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Education and Cardiovascular Diseases: A Case Study of Patients at the Institute Of Cardiovascular Diseases of Vojvodina (Northern Serbia)

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Abstract: ***Investigating the relationship between education level and disease incidence is a critical indicator of population health. This study examines the relationship between educational attainment and cardiovascular diseases (CVDs) among patients treated at the Institute for Cardiovascular Diseases of Vojvodina (ICDV) in Sremska Kamenica, northern Serbia. The study period spans from 2003 to 2023. To perform statistical analysis, data processing, and visualisation, several Python modules were utilised. A chi-squared test was first conducted, yielding a values indicating a statistically significant relationship between education level and the number of admitted CVDs patients. Subsequently, a Poisson regression model was applied to aggregated patient admission data to assess the association between educational attainment and CVDs incidence over time. The results confirmed strong statistical significance for both the main effects and their interactions, with all interaction terms showing p-values smaller than 10^{-18}. Additionally, this study conducted an Emerging Hot Spot (EHS) analysis by the education level of patients. Spatial patterns were identified in 152 settlements. All of these settlements exhibited hot spots only, specifically "Consecutive Hot Spot" and "Sporadic Hot Spot" patterns. These findings indicate that temporal trends in hospitalisation rates vary significantly by education level, emphasising the need for targeted preventive measures among lower-educated populations. Studies of this kind can serve as a model for similar research in other regions, helping to inform evidence-based public health strategies and contribute to a better understanding of the social determinants of health on a broader scale.***

Index Terms: ***Education, Cardiovascular Diseases, Institute of Cardiovascular Diseases of Vojvodina, Poisson Regression, Emerging Hot spot analysis.*** [1]

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1. Introduction

Human health is characterised not by a single indicator, but by a complex of factors [1]. It has long been accepted that the health status of a population is determined by economic and social conditions [1,2]. Living standards, lifestyle, customs, economic development, settlement type, population density, literacy, education, occupation, the development of social and healthcare services, and many other factors shape the health status and prevalence of diseases [1,3]. The number of factors related to socioeconomic conditions is so vast that it is not always easy to determine which specific ones are responsible for differences in disease incidence [1,4].

One of the key social determinants of health is the population's level of education. Individuals with higher levels of education are more likely to be employed, to secure jobs with stable income, and, consequently, to enjoy better health [5]. Education also equips people with the necessary skills to identify and solve both individual and collective problems [5]. People with lower levels of education generally exhibit poorer cardiovascular health, have more comorbidities, and face an overall higher risk of developing cardiovascular diseases [6,7]. The level of education influences both morbidity and mortality from numerous diseases [5]. Limited health literacy and overall literacy can prevent individuals from learning about health, using medications correctly, and taking advantage of preventive health services [8].

CVDs represent a major global public health challenge, contributing significantly to the disease burden across both high- and low-income countries [9]. Their development is influenced by a complex interplay of cardiometabolic, environmental, and social risk factors [7].

In Serbia, the burden of CVD remains substantial, with an incidence rate of 920 per 100,000 inhabitants in 2019, placing Serbia 18th among 54 countries in terms of CVD incidence [10].

According to the results of the 2022 Census, more than half of the population aged 15 and over in the Republic of Serbia had completed secondary education (53.1%) [11]. Additionally, 17.8% of the population had completed primary (eight-year) education, while 22.4% held a diploma from a college or university [11]. Conversely, 6.3% of the population either had no formal education or had not completed primary school [11]. Between the 2011 and 2022 censuses, the share of individuals with higher education increased significantly – from 16.24% in 2011 to 22.44% in 2022 [11,12,13]. The proportion of those with secondary education also rose, from 48.93% to 53.08%, while the share of individuals without formal education or with incomplete primary education declined sharply – from 13.68% in 2011 to just 6.28% in 2022 [11,12,13].

This study aims to examine the association between educational attainment and CVDs among patients treated at the Institute for Cardiovascular Diseases of Vojvodina (ICDV), located in Sremska Kamenica (Northern Serbia). The analysis encompasses the entire territory of Serbia, as patients originate from across the country. Additionally, this study conducted an Emerging Hot Spot (EHS) analysis by the education level of patients. The application of Geographic Information Systems (GIS) is crucial for identifying spatial disparities and clusters. By integrating geospatial and socioeconomic data, GIS enables the visualisation of patterns, guides targeted interventions. Investigating the relationship between education level and disease incidence is a critical indicator of population health. Identifying the most affected population groups can inform targeted public health measures, especially for vulnerable categories. Such findings can also contribute to the revaluation of existing health policies and the development of new strategies aimed at reducing the burden of cardiovascular diseases.

1.1. Literature Review

A growing body of research highlights the significant influence of educational attainment on cardiovascular health, emphasising its role in shaping health outcomes across various populations and contexts. Liu et al. investigated whether higher levels of education causally reduce CVD risk among European populations [7]. Similarly, Dégano et al. demonstrated an inverse association between education and CVD incidence in North-Eastern Spain, showing that individuals with university degrees had a lower risk compared to those with only primary or no education [14]. In Sweden, Erikson (2001) found that men with only primary education had a mortality rate twice as high as those with doctoral degrees [5,15].

Furthermore, the causal associations of education level with cardiovascular diseases (CVD) have been extensively studied worldwide, reflecting the global recognition of education as a critical social determinant of health.

Mallaiah reviews the critical role of education in cardiovascular disease (CVD) prevention, emphasizing how educational factors influence lifestyle choices, health behaviors, and access to healthcare resources. The paper synthesizes existing research and empirical findings to highlight the strong correlation between educational attainment and cardiovascular outcomes, advocating for public health strategies that target education as a key upstream determinant to reduce CVD burden. [16]

Marzà-Florensa et al. examined educational inequalities in secondary prevention of coronary heart disease (CHD) using data from the multinational SURF CHD II audit involving nearly 14,000 patients across 29 countries. The study found that patients with higher education were more likely to meet guideline-recommended risk factor targets, use cardio protective medications, and participate in cardiac rehabilitation. Despite widespread poor control of risk factors overall, educational disparities persisted across countries of varying income levels, highlighting the need to address socioeconomic barriers in CHD management. [17]

Jones et al. used Mendelian randomization analyses with sibling data from large cohorts to investigate the causal impact of educational attainment on CVD risk and serum lipid levels in the UK Biobank. Their findings show that higher education is associated with a reduced risk of CVD and favourable lipid profiles, effects that persist even after accounting for family-related factors. This suggests that increasing education may directly contribute to improved cardiovascular health independently of shared familial influences. [18]

Hu et al. used two-sample Mendelian randomization to examine the causal effects of educational attainment on CVD, biomarkers, and socioeconomic factors. Analysing genetic data, the study found that higher genetically predicted education significantly reduced the risk of multiple CVD outcomes, improved key cardiovascular biomarkers (e.g., blood pressure, BMI, CRP), and was associated with healthier behaviours and higher income. These findings support a causal link between education and cardiovascular health, emphasizing the role of education equity in CVD prevention. [19]

Tao et al. investigated the relationship between educational attainment, cardiovascular risk factor control, and the incidence of CVD in China using data from the Kailuan Study. Analysing over 92,000 participants over a 14.5-year follow-up, the study found that lower educational levels were significantly associated with higher CVD risk. This association was partly mediated (14.2%) by poorer control of key risk factors such as blood pressure, glucose, cholesterol, smoking, and BMI. The findings highlight the role of education in shaping health outcomes through its impact on risk factor management. [20]

Magnani et al. explored the link between educational attainment and lifetime CVD risk using pooled data from six U.S. cohort studies (1985-2015) involving over 40,000 adults. The study found that lower education levels were associated with significantly higher lifetime CVD risk and shorter periods of life lived free from CVD. While education was linked to healthier longevity, it contributed minimally to improving traditional CVD risk prediction models. The findings underscore education as a key social determinant influencing long-term cardiovascular health outcomes. [21]

Lynch et al. explored the relationship between socioeconomic statuses – measured through education, income, and occupation – and carotid atherosclerosis among men in Eastern Finland [22]. Davies et al. analysed UK Biobank data to examine the causal effects of education on health outcomes [23], while Rose and Marmot investigated the role of social class in coronary heart disease in England and Wales [24]. In the UK, Floud et al. found that lower education combined with higher area deprivation was associated with increased CHD risk [25]. Galama et al. further examined the links between education, health, and mortality [26].

In the United States, Choi et al. analysed associations between educational attainment, chronic disease, and mortality [27], while Havranek et al., in a statement from the American Heart Association, emphasized that lower education is consistently linked to higher prevalence of cardiovascular risk factors [28]. Mackenbach et al. compared educational differences in mortality from ischemic heart disease, cerebrovascular disease, and overall CVD across the United States and 11 Western European countries, consistently reporting higher mortality among individuals with lower education [29].

Meara et al. examined educational disparities in mortality and life expectancy among non-Hispanic Black and White populations in the 1980s and 1990s [30]. Van Lenthe et al. quantified the contributions of material and behavioural factors to educational differences in acute myocardial infarction incidence [31]. Loucks et al. confirmed the link between lower education and increased CHD risk [32]. Tillmann et al. employed genetic data to explore the causal relationship between education and coronary heart disease [33]. Carter et al. assessed the mediating roles of body mass index (BMI), systolic blood pressure, and smoking behaviour in the relationship between education and CVD outcomes [34]. Gill et al. investigated cardio metabolic factors underlying the clustering of osteoarthritis with CVD, as well as how these mediate the effects of educational attainment [35]. Huang et al. examined spatial patterns of educational differentiation in Guangdong Province and their alignment with objective indicators from a spatial equity perspective [36].

Various studies have applied geographic information systems (GIS) and spatial statistical methods in geographical-medical research to analyse spatial patterns and temporal dynamics of health outcomes [37,38,39,40,41,42].

Janković et al. examined the association between socioeconomic statuses – measured by educational level – and cardiovascular health in the adult population of the Republic of Srpska [43].

In Serbia, geographic-medical investigations into CVDs are still relatively scarce. Maksimović et al. investigated the association between socioeconomic status – measured through education – and risk factors for carotid atherosclerosis in Belgrade during 2006-2007 [44]. Janković et al. assessed the prevalence of ideal cardiovascular health (CVH) across sex and age groups in Serbia and examined how demographic and socioeconomic factors relate to CVH metrics [45]. Šašić et al. explored socio-demographic differences in CVD prevalence and its association with risk factors [46], while Kričković et al. provided a geographic-medical overview of non-communicable diseases, including CVDs in the Autonomous Province of Vojvodina (AP Vojvodina) [47]. Markov analysed changes in the educational structure of the population of AP Vojvodina during the second half of the 20th century, noting a significant rise in the number of individuals with vocational and specialized education and a decline in illiteracy and incomplete primary education [48]. Tomašević et al. examined the growing public health challenges of obesity and hypertension in AP Vojvodina [49], and Petrović and Čanković studied obesity prevalence and socio-demographic influences among adolescents aged 15-19 in the same region [50]. Kričković et al. conducted a spatio-temporal analysis of hypertension among patients treated at the ICDV from 2000 to 2023 [51]. The level of grammar school students' knowledge in Novi Sad about cardiovascular disease risk factors was investigated by Jaraković et al. [52].

2. MATERIALS AND METHODS

This section presents the dataset used in the study, along with the chi-square test, Poisson regression and Emerging Hot spot (EHS) analyses. It offers a detailed description of the data and the methodological approaches applied.

2.1 Data Set

For this study, data were sourced from the reference database of the ICDV [51,53]. The database is organised according to the 10^{th} Revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10), as established by the World Health Organization (WHO) [51,54]. Although the WHO introduced the 11th Revision (ICD-11) at the 72^{nd} World Health Assembly in 2019, which became effective on January 1, 2022 [51,55], the ICD-10 remains the standard classification system used in the Republic of Serbia. In Figure 1 recorded patients through the settlements in the Republic of Serbia in the ICDV are presented.

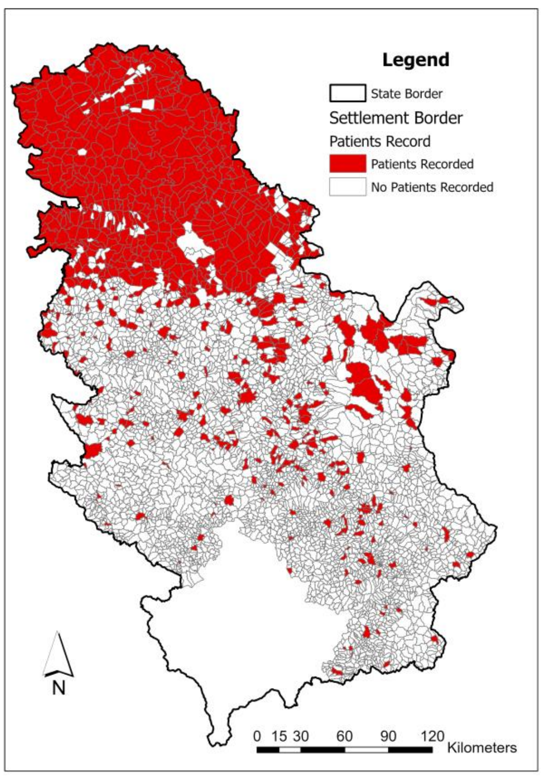

Figure 1: Patients recorded in the ICDV

Although patients from settlements in the Autonomous Province of Kosovo and Metohija (AP KiM) were recorded in the ICDV database, they were excluded from this study due to the unavailability of settlement-level data from the open-access sources of the Republic Geodetic Authority (RGA) of the Republic of Serbia. As illustrated in Figure 1, settlement boundaries for the AP KiM region are not publicly available.

Research process diagram is presented in the Figure 2. Each record in the dataset represented an individual hospital admission, with the patient's education level, and the year of admission extracted from the admission date. During this process, it was observed that the column containing information on patients' education levels included values that did not align with the database description. Out of a total of 1,387,598 recorded cases, 363,093 entries either contained invalid values or were missing education level data. Consequently, 1,024,505 cases with valid information on education level were retained for further analysis.

The education level variable comprised five categories:

- Value 1 represented patients with no formal education;
- Value 2 corresponded to those with primary education;
- Value 3 denoted patients with secondary (high school) education;
- Value 4 indicated patients with post-secondary (higher) education, and
- Value 5 included those with university-level education or higher

The ICDV's database was in *.CSV format, and the observed period was from 2003 to 2023. Following data cleansing, Figure 3 presents the total number of patients stratified by education level.

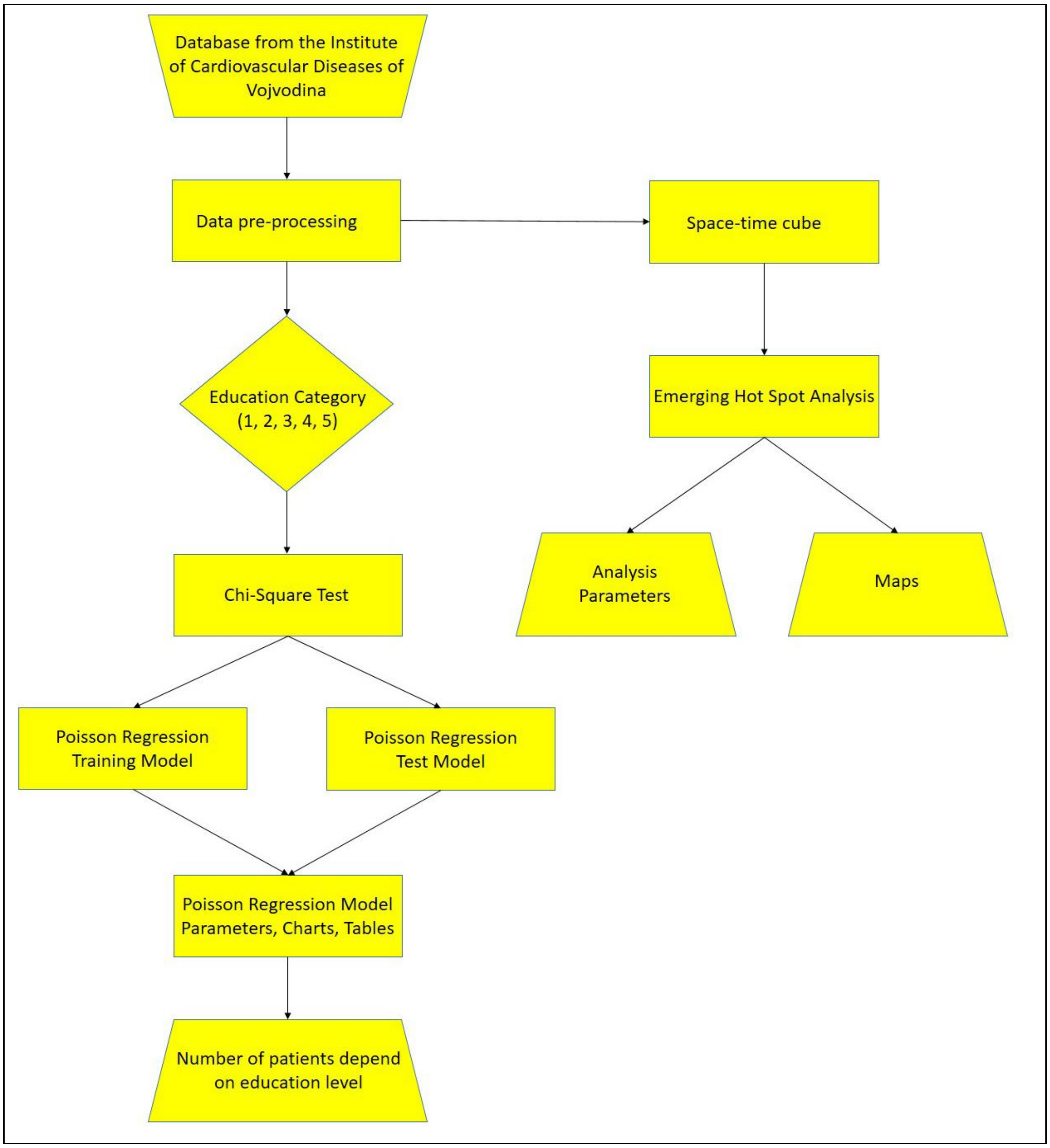

Figure 2: Schematic representation of the research process.

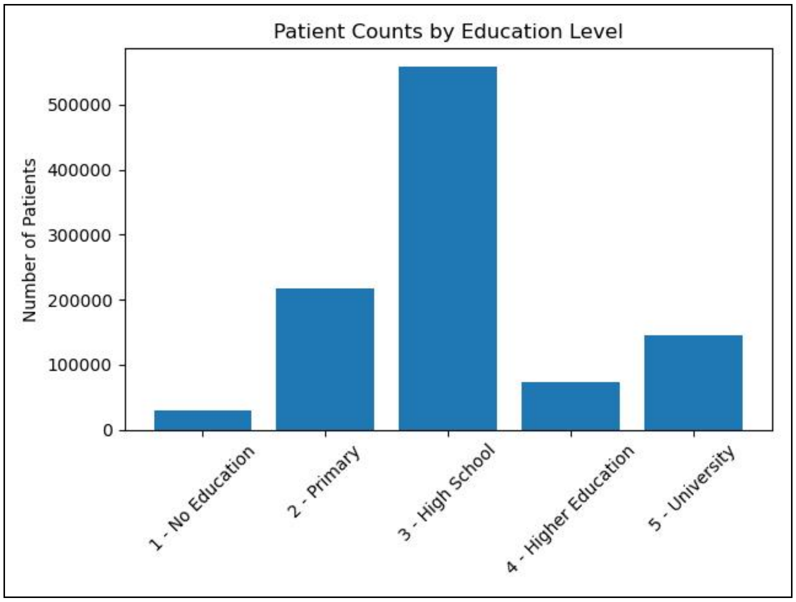

Figure 3: Total number of patients in the ICDV by education level.

For this analysis, several Python modules were utilized to perform statistical operations, data processing, and visualization. This included libraries such as “scipy”, “pandas”, “statsmodels”, “numpy”, and “matplotlib” [56,57,58,59,60].

2.2 Chi-Square Test

The chi-square test is a non-parametric statistical method used to assess the difference or association between observed and expected categorical variables in a dataset [61,62]. Developed by Karl Pearson (1857-1936), it has become a key tool in hypothesis testing, particularly when dealing with categorical data [62,63]. One of the main advantages of Pearson's chi-square test is its ability to use statistical methods that do not assume a normal distribution [62]. The significance of the chi-square value is determined by consulting a chi-square table, taking into account the appropriate degrees of freedom and the chosen level of significance [62,63]. The chi-square test serves two primary purposes: determining whether there is an association between two or more groups, populations, or criteria, and evaluating how well the observed data distribution fits the expected distribution [62,64].

Both of Pearson’s chi-square tests use the same equation to calculate the test statistic, chi-square (X^2) [61] expressed in equation (1):

$$X^2 = \sum \frac{(O-E)^2}{E} \qquad (1)$$

where X^2 is the chi-square test statistic, Σ is the summation operator, O is the observed frequency, and E is the expected frequency.

The larger the difference between the observations and the expectations ($O - E$ in the equation), the bigger the chi-square will be. To decide whether the difference is big enough to be statistically significant, you compare the chi-square value to a critical value [61].

If the p-value is less than the significance level (typically 0.05), reject the null hypothesis, indicating a significant relationship between the variables. If the p-value is greater than 0.05, fail to reject the null hypothesis, meaning no significant relationship was found. [65]

2.3 Poisson Regression

In this study, a Poisson regression model was employed to examine the relationship between the level of education and the incidence of CVDs. Given that the dependent variable (the number of recorded CVD cases) represents count data and is assumed to follow a Poisson distribution, this statistical method is well-suited for the analysis.

Poisson regression is the simplest count regression model. Coefficients are exponentiated, since counts must be 0 or greater. Poisson regression assumes a Poisson distribution, often characterised by a substantial positive skew (with most cases falling at the low end of the dependent variable's distribution) and a variance that equals the mean. Because count data distributions (e.g., visit counts) often have a Poisson distribution, Poisson regression tends to fit these data better than linear regression does (which assumes a normal distribution). [66]

This allows the analysis of dependent variables, which follow Poisson distribution, i.e., a distribution frequently encountered when counting a number of events, or concerning the rate of occurrence with nonnegative integers [67,68]. The Poisson regression model, applied in both analyses, assumes that the logarithm of the expected count is a linear function of the predictor variables. The general form of the model is shown in equation (2):

$$\log(\mu) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \quad (2)$$

where μ is the expected count (the number of hospital admissions per year), $X_1, X_2, \cdots, X_n$ are the predictor variables (education level), β_0 is the intercept, $\beta_1, \beta_2, \cdots, \beta_n$, are the regression coefficients for each predictor. Since a Poisson variable is assumed to have a mean > 0, *log* transformation ensures that the model-based predictions of rates are constrained to be greater than, or equal to, zero. A P-value of less than 0.05 was considered statistically significant in this study [68].

2.4 EHS Analysis

The Getis-Ord G_i^* statistic, implemented through the EHS Analysis (Space-Time Pattern Mining) tool, was utilized to identify areas classified as "hotspots" and "coldspots" [47,51,69,70,71] concerning education level. This method categorizes spatial patterns into clusters and outliers, with clusters representing either positive patterns (hotspots) or negative patterns (cold spots) [47,51,69,72]. Outliers, on the other hand, are spatial features with attribute values that significantly differ from those of their surrounding neighbours [47,39,69]. This hotspot analysis is based on the G_i^* statistic, which is calculated using the following equation (3) [47,51,39,69,72]:

$$G_i^* = \frac{\sum_{j=1}^{n} \omega_{i,j} x_j - \bar{X} \sum_{j=1}^{n} \omega_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} \omega_{i,j}^2 - \left(\sum_{j=1}^{n} \omega_{i,j} \right)^2 \right]}{n-1}}} \quad (3)$$

where G_i^* is the spatial autocorrelation (spatial dependency) statistics of an event i over the n events, the term x_j defines the magnitude of the variable x at the events j over all n, and the term $\omega_{i,j}$ defines the weight value between the events i and j that represents their spatial interrelationship and in more detail, $\bar{X}$ shown in equation (4):

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (4)$$

and S in equation (5):

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (5)$$

The G_i^* statistic evaluates the magnitude of each feature in relation to the values of its neighbouring features. The local sum of a feature and its neighbours is compared to the sum of all features. If the local sum differs significantly from the expected sum, with the difference being too large to attribute to random variation, a statistically significant z-score is obtained [47,51,39,69,70,71,72].

3. Results

The results of this study are presented across separate subsections, providing detailed findings from the chi-square test, Poisson regression, and EHS analyses.

3.1. Results of Chi-square test and Poisson regression

As previously mentioned, a chi-squared test was conducted to assess the statistical significance of the differences in patient numbers across education levels. The test yielded a chi-squared value of 729,405.92 with a p-value less than 0.005, indicating a statistically significant association between education level and the number of admitted patients.

To assess whether the number of hospitalized patients over time is associated with their level of education, a Poisson regression model was employed using aggregated patient admission data. Following data cleaning and grouping by education level and year, a train/test split based on time was conducted. The training set covered the period from 2003 to 2018 (80 grouped observations), while the test set spanned 2019 to 2023 (25 grouped observations), ensuring that all education levels were present in both subsets. This allowed both for baseline differences between education levels and for interaction terms to model education-specific temporal trends. Education level 5 (university degree) was used as the reference category, enabling direct comparisons with all other education levels.

The full model results are shown in Table 1, which includes estimated coefficients, standard errors, z-values, 95% confidence intervals, and associated p-values. All main effects and interactions were highly statistically significant ($p < 0.01$), indicating that education level significantly influences both the number of hospitalizations and their temporal trends.

To aid interpretation, the coefficients and their 95% confidence intervals are visualized in Figure 4. All coefficients are significantly different from zero (as shown by intervals that do not cross the vertical line at zero), especially the interaction terms involving education levels 2 (primary school) and 3 (high school), which exhibit steeper increases over time compared to the reference group.

Table 1. Poisson Regression Results for ICDV Admissions by Education Level (2003-2018), with coefficient values, standard errors, z-values, p-values and confidence intervals.

Term	Coefficient	Std. Error	z-value	p-value	95% CI (Lower)	95% CI (Upper)
Intercept	-8.7451	3.292	-2.657	7.89×10^{-3}	-15.197	-2.293
C(education)[T.2.0]	-39.3916	3.542	-11.122	9.80×10^{-29}	-46.333	-32.450
C(education)[T.3.0]	-56.4781	3.406	-16.581	9.51×10^{-62}	-63.154	-49.802
C(education)[T.4.0]	-35.0770	4.043	-8.676	4.11×10^{-18}	-43.001	-27.153
C(education)[T.5.0]	-54.2657	3.730	-14.548	5.97×10^{-48}	-61.576	-46.955
year	0.0078	0.002	4.784	1.72×10^{-6}	0.005	0.011
C(education)[T.2.0]:year	0.0205	0.002	11.646	2.42×10^{-31}	0.017	0.024
C(education)[T.3.0]:year	0.0294	0.002	17.362	1.60×10^{-67}	0.026	0.033
C(education)[T.4.0]:year	0.0178	0.002	8.845	9.18×10^{-19}	0.014	0.022
C(education)[T.5.0]:year	0.0276	0.002	14.889	3.88×10^{-50}	0.024	0.031

Predictions were generated on the test set (2019-2023) to assess model generalization. Figure 5 presents a comparison of predicted vs. observed patient counts across years and education levels. The model generally aligns with the observed trends, though it slightly under predicts counts for lower education levels – particularly for patients with primary and high school education – suggesting potential structural changes or external factors not captured in the model.

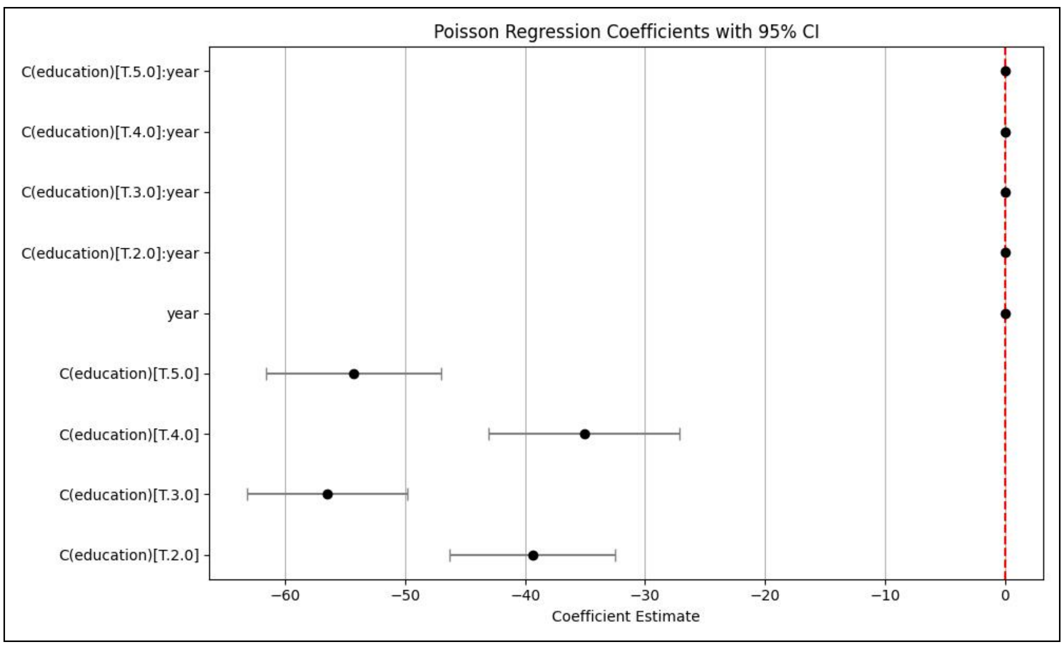

Figure 4: Poisson Regression Coefficients with 95% Confidence Intervals.

Despite this under prediction, residuals remained within statistically interpretable bounds and did not exhibit signs of systematic bias (see Table 2 for a selection of test set residuals). The university-educated group (education level 5) had the most accurate predictions, further reinforcing the stratified trend differences identified in the regression analysis.

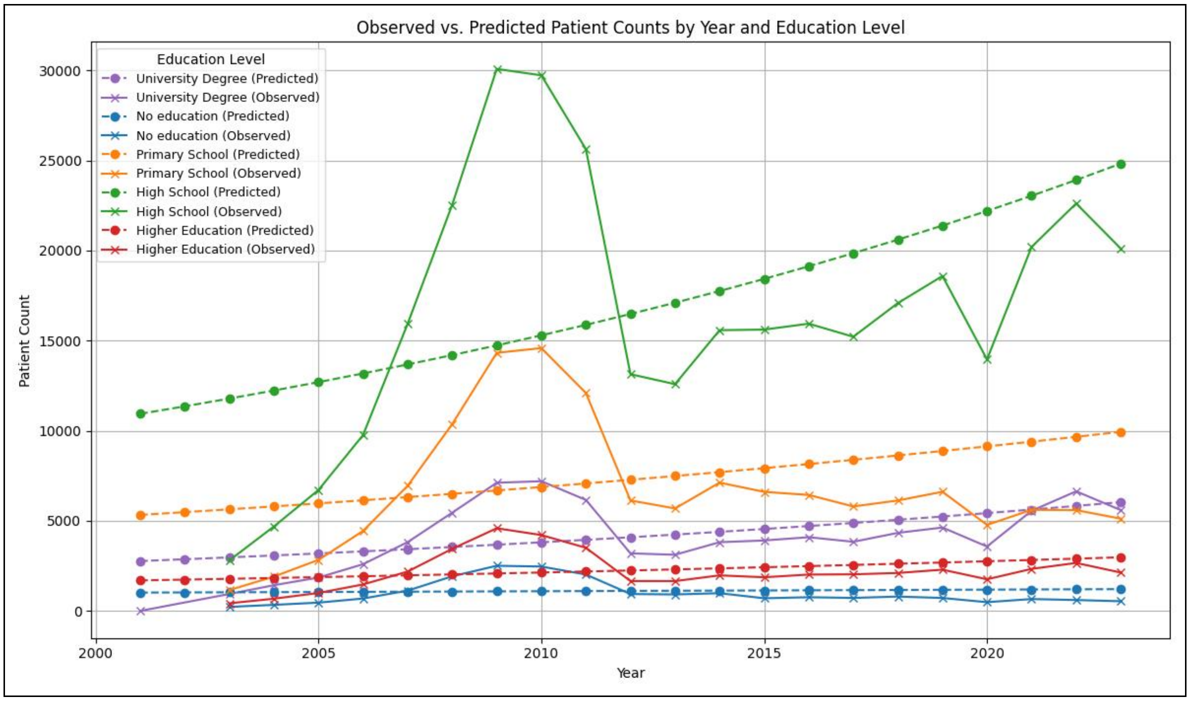

Figure 5: Observed vs. Predicted Patient Counts by Year and Education Level.

Table 2. Example Residuals from Test Set (2019-2023).

Education Level	Year	Observed Count	Predicted Count	Residual
No Education	2019	718	1,173.02	−455.02
No Education	2020	486	1,182.24	−696.24
No Education	2021	659	1,191.54	−532.54
No Education	2022	605	1,200.90	−595.90
No Education	2023	537	1,210.35	−673.35
Primary School	2019	6,614	8,877.57	−2,263.57
Primary School	2020	4,775	9,132.80	−4,357.80
Primary School	2021	5,612	9,395.37	−3,783.37
Primary School	2022	5,595	9,665.49	−4,070.49
Primary School	2023	5,121	9,943.38	−4,822.38
High School	2019	18,589	21,390.65	−2,801.65
High School	2020	13,961	22,202.33	−8,241.33
High School	2021	20,203	23,044.80	−2,841.80
High School	2022	22,617	23,919.24	−1,302.24
High School	2023	20,116	24,826.87	−4,710.87
Higher Education	2019	2,291	2,687.33	−396.33
Higher Education	2020	1,756	2,757.06	−1,001.06
Higher Education	2021	2,335	2,828.59	−493.59
Higher Education	2022	2,664	2,901.99	−237.99
Higher Education	2023	2,132	2,977.28	−845.28
University Degree	2019	4,629	5,240.99	−611.99
University Degree	2020	3,575	5,430.12	−1,855.12
University Degree	2021	5,559	5,626.07	−67.07
University Degree	2022	6,638	5,829.10	+808.90
University Degree	2023	5,599	6,039.45	−440.45

P-values for all regression coefficients are provided in Table 1 and reaffirm the strong statistical support for both main and interaction effects. All interaction terms had p-values smaller than 10^{-18}, confirming that temporal trends in hospitalization counts differ significantly by education level.

3.2. Results of the EHS Analysis by Education Level

The EHS analysis was conducted by converting settlement polygons into points. This step was necessary because the analysis required the creation of a Space Time Cube through point aggregation. In this way, all admitted patients were geolocated by merging data from the CSV database with spatial data from the RGA. Using the admission date from the database, a temporal parameter was defined. This procedure enabled the construction of the Space Time Cube and the identification of potential cold or hot spots through EHS analysis.

The analysis was performed separately for each education level. For all cubes created, a uniform configuration was applied: the time field was set, the time-step interval was fixed at one year, the time-step alignment was set to the end time, and a fishnet grid was used as the aggregation shape. The coordinate system applied was WGS 1984 UTM Zone 34N.

According to the supplementary data file (IPSI Journal Education and Cardiovascular Diseases a Case Study - Supplementary data), spatial patterns were identified in 152 settlements. All of these settlements exhibited hot spots only, specifically “Consecutive Hot Spot” and “Sporadic Hot Spot” patterns. This is attributed to an increasing trend detected in the Space Time Cube, generated from aggregated settlement points, with a high level of statistical confidence. In 45 settlements, hot spots were observed across all education levels. This indicates that in approximately one-third of the settlements, EHS analysis consistently identified hot spots regardless of education level. In 27 settlements, at least one pattern per education level was recorded. The most frequent pattern detected was the “Consecutive Hot Spot.” Figure 6 presents the EHS analysis across education levels: no education, primary education, high school education, higher education, and university/higher education.

When examining the number of settlements identified for each education level, the lowest count was recorded for the no-education category (50 settlements), while the highest was found in the primary education category (127 settlements). High school education was associated with 126 settlements, university and higher education with 115 settlements, and higher education alone with 97 settlements. Consistent with the previous analyses, the lowest number of detected settlements in the EHS analysis corresponded to the lowest education level.

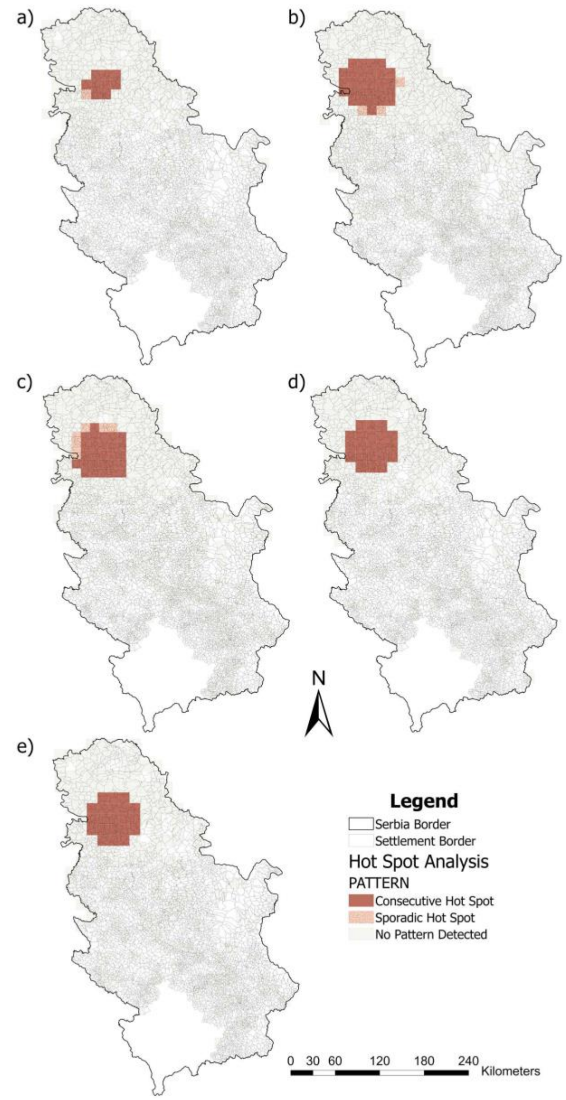

Figure 6: EHS analysis by education level: a) No education, b) Primary education, c) High School education, d) Higher Education, e) University and higher education.

4. Discussion

Education plays a crucial role in shaping health outcomes, particularly in the context of CVDs [7]. This study confirmed a significant association between education level and the number of hospitalised patients. The model also showed that hospitalisation rates and their temporal trends vary across education groups. Most patients at the ICDV in Sremska Kamenica had completed secondary education, followed by those with primary education. A study conducted by Markov revealed that during the second half of the 20th century in AP Vojvodina, there was a notable rise in literacy levels and an improvement in the educational structure by level of education [48]. This was largely attributed to the expansion of the educational network, which significantly increased the number of individuals with vocational and professional qualifications, while the number of illiterate persons and those with incomplete primary education declined at a slower pace, highlighting the importance of understanding this relationship for guiding targeted prevention strategies, especially for vulnerable populations with lower levels of education [48].

Our findings are consistent with international research highlighting the protective effects of higher educational attainment. A large-scale Swedish study [73] found that completing compulsory education was significantly associated with reduced mortality. Liu et al. further demonstrated, through genetic and epidemiological analysis, that individuals with higher education had a lower incidence of ten distinct cardiovascular conditions [7]. Sulo et al. and Tillmann et al. also identified education as a key determinant of disease progression and prognosis [33,74].

In Serbia and the broader region, similar results have been observed. Janković et al. (2014), Janković et al. (2019) and Maksimović et al. reported that individuals with higher education had more ideal CVH metrics and fewer metabolic risk factors [43,44,45,]. Šašić et al. using data from the 2019 National Health Survey, confirmed strong links between CVDs prevalence and preventable risk factors – such as obesity, hypertension, alcohol use, and smoking – closely tied to socio-economic inequalities [46]. These findings underscore the role of education not only as a social determinant but also as a modifiable factor influencing behavioural and biological risk pathways [34,35].

This study is based on data from a single healthcare institution, the ICDV, which treats patients from across the Republic of Serbia. However, most patients come from AP Vojvodina, which reflects the institution's location. Figure 7 illustrates the distribution of ICDV patients by their dominant education level. As shown in the figure, the majority of patients have attained a high school level of education; however, it is also evident that university and higher education levels are dominant in some urban areas, e.g. university centres.

While the data provide important insights, a more comprehensive and nationally representative picture requires data from multiple institutions across different regions. Such efforts demand financial and logistical resources and strong inter–institutional collaboration.

Moreover, this study focused on education as a predictor of CVDs but did not explore lifestyle behaviours. Future research should incorporate behavioural, environmental, and genetic data to better understand the mechanisms through which education influences cardiovascular health.

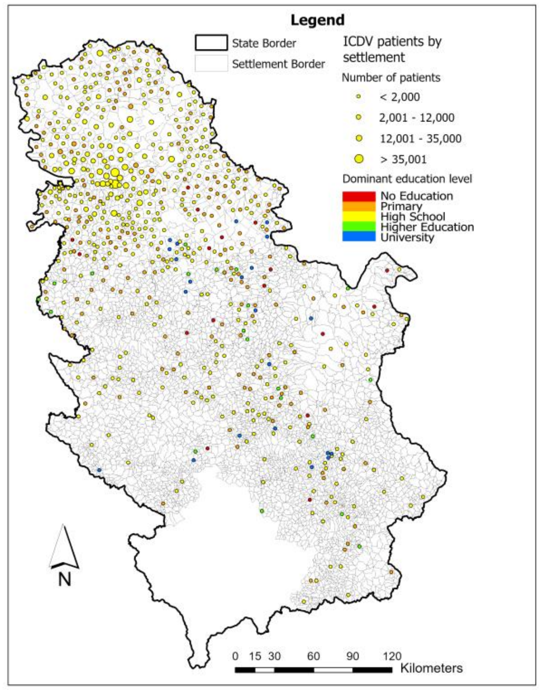

Figure 7: ICDV patients by settlement.

Improving access to education, especially for socially and economically disadvantaged populations, remains a vital public health objective. Expanding educational infrastructure, reducing tuition fees, increasing scholarships, and supporting adult learning are all measures that can improve health outcomes indirectly by promoting healthier lifestyles and improving health literacy [1]. In addition, continuous professional development and adequate support for teachers are essential to maintaining high-quality education across regions. Public awareness campaigns highlighting the benefits of education for personal growth, employability, and health can further reinforce these efforts, particularly when local communities and parents are actively engaged. Integrating technology through digital tools, internet access, and interactive learning platforms will also help bridge educational gaps and modernise the system. It is also important to monitor how changes in the education system over time – such as curriculum reforms or digitalisation – affect population health in the long term.

Strengthening the collaboration between the health and education sectors – particularly through school-based health education programs – can foster healthier behaviours from an early age and reduce the lifetime risk of CVDs. Embedding cardiovascular health literacy into formal curricula may be a long-term strategy for breaking intergenerational cycles of disadvantage.

However, education alone cannot address all health disparities. CVH is shaped by a complex interplay of social, economic, and environmental factors, as well as access to healthcare. National health policies must align with the Sustainable Development Goals and account for local needs and constraints [46]. As Lakić et al. showed, CVDs poses a significant economic burden in Serbia, underscoring the urgency of strategic investment in prevention [75].

Analysing the relationship between educational attainment and disease prevalence provides a critical lens for understanding population health dynamics and social determinants that drive health disparities. Education not only influences individual health behaviours and access to healthcare but also reflects broader socioeconomic conditions that shape disease risk across communities. By uncovering how education levels correlate with cardiovascular disease incidence, researchers and policymakers can identify high-risk groups more accurately and target interventions where they are most needed. These insights enable the design of more equitable, interdisciplinary, and evidence-based public health strategies that address both the medical and social drivers of disease. Ultimately, such approaches are essential to reducing the overall burden of cardiovascular diseases and advancing health equity throughout Serbia, ensuring that vulnerable populations receive tailored support to achieve better health outcomes.

5. *Conclusion*

This study is among the first geo-medical investigations in AP Vojvodina and the Republic of Serbia to explore the complex link between educational attainment and CVD incidence, revealing a significant association between lower education levels and higher CVD risk. By using patient data from the ICDV in Sremska Kamenica and incorporating GIS and geospatial analysis, the study effectively captures socio-spatial disparities that influence disease patterns, demonstrating the suitability of these tools in medical geography to identify vulnerable populations and spatial clusters of disease. GIS enables the integration of epidemiological data with environmental and socioeconomic variables, offering a powerful framework to visualize and analyse how education and other social determinants interact with geographic factors to affect cardiovascular health. While the study's strengths lie in its innovative combination of spatial and clinical data, its cross-sectional design and focus on a single centre limit causal inference and generalizability. Additionally, educational attainment, though a valuable proxy, does not fully encompass the complexity of socioeconomic influences. Future research should expand to longitudinal, multi-regional studies incorporating broader social and environmental determinants and apply advanced spatial-temporal modelling to better understand dynamic CVD patterns. These insights reinforce the importance of targeted public health interventions focused on education, health literacy, and equitable healthcare access, highlighting how GIS-based geospatial analysis can guide precision public health strategies to reduce health inequalities and improve cardiovascular outcomes in Serbia and beyond.

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