As previously mentioned, lower values of the summatory index indicate poorer level of urban quality, while higher values reflect better urban quality. Q1 represents the quartile with the lowest summatory index values (poorest urban quality), while Q4 represents the highest values (best urban quality). No significant differences were observed across all quartiles for the analyzed variables concerning frailty prevalence ($p>0.05$). However, when comparing Q4 with Q1, participants in Q4 exhibited a significantly higher FTS-5 score (15.2 ± 7.4 vs. 11.8 ± 6.4 , $p=0.0334$) and a significant decrease in handgrip strength (19.1 ± 4.4 vs. 22.8 ± 7.3 , $p=0.0059$). No significant differences were found between Q4 and Q1 for frailty prevalence, gait speed, or BMI ($p>0.05$).

Relationship between Frailty and Distances to Urban Facilities and Urban Quality

Figure 3 presents the comparison of average distance to urban facilities by frailty status, as assessed using the FTS-5 clinical tool. No significant differences were observed in the distance between frail and non-frail groups for key urban areas such as vegetable and fruit shops (Figure 3A), senior centers or communities

(Figure 3B), pharmacies (Figure 3C), and main squares and parks (Figure 3E) ($p>0.05$). However, Figure 3A suggests a trend where frail individuals tend to live farther from vegetable and fruit shops. In contrast, Figure 3D shows that the frail group is significantly closer to emergency health centers ($p<0.0001$). Similarly, the frail group was significantly closer to family or community health centers (Figure 3F) ($p<0.05$) and stadiums and sports fields (Figure 3G) ($p<0.05$).

Figure 4 presents the correlation analysis between frailty scores and the summatory index and compares this parameter by frailty status. In Figure 4A, the linear regression between the summatory index and the FTS-5 score shows a positive correlation, where an increase in the summatory index corresponds to a higher FTS-5 score. This correlation is statistically significant, with a Pearson R of 0.1319 ($p=0.0368$). A similar trend is observed in Figure 4B, which illustrates the correlation between the summatory index and the FTS-3 score (a shortened version of FTS-5), showing a Pearson R of 0.1562 ($p=0.0132$). Figure 4C compares the summatory index by frailty status, demonstrating a modest but significant increase in the frail group ($p=0.0310$).

Relationship between Urban Quality and Biochemical and Hematological Parameters

Table 4 presents the results of the correlation analysis between the summatory index and the biochemical and hematological parameters of the older adult participants. At the biochemical level, only bilirubin levels showed a significant correlation with the summatory index (Spearman $R=0.3325$) ($p=0.0049$). Figure 5A displays the linear regression for this parameter, illustrating a direct relationship where higher summatory index values are associated with increased bilirubin levels in older adults. At the hematological level, several parameters showed a significant correlation with the summatory index. Serum iron exhibited a positive correlation (Pearson $R=0.272$, $p=0.0272$), as illustrated in Figure 5E, where higher summatory index values correspond to increased serum iron levels. Similarly, transferrin saturation (Spearman $R=0.2478$, $p=0.0386$), red blood cell (RBC) count (Pearson $R=0.2629$, $p=0.0303$), and red cell distribution width (RDW) (Pearson $R=0.2391$, $p=0.0462$) also displayed positive correlations with the summatory index. The linear regression graphs in Figures 5B, 5D, and 5E, corresponding to each parameter, respectively, further illustrate this direct relationship, where an increase in the summatory index is associated with higher values of these hematological parameters.

Nutritional Status Assessed by CONUT Score According to Frailty Status and Its Correlation with Urban Quality

Figure 6 presents a comparison of the CONUT score by frailty status and its correlation with urban quality, measured through the summatory index. In Figure 6A, the frail group shows a significantly higher CONUT score ($p=0.0323$), indicating poorer nutritional status. Meanwhile, Figure 6B displays the linear regression analysis between the CONUT score and the summatory index, revealing a significant positive correlation between both variables (Spearman $R=0.2513$, $p=0.0359$).

DISCUSSION

Principal Findings

Our findings indicate that frailty prevalence in the studied cohort was 17.5%, which aligns with previous research reporting frailty rates ranging from 12% to 27% in Chilean older adults [19, 20]. The higher BMI observed in frail individuals is consistent with studies suggesting that obesity exacerbates physical limitations and inflammation, contributing to frailty [21, 22, 23]. Although the frail group had a higher mean age, the difference was not statistically significant. Age is a well-known factor for frailty, which prevalence increasing in advanced age, particularly in individuals aged 80 and older [24, 25]. However, it is important to consider that environmental and lifestyle factors may play a more substantial role than age alone [3]. The lack of significant differences in frailty prevalence across spatial clusters suggests a uniform distribution of risk factors in the evaluated area. This also highlights the need to expand the geospatial analysis to different urban and rural areas to capture the variations in frailty prevalence and associated risk [8].

In accordance with the previous findings, no significant difference in frailty prevalence was observed across quartiles based on the summatory index. However, Q4 did show a higher prevalence of frailty compared to Q1, though this difference was not statistically significant, suggesting that increasing the sample size might be necessary to confirm this trend. Additionally, Q4 exhibited a higher FTS-5 score, indicating a greater level of frailty. These results suggests that frail older adults may tend to cluster in areas with better urban quality, potentially as a compensatory measure in response to declining health and quality of life [26, 27]. For instance, greater access to natural environments (an important component of urban quality) is associated with lower levels of health inequality related to income deprivation, suggesting that older adults may choose to reside in areas with better urban features to support their health [28]. Similarly, increased greenery in urban neighborhoods is linked to better physical and mental health, which may lead frail older adults to prefer or remain in such areas to mitigate declines in their overall well-being [29].

On the other hand, Q4 also showed a significant decrease in handgrip strength, which correlates with a high FTS-5 score and greater frailty prevalence. A decline in handgrip strength is associated with poorer muscle condition, increased risk of sarcopenia, and a higher risk of mortality and chronic diseases. These results support the hypothesis that frail older adults may cluster in higher-quality urban areas, exhibiting a higher risk of sarcopenia and low handgrip strength, potentially due to selective migration and clustering effects [30]. Furthermore, these findings suggest that addressing sarcopenia could be a key focus in areas with better urban quality when designing strategies to prevent frailty and promote healthy aging in Chilean older adults [25, 31].

According to our findings, frail individuals lived noticeably closer to sports fields, community health centers, and emergency medical facilities. This clustering likely reflects the increased healthcare demands and compensatory behaviors of frail populations, rather than merely indicating improved overall accessibility. While proximity to sports fields suggests that even frail older adults may prioritize access to recreational spaces that support physical activity and social interaction, the closeness to emergency and community health centers likely provides essential support for managing both acute and chronic health conditions [29, 32]. Furthermore, the negative correlation observed between the summatory index (where lower values indicate poorer urban quality) and frailty scores supports the hypothesis that frail individuals tend to reside in areas with better urban

quality, potentially as a compensatory strategy, as previously discussed.

Our results support the notion that environmental factors play a significant role in determining the health status of older adults, demonstrating a strong correlation between frailty, urban quality, and key biochemical and hematological parameters. The correlations observed offer valuable insights into the impact of urban environments on the nutritional status and metabolic health of older populations. Better urban settings may be associated with improved liver function and oxidative stress regulation, as evidenced by the positive correlation between bilirubin and the summatory index. Bilirubin, an established antioxidant, has been linked to reduced cardiovascular risk and inflammation in previous studies [33]. Higher urban quality may also promote healthier lifestyles, including increased physical activity and dietary habits that support liver health and metabolic homeostasis [17]. Additionally, the positive correlation between serum iron, red blood cell (RBC) count, transferrin saturation, and red blood cell distribution width (RDW) with urban quality suggests that better urban environments contribute to improved hematological health [34]. These parameters are critical for assessing anemia and overall oxygen transport capacity, both of which are key determinants of functional capacity and frailty [18]. Poor urban quality, characterized by limited access to nutrient-dense food sources and inadequate healthcare services, has been associated with increased risks of anemia and micronutrient deficiencies [35]. Our findings align with studies suggesting that built environments influence dietary patterns, potentially affecting blood parameters [16].

Finally, our results reveal an association between frailty and a higher CONUT score, highlighting the interplay between nutritional status and frailty. Malnutrition is a known contributor to frailty, and the CONUT score has been validated as a reliable marker of nutritional risk in frail older adults [36, 37]. Our findings suggest that frail individuals have poorer nutritional status, which aligns with previous research emphasizing the role of malnutrition in sarcopenia, immune dysfunction, and increased morbidity [19, 38, 39]. The observed correlation between urban quality and the CONUT score suggests that individuals in areas with better urban infrastructure tend to have improved nutritional status. Access to fresh food markets and community resources likely supports better dietary intake, reducing the prevalence of malnutrition and related chronic diseases [40, 41]. In contrast, areas with lower urban quality may face food insecurity and limited nutritional options, potentially exacerbating frailty risk due to inadequate protein and micronutrient intake [35, 42].

CONCLUSIONS

Our research demonstrates that, among older adults in Chile, urban quality has a significant impact on their metabolic health, nutritional status, and frailty. Frail individuals residing in areas with better urban quality exhibited lower handgrip strength and higher frailty scores. Additionally, frail individuals lived closer to emergency rooms, community health centers, and sports fields, suggesting a compensatory behavior to address their increased healthcare needs while promoting social and physical activity. Moreover, higher CONUT scores in frail individuals and positive correlations between urban quality and key biochemical/hematological parameters indicate that better urban environments may support healthier metabolic and nutritional profiles. Given the cross-sectional design and localized scope of this study, future research should incorporate longitudinal approaches and larger, more diverse cohorts to confirm these associations and explore the underlying mechanisms. The integration of urban planning and public health strategies aimed at creating age-friendly environments should be prioritized to prevent and reduce frailty,

ultimately enhancing the overall well-being of older adults.

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Conceptualization, DA, NM, YO, JCC; data curation, formal analysis, DA, YO; funding acquisition, CM, IP, EF; investigation, DA, YO, JCC; methodology, DA, NM, YO, JCC; project administration, CM, IP, EF; resources, CM, IP; software, YO; supervision, CM, IP; validation, CM, IP; writing-original draft and writing-review & editing, DA, YO. ANID/FONDECYT grant N°3230783 has funded this work.

Conflicts of Interest

None declared.

Abbreviations

ANOVA: Analysis of variance
BMI: Body mass index
BUN: Blood Urea Nitrogen
CI: Confidence interval
CONUT: Controlling Nutritional Status
CRP: C-Reactive Protein
EDTA: Ethylenediaminetetraacetic Acid
ESR: Erythrocyte Sedimentation Rate
FTS: Frailty Trait Scale
GOT: Glutamic-Oxaloacetic Transaminase
GIS: Geographic Information Systems
LDH: Lactate Dehydrogenase
MCHC: Mean Corpuscular Hemoglobin Concentration
MCV: Mean Corpuscular Volume
MPV: Mean Platelet Volume
PASE: Physical Activity Scale for Elderly
RBC: Red Blood Cells
RDW: Red Blood Cell Distribution Width
SD: Standard Deviation
SEM: Standard Error of the Mean
TIBC: Total Iron Binding Capacity
WBC: White Blood Cell
WHO: Worldwide Health Organization

FIGURES AND TABLES

Table 1. Distances ranges and corresponding values assigned to each urban physical facility.

Facility	Distance Ranges (m)		
Vegetables and fruits shops	< 300	300 – 600	> 600
Senior centers or communities	< 500	500 – 1,000	> 1,000

Pharmacies	< 500	500 – 1,000	> 1,000
Emergency health centers	< 1,000	1,000 – 2,000	> 2,000
Main squares and parks	< 200	200 – 400	> 400
Family or community health centers	< 700	700 – 1,400	> 1,400
Stadiums and sports fields	< 400	400 – 600	> 600
	Value		
	3	2	1

Table 2. Sociodemographic description and geospatial distribution of the studied sample of older people according to frailty status.

		Non-frail (n=207)	Frail (n=44)	P-value
Variable	Female % (95% CI)	73.9 (67.5-79.4)	77.2 (63.0-87.1)	0.6424
	Age (mean $\pm$ SD)	73.8 $\pm$ 5.2	75.6 $\pm$ 7.4	0.0583
	BMI (mean $\pm$ SD)	28.5$\pm$4.5	31.5$\pm$4.4	0.0001
Spatial Cluster				
	Cluster 1 (95% CI)	12.6 (8.7-17.7)	6.8 (2.3-18.2)	0.2792
	Cluster 2 (95% CI)	17.4 (12.8-23.1)	18.2 (9.5-31.9)	0.5918
	Cluster 3 (95% CI)	17.9 (13.2-23.6)	22.7 (12.8-36.9)	0.4536
	Cluster 4 (95% CI)	11.6 (7.9-16.7)	6.8 (2.3-18.2)	0.3531
	Cluster 5 (95% CI)	23.1 (17.9-29.4)	27.3 (16.3-41.8)	0.5640
	Cluster 6 (95% CI)	17.4 (12.8-23.1)	18.2 (9.5-31.9)	0.5918

Table 3. Frailty prevalence, handgrip strength, gait speed, and BMI according to quartile distribution of summatory index.

Frail status	Q1 (12-17)	Q2 (>17-19)	Q3 (>19-20)	Q4 (>20-22)	P-value
Frail % (95% CI)	15.3 (8.7-25.3-)	17.8 (11.6-26.4)	17.3 (9.4-29.7)	23.1 (11.0-42.0)	0.8462
FTS-5 score (mean $\pm$ SD)	11.8 $\pm$ 6.4	13.6 $\pm$ 7.9	13.7 $\pm$ 8.3	15.2 $\pm$ 7.4*	0.2092
Handgrip strength (kg, mean $\pm$ SD)	22.8 $\pm$ 7.3	21.3 $\pm$ 7.3	22.4 $\pm$ 7.2	19.1 $\pm$ 4.4*	0.2620
Gait speed (m/s, mean $\pm$ SD)	1.028 $\pm$ 0.289	0.989 $\pm$ 0.252	0.966 $\pm$ 0.228	0.932 $\pm$ 0.214	0.6593
BMI (kg/m², mean $\pm$ SD)	29.34 $\pm$ 4.32	29.36 $\pm$ 4.11	29.08 $\pm$ 4.43	28.53 $\pm$ 4.21	0.7723

* P-value<0.05 respect to Q1.

Table 4. Correlation analysis between summatory index and biochemical and hematological parameters in older adults (n=70).

Parameters	Spearman R	P-value
Biochemicals		
GOT	-0.08882	0.4647
Alkaline phosphatase	-0.09997	0.4103
LDH	0.01318	0.9138
Bilirubin	0.33250	0.0049

Glycaemia	0.32420	-0.1196
Uric acid	0.09523	0.4329
Total Cholesterol	-0.13830	0.2537
BUN	-0.19880	0.0989
Calcium	0.03809	0.7542
Phosphorus	-0.10790	0.3741
Total proteins	-0.11900	0.3265
Albumin	0.10920	0.3683
CRP	-0.08326	0.4932
Hematological		
ESR	-0.20620	0.0868
Serum iron	0.27200	0.0272
TIBC	-0.02094	0.8634
Transferrin saturation	0.24780	0.0386
Hemoglobin	0.19150	0.1122
Hematocrit	0.21360	0.0758
RBC count	0.26290	0.0303
MCHC	-0.07245	0.5511
MCV	-0.11250	0.3537
RDW	0.23910	0.0462
WBC count	-0.06780	0.5770
Platelet count	0.07734	0.5245
MPV	0.07038	0.5626

GOT, glutamic-oxaloacetic transaminase; LDH, lactate dehydrogenase; BUN, blood urea nitrogen; CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; TIBC, total iron binding capacity; RBC, red blood cells; MCHC, mean corpuscular hemoglobin concentration; MCV, mean corpuscular volume; RDW, red blood cell distribution width; WBC, white blood cell; MPV, mean platelet volume.

Figure 1. Locations of each older adult in the study within the city of Talca, alongside the available urban physical facilities.

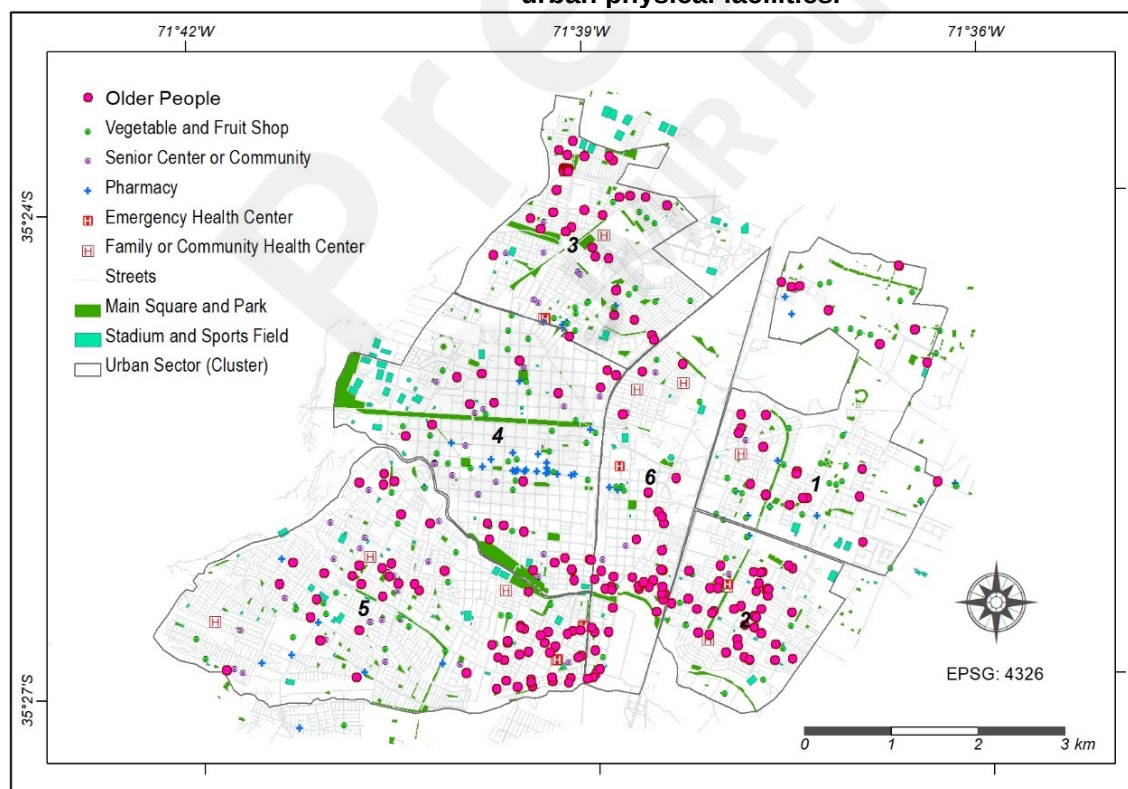
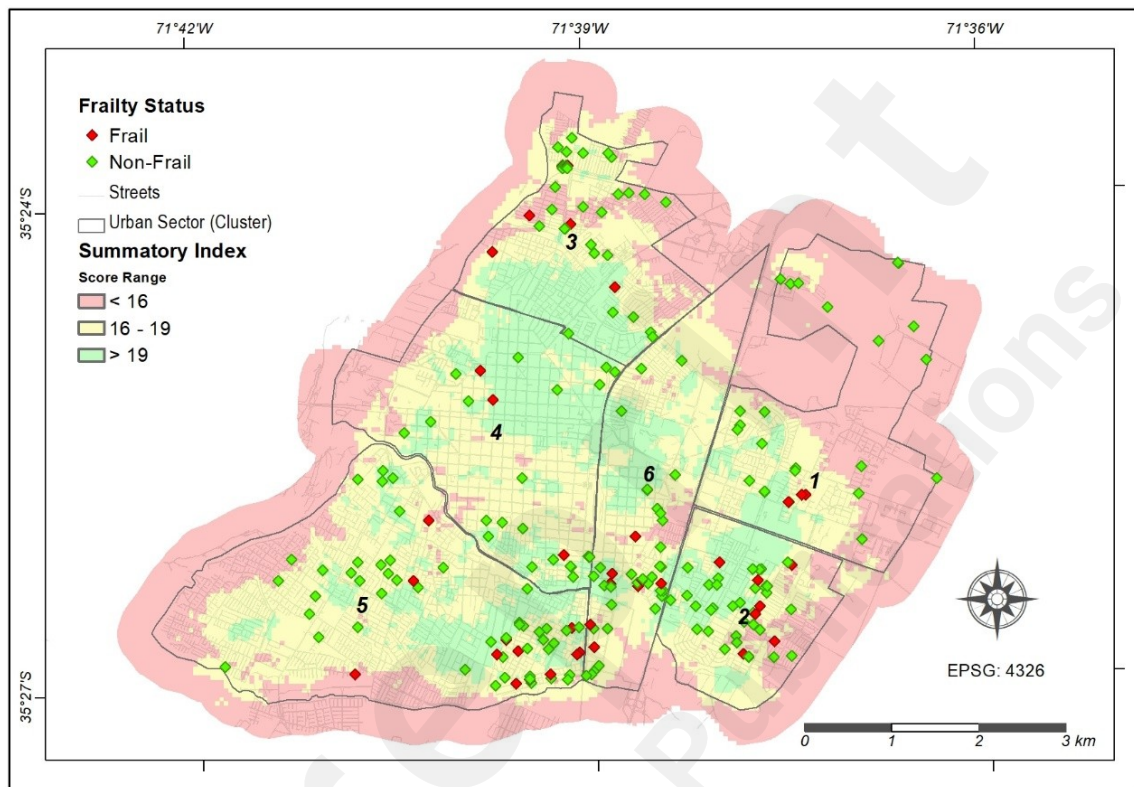


Figure 2. Frailty status of older adults across the summary index within the geospatial clusters defined for the city of Talca.



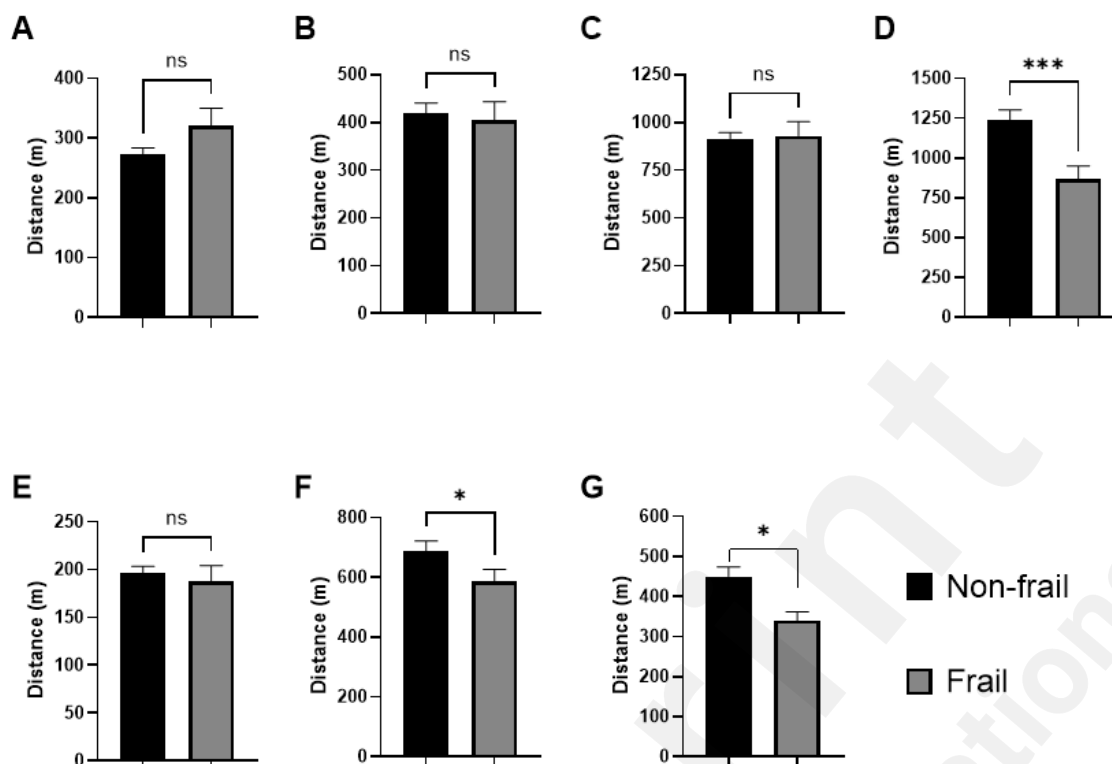


Figure 3. Comparison of mean distance for different frailty status diagnosed by FTS-5 scale with respect to relevant urban facilities: A) Vegetables and fruits shops; B) Senior centers or communities; C) Pharmacies; D) Emergency health centers; E) Main squares and parks; F) Family or community health centers; G) Stadiums and sports fields. The data presented is mean $\pm$ SEM. Statistical analysis was performed using the test-t or Mann-Whitney test, as appropriate. * $p < 0,05$; *** $p < 0,0001$.

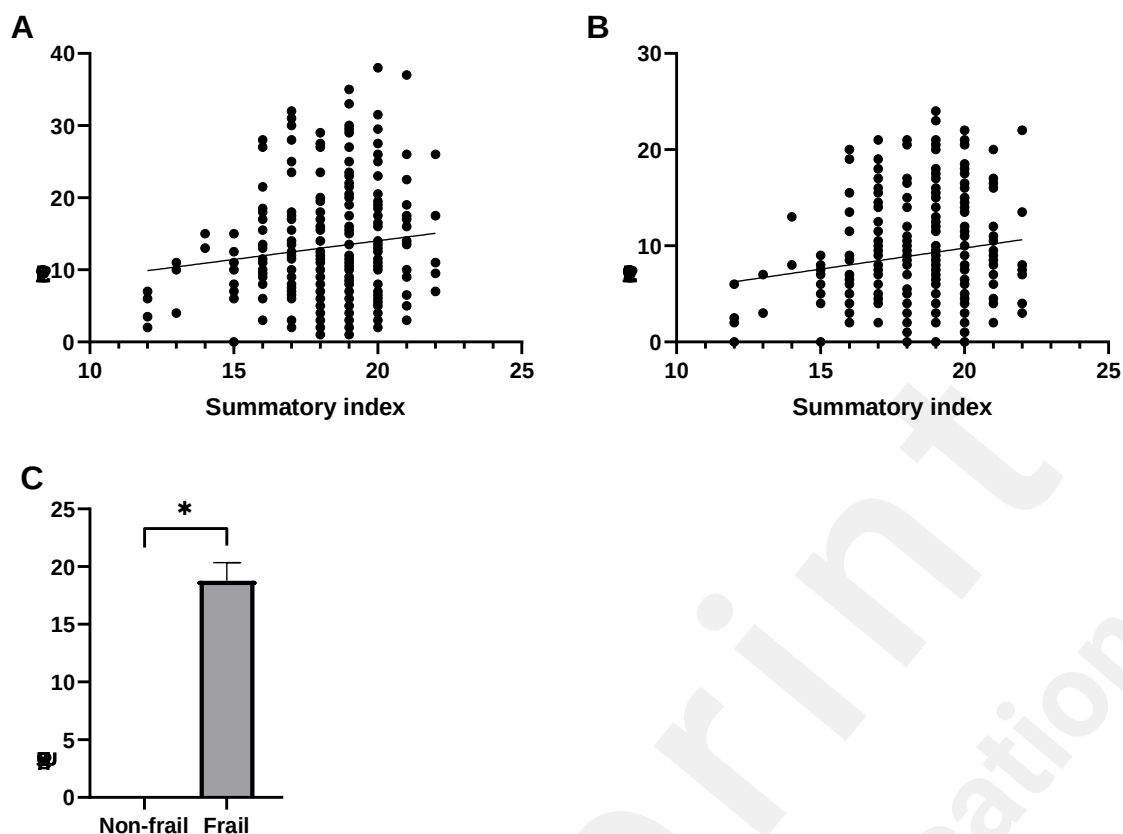


Figure 4. Linear regression between frailty scores and summatory index, and comparison of the summatory index by frailty status. A) Linear regression between summatory index and FTS-5 score; B) Linear regression between summatory index and FTS-3 score; C) Comparison of mean summatory index by frailty status diagnosed by FTS-5; D) Comparison of mean population density by frailty status diagnosed by FTS-5. The data presented is mean $\pm$ SEM. Statistical analysis was performed using the test-t or Mann-Whitney test, as appropriate. * $p < 0.05$.

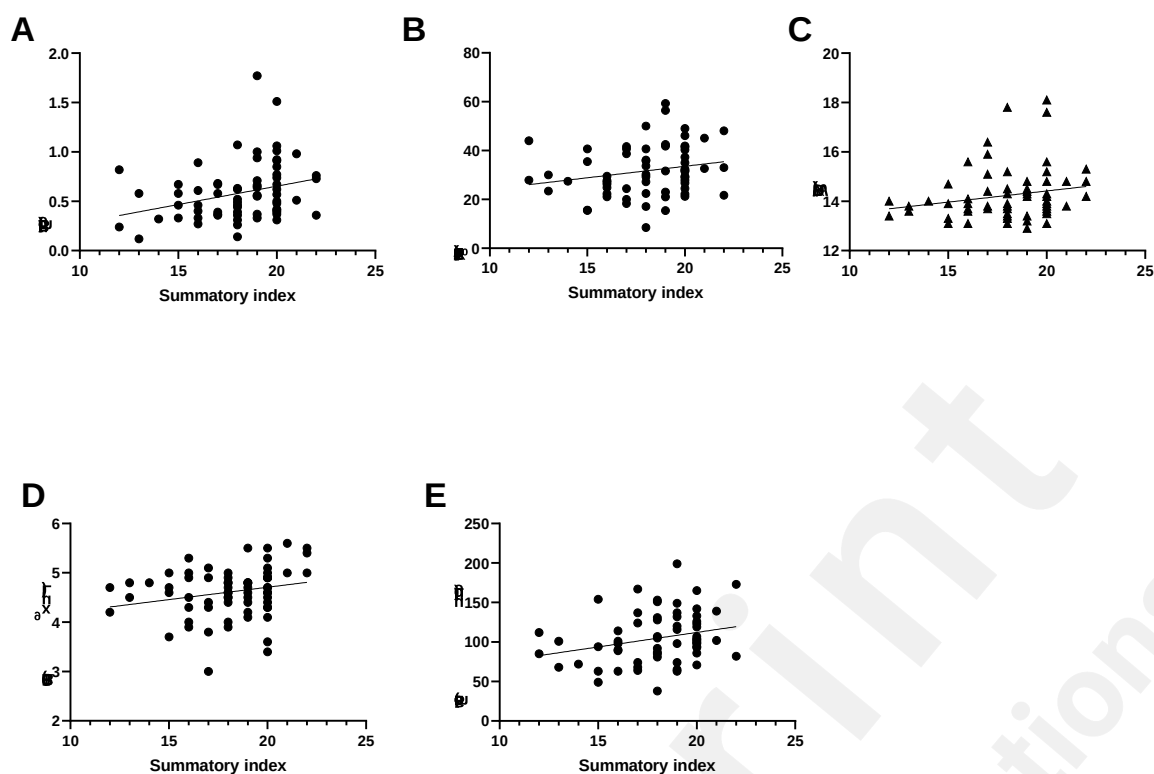


Figure 5. Linear regression analysis between summatory index and hematological and biochemical parameters. A) Bilirubin; B) Transferrin saturation; C) RDW; D) RBC; E) Serum iron. Statistical analysis was performed using linear regression and Spearman correlation analysis.

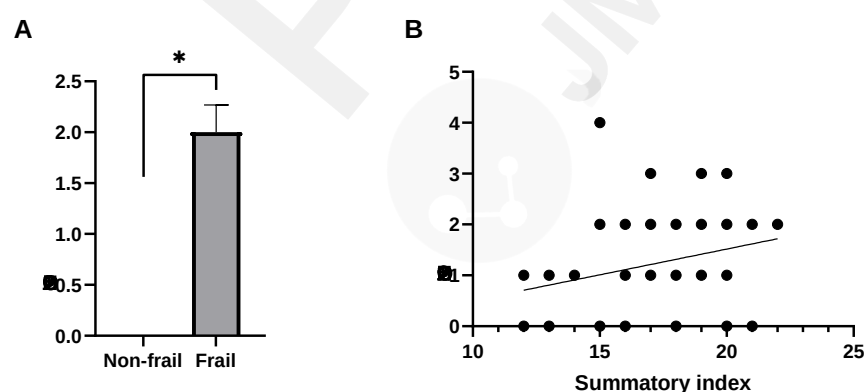


Figure 6. Relationship between nutritional status assessed using the CONUT score, frailty, and summatory index in older adults. A) Comparison of CONUT score based on frailty status according to the FTS-5 scale; B) Linear regression analysis between CONUT score and summatory index. Statistical analysis was performed by test-t.

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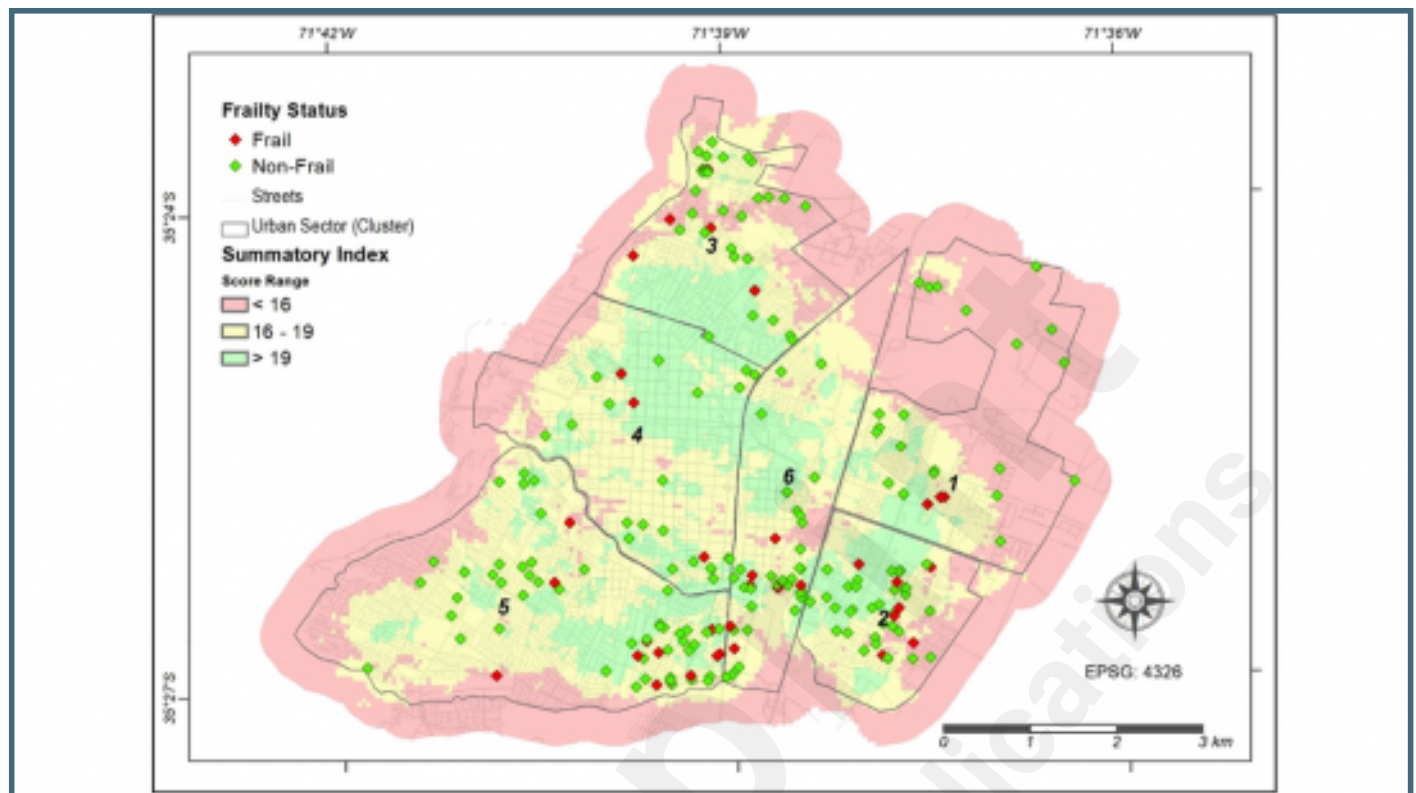
Supplementary Files

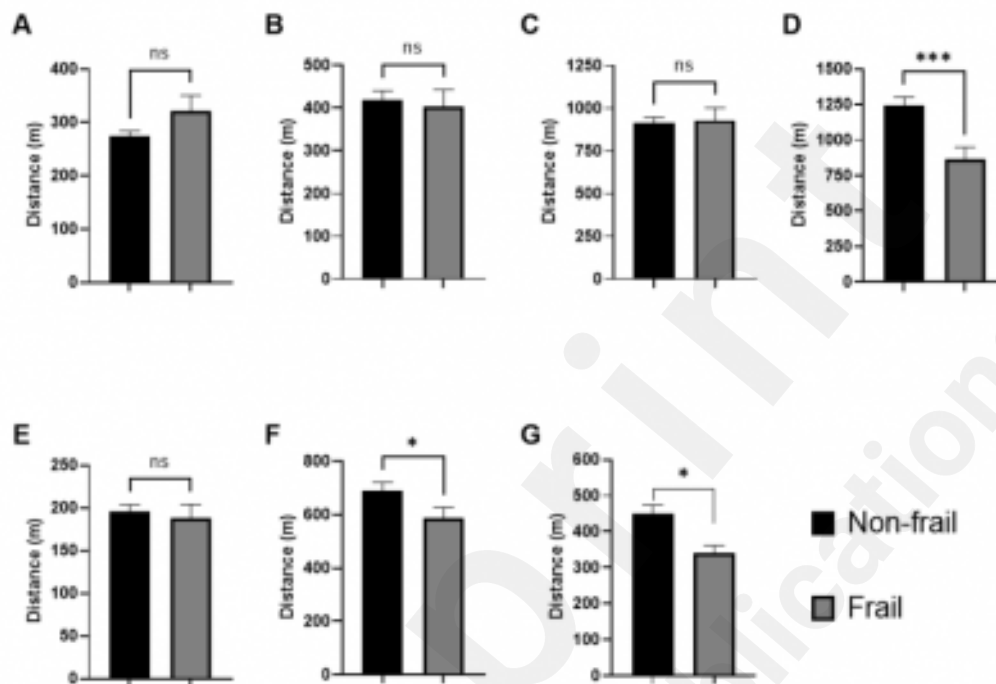
Figures

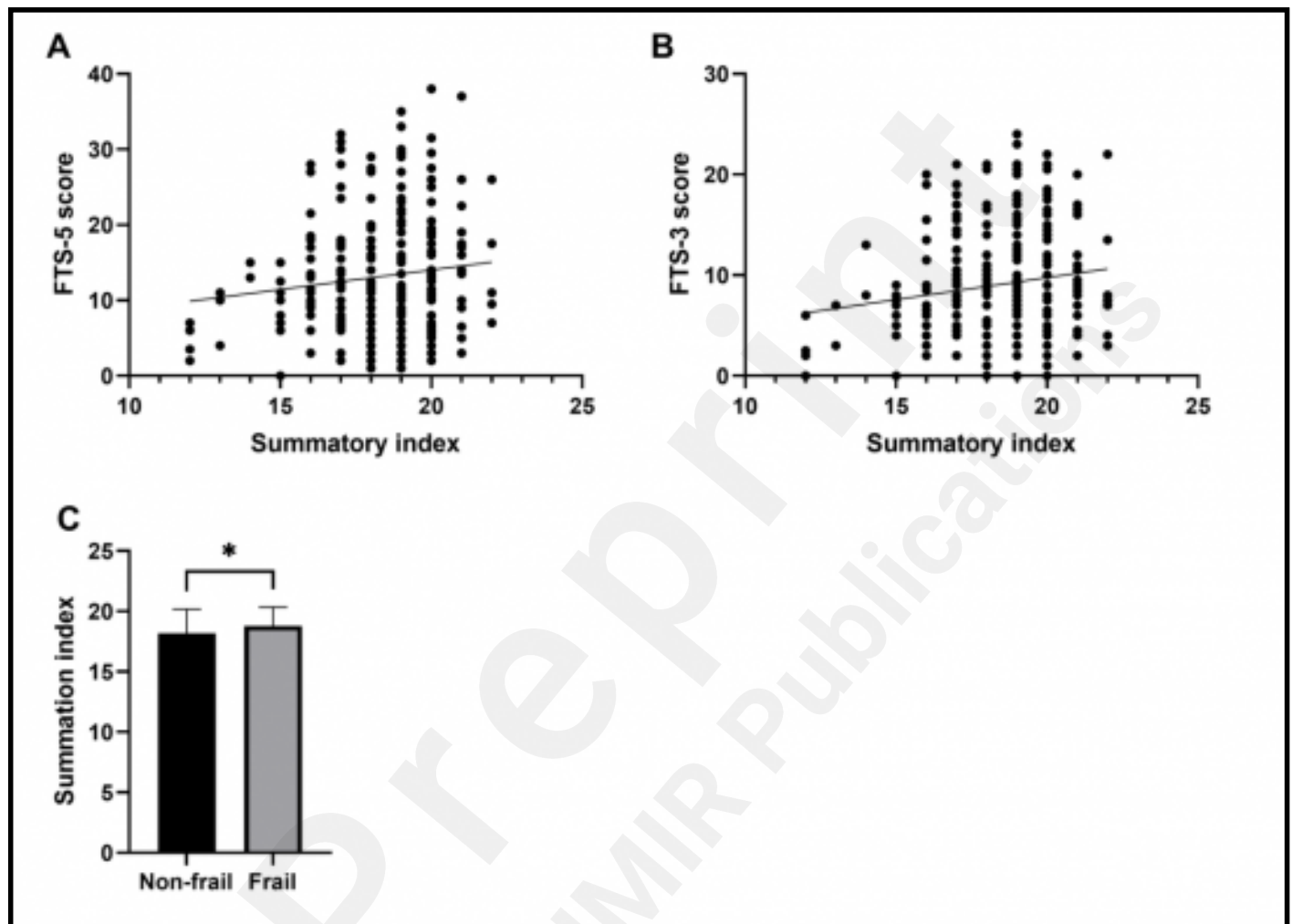
Locations of each older adult in the study within the city of Talca, alongside the available urban physical facilities.



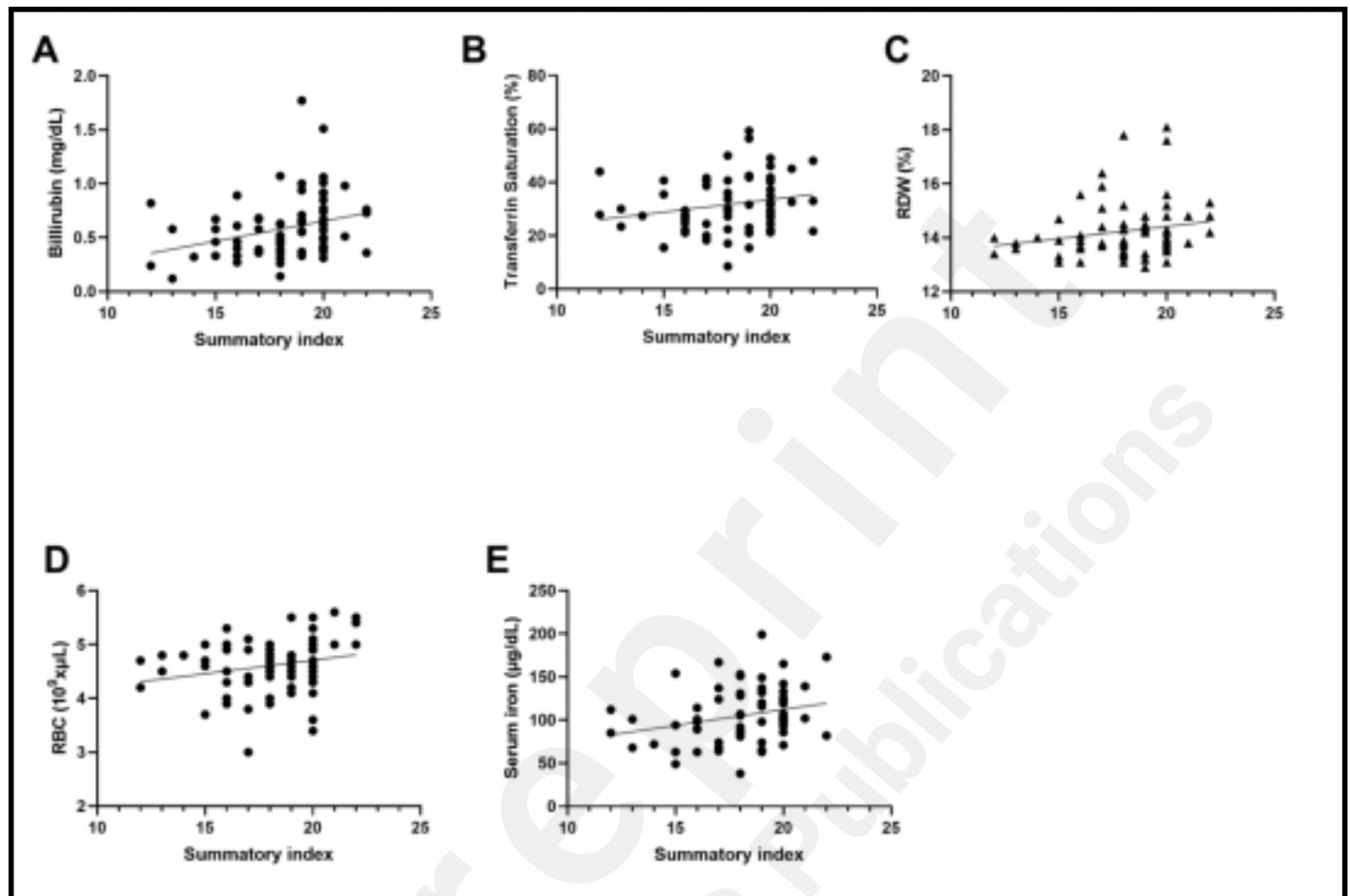
Frailty status of older adults across the summary index within the geospatial clusters defined for the city of Talca.







Linear regression analysis between summatory index and hematological and biochemical parameters. A) Bilirubin; B) Transferrin saturation; C) RDW; D) RBC; E) Serum iron. Statistical analysis was performed using linear regression and Spearman correlation analysis.



Relationship between nutritional status assessed using the CONUT score, frailty, and summatory index in older adults. A) Comparison of CONUT score based on frailty status according to the FTS-5 scale; B) Linear regression analysis between CONUT score and summatory index. Statistical analysis was performed by test-t.

