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Association between contextual factors and vaccine coverage against human papilomavirus in adolescents in the state of Minas Gerais, Brazil: global spatial regressions

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Abstract

This study aimed to identify the associations between socioeconomic factors, the social environment, and human papillomavirus (HPV) vaccine coverage among adolescents in the state of Minas Gerais (MG), Brazil. This ecological study utilized secondary data from 853 municipalities in MG, covering female adolescents from 2014 to 2022 and male adolescents from 2017 to 2022, as provided by the information system of the National Immunization Program. Spatial statistical analysis was conducted to assess spatial dependence and identify spatial clusters of municipalities with high and low HPV vaccine coverage. The first and second dose coverage among male adolescents in most municipalities in MG was classified as very low (< 50%) or low (≥ 50% to < 80%). Among female adolescents, the majority of coverage rates were adequate (≥ 80%) or low (≥ 50% to < 80%). Socioeconomic factors, area-specific factors, and their interactions may influence HPV vaccination rates. The disparities in vaccination coverage rates observed across the state highlight the need for targeted interventions to increase coverage and reduce health issues, such as cervical cancer.

Keywords Papillomavirus vaccines, Adolescents, Epidemiology, Social Environment

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Introduction

Human papillomavirus (HPV) is a virus that infects the skin and mucous membranes (oral, genital and anal) and is the most prevalent sexually transmitted infection (STI) in the world; more than 200 viral subtypes that cause this infection have been identified [1, 2]. The World Health Organization (WHO) estimates that 14 million new HPV infections arise every year worldwide, that the risk of an individual being subjected to one or more types of HPV throughout their life is greater than 80%, and that two-thirds of women worldwide acquire an HPV infection within two years of becoming sexually active [1, 2].

In the Brazilian population, the incidence of this infection is high and varies greatly depending on the region, with its highest incidence occurring in the Northeast region [3]. The viral subtypes of HPV considered high risk are 16 and 18, both of which are associated with one of the main causal factors for the development of cervical cancer and are responsible for more than 70% of cases of this cancer. These and other viral subtypes of HPV are also associated with the development of other types of cancer, such as those of the vagina, vulva, anus, penis, and oropharynx [2, 4, 5].

The WHO recognizes cervical cancer and HPV-related diseases as global public health problems and recommends the inclusion of the HPV vaccine as a global strategy in national vaccination programs, aiming to reduce the incidence of new cases of this disease neoplasia, as well as related cancers [2, 6].

In this scenario, the HPV vaccine is part of immunization programs in several countries. The National Immunization Program (PNI) calendar started to include Brazil in 2014 [2, 7, 8]. One of the public health strategies adopted for the global elimination of cervical cancer is expected to achieve, by the year 2030, the following goals: 90% coverage of the HPV vaccine for girls up to 15 years of age; 70% for cancer screening, carried out correctly through Pap smears; and 90% for women diagnosed with the disease treated correctly and early [6].

Currently, the Brazilian Unified Health System (SUS) offers the human papillomavirus 6, 11, 16 and 18 (recombinant) vaccine HPV4, which is recommended for girls and boys aged 9 to 14 years. The adopted regimen consisted of two doses applied six months apart [9]. However, despite the SUS providing the vaccine free of charge, its coverage is below the expected target, far from the ideal of 80% for the full-dose schedule [10].

Data from the Ministry of Health (MS), via the PNI, revealed that the coverage of the second dose of the HPV4 vaccine in 2014 in girls aged 9 to 14 was 64.59%. In 2015, this percentage fell to 44.75% [9, 11], and in 2017, after the introduction of the HPV4 vaccine for boys, considering the second dose, the coverage was 10.41% for girls and 9. 65% for boys [9, 11].

In general, vaccine acceptability is a complex process that can be affected by several factors. In 2014, the *Strategic Advisory Group of Experts* (SAGE) [12] developed a model organized into three main domains: 1. Contextual influences—historical, sociocultural, environmental, health system/institutional, economic or political factors; 2. Individual and group influences—raising from personal perceptions of the vaccine or influences from the social environment; and 3. The questions were specific to the vaccines and directly related to their characteristics or the vaccination process. He also defined the term "vaccine hesitancy" as the delay in accepting or refusing vaccination, despite the availability of services to do so.

In the context of adolescence, there are many changes in human development, such as physiological, psychological and social changes [3], which may explain the low vaccination coverage among this population. Following the theoretical model described by Beharry and collaborators [13], this phenomenon can be justified by reasons grouped into three major organizational levels, namely, reasons related to the user/patient (adolescent) themselves, reasons related to professionals who provide care to adolescents and reasons related to the organization of the health service and social structures. A study carried out in Minas Gerais, a state in the southeastern region of Brazil, showed that factors in the social environment, such as violence rates in municipalities, can interfere with HPV vaccine coverage among adolescents [14].

Geographic heterogeneity in factors related to population characteristics (such as ethnicity, age and education level) and the context in which people live (such as neighborhood-level deprivation and proximity to health services) can help to explain disparities in vaccination coverage, in addition to identifying at-risk populations that require specific interventions [15, 16].

The present study hypothesized that sociodemographic and social environmental factors may be associated with meeting the PNI goals for the HPV vaccine.

Given the above, this study aimed to identify the association between socioeconomic factors and the social environment and HPV vaccine coverage rates in adolescents in the state of Minas Gerais, Brazil.

Methods

This is an ecological study carried out with secondary data from the State of Minas Gerais, Brazil, for girls from 2014 to 2022 and boys from 2017 to 2022; the data were generated by the *National Immunization Program Information System* (SI-PNI) and are available at <http://tabnet.datasus.gov.br/cgi/dhdat.exe?bd_pni/cpnibr.def>, about the HPV vaccine.

The State of Minas Gerais comprises 853 municipalities; the state with the largest number of municipalities in Brazil is distributed across a territory of 586,514 km2, with an estimated population of 20,539,989 inhabitants in 2022 [17]. Considering its territorial basis for health planning, the state divides its territory into 14 expanded health regions according to demographic, socioeconomic, geographic, sanitary, and epidemiological characteristics; the provision of health services; and the relationships between municipalities. The regions are as follows: South; South Center; Center; Jequitinhonha; West; East; Southeast; North; Northwest; Southeast; North East; South Triangle; Northern Triangle; and Steel Valley.

The State of Minas Gerais is also divided into 19 Regional Health Superintendences (SRS) and 9 Regional Health Management (GRS) states. Municipalities are delimited based on cultural, economic and social identities; shared communication networks; and transport infrastructure, with the purpose of integrating the organization and planning of health actions and services.

Data collection

Outcome

The HPV vaccine, the dependent variable of this study and made available by the PNI, is recommended for girls and boys aged 9 to 14 years. For the public in question, the threatening vaccine is administered on a two-dose schedule. As of 2016, the Ministry of Health adopted the calculation by age cohort as a methodology for evaluating vaccination coverage of the HPV vaccine. This method of calculation considers the cumulative doses since the year the vaccine was implemented for each cohort, considering that the scheme comprises two doses, which can be applied in different years. The coverage calculation was carried out in a similar way for both the first and second doses and was compared with the target stipulated by the PNI (80%) [18].

To calculate vaccination coverage (VC), cohorts were defined from 9 to 15 years of age for the female population and from 11 to 15 years for the male population vaccinated in the state of Minas Gerais. The second dose of the vaccine was evaluated in the population up to 15 years of age of both sexes according to the cohort monitoring strategy followed by the PNI [19]. The VC calculations were carried out according to the following criteria: population aged 9 years: vaccinated population aged 9 years in 2021; population aged 10 years: population vaccinated aged 9 years in 2020 added to the population vaccinated aged 10 years in 2021; population aged 11 years: sum of populations vaccinated at 9 years of age in 2019; population at 10 years old in 2020; population at 11 years old in 2021; population aged 12: sum of populations vaccinated at 9 years of age in 2018; population at 10 years old in 2019; population at age 11 in 2020; and population at 12 years of age in 2021. This procedure was carried out successively for the population vaccinated at 13, 14 and 15 years of age. When calculating the doses applied, the first and second doses were considered for females and males, respectively.

VC was categorized according to the following criteria established by the PNI: greater than or equal to 80% for immunobiologicals administered to adolescents; very low (0% to < 50%); low (≥ 50% and lower than the target); and adequate (≥ the target).

The VC content of each mixture was classified into three categories according to the dose. A VC percentage less than 50% was classified as “very low”. If the observed value was equal to or greater than 50% of the target, which is 80%, it was categorized as “Low”. When the percentage is equal to or greater than 80%, “adequate”.

Explanatory variables

As independent variables of this study, the sociodemographic variables of the municipalities were adopted (population, number of families with an income of up to half a minimum wage, percentage of the poor population in unique registration, proportion of the population served by the family health strategy, and urbanization rate).

Data analysis and processing

Initially, multivariate linear regression was applied [20]. For the modeling process, the backward method was adopted based on theoretical criteria. The multicollinearity condition number was also used to identify the collinearity of the explanatory variables included in the model, as this test shows collinearity of the explanatory variables when their value is greater than 30. The multicollinearity condition number is more appropriate than the VIF (Variance Inflation Factor). This is because the condition number assesses the numerical stability of the entire set of explanatory variables, while the VIF examines the collinearity of each variable individually. In global spatial models, where the relationship between variables can be more complex and interdependent, the condition number makes it possible to identify multicollinearity problems on a broader level, capturing interactions that the VIF may not adequately detect.

The OLS model provides estimates of spatial dependence diagnoses through Tests Langrange multipliers, which shows the need to consider models that incorporate spatial effects.

Subsequently, models with global spatial effects were constructed that consider spatial effects, namely, spatial lag and spatial error. Using Lagrange multiplier tests, the model that presented the highest likelihood-like value and lowest Akaike information criterion (AIC) and Schwarz Bayesian criterion values was considered the like model [20, 21].

The spatial lag model does not attribute ignored spatial autocorrelation to the response variable. In this model, spatial autocorrelation is incorporated as a component of the model itself. The spatial error model considers spatial effects as noise, that is, a factor to be removed, since the effects of spatial autocorrelation are associated with the error term.

Finally, the Global Moran index was used to assess whether the spatial autocorrelation of the residues had been eliminated [20]. Geoda software (version 1.20.0.8) was used for the analysis of this study.

Ethical approval

Due to the nature of this study of using freely accessible data, available from the Information Technology Department of the Brazilian National Health System (Datasus), it was not necessary to submit the present study to the Research Ethics Committee in accordance with Resolution 466/2012 of the National Brazilian Health Council.

Table 1 Vaccination coverage between males (2016–2022) and females (2014–2022) after the first and second doses of the HPV vaccine, Minas Gerais, Brazil

Dose	Applied doses	Population	VC (%)
Male			
1ª dose	408,461	811,437	50.3%
2ª dose	340,742	955,215	35.7%
Female			
1ª dose	664,709	775,425	85.7%
2ª dose	634,453	912,920	69.5%

VC Vaccination coverage

Results

In the 853 municipalities of the state of Minas Gerais, in the first dose, 408,461 vaccines were administered among 811,437 male children and adolescents, resulting in a VC of 50.3%.

Among female children and adolescents, 85.7% of the participants were vaccinated, for a total of 664,709 vaccinations administered to a population of 775,425. At the second dose, of which 955,215 were male children and adolescents, 340,742 received the vaccine, resulting in a VC of 35.7%.

A total of 634,453 female children and adolescents received the dose out of a population of 912,920, with a final coverage of 69.5% (Table 1).

Coverage in the first and second doses among males in most of the 853 municipalities in the state of Minas Gerais was considered very low (34.8% dose 1 and 74.9% dose 2) or low (55.5% dose 1 and 24.3% dose 2). Among females, the highest percentages were for adequate (77.5% dose 1 and 48.5% dose 2) or low (21.6% dose 1 and 46.2% dose 2). The data can be seen in Fig. 1.

Figure 2 and Supplementary Material 1 show the vaccination coverage figures for the first and second doses given by the Regional Health Units (URS)(in Portuguese—*Unidades Regionais de Saúde*), as well as the number and percentage of municipalities in each of the

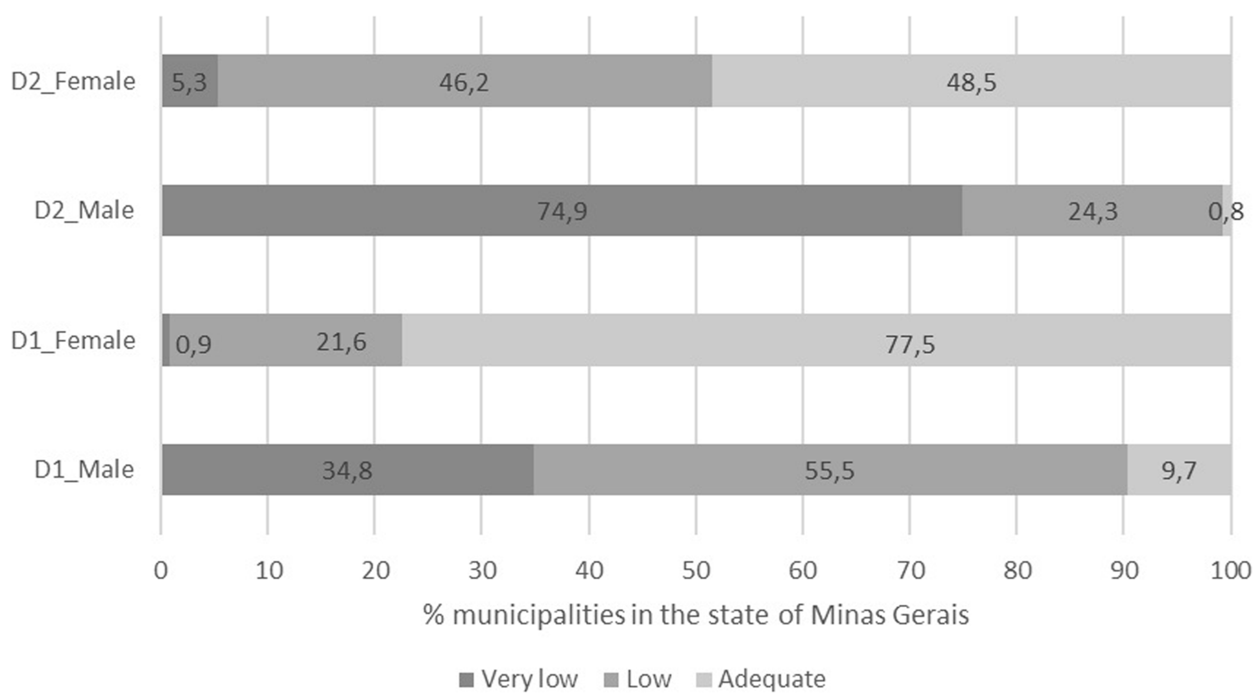

Fig. 1 Percentages of vaccination coverage categories between sexes for the first and second doses of the vaccine among municipalities in Minas Gerais, Brazil. Note: n: 853 municipality; D1= Dose 1; D2= Dose 2

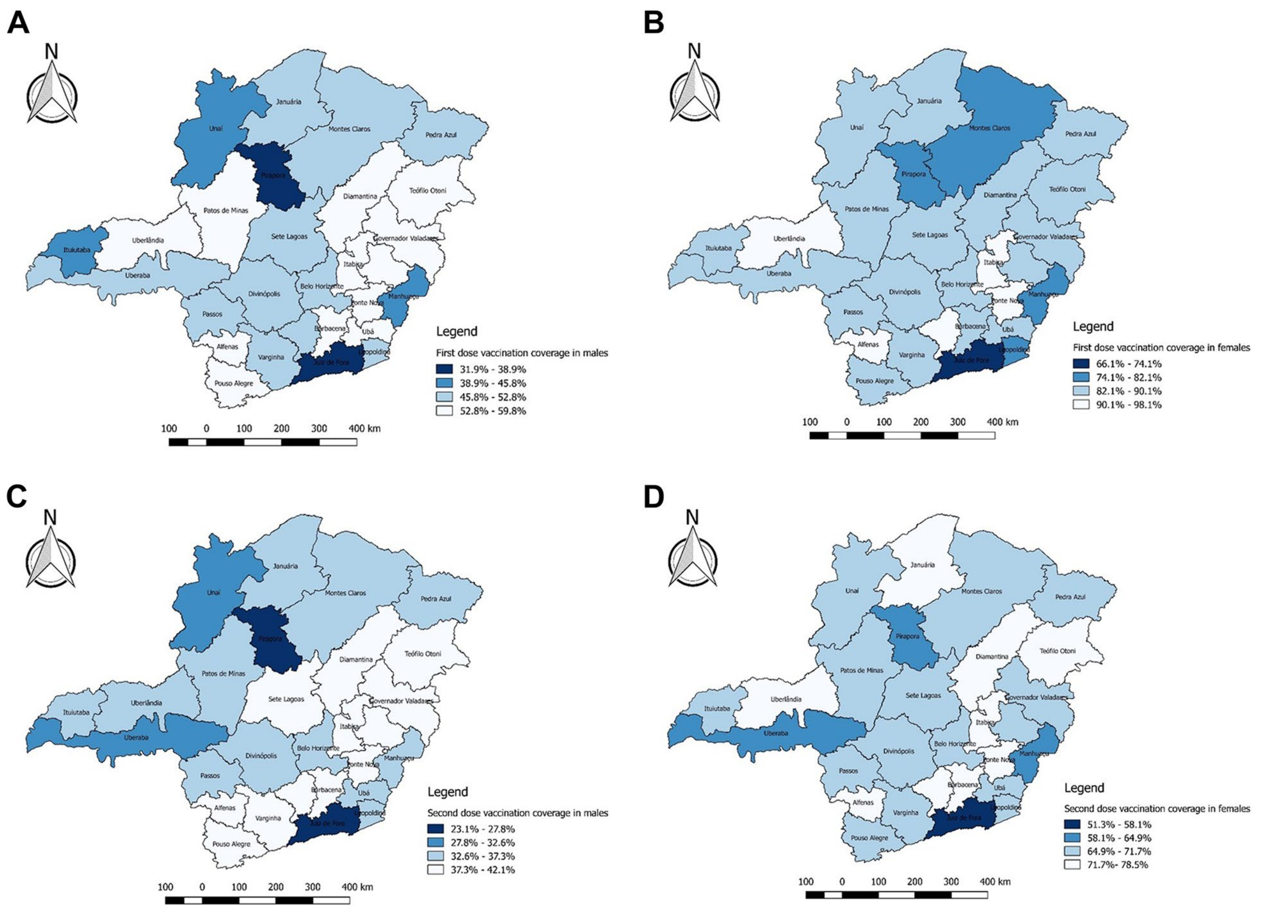

Fig. 2 .

URSs that were classified as 'adequate' in relation to the vaccination target for both sexes.

Among vaccinated males, the URS of Itabira had the highest VC, at 59.75 (Fig. 1A). However, only 4 (16.67%) of the municipalities belonging to the URS had an adequate level for the first dose. For the first dose among females (Fig. 2B), the highest vaccination coverage was in the URS of Uberlândia, at 98.14%; however, 11 (61.11%) of the municipalities were vaccinated at or above 80%. Regarding the second dose (Fig. 2C), the URS that presented the highest VC for men was Ponte Nova, with 42.07. However, one (3.33%) municipality reached the adequacy target. With respect to the second dose applied to females (Fig. 2D), the highest VC concentration was observed in the URS of Alfenas, for which 78.46 and 15 municipalities achieved the target, representing 62.50% of the URS.

Table 2 and Supplementary Material 2 shows that the OLS model for the first male dose has a portion of spatial correlation that can improve the model, with Moran's global index equal to 0.0534. Lagrange multipliers were significant, indicating that spatial models should be estimated (p value < 0.001). Among the two spatial models, spatial error was the best, with lower AIC and Schwarz criterion values and higher R2 and logarithm of likelihood values (Supplementary Material 2).

According to the best model obtained, the area of the municipality significantly decreased the value of vaccination coverage (p value < 0.05). The urbanization rate was also significantly different: the higher the urbanization rate was, the lower the VC values were. The proportion of families served by the family strategy was significant, demonstrating that the greater their proportion in the municipality was, the greater the VC values were.The effect of the second dose on males did not change compared to that of the first dose.

The global Moran's index showed a value of 0.06 and the Lagrange multipliers were significant, leading to an improvement in the model through spatial correlations. The value of 0.06 suggests weak spatial autocorrelation, but the significance of the Lagrange multipliers indicates that there is a relevant spatial dependence that should be considered in the model. The model with the best indicators was Spatial Error, which means that

Table 2 OLS, *spatial error and spatial lag* models for the first and second doses to males

Models	Fisrt dose						Second dose					
	OLS		Spatial Error		Spatial Lag		OLS		Spatial Error		Spatial Lag	
	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value
Variables												
AREA_KM2	−0.0023	0.0003	−0.0022	0.0022	−0.0019	0.0018	−0.0017	< 0.001	−0.0016	0.0030	−0.0014	0.0015
D1_male	0.0012	0.0730	0.0010	0.1346	0.0012	0.0716	0.0006	0.1169	0.0006	0.1226	0.0007	0.0812
N_min	−0.0009	0.0367	−0.0007	0.1020	−0.0008	0.0417	−0.0006	0.0707	−0.0005	0.0912	−0.0006	0.0505
P_single	−0.1060	0.0429	−0.0303	0.6113	−0.0646	0.2083	−0.0658	0.0886	−0.0166	0.7089	−0.0428	0.2571
P_ strategy	0.1632	0.0006	0.1505	0.0013	0.1549	0.0008	0.1500	< 0.001	0.1312	< 0.001	0.1374	< 0.001
Rate_Urb	−0.1441	0.0017	−0.1667	0.0004	−0.1403	0.0019	−0.1424	< 0.001	−0.1557	< 0.001	−0.1355	< 0.001

Area_KM2: area per square kilometer; D1_male: first dose of vaccine for the female population; N_min: number of families with an income of up to half the minimum wage; P_single: percentage of the population with a single registration; P_ strategy: proportion of the population served by the family health strategy; Rate_Urb: urbanization rate

incorporating the spatial dependence structure into the model's errors improved the quality of the analysis. This model considers that the errors are not independent, but spatially correlated, which is important in analyses where geographical location can influence the results (Supplementary Material 2). The significant coefficients included the following variables: area, proportion of families served by the family strategy and urbanisation rate (Table 2). The significant coefficients found in the model indicate the relationships between the variables analysed, as follows:

Area: There is an inverse relationship with VC, suggesting that the larger the area, the lower the VC. This may indicate that larger municipalities, in terms of area, have more stability or less variation in the observed characteristics.

Proportion of families served by the family strategy: This has a direct relationship with the VC, suggesting that the greater the coverage by the family strategy, the greater the municipality's VC. This may indicate that the expansion of family strategy coverage is associated with variations in the health characteristics of municipalities.

Urbanisation rate: Also inversely related to VC, suggesting that more urbanised municipalities tend to have lower VC, which may indicate greater homogeneity or less variation in more urbanised municipalities.

Table 3 and Supplementary Material 3 shows a higher spatial correlation for the first dose given to girls, with an overall Moran's index of 0.0814. Although the value is not extremely high, it still points to a relevant spatial autocorrelation that justifies spatial modelling. Among the spatial models, Spatial Error again showed the best results, with the lowest AIC and Schwarz criterion values and the highest R^2 and log-likelihood values. showed the best results, with the lowest AIC (Akaike Information Criterion) and Schwarz criterion values, as well as the highest R^2 and log-likelihood values, indicating that this model better explains the variations observed in the data(Supplementary Material 3). In this model, the coefficients of all the variables

Table 3 OLS, *spatial error and spatial lag* models for the first and second doses to females

Models	Fisrt dose						Second dose					
	OLS		Spatial Error		Spatial Lag		OLS		Spatial Error		Spatial Lag	
	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value	Coef	*p*-value
Variables												
AREA_KM2	−0.0027	0.0004	−0.0025	0.0048	−0.0024	0.0011	−0.0023	0.0012	−0.0022	0.0075	−0.0021	0.0025
D1_female	0.0026	0.0016	0.0020	0.0106	0.0026	0.0011	0.0019	0.0034	0.0016	0.0117	0.0019	0.0023
N_min	−0.0018	0.0004	−0.0014	0.0066	−0.0018	0.0003	−0.0016	0.0009	−0.0013	0.0057	−0.0016	0.0007
P_single	0.1550	0.0168	0.3512	0.0000	0.1937	0.0022	0.1036	0.0844	0.2330	0.0009	0.1246	0.0353
P_ strategy	0.1747	0.0028	0.1466	0.0101	0.1507	0.0078	0.2182	0.0001	0.1899	0.0004	0.1976	0.0002
Rate_Urb	−0.0446	0.4310	−0.1059	0.0671	−0.0564	0.3069	−0.1134	0.0313	−0.1576	0.0035	−0.1163	0.0245

Area_KM2: area per square kilometer; D1_female: first dose of vaccine for the female population; N_min: number of families with an income of up to half the minimum wage; P_single: percentage of the population with a single registration; P_ strategy: proportion of the population served by the family health strategy; Rate_Urb: urbanization rate were statistically significant (p-value < 0.05), with the exception of the urbanisation rate. For the area of the municipality and the number of families earning just one minimum wage, the coefficients indicated that the higher the observed values, the lower the CV in the municipalities. For the variables opposite-sex population and proportion of families served by the Family Strategy programme, the higher the observed values, the higher the CV for the first dose in females.

The coefficients are interpreted as follows: Area of the municipality and number of families earning only one minimum wage: The higher these values, the lower the VC for the first dose applied to women. This suggests that larger municipalities, with more low-income families, have less variation in the application of the first dose.

Population of opposite sex and proportion of families served by the Family Strategy Programme: The higher the values for these variables, the higher the VC for the first dose. This may indicate that the presence of a larger population of the opposite sex and the greater coverage of the Family Strategy programme are associated with greater variability in the application of the first dose in women.

For the second dose applied to women, the adjustment results showed that the Spatial Error model was the best. Lower fit values were obtained for the AIC and Schwarz criteria and higher results for the log-likelihood and R2 (Supplementary Material 3). Unlike what was found for the first dose, all the coefficients were significant: Municipal Area, Number of Households earning a Minimum Wage and Urbanisation Rate: These coefficients indicate that the higher these values, the lower the VC for the second dose. This suggests less variability in the application of the second dose in larger, more urbanised municipalities with a greater number of low-income families. Regarding the variables Opposite Sex Population, Percentage of Poor Population and Proportion of Families Served by the Family Strategy Programme: The higher these variables, the higher the VC for the second dose. This may reflect challenges in equitable coverage of the second dose in contexts with greater poverty and greater presence of people of the opposite sex. The results indicate that spatial dependence is an important factor in analysing the distribution of vaccine doses, especially between the different demographic and socioeconomic characteristics of the municipalities. The use of the Spatial Error Model makes it possible to capture these spatial correlations and provide a more robust analysis, highlighting patterns that can guide more targeted and effective public health policies (Table 3).

Discussion

This study showed that the incidence of HPV infection, which occurred during both the first and second doses among male adolescents in most municipalities in the state of Minas Gerais, was considered very low (< 50%) or low (≥ 50% to < 80%). Among female adolescents, the highest percentages were adequate (≥ 80%) or low (≥ 50% to < 80%).

In Brazil, the HPV vaccine faces challenges, such as changes in the target population and in the vaccination schedule over time, and it is currently offered free of charge in the SUS for individuals aged 9 to 14 years based on a scheme of two doses, with an application interval of six months [22].

Since their licensing in 2006, HPV vaccines have been progressively introduced in many countries. European countries started their vaccination schedule earlier in their immunization programs, and in some of them, HPV vaccination programs were successful from the beginning and maintained high vaccination coverage. However, in other regions, such as Japan, Ireland and Denmark, there has been a significant decrease in VC since the introduction of the vaccine [23].

In Brazil, coverage rates are not very different from those in these countries, and at the beginning of the vaccine introduction campaign, 87% of Brazilian municipalities reached the recommended target in the first dose in 2014, but only 32% of them reached the recommended target in the second dose [9, 11]. This scenario of falling global VC, including that of the HPV vaccine, has been worrying to health managers on a universal scale [24].

The introduction of a new vaccine to the population can contribute to vaccine hesitancy [25] and, consequently, interfere with VL. However, other factors, as highlighted by Beharry and collaborators [13], can also contribute to adolescents' VC. In this scenario, adolescents rarely attend health services and rarely engage in health promotion activities, both due to the characteristics of biopsychosocial development and because of the lay understanding that the age group has "good health" and would not benefit from medical consultations. routine [26, 27]. Furthermore, many adolescents (and family members) are not aware of the need for vaccination in their age group [28]; for example, the lack of health education at school, where adolescents spend a large part of their time, also contributes to a lack of this knowledge or greater care.

Vaccination against HPV has proven to be crucial in the prevention of cervical cancer, one of the leading causes of mortality among women worldwide. International studies, such as those conducted by the WHO and the Centers for Disease Control and Prevention (CDC) in the United States, have demonstrated that the vaccine is highly effective in reducing infections by HPV strains responsible for approximately 70% of cervical cancer cases. Countries that have implemented widespread vaccination programs, like Australia, which aims to eliminate cervical cancer by 2035, have seen a significant decrease in the incidence of this disease. Moreover, the HPV vaccine is widely recognized as cost-effective, as it prevents HPV infection, reducing the need for expensive treatments for cancer and pre-cancerous lesions, while also lowering the social and public health costs associated with the disease [6, 12].

Another relevant factor for vaccinating adolescents is professionals, especially ESF professionals, as not everyone is prepared to address the idiosyncrasies of adolescence [27]. Furthermore, not everyone encourages the updating of adolescents' vaccination schedules when they attend health care services [28]. They also use the myth of the father or guardian's need to offer care/interventions, not guaranteeing the adolescent's rights.

Finally, it is known that there are intrinsic reasons for the organization of the health system and the social constructions that can impede the path of adolescents to primary care centers [27]. This factor deserves much attention, especially in a country such as Brazil, where 61% of children and adolescents live in conditions of socioeconomic vulnerability.

The role of the COVID-19 pandemic in reducing VC in children and adolescents cannot be ignored [29–32]. A study carried out with another immunobiological agent, exclusively for the adolescent population in Minas Gerais, showed that in 2020, the VC for this immunobiological agent was 52.28% for the first dose and 25.69% for the second dose [33].

Another finding of this study was that, in relation to males, for both the first and second doses, the higher the urbanization rate was, the lower the VC values were. For females, for area and number of families with a minimum wage, the coefficients indicate that the higher the values observed are, the lower the VC in the municipalities. For the variable population of the opposite sex and proportion of families served by the ESF, the higher the values observed were, the greater the VC was at the first dose.

In the U.S., a study on the association between HPV vaccination, income and type of health care (with health insurance and/or without) produced similar results. A study showed that adolescents from low-income families without health insurance were more likely to start the HPV vaccination process [34].

Work carried out in Brazil showed that HPV vaccine coverage increased in the population who lived only with their mother and had a higher level of education [35].

These findings emphasize that, in the absence of universal public policies, adolescents in a context of greater social vulnerability will have reduced access to vaccination and will be more subject to health problems, such as cervical cancer [35].

In this sense, the ESF, first named the Family Health Program (FHP), officially implemented in the Brazilian territory in 1994, represents a milestone in the history of health policies in Brazil, as it reorganized the health care model [36]. In Minas Gerais, the proportion of the population served in ESF units was 72.3% in 2013, and in 2019, it was 73.0% [37]. However, Minas Gerais has its own complexities. In this sense, through the Primary Health Care Secretariat of the Ministry of Health, in May 2019, and with updates to the publication of Ordinance No. 397/GM/MS, of March 16, 2020, the Ministry of Health launched the Health in the Hour Program, which provides for the extension of opening hours at UBS in municipalities that join the program, enabling easier access for the population to services offered in primary care, including immunization actions [25, 38].

Finally, this work demonstrated that, in relation to the proportion of families served by the ESF, the higher their proportions in the municipality were, the greater the VC values for the first and second doses of the HPV vaccine. The second dose applied to females, the area of the municipality, the number of families with a minimum wage and the urbanization rate indicated that the higher the VC values were in the second dose, the lower they were. However, the larger the population of the opposite sex, the greater the percentage of the "poor" population in the single registry and the greater the proportion of families served by the family strategy, the greater the VC in the second dose.

A study by Staples et al. [39] revealed contrasting effects of area-level socioeconomic factors on the initiation and completion of the HPV vaccine among adolescents, with regions with the lowest coverage rates being less populated, less educated, and having a lower median family income and higher rates of poverty and unemployment [39]. Among male adolescents, those in these areas had a significantly lower density of primary care providers [39].

Other studies have shown that area-level characteristics such as ethnic composition, population density, sex distribution, area-level socioeconomic status, geographic location, and local health services are associated with geospatial patterns of HPV vaccination coverage in different populations [39, 40]. As in this study, the work of Grampos et al. showed that the least disadvantaged regions recorded the highest vaccination completion rates, which is consistent with an analysis of secondary data from the 2012 and 2013 NIS-Teen survey. These findings demonstrate that boys who lived in high-poverty areas were more likely to complete the vaccination schedule than boys in low-poverty areas were [41], which is justified by the fact that this more vulnerable population is covered by the health system more effectively.

Nevertheless, in relation to geographic location, studies show that less economically disadvantaged places have more actions related to neighborhood safety; consequently, programs aimed at public health, such as the ESF, are more active and subsidize actions aimed at vaccination programs, which favor higher HPV vaccine rates [42, 43].

The limitations of this study are related to the inaccuracy of the use of secondary data regarding VC calculations and data on individual characteristics. On the other hand, the study advances by comparing the cumulative vaccination coverage of the HPV vaccine in multiple cohorts of adolescents to socioeconomic factors and the social environment in the state of Minas Gerais. It is also worth highlighting the innovation of this study regarding adolescent health and vaccination, a topic that is still scarce in the Brazilian and global literature.

Conclusion

This study demonstrated that socioeconomic factors, geographical area and their interactions can influence HPV vaccination efficacy. The disparities found in this study related to VC rates throughout the state of Minas Gerais demonstrate the need to implement intervention actions aimed at this population to increase VC and, consequently, reduce health problems, such as cervical cancer.

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Clinical trial number

Not applicable.

Authors' contributions

BMOL- (DESIGN OF THE STUDY, EXTRACTION OF DATA, ANALYSIS AND INTERPERETATION, WRITING OF THE ARTICLE, FINAL APPROVAL OF THE VERSION TO BE SUBMITTED;All authors reviewed the manuscript); TPRS- (DESIGN OF THE STUDY, EXTRACTION OF DATA, ANALYSIS AND INTERPERETATION, WRITING OF THE ARTICLE, FINAL APPROVAL OF THE VERSION TO BE SUBMITTED;All authors reviewed the manuscript); JDG- (STUDY DESIGN, ANALYSIS AND INTERPRETATION, ARTICLE WRITING, FINAL APPROVAL OF THE VERSION TO BE SUBMITTED;All authors reviewed the manuscript); MLF- (STUDY DESIGN, ANALYSIS AND INTERPRETATION, ARTICLE WRITING, FINAL APPROVAL OF THE VERSION TO BE SUBMITTED;All authors reviewed the manuscript); LMDN- (STUDY DESIGN, ANALYSIS AND INTERPRETATION, ARTICLE WRITING, FINAL APPROVAL OF THE VERSION TO BE SUBMITTED;All authors reviewed the manuscript); LPG- (STUDY DESIGN, ANALYSIS AND INTERPRETATION, ARTICLE WRITING, FINAL APPROVAL OF THE VERSION TO BE SUBMITTED;All authors reviewed the manuscript); FPM- (DESIGN, CONCEPTION OF THE STUDY, WRITING OF THE ARTICLE, FINAL APPROVAL OF THE VERSION TO BE SUBMITTED;All authors reviewed the manuscript).

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Data Availability

Data are provided in the manuscript in the methodology session, secondary data from the State of Minas Gerais, Brazil, for girls from 2014 to 2022 and boys from 2017 to 2022; the data were generated by the National Immunization Program Information System (SI-PNI) and are available at <http://sipni.datasus.gov.br/,> , about the HPV vaccine.

Declarations

Ethics approval and consent to participate

Because it is non -nominal public data, available by Datasus, it was not necessary to approve the study project by a research ethics committee. All procedures performed in studies involving human participants were in compliance with the ethical standards of the institutional research committee, as well as with the 1964 Helsinki declaration and with its later amendments or comparable ethical standards.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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