Geographic Inequalities in Cardiologist Distribution and Cardiovascular Disease Mortality in the Greek National Health System: A Geo-Epidemiological Study

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Abstract
This study aimed to assess geographic variation in cardiologist supply within the Greek National Health System (NHS) and to examine its spatial patterns alongside regional cardiovascular disease (CVD) mortality across Greece, using an ecological epidemiological design. Population-based CVD mortality data for 2022, and socioeconomic and geographical data at the prefecture level were obtained from the Hellenic Statistical Authority. Cardiologist counts in public hospitals were collected from national professional registries. Crude and indirectly age-standardized CVD mortality ratios (SMR) were calculated overall and by sex. Cardiologist availability was expressed per 100,000 inhabitants and standardized relative to the national average. For the population aged ≥40 years, mortality rates were expressed relative to the national mean, while cardiologist availability was standardized relative to the national median. Prefectures were subsequently classified into four categories according to their relative position in these two indices. Differences in socioeconomic and geographical characteristics across prefecture categories were assessed using the Kruskal–Wallis test and Pearson's Chi-square test of independence. Spatial patterns were visualized using geographic information systems. Marked geographic inequalities were observed in both CVD mortality and cardiologist distribution. Several prefectures exhibited excess age-standardized CVD mortality alongside lower-than-expected cardiologist availability. Significant differences between prefecture categories were observed in tertiary education levels and degree of urbanization, while insularity was significantly associated with category classification. Substantial spatial disparities between cardiovascular health needs and public-sector cardiologist supply persist in Greece. These findings highlight the demand for needs-based health workforce planning to reduce inequities and improve cardiovascular outcomes within the NHS.

Keywords: Spatial epidemiology; Cardiovascular mortality; Cardiologist supply; Geographic Analysis; Health inequalities; Geographic Information Systems (GIS)

1. Introduction

Cardiovascular diseases (CVD) remain the dominant cause of morbidity and mortality worldwide, despite decades of progress in prevention and treatment. Contemporary Global Burden of Disease (GBD) estimates confirm that CVD continues to account for the largest share of deaths globally, with substantial variation in mortality rates across countries and within regions (Wang et al., 2024, GBD 2021 Demographics Collaborators, 2024). In Europe, diseases of the circulatory system, with its main determinant, i.e., CVDs, remain a leading cause of death and a major driver of health-system expenditure and productivity loss, reinforcing the importance of equitable access to effective cardiovascular care (EUROSTAT, 2025). In Greece, the burden of CVD is similarly profound. National cause-of-death statistics document circulatory-system diseases among the principal causes of death, underscoring the persistent public health impact of ischemic heart disease, stroke, and heart failure. Greece also exhibits adverse trends in key cardiometabolic risk factors and a long-standing prominence of CVD mortality in epidemiological and health-services research, supporting the need for system-level interventions that extend beyond individual risk modification (Panagiotakos et al., 2025).

Alongside CVD prevention, the availability of diagnostic and specialist cardiovascular services is considered an important factor associated with cardiovascular outcomes. However, health-system performance depends not only on the absolute number of clinicians, but also on their geographic distribution, sectoral deployment (i.e., public vs private), and alignment with population need. Policy analyses have emphasized that physician maldistribution is a recurrent and difficult-to-correct phenomenon internationally, with important implications for the equitable distribution of healthcare resources and population health outcomes (Kulkarni et al., 2013, Boom t al., 2012). Greece is a salient case; while it is reported to have among the highest cardiologist densities in Europe overall, health workforce challenges persist within the public system and across regions, reflecting broader structural issues in workforce planning and the balance between primary and specialist care. Recent national professional registries further indicate substantial regional variation in physician counts, consistent with concerns about unequal coverage between metropolitan areas and island or rural regions (OECD/European Observatory on Health Systems and Policies, 2025).

At the same time, a growing body of research suggests that the socioeconomic and geographic characteristics of regions play an important role in shaping both population health and the availability of specialized healthcare services (Afni, 2023, Kapwata and Manda, 2018). Educational level, economic resources, and geographical accessibility have been associated with variations in cardiovascular risk factors, use of health services and availability of medical staff between regions (Sun et al., 2020). Regional, rural, and island areas in particular often face structural constraints related to transportation, infrastructure, and the distribution of health professionals.

A growing international literature suggests that specialist supply may be associated with population health outcomes, including mortality, although findings vary by context and methodology. Notably, previous ecological analyses have linked regional cardiologist density to cardiovascular mortality patterns, raising important questions regarding the spatial organization of specialist services within integrated care systems (Faridi et al., 2025, Chen et al., 2024).

Therefore, this study aimed to was to systematically assess geographic variation in cardiologist supply within the Greek National Health System and to examine its association with regional CVD mortality across Greece, using an ecological epidemiological design. Specifically, the study sought to quantify disparities in cardiologist density and CVD mortality, to classify prefectures according to their relative position in these indicators, to explore associated socioeconomic and geographical characteristics, and to generate evidence that may inform equitable health workforce planning and policy interventions aimed at improving population health outcomes.

2. Materials and Methods

2.1 Design

This study was based on population-based mortality data from CVD at the prefecture level in Greece in 2022 (see Hellenic Statistical Authority, ELSTAT, 2022). For each prefecture, the number of deaths from CVD by sex and age group (i.e., <40, 40–59, ≥60) was available, as well as the corresponding population sizes derived from the 2021 national census (see Hellenic Statistical Authority, ELSTAT, 2021). The same age classification was used at the national level to ensure the comparability of the calculations. Information on the number of professional cardiologists in public hospitals (i.e., National Health System, NHS) per prefecture were collected from the Hellenic Cardiovascular Research Society, a Greek scientific, non-profit professional society dedicated to the advancement of cardiovascular research and the promotion of evidence-based cardiovascular medicine in Greece (see https://cardioresearch.com/cardio-map-greece/).

Additional prefecture-level socioeconomic and geographical variables were retrieved from the Hellenic Statistical Authority (ELSTAT, 2021 census). These included GDP per capita, percentage of the population with tertiary education, percentage of urban population, percentage of hilly, mountainous and lowland population, and insularity (binary variable: 1 = island prefecture; 0 = non-island). These variables were incorporated to explore potential structural, socioeconomic and geographical correlates of cardiovascular mortality and cardiologist availability.

2.2 Measurements

Crude CVD mortality rates per 100,000 inhabitants were calculated for each prefecture, as the ratio of total deaths to the corresponding population.

$$MortalityRate_i = \frac{D_i}{P_i} \times 100{,}000$$

where:

D_i = CVD deaths in prefecture i,

P_i = population in prefecture i.

Mortality rates were calculated for the total population as well as separately by sex. These indicators describe the actual mortality burden in each prefecture, but they are influenced by differences in the age structure of the population.

Given that cardiovascular mortality increases sharply with age, indirect age standardization was applied to estimate comparative mortality across prefectures. In the first stage, national age-specific mortality rates from CVD were calculated by dividing the number of deaths in each age group by the corresponding population at the national level.

$$MortalityRate_{GR,k} = \frac{D_{GR,k}}{P_{GR,k}}$$

where for each age group k:

$D_{GR,k}$ = CVD deaths in national level,

$P_{GR,k}$ = total Greek population.

These rates were expressed as probabilities rather than per 100,000 inhabitants.

Next, for each prefecture and age group, the expected deaths were calculated as the product of the local population and the corresponding national age-specific rate.

$$E_{i,k} = P_{i,k} \times MortalityRate_{GR,k}$$

where for each age group k:

$D_{i,k}$ = CVD deaths in prefecture i,

$P_{i,k}$ = population in prefecture i.

The sum of the expected deaths in all age groups produced the total expected number of deaths for each prefecture.

$$E_i = \sum_k E_{i,k}$$

The observed deaths were calculated as the sum of recorded deaths from CVD in all age groups.

$$O_i = \sum_k D_{i,k}$$

Finally, the indirectly standardized mortality ratio (SMR_i) was calculated as the ratio of observed to expected deaths for each prefecture:

$$SMR_i = \frac{O_i}{E_i}$$

SMR_i values equal to 1 indicate mortality consistent with the national reference, values greater than 1 indicate excess mortality, and values less than 1 indicate lower than expected mortality. The index was calculated for the total population, as well as separately for males and females. In practice, this index expresses the ratio of the age-standardized mortality rate (ASMR) of each prefecture to the corresponding national index.

To capture sex inequalities in CVD mortality within each prefecture, the sex ratio was calculated, defined as the ratio of the age-standardized mortality rate for males to that for females in the same prefecture.

$$ASMR_i^{sex} = \frac{ASMR_{m,i}}{ASMR_{f,i}}$$

where:

$ASMR_{m,i}$ = male age-standardized CVD mortality in prefecture *i*,

$ASMR_{f,i}$ = female age-standardized CVD mortality population in prefecture *i*.

Sex ratio values greater than one indicate higher male mortality, whereas values less than one indicate lower male mortality. The use of age-standardized indices allows for a fair comparison of sexes within and between prefectures, regardless of differences in their age composition.

To assess whether the local sex gap deviates from the national norm, the relative sex gap index was calculated as the ratio of the local sex ratio to the corresponding national ratio of male to female age-standardized mortality.

$$SexGap_i = \frac{ASMR_{m,i}/ASMR_{f,i}}{ASMR_{m,GR}/ASMR_{f,GR}}$$

where:

$ASMR_{m,i}$ = male age-standardized CVD mortality in prefecture *i*,

$ASMR_{f,i}$ = female age-standardized CVD mortality population in prefecture *i*.

$ASMR_{m,GR}$ = national male age-standardized CVD mortality,

$ASMR_{f,GR}$ = national female age-standardized CVD mortality.

Sex-gap values greater than one indicate that the sex gap in CVD mortality in the specific prefecture is greater than the national average, while values less than one indicate less sex inequality than the national average.

Next, the professional cardiologist in NHS data were used to calculate the cardiologist-to-population rate for each prefecture, defined as the number of cardiologists in public hospitals per 100,000 inhabitants:

$$CardioRate_i = \frac{Cardiologists_i}{P_i} \times 100{,}000$$

where:

$Cardiologists_i$ = number of cardiologists in public hospitals in prefecture *i*,

P_i = population in prefecture *i*.

To quantify the relative availability of cardiologists across prefectures, a population-standardized cardiologist supply index (CardioIndex) was constructed. The national cardiologist-to-population ratio was calculated by dividing the total number of cardiologists by the total population of Greece.

$$CardioRate_{GR} = \frac{\sum_i Cardiologists_i}{\sum_i P_i}$$

where:

$Cardiologists_i$ = number of cardiologists in public hospitals in prefecture *i*,

P_i = population in prefecture *i*.

Expected numbers of cardiologists for each prefecture were then derived by applying this national ratio to the prefecture-specific population size.

$$CardioE_i = P_i \times CardioRate_{GR}$$

The cardiologist supply index was defined as the ratio of observed to expected cardiologists.

$$CardioIndex_i = \frac{Cardiologists_i}{CardioE_i}$$

where:

$Cardiologists_i$ = number of cardiologists in public hospitals in prefecture *i*,

Cardio-index values greater than one indicate higher than expected availability of cardiologists relative to the national reference, whereas values below one indicates lower than expected availability.

Given that cardiovascular mortality occurs predominantly in middle-aged and older adults, and that these age groups are more likely to require cardiology services, additional standardized indices were calculated for the population aged ≥40 years. Restricting the analysis to this age group was intended to provide a more relevant evaluation of the association between cardiovascular mortality burden and cardiologist workforce availability, while minimizing potential distortion arising from younger populations, in whom CVD-related mortality is comparatively low.

For each prefecture, crude CVD mortality rates per 100,000 inhabitants aged ≥40 years were calculated. These were subsequently expressed relative to the national mean mortality rate for the same age group.

$$ASDR_i = \frac{DR_i}{DR_{GR}}$$

where:

DR_i = CVD mortality rate (≥40 years) in prefecture *i*,

DR_{GR} = national mean CVD mortality rate (≥40 years)

Values greater than 1 indicate higher than average mortality, whereas values below 1 indicate lower than average mortality compared to the national level.

To assess healthcare supply, the number of cardiologists working in NHS was calculated per 100,000 inhabitants aged ≥40 years for each prefecture. To allow inter-prefecture comparability, the indicator was expressed relative to the national median. In contrast to the ASDR indicator, for which the mean was used because it represents the national average mortality burden and is directly interpretable as a population-level reference value, the median was preferred for the MSCR indicator because cardiologist availability across prefectures displayed substantial variability and could be disproportionately influenced by a small number of prefectures with particularly high values. As a more robust measure of central tendency, the median reduces the influence of extreme observations and provides a stable reference point for distinguishing areas with relatively lower or higher specialist availability. Therefore, it was considered a more appropriate reference for classifying prefectures according to typical relative specialist availability.

$$MSCR_i = \frac{CR_i}{CR_{GR}}$$

where:

CR_i = cardiologists per 100,000 inhabitants (≥40 years) in prefecture i,

DR_{GR} = median cardiologist rate

Values greater than 1 indicate higher than median cardiologist availability, whereas values below 1 indicate lower than median availability.

Then, prefectures were categorized according to their relative position in both indices:

- High-High: ASDR>1 and MSCR>1

- High-Low: ASDR>1 and MSCR<1

- Low-High: ASDR<1 and MSCR>1

- Low-Low: ASDR<1 and MSCR<1

This classification was used to explore patterns of concordance or discordance between mortality burden and physician supply (Alter et al., 2008).

For ASDR, MSCR, socioeconomic and geographical indicators, descriptive statistics were calculated separately for each prefecture category (High-High, High-Low, Low-High, Low-Low).

To assess differences between prefecture categories in GDP per capita, tertiary education, urban population, and morphological variables, Kruskal-Wallis test was applied. The association between prefecture category and insularity (binary variable) was examined using the Pearson Chi-square test of independence. The level of statistical significance was set at $\alpha = 0.05$.

All indicators were geocoded and linked to the prefecture-level spatial framework of Greece by assigning each value to its corresponding prefectural unit. All the indices, including crude mortality indices, indirect age standardization index, sex ratio, and relative sex gap index, CVD mortality rates for the population aged ≥40 years (ASDR ≥40), cardiologist availability in the NHS (MSCR), and the prefectural classification (High-High, High-Low, Low-High, Low-Low), were mapped at the prefecture level to highlight spatial patterns and inequalities in CVD mortality in Greece. The thematic maps were classified using a mean-based classification approach. For mortality rates and cardiologist density maps, class boundaries were derived iteratively from the overall mean and the means of observations above and below the overall mean, generating five categories that reflect the underlying distribution of the data. For ratio-based indicators (SMRi, CardioIndex, ASDR, and MSCR), classification was centered on the reference value of 1.0, with additional intervals defined to distinguish moderate deviations (0.81–1.00 and 1.01–1.20) from more pronounced deviations (≤0.80 and ≥1.21).

All statistical analyses were conducted using STATA version 18 (STATA Corp., College Station, Texas, USA). Maps were derived using the ArcGIS software (ESRI, USA).

3. Results

The analysis of mortality data from CVD and the distribution of cardiologists at the prefecture level revealed marked spatial and sex inequalities in Greece. Specifically, CVD mortality rates for the year 2022, per 100,000 inhabitants showed significant geographical variation, with higher rates recorded mainly in prefectures of Northern and Central Greece, while lower rates were observed mainly in island and metropolitan areas (**Fig. 1a**) ($p<0.001$). Similar spatial patterns were observed when the analysis was stratified by sex (**Fig. 1b and Fig. 1c**), with crude rates being higher on average among females than among males (p<0.001). Nevertheless, because crude rates are directly influenced by the different age composition of the population by prefecture, the observed patterns cannot be interpreted solely as differences in underlying CVD risk. For this reason, these results constitute the first descriptive stage of the analysis and are subsequently supplemented by indirect age standardization indices, which allow for a more comparable assessment of the spatial distribution of mortality.

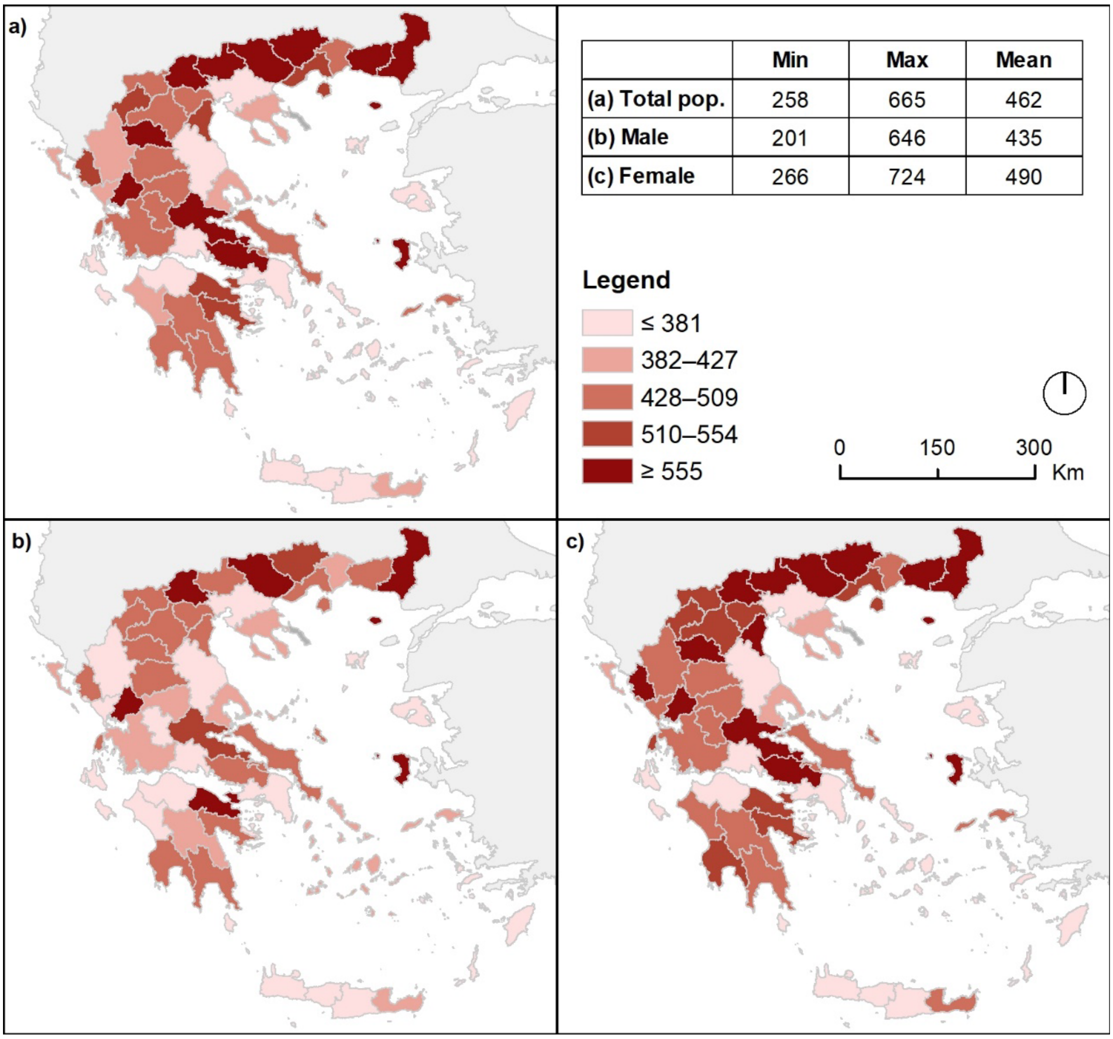

Fig. 1. CVD mortality rates in Greece, year 2022. a) Total population CVD mortality rate per 100,000 population. b) Male CVD mortality rate per 100,000 males. c) Female CVD mortality rate per 100,000 females.

After applying indirect age standardization, spatial inequalities in CVD mortality remained apparent (**Fig. 2**). The indirectly SMR_i for the entire population ranged from 0.66 to 1.59, with a mean value slightly greater than unity, indicating an overall increase in mortality relative to the national standard. Prefectures with SMR_i greater than unity had more observed deaths than expected, and were mainly located in Northern Greece, but also in parts of Central Greece and Peloponnese, while prefectures with SMR_i less than unity were mainly concentrated in Southern Greece, parts of Thessaly and Epirus, and insular prefectures (**Fig. 2a**). In the male population, SMR_i values indicated that increased male mortality was mainly located in Northern and west Central Greece (**Fig. 2b**), while in the female population, SMR_i values were on average higher, with several prefectures showing excess mortality compared to the national level (**Fig. 2c**).

A sex-specific analysis revealed significant differences regarding the age-SMR in most prefectures; specifically, the sex-specific (male vs female) age-SMR was less than one in the majority of Greek regions, indicating higher age-standardized mortality in female than in male (**Fig. 3a**). This pattern is widespread throughout Greece, while sex ratios greater than one, indicating excess male mortality, are observed in a limited number of prefectures, mainly in island areas and in certain parts of southern Greece. The relative sex gap index, as reflected by the ratio of the local sex ratio to the national sex ratio, revealed further spatial heterogeneity, with several prefectures in most of the mainland showing sex inequality below the national average, while in several island prefectures and prefectures of western mainland Greece, sex differentiation was more pronounced than the national norm (**Fig. 3b**).

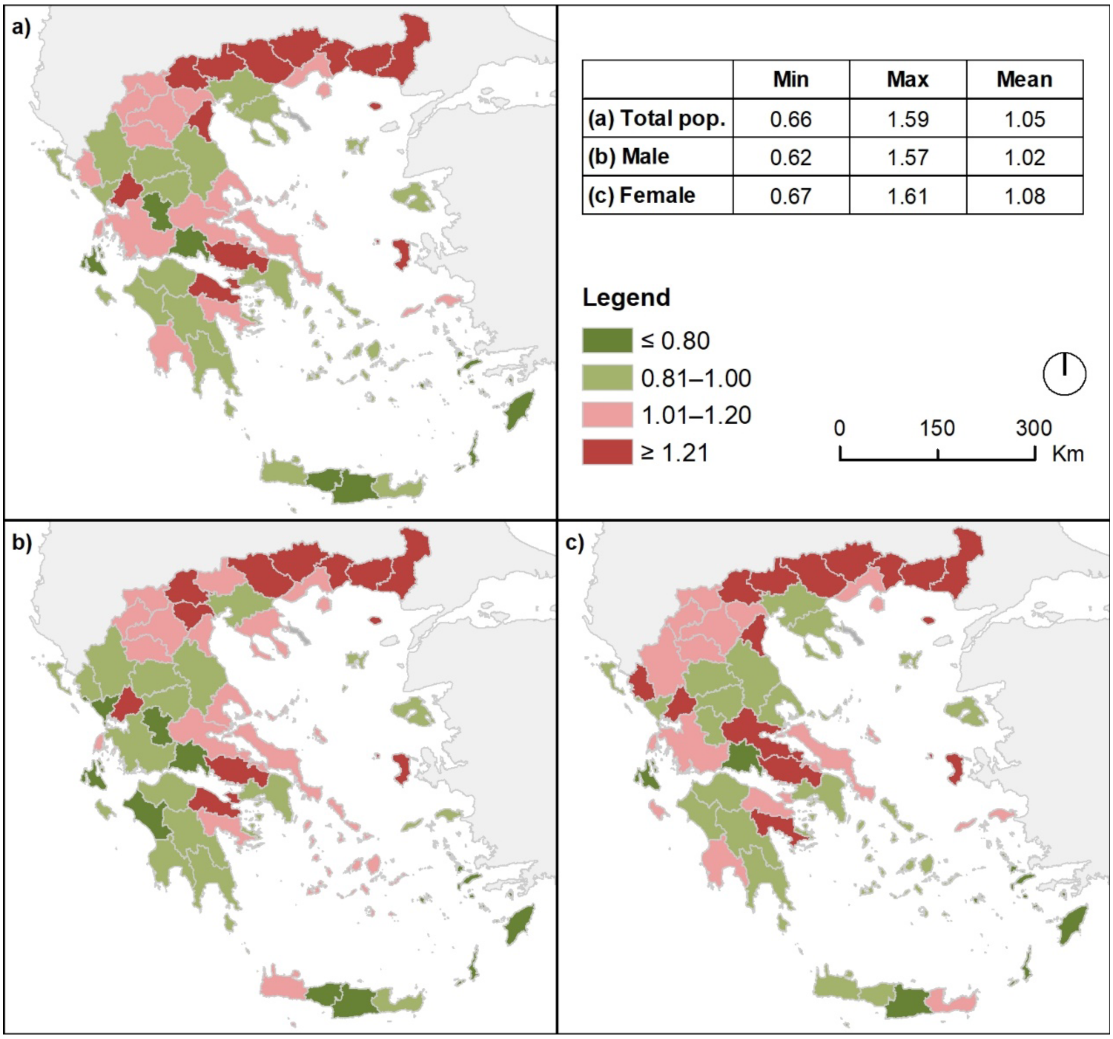

Fig. 2. CVD indirectly age-standardized mortality ratio in Greece, year 2022. Values of SMR_i greater than unity suggest more observed deaths than expected. a) Total population CVD indirectly age-standardized mortality ratio. b) Male CVD indirectly age-standardized mortality ratio. c) Female CVD indirectly age-standardized mortality ratio.

The analysis then focused on the distribution of cardiologists in public hospitals within NHS. As shown in **Fig. 4a** the number of cardiologists in the NHS in Greece per 100,000 inhabitants ranged from 2.42 to 28.61 cardiologists per 100,000 inhabitants, with an average value of 8.87. Substantial spatial variations were revealed (see **Fig. 4**). Higher number of cardiologists was observed mainly in prefectures of Western Greece. In contrast, lower values were observed in most insular prefectures and in some prefectures of the southern mainland, where the availability of cardiologists per population appears to be limited. When this distribution was adjusted for population size using the population-standardized availability of cardiologists' index (i.e., CardioIndex), the majority of prefectures showed values below unity, indicating lower than expected availability of cardiologists compared to the national standard (**Fig. 4b**). This pattern is particularly widespread in southern and northern Greece, as well as in most island prefectures. Prefectures with higher unit values show higher than expected availability of cardiologists, relative to the national standard. These areas are mainly located in selected prefectures of northwestern Greece, central Greece, and certain island prefectures, indicating a relative concentration of cardiologists beyond the level expected based on population size.

Table 1. Descriptive statistics of mortality, cardiologist availability and socioeconomic characteristics across prefecture categories.

Category	Number of prefectures	Variable	Statistics				
High-High	14	ASDR	Min	Max	Mean	St.Dev.	CV
			1.05	1.51	1.19	0.15	0.13
		MSCR	Min	Max	Mean	St.Dev.	CV
			1.00	2.20	1.63	0.35	0.22
		National population share (%)	10.33				
		GDP per capita (€)	11,957				
		Tertiary education (%)	16.02				
		Urban population (%)	60.60				
		Lowland population (%)	59.66				
		Hilly population (%)	24.36				
		Mountain population (%)	15.98				
High-Low	10	ASDR	Min	Max	Mean	St.Dev.	CV
			1.04	1.33	1.16	0.10	0.08
		MSCR	Min	Max	Mean	St.Dev.	CV
			0.42	0.91	0.72	0.19	0.27
		National population share (%)	12.83				
		GDP per capita (€)	14,444				
		Tertiary education (%)	15.80				
		Urban population (%)	61.51				
		Lowland population (%)	57.18				
		Hilly population (%)	30.29				
		Mountain population (%)	12.53				
Low-High	12	ASDR	Min	Max	Mean	St.Dev.	CV
			0.65	0.97	0.82	0.09	0.11
		MSCR	Min	Max	Mean	St.Dev.	CV
			1.13	3.97	1.80	0.78	0.43
		National population share (%)	62.14				
		GDP per capita (€)	14,561				
		Tertiary education (%)	24.39				
		Urban population (%)	90.52				
		Lowland population (%)	77.61				
		Hilly population (%)	18.49				
		Mountain population (%)	3.90				

Low-Low	15	**ASDR**	**Min**	**Max**	**Mean**	**St.Dev.**	**CV**
			0.64	0.99	0.85	0.10	0.12
		MSCR	**Min**	**Max**	**Mean**	**St.Dev.**	**CV**
			0.36	0.98	0.66	0.20	0.31
		National population share (%)					14.70
		GDP per capita (€)					13,566
		Tertiary education (%)					15.19
		Urban population (%)					55.34
		Lowland population (%)					70.11
		Hilly population (%)					21.64
		Mountain population (%)					8.25

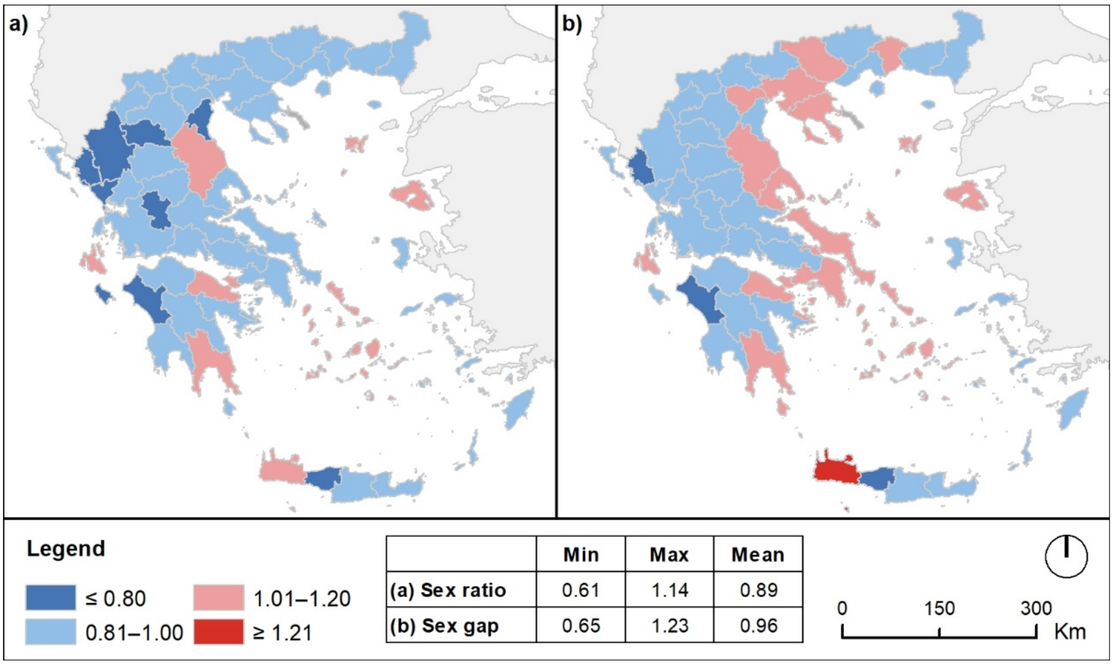

Fig. 3. a) Sex ratio of age-standardized CVD mortality. b) relative sex gap in age-standardized CVD mortality. Values less than one indicate higher age-standardized mortality rate in female than in male.

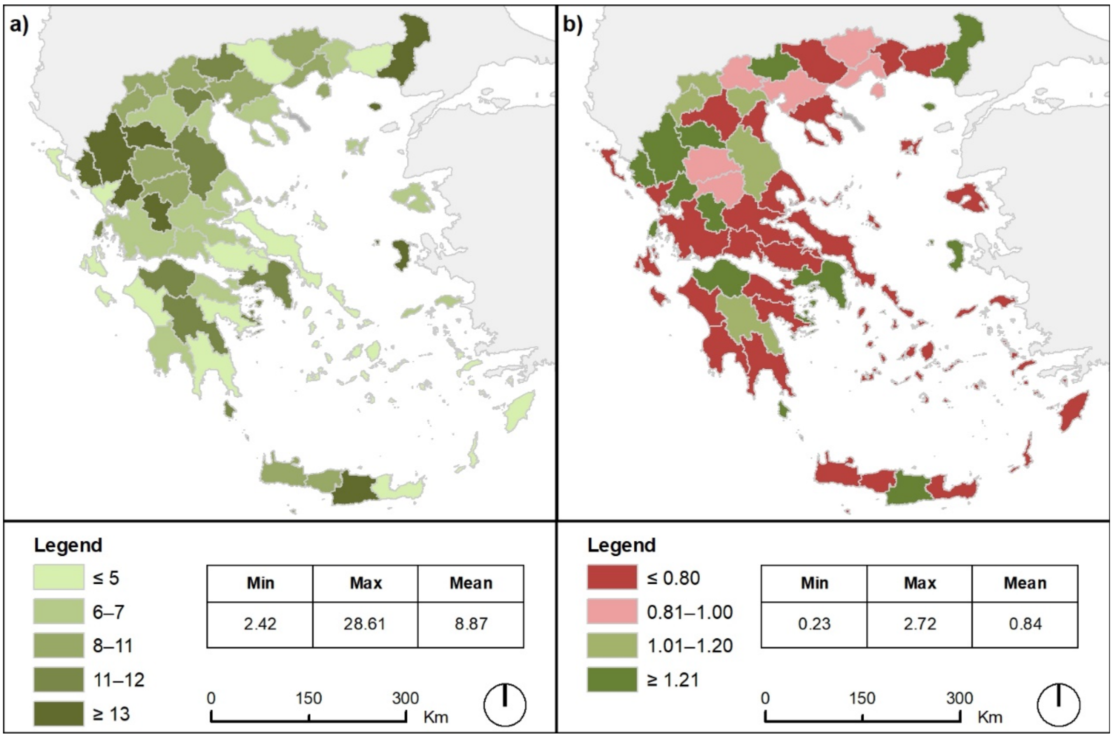

Fig. 4. a) Cardiologists rate per 100,000 population. b) Population-standardized cardiologist supply index (CardioIndex). Values below unity indicate lower than expected availability of cardiologists within the NHS as compared to the national standard.

Table 2. Socioeconomic and geographical differences across prefecture categories.

	Kruskal–Wallis tests		**Dunn tests**
Variable	**H statistic**	**p-value**	**Significant post-hoc comparison**
GDP per capita (euro)	6.17	0.104	-
Tertiary education (%)	10.74	0.013*	Low-High vs Low-Low (adj. p=0.005)
Urban population (%)	10.45	0.015*	Low-High vs Low-Low (adj. p=0.008)
Hilly population (%)	4.31	0.230	-
Mountain population (%)	2.50	0.476	-
Lowland population (%)	0.90	0.826	-
	Pearson Chi-square test		**Pairwise proportion tests**
Variable	**χ^2**	**p-value**	**Significant post-hoc comparison**
Insularity	10.23	0.017*	None remained significant after Bonferroni adjustment

*Statistically significant at α = 0.05

The spatial distribution of the ASDR (≥40 years) and MSCR (≥40 years) indicators, as well as the categorization of prefectures based on their relative position in these two indicators (**Fig. 5**) reveals a clear geographical pattern in both CVD mortality and the availability of cardiologists. The highest ASDR values are mainly concentrated in northern and some mainland areas (**Fig. 5a**), while lower values are observed in more urbanized and island areas. In contrast, the availability of cardiologists (MSCR) shows increased values in large urban centers and regional hubs, while lower values are recorded in less densely populated or island areas (**Fig. 5b**). The categorization of prefectures (High-High, High-Low, Low-High, Low-Low) shows a spatial concentration of categories, with Low-High areas mainly corresponding to highly urbanized areas and Low-Low areas mainly including island or less developed areas (**Fig. 5c**).

The analysis of descriptive statistics reveals significant differences between the four categories (**Table 1**). The High-High category (n=14) has a high mean ASDR (1.19) and, at the same time, increased availability of cardiologists (mean MSCR=1.63), suggesting a coexistence of increased workload and relatively enhanced service provision. The High-Low category (n=10) is characterized by increased mortality (mean ASDR=1.16) but low availability of cardiologists (mean MSCR=0.72), suggesting a possible imbalance between demand and supply. In contrast, the Low-High category (n=12) has low mortality (mean ASDR=0.82) and high availability of cardiologists (mean MSCR=1.80), while it accounts for the largest percentage of the national population and has the highest levels of urbanization (90.5%) and tertiary education (24.4%). The Low-Low category (n=15) has low mortality (mean ASDR=0.85) but also limited availability of cardiologists (mean MSCR=0.66), with lower levels of urbanization and education compared to the Low-High category.

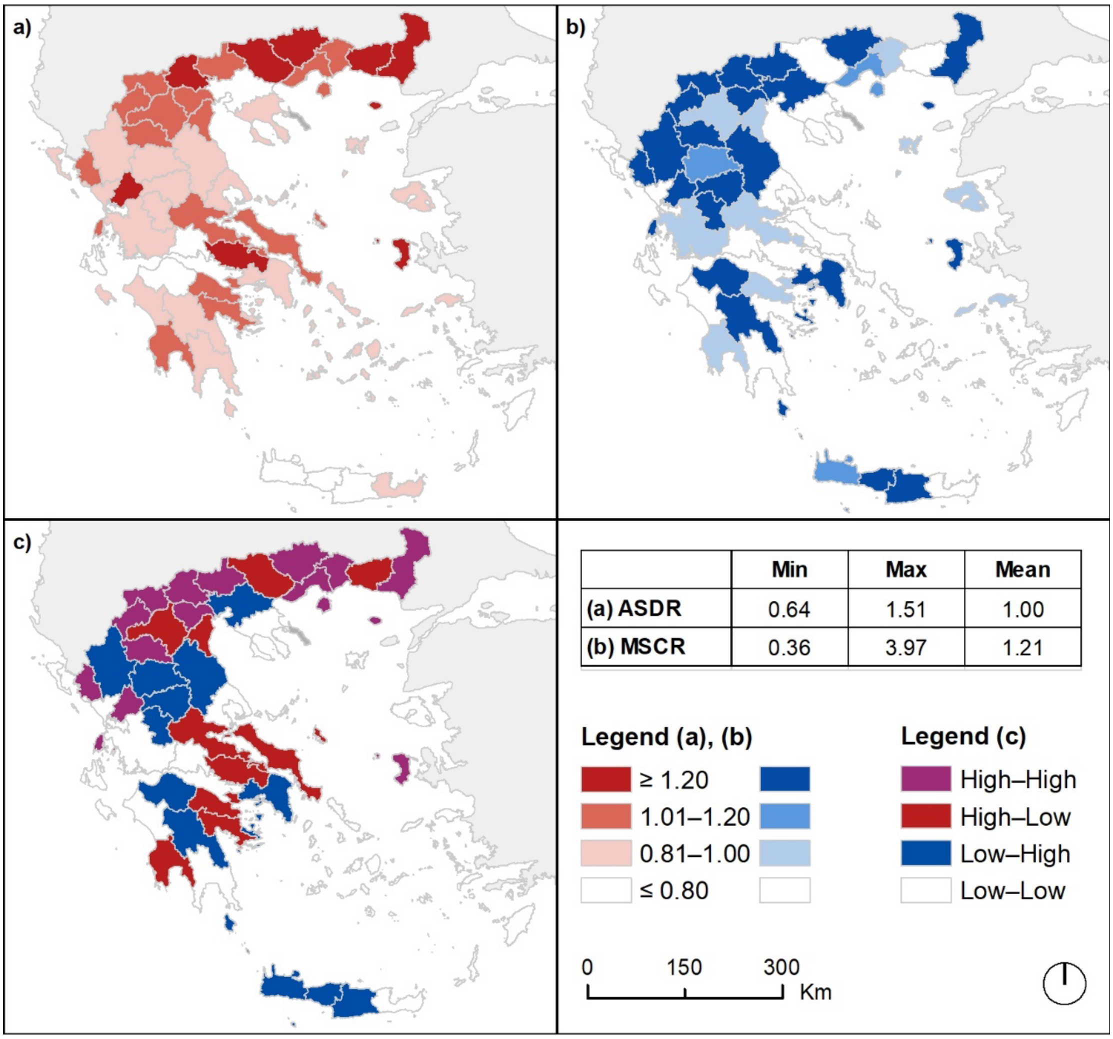

Fig. 5. a) Spatial distribution of standardized cardiovascular mortality (ASDR ≥40). b) Cardiologist availability (MSCR ≥40). c) Prefecture classification according to mortality-cardiologist balance in Greece. For ASDR, values greater than 1 indicate excess cardiovascular mortality compared to the national average. For MSCR, values lower than 1 indicate lower than national median cardiologist availability.

The comparison of sociodemographic and geographic variables between the four categories using the Kruskal–Wallis test (**Table 2**) revealed statistically significant differences for the percentage of the population with tertiary education (H=10.74, p=0.013), the percentage of urban population (H=10.45, p=0.015), while marginal or insignificant differences were observed for morphological variables. No statistically significant difference was observed in terms of per capita GDP (H=6.17, p=0.104). The Pearson Chi-square test (**Table 2**) showed a statistically significant correlation between the category of prefectures and insularity (χ^2=10.23, p=0.017), suggesting that island prefectures are not evenly distributed among the four categories. Post-hoc evaluation using Dunn tests with Bonferroni adjustment identified significant differences between the Low-High and Low-Low categories for tertiary education (adjusted p = 0.005) and urban population (adjusted p = 0.008) (**Table 2**). Pairwise proportion comparisons further indicated a higher representation of island prefectures in the Low-Low category than in the High-High and High-Low categories, although these individual pairwise differences were not statistically significant after adjustment for multiple comparisons. Overall, the results suggest that the classification of prefectures in terms of the relationship between mortality and the availability of cardiologists is mainly related to the degree of urbanization, educational level, and broader geographical characteristics, rather than economic level.

4. Discussion

The present study assessed geographic distribution in cardiologist supply within the NHS in Greece and examined its spatial relationship with regional CVD mortality using an ecological epidemiological approach. Specifically, it quantified regional disparities in cardiologist density and cardiovascular mortality, classified prefectures according to their relative position in these indicators, and examined associated socioeconomic and geographical characteristics. Overall, the findings revealed pronounced spatial inequalities in both CVD mortality and the distribution of cardiologists in public hospitals. The observed spatial patterns of cardiovascular mortality and specialist availability were significantly differentiated according to levels of urbanization and educational attainment, suggesting that structural and socioeconomic factors may play an important role in shaping regional healthcare provision.

Addressing regional inequalities in cardiology workforce allocation should be considered an important policy priority in regions characterized by higher cardiovascular mortality and lower specialist availability . By identifying spatial disparities in both cardiovascular mortality and specialist distribution, the study provides evidence to inform more equitable and data-driven health workforce planning. These findings underscore the importance of aligning health service organization with regional population characteristics and structural conditions, supporting evidence-based resource allocation, targeted policy interventions, and a more equitable distribution of cardiovascular services within the NHS.

The strategic, evidence-informed planning of human resources in health care systems, particularly within National Health Systems, has long been recognized as a critical challenge across several countries around the world (Aneja et al., 2011). Persistent imbalances in the distribution, availability, and specialization of health professionals have strained service delivery, exacerbated regional inequalities, and limited system efficiency. Despite repeated reforms, workforce planning often remains reactive rather than data-driven, insufficiently aligned with population health needs and epidemiological trends. As health systems face demographic ageing, rising chronic disease burden, and fiscal constraints, the need for robust, analytically grounded approaches to human resource allocation has become increasingly urgent to ensure equitable distribution of healthcare resources, sustainability, and improved health outcomes. Health human resources, and medical specialists in particular, constitute a finite and high-cost component of health system capacity, and their distribution plays a decisive role in shaping service availability, quality of care, and ultimately population health outcomes (Aneja et al., 2011, Rosenthal et al., 2005). In the context of CVD, where timely diagnosis, continuous follow-up, and acute care are important components of cardiovascular management, the geographic distribution of cardiologists within the public hospital network represents a relevant health-system characteristic that may be associated with regional differences in service availability and population health outcomes. Our results demonstrate that, despite Greece's relatively high overall cardiologist density at the national level, substantial intra-country disparities persist within the NHS. This pattern highlights a fundamental limitation of health workforce planning approaches that focus on national aggregates rather than regional needs. Strategic planning requires moving beyond headcounts toward dynamic models that integrate epidemiological indicators, demographic ageing, regional disease burden, and accessibility constraints (Kulkarni et al., 2013).

The observed spatial disparities between age-standardized CVD mortality and cardiologist availability suggest that existing allocation mechanisms may not fully incorporate regional epidemiological and structural characteristics. From a public health perspective, such spatial imbalances may pose challenges to the efficiency and equity objectives of the NHS, particularly in peripheral, rural, and insular areas where alternative care pathways are limited. Addressing these challenges necessitates coordinated national workforce policies, including incentives for redistribution, strengthened regional planning capacities, and alignment of specialist deployment with long-term population health projections and planning approaches that account for demographic and geographic variability rather than short-term administrative or market-driven considerations.

The findings of this study are largely consistent with previous research documenting geographic maldistribution of medical specialists, while also contributing novel evidence specific to the Greek context. Earlier studies from North America and Europe have shown that higher regional densities of cardiologists are associated with improved outcomes for acute myocardial infarction and heart failure, although these associations vary depending on health system organization and care pathways. Notably, research from Canada and the United States has reported cases where the regional burden of CVD and the distribution of specialist physicians do not appear to be proportionally aligned. These findings reflect broader concerns about the spatial organization of specialized health services, a topic that is also relevant to the context of this analysis. European studies, as well as studies around the world have also highlighted pronounced rural–urban and core–periphery gradients in specialist availability, with rural and remote areas exhibiting lower specialist density, structural access constraints, and higher mortality (Rosenthal et al., 2005, Kulkarni et al., 2013, Kim et al., 2024, Geiger et al., 2023; Marco et al., 2021).

Furthermore, previous research has highlighted that structural and socioeconomic barriers, including lower educational attainment, socioeconomic disadvantage, transportation limitations, and geographic isolation, significantly affect the utilization of CVD prevention and rehabilitation services across health systems (Ruivo et al., 2023; Sun et al., 2020). Our results similarly demonstrate substantial intra-country variation in cardiologist availability within the Greek NHS, alongside pronounced geographic differences in cardiovascular mortality. Importantly, the prefecture categories based on mortality and cardiologist availability were significantly associated with educational attainment, urbanization and insularity. Post-hoc analyses further indicated that the clearest differences were observed between the Low-High and Low-Low categories for educational attainment and urbanization, while insularity exhibited a broader overall association with category classification rather than statistically robust pairwise contrasts after adjustment for multiple comparisons. These findings highlight the role of contextual socioeconomic and geographic differences across regions. While some international studies have focused on all physicians or mixed public–private systems, our exclusive focus on cardiologists employed in public hospitals provides a more policy-relevant perspective for NHS planning. At the same time, it should be acknowledged that the ecological nature of the analysis precludes causal inference, and that specialist availability is only one component of a complex care continuum that includes primary care, emergency services, and hospital infrastructure. Nevertheless, the consistency of the observed spatial inequalities with prior international evidence supports the external validity of the observed patterns and reinforces concerns about persistent structural inequities in specialist care provision.

Beyond the specific issue of cardiologist distribution, the present study points to a broader and more systemic challenge, the need for better functional and geographic polarization of medical specialties within a country to effectively address health gaps and population needs. Polarization, in this context, does not imply concentration for its own sake, but rather a deliberate and rational alignment of specialized services with epidemiological demand, referral networks, and accessibility considerations (Geiger et al., 2023, Duncan et al., 2023). In Greece, the concentration of medical specialists in selected urban centers coexists with under-coverage in large parts of the mainland and island regions, contributing to pronounced spatial disparities within the NHS. This imbalance is particularly problematic for chronic and acute cardiovascular conditions, where delays in specialist cardiovascular evaluation can have immediate and long-term consequences for survival and quality of life. Our findings suggest that a more nuanced approach to specialty planning is required, one that integrates cardiology services into regionally differentiated care models, supported by referral pathways, telemedicine, and task-sharing with primary care where appropriate. Such an approach could mitigate the adverse effects of geographic isolation while preserving efficiency. From a policy standpoint, these findings support the development of targeted incentives for specialist placement, regional service planning frameworks, and continuous monitoring of regional distribution patterns using standardized indicators. Ultimately, addressing geographic disparities in specialist availability is not merely a technical workforce issue but a central component of health system stewardship, with important implications for aligning cardiovascular service provision with population health needs and ensuring that the benefits of medical advances are equitably distributed across the population (Lupu et al., 2018, Naylor et al., 2019).

4.1 Strengths and Limitations

This study has several strengths that enhance its relevance for public health and health services research. First, it integrates nationwide, population-based mortality data with systematically collected information on cardiologists employed in public hospitals, allowing for a comprehensive assessment of geographic inequalities within the Greek NHS. The use of indirect age standardization strengthens comparability across prefectures with differing demographic structures, while the standardized indices of mortality and specialist availability provide an interpretable framework for examining regional variation in cardiovascular burden and service distribution. In addition, the geographic analysis and cartographic visualization facilitate the identification of regions characterized by elevated mortality and comparatively lower specialist availability, offering actionable insights for health workforce planning.

At the same time, several limitations should be acknowledged. The ecological design precludes inference at the individual level and does not allow causal conclusions regarding the relationship between cardiologist availability and cardiovascular mortality. Consequently, the findings are subject to the ecological fallacy, whereby associations observed at the prefecture level may not necessarily reflect relationships at the individual level. Furthermore, the use of prefectures as the unit of analysis may introduce spatial aggregation bias (modifiable areal unit problem), as findings may differ depending on the geographic scale or administrative boundaries chosen. Prefecture-level indicators may also conceal substantial within-prefecture heterogeneity in both mortality risk and specialist distribution, particularly in larger or more diverse prefectures where urban centers and rural peripheries coexist. An additional consideration is the substantial concentration of population and specialist physicians in metropolitan Athens. Because national reference values were derived using data from all prefectures, these benchmarks may be influenced to some extent by the healthcare and demographic profile of the capital region. Although the use of population-standardized indicators and the national median for MSCR reduces the influence of extreme observations, the potential impact of metropolitan concentration on national summary measures should be considered when interpreting the findings. Cardiologist supply was measured quantitatively and did not account for differences in workload, subspecialization, service quality, or the contribution of private-sector cardiologists. In some prefectures, private-sector cardiologists may partially compensate for shortages in public hospital-based provision. However, the availability of private providers does not necessarily imply equitable or effective access to care, as access may remain constrained by out-of-pocket costs, insurance coverage, geographic proximity, and differences in service organization. Therefore, the present findings should be interpreted as reflecting spatial inequalities in public-sector specialist availability within the NHS, rather than overall access to cardiology services. Moreover, cardiovascular mortality reflects cumulative exposures and care over time and may not fully capture current service provision. The observed spatial patterns may also reflect the influence of factors not captured in the present analysis, including variations in primary healthcare infrastructure, hospital capacity, emergency transport systems, geographic accessibility, and regional socioeconomic and cardiovascular risk-factor profiles.

4.2 Policy Implications and Conclusions

The findings of this study have clear and actionable implications for health policy and workforce planning within the Greek National Health System. Despite the limitations, the study provides robust, population-level evidence of geographic disparities in cardiovascular mortality and specialist distribution that are highly relevant for strategic planning within the NHS. The documented geographic disparities in CVD burden and the availability of cardiologists in public hospitals indicate that current allocation mechanisms do not sufficiently align specialist resources with population health needs. These patterns suggest the need for more region-sensitive workforce planning that incorporates epidemiological indicators, demographic trends, and geographic factors affecting service availability and accessibility into decision-making processes. Policy measures may include targeted incentives for specialist placement in underserved areas, strengthening of regional hospital networks, and the integration of complementary strategies such as telecardiology and enhanced referral pathways. Establishing routine monitoring tools using standardized regional indicators can support continuous evaluation and adaptive planning. Ultimately, improving the spatial alignment of cardiology services within the NHS may contribute to a more equitable distribution of cardiovascular services and strengthening the overall performance of the health system.

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Supplementary Table S1. Prefecture-specific values of Standardized Mortality Ratio (SMR), CardioIndex, Age-Standardized Death Rate (ASDR), Median-Standardized Cardiologist Ratio (MSCR), and corresponding ASDR–MSCR category classification.

Prefecture	**Standardized Mortality Ratio (SMR)**	**CardioIndex**	**Age-Standardized Death Rate, aged ≥40 years (ASDR)**	**Median-Standardized Cardiologist Ratio, aged ≥40 years (MSCR)**	**Category (ASDR – MSCR classification)**
Rodopi	1.342	0.456	1.267	0.681	High-Low
Drama	1.287	0.987	1.263	1.372	High-High
Evros	1.441	1.491	1.427	2.192	High-High
Kavala	1.151	0.808	1.092	1.133	High-High
Xanthi	1.241	0.615	1.062	1.000	High-High
Thessaloniki	0.905	0.930	0.781	1.413	Low-High
Imathia	1.162	1.161	1.102	1.652	High-High
Kilkis	1.202	1.213	1.188	1.676	High-High
Pella	1.380	0.975	1.305	1.374	High-High
Pieria	1.250	0.637	1.165	0.907	High-Low
Serres	1.297	0.314	1.333	0.416	High-Low
Chalkidiki	0.989	0.558	0.895	0.810	Low-Low
Kozani	1.169	0.623	1.093	0.883	High-Low
Grevena	1.102	1.430	1.155	1.860	High-High
Kastoria	1.114	1.034	1.065	1.390	High-High
Florina	1.113	1.059	1.045	1.531	High-High
Ioannina	0.936	2.719	0.915	3.969	Low-High
Arta	1.263	1.342	1.331	1.771	High-High
Thesprotia	1.078	1.397	1.111	1.865	High-High
Preveza	0.848	0.521	0.862	0.704	Low-Low
Larissa	0.896	1.166	0.823	1.719	Low-High
Karditsa	0.908	0.894	0.919	1.220	Low-High
Magnesia	1.009	0.548	0.936	0.795	Low-Low
Trikala	0.955	0.856	0.965	1.160	Low-High
Phthiotis	1.196	0.621	1.167	0.843	High-Low
Boeotia	1.388	0.358	1.248	0.517	High-Low
Euboea	1.135	0.316	1.060	0.453	High-Low
Evrytania	0.738	1.636	0.830	2.070	Low-High
Phocis	0.655	0.525	0.686	0.684	Low-Low
Corfu	0.964	0.281	0.889	0.397	Low-Low
Zakynthos	0.957	0.462	0.816	0.703	Low-Low
Kefalonia	0.768	0.488	0.732	0.697	Low-Low
Lefkada	1.112	1.249	1.062	1.791	High-High
Achaea	0.862	1.273	0.773	1.973	Low-High
Aetolia-Acarnania	1.007	0.642	0.967	0.913	Low-Low
Ilia	0.875	0.317	0.845	0.458	Low-Low

Arcadia	0,871	1,102	0,880	1,484	Low-High
Argolis	1,187	0,510	1,102	0,713	High-Low
Corinthia	1,237	0,618	1,165	0,873	High-Low
Laconia	0,947	0,338	0,932	0,467	Low-Low
Messenia	1,061	0,650	1,038	0,900	High-Low
Attica	0,943	1,271	0,813	1,878	Low-High
Lesvos	0,890	0,568	0,842	0,850	Low-Low
Samos	1,006	0,666	0,998	0,978	Low-Low
Chios	1,590	1,471	1,515	2,198	High-High
Cyclades	0,934	0,236	0,815	0,357	Low-Low
Dodecanese	0,767	0,230	0,644	0,371	Low-Low
Heraklion	0,793	1,433	0,680	2,273	Low-High
Lasithi	0,976	0,488	0,945	0,713	Low-Low
Rethymno	0,786	0,784	0,655	1,318	Low-High
Chania	0,936	0,728	0,801	1,129	Low-High