



Spatio-Temporal Dynamics and the Influence of Socio-Economic Factors on the Crude Incidence Rate of Type 2 Diabetes Mellitus in South Sulawesi (2020-2023)

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Abstract

Type 2 diabetes mellitus (type 2 DM) is a major public health problem in Indonesia. In South Sulawesi, the Crude Incidence Rate (CIR) exhibits substantial variation across district and cities, potentially reflecting underlying socioeconomic heterogeneity. This study analyzed the spatio-temporal distribution of type 2 DM CIR from 2020 to 2023 and examined its socioeconomic determinants. An ecological panel study was conducted using secondary data on type 2 DM CIR and ten socioeconomic indicators across all 24 districts and cities in South Sulawesi Province. Spatio-temporal relationships were examined using Geographically and Temporally Weighted Regression (GTWR), complemented by descriptive and spatial statistical analyses. The CIR increased significantly from 2020 to 2023, with Palopo City recording the highest burden. Global Moran's I showed no significant spatial autocorrelation. Mean Years of Schooling ($r = 0.740-0.789$), Open Unemployment Rate ($r = 0.644-0.693$), Human Development Index ($r = 0.682-0.749$), and Per Capita Expenditure ($r = 0.542-0.612$; $p < 0.01$) were consistently significant predictors. GTWR confirmed their spatio-temporal influence across districts and cities in South Sulawesi. Socioeconomic factors significantly shape the spatio-temporal variation of type 2 DM burden in South Sulawesi, highlighting the need for targeted community-based interventions and inclusive socioeconomic policies to reduce disease burden.

INTRODUCTION

Recent studies have projected that the Crude Incidence Rate (CIR) of type 2 Diabetes Mellitus (type 2 DM) in Indonesia will significantly increase in the coming decades. It is estimated that the CIR of type 2 DM will rise from 9.19% in 2020 to 16.09% in 2045, with the number of cases predicted to reach 40.7 million. (Wahidin et al.,

2024). Studies have indicated that type 2 DM can have significant socioeconomic impacts, such as increased healthcare costs, decreased work productivity, and reduced quality of life for patients and their families (Patty et al., 2021). Those living in urban areas tend to be more vulnerable to diabetes than rural residents, possibly due to unhealthy lifestyles and easier access to processed

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foods (Indrahadi et al., 2021).

A study found that type 2 DM influences the occurrence of hypertension in the South Sulawesi region. In addition, the CIR of type 2 DM was substantially higher in East Luwu District than in Makassar City, even though Makassar City has the largest population and highest population density in South Sulawesi Province (Zainuddin et al., 2023). This study found that a high population size and density did not explain the variation of the CIR of type 2 DM. This aligns with the research by Carnegie et al. (2022), who found that diabetes incidence occurs more frequently in lower-density populations. Other factors, such as education and access to health care, have a greater influence than population density (Carnegie et al., 2022).

Although population density and size may influence the CIR of disease, growing evidence suggests that the burden of type 2 DM is more strongly shaped by social determinants of health (SDH), including education level, employment status, income, and accessibility to health services (Tol et al., 2013). Previous studies have shown that communities with limited access to education and healthcare services are more vulnerable to developing type 2 diabetes because of a lack of understanding and management of the condition (Faletau et al., 2020). In addition, income factors contribute to the inability of some segments of the population to access healthy food and regular medical check-ups, which can increase the risk of the disease (Wolfson et al., 2019). Because these socioeconomic determinants vary across geographic areas and over time, understanding their spatial and temporal distribution is essential for identifying populations at greater risk and informing targeted public health interventions.

Consistent with these findings, a number of sustainable development objectives, including the reduction of poverty (SDG 1), enhancement of food security (SDG 2) (Annur & Noordin, 2025), and quality education (SDG 4) (Singh et al., 2025) collectively address the social and economic conditions underlying non-communicable diseases such as type 2 DM. Accordingly, this study aimed to examine the spatio-temporal distribution of the crude incidence rate (CIR) of type 2 DM and identify the socioeconomic factors associated with its variation across districts and cities in South Sulawesi Province using a geo-spatial analytical approach district and cities

METHOD

This study used a panel ecological approach. The data used in this study were aggregate-

level data across all 24 district and cities in South Sulawesi Province over a four-year observation period (2020–2023). The outcome variable was the CIR of type 2 DM, derived from the total visit records of BPJS Kesehatan participants at Advanced-Level Referral Health Facilities (secondary outpatient and inpatient care) with a confirmed diagnosis of type 2 DM retrieved from the national BPJS health information system following a tiered verification process for 64,683 patients and did not include capitation- or non-capitation-based services delivered at First-Level Health Facilities (FKTP). Therefore, the findings should be interpreted as representing the burden of type 2 DM cases requiring or accessing referral-level care within the BPJS Kesehatan system. The complete dataset specifications, including total visit counts per district and cities per year, are presented in Supplementary Table S1. The CIR of type 2 DM was operationally defined as the number of newly diagnosed and referred type 2 DM cases recorded within the BPJS Kesehatan FKRTL claims system in each district and cities during a given year, divided by the annual population of the corresponding district and cities in that year (obtained the Central Statistics Agency (BPS) of South Sulawesi Province), expressed per 100,000 population. The term crude indicates that the rate was not adjusted for age, sex, or other demographic structure across district and cities. Because the numerator was restricted to cases identified and verified through the referral-level (FKRTL) claims and diagnostic verification process, CIR in this study should be understood as a measure of diagnosed and treated caseload accessing referral-level care within the BPJS Kesehatan system, rather than a population-based estimate of true community-level type 2 DM incidence obtained through active case-finding or population screening.

Socioeconomic indicators were obtained from the Central Statistics Agency (BPS) of South Sulawesi Province, comprising ten variables: (1) Gini Ratio, a measure of income inequality within a population ranging from 0 (perfect equality) to 1 (perfect inequality); (2) Poverty Rate, the percentage of the population living below the regional poverty line; (3) Economic Growth Rate, the annual percentage change in regional gross domestic product reflecting local economic performance; (4) Per Capita Expenditure, the average monthly household expenditure per person as a proxy for purchasing power and living standards; (5) Gross Regional Domestic Product (GRDP), the total monetary value of all goods and services produced within a district and

cities in a given year; (6) Mean Years of Schooling (MYS), the average number of years of formal education completed by the population aged 25 years and older; (7) Labor Force Participation Rate (LFPR), the proportion of the working-age population that is either employed or actively seeking employment; (8) Open Unemployment Rate (OUR), the percentage of the labor force that is jobless and actively seeking work; (9) Human Development Index (HDI), a composite index measuring achievements in health, education, and standard of living; and (10) Life Expectancy at Birth (LEB), the average number of years a newborn is expected to live under current mortality conditions. All data processing and analysis were conducted at the Department of Public Health and Community Science, Faculty of Medicine, Universitas Hasanuddin, using R version 4.4.0 and RStudio version 2025.05.0+496 with the relevant statistical and spatial packages.

The analytical procedure was performed in five sequential stages. The first stage comprised a descriptive analysis of the outcome variable and all ten socioeconomic indicators. Descriptive statistics, including the minimum, maximum, mean, and standard deviation, were calculated for the CIR of type 2 DM and each socioeconomic indicator at the district and cities level for every study year (2020–2023), providing a baseline characterization of the distribution and variability of both disease burden and socioeconomic conditions across South Sulawesi Province. The second stage assessed annual trends in CIR values using a Paired T-Test to identify statistically significant inter-annual differences across consecutive study years (2020–2021, 2021–2022, and 2022–2023). To quantify the magnitude of observed changes, effect size was calculated using Cohen's *d*, interpreted according to conventional benchmarks (small: $d = 0.2$, medium: $d = 0.5$, large: $d \geq 0.8$), and mean differences with 95% confidence intervals (95% CI) were reported to provide precise estimates of the direction and magnitude of year-to-year CIR changes (Steinmetz et al., 2021). The results of the trend test were visualized using the *ggplot2* and *ggpubr* packages to clarify the differences in annual patterns (Quicke et al., 2021). The third stage involved the classification of CIR values for type 2 DM into vulnerability categories based on the natural distribution of the data using the Natural Breaks (Jenks) method. This method was chosen because it can identify class boundaries that statistically separate the data values into natural clusters. The main purpose of using natural breaks is to enable the identification of areas with similar levels of vulnerability, thereby

supporting a more accurate spatial interpretation (Yoo et al., 2023).

Spatial analysis was continued with the calculation of Global Moran's *I* to evaluate the spatial pattern of the CIR distribution each year from 2020 to 2023. The results of the classification and spatial analysis were visualized in the form of thematic maps using *tmap* (Tennekes, 2018) and *sf* (Pebesma, 2018). The fourth stage involved Bivariate Pearson Correlation analyses between each of the ten socioeconomic indicators and the annual CIR values to identify variables with a statistically significant and consistent association across all study years. Only indicators demonstrating significant correlations across the observation period were retained for subsequent modeling, as non-significant variables were considered to contribute insufficient explanatory power to the spatial variation of CIR (Darvishi et al., 2024). Variables with $p < 0.05$ in the correlation analysis across all study years were retained for further analysis. The final stage of the analysis was conducted using Geographically and Temporally Weighted Regression (GTWR) modeling with the *GWmodel* package (Gollini et al., 2015). The GTWR model is a geospatial analysis that integrates spatial and temporal dimensions simultaneously to uncover the dynamics of the relationships between variables on both scales (Dong et al., 2025). To further justify the application of GTWR relative to global regression approaches, model fit was compared using R^2 , Adjusted R^2 , and the corrected Akaike Information Criterion (AICc), with a difference of $\Delta AICc > 3$ considered indicative of substantially stronger model support (Anderson & Burnham, 2002; Burnham & Anderson, 2004). With this approach, this study can provide a more holistic understanding of the dynamics of the determining factors of Type 2 DM at the district and cities level in South Sulawesi.

RESULT AND DISCUSSION

The CIR of type 2 DM demonstrated a consistent upward trajectory throughout the observation period, with provincial mean increasing from 132.94 ± 118.68 per 100,000 population in 2020 to 212.75 ± 185.37 per 100,000 population in 2023, representing a cumulative increase of approximately 60.0% over four years. Notably, the minimum CIR approximately doubled across the observation period, rising from 33.91 in 2020 to 65.87 in 2023, while the maximum CIR increased substantially from 481.92 to 782.84 per 100,000 population district and cities. Together with the persistently large standard deviations, these findings indicate considerable inter-district hetero-

geneity in the type 2 DM burden across South Sulawesi Province, with evidence of widening variability across the study period.

With respect to socioeconomic conditions, the Gini Ratio remained relatively stable across the study period, with mean values declining slightly from 0.368 in 2020–2021 to 0.362 in 2022–2023, suggesting minimal change in district-level income inequality. The Poverty Rate similarly showed modest improvement, from $9.42 \pm 2.92\%$ in 2020 to $9.33 \pm 2.74\%$ in 2023, though inter-district variation remained considerable. The Economic Growth Rate declined gradually from $1.31 \pm 0.56\%$ in 2020 to $1.19 \pm 0.33\%$ in 2023. In contrast, Per Capita Expenditure showed a consistent upward trend, increasing from IDR 10,901,458 $\pm$ 2,050,529 in 2020 to IDR 11,684,667 $\pm$ 2,090,663 in 2023. Similarly, the Gross Regional Domestic Product (GRDP) increased steadily from IDR 47,227,083 $\pm$ 20,371,157 million in 2020 to IDR 59,407,792 $\pm$ 26,072,150 million in 2023, with substantial inter-district variation persisting throughout the period.

Human capital indicators also showed a progressive improvement over the study period. Mean Years of Schooling increased from 8.15 ± 1.18 years in 2020 to 8.52 ± 1.14 years in 2023, while the Human Development Index (HDI) rose from 70.53 ± 4.01 in 2020 to 72.15 ± 3.84 in 2023, reflecting gradual but consistent improvements in educational attainment and overall human development across district and cities. Life Expectancy at Birth likewise demonstrated a steady increase, from 69.49 ± 1.99 years in 2020 to 70.13 ± 1.93 years in 2023. The Labor Force Participation Rate increased from a mean of $64.59 \pm 5.39\%$ in 2020 to $66.99 \pm 6.12\%$ in 2023, albeit with notable inter-district variability, as maximum values ranged as high as 85.11% in 2022. Conversely, the Open Unemployment Rate declined markedly from a mean of $4.99 \pm 3.00\%$ in 2020 to $3.84 \pm 2.13\%$ in 2023, suggesting an overall improvement in labor market conditions across South Sulawesi, although district-level disparities remained, with minimum values as low as 0.58% and maximum values as high as 15.92% recorded during the observation period (Table 1).

These descriptive findings reveal that while aggregate socioeconomic conditions in South Sulawesi showed gradual improvements across most indicators during 2020–2023, the concurrent and accelerating rise in the burden of type 2 DM alongside persistent and widening inter-district disparities in both disease burden and socioeconomic conditions underscores the complexity of the relationship between socioeconomic determi-

nants and diabetes incidence at the subnational level. In the Indonesian context, substantial socioeconomic and geographical inequalities in the use, quality, and outcome of diabetes management programs persist across district and cities, suggesting that improvements in aggregate socioeconomic indicators do not automatically translate into equitable reductions in diabetes burden at the local level (Mulyanto et al., 2023).

To formally assess the statistical significance and magnitude of annual changes in CIR, Paired T-Test analyses were conducted across consecutive study years (Figure 1). The increase from 2020 to 2021 was not statistically significant ($p = 0.105$), with a small effect size (Cohen's $d = 0.345$) and a mean difference of 11.894 (−2.677–26.465), suggesting that the substantial inter-district variability in CIR during this period may have obscured a detectable aggregate change at the provincial level. In contrast, the increase from 2021 to 2022 reached statistical significance ($p = 0.001$), accompanied by a moderate effect size (Cohen's $d = 0.763$) and a mean difference of 34.196 (15.283–53.109), indicating a clinically meaningful acceleration in disease burden across district and cities. The increase from 2022 to 2023 was likewise statistically significant ($p < 0.001$), with a moderate effect size (Cohen's $d = 0.788$) and a mean difference of 33.717 (15.643–51.792), confirming the sustained and substantial nature of the upward trajectory.

Collectively, these findings indicate that while the CIR of type 2 DM showed a modest and non-significant change in the early observation period (2020–2021), a significant and practically meaningful acceleration in disease burden occurred from 2021 onward, persisting through 2023. The increasing trajectory observed in this study is consistent with regional evidence documenting a persistent upward trend in diabetes incidence across Asia, with heterogeneous temporal patterns observed across subregions throughout the 1990–2021 period (Shahid et al., 2025). The widening confidence intervals across years further reflect increasing inter-district heterogeneity in CIR over time, as spatial pattern disparities in socioeconomic risk factors are known to contribute to spatial heterogeneity in diabetes burden and health inequalities at the subnational level (Lord & Odoi, 2024; Xu et al., 2024). Understanding the factors that contribute to geographic disparities can guide resource allocation and help ensure that future interventions are designed to meet the specific needs of local communities, underscoring the need for spatially targeted analysis to identify the socioeconomic determinants driving

Table 1. Descriptive statistics of the CIR of type 2 DM and ten socioeconomic indicators across 24 district and cities in South Sulawesi Province during 2020–2023

Variables	Years	Descriptive Statistics	
		Mean±SD	Median (Min - Max)
CIR of Type 2 DM per 100,000 population	2020	132.939±118.684	106.003 (33.914-481.915)
	2021	144.833±132.677	102.383 (37.718-621.723)
	2022	179.028±154.342	134.362 (53.662-671.618)
	2023	212.746±185.373	149.339 (65.87-782.839)
Gini Ratio	2020	0.368±0.021	0.363 (0.344-0.405)
	2021	0.368±0.018	0.364 (0.332-0.406)
	2022	0.362±0.018	0.363 (0.32-0.395)
	2023	0.362±0.019	0.364 (0.336-0.393)
Poverty Rate	2020	9.418±2.919	8.905 (4.54-14.58)
	2021	9.468±2.915	8.825 (4.82-14.28)
	2022	9.318±2.83	8.795 (4.58-13.92)
	2023	9.332±2.744	8.725 (5.07-13.4)
Economic Growth Rate	2020	1.305±0.561	1.21 (-0.15-2.34)
	2021	1.241±0.333	1.235 (0.45-1.72)
	2022	1.206±0.332	1.18 (0.47-1.69)
	2023	1.189±0.332	1.165 (0.47-1.68)
Per Capita Expenditure	2020	10901.458±2050.529	10883.5 (7217-16873)
	2021	11016.042±2069.747	10995 (7434-17097)
	2022	11272.333±2073.912	11229 (7584-17406)
	2023	11684.667±2090.663	11674 (8017-17889)
Gross Regional Domestic Product	2020	47227.083±20371.157	44015 (25696-125324)
	2021	50569.958±21628.438	47648 (27276-132678)
	2022	55839.208±24199.392	52416.5 (28739-144604)
	2023	59407.792±26072.15	56041.5 (29318-155952)
Mean Years of Schooling	2020	8.148±1.176	7.85 (6.59-11.21)
	2021	8.272±1.199	7.975 (6.6-11.43)
	2022	8.36±1.196	8.045 (6.75-11.55)
	2023	8.519±1.136	8.305 (7-11.56)
Labor Force Participation Rate	2020	64.593±5.39	64.69 (56.92-73.25)
	2021	65.831±5.749	65.565 (57.78-77.99)
	2022	67.294±6.723	66.375 (57.63-85.11)
	2023	66.988±6.119	66.71 (55.49-82.35)
Open Unemployment Rate	2020	4.985±2.999	4.3 (2.31-15.92)
	2021	4.748±2.402	4.11 (2.34-13.18)
	2022	3.632±2.429	2.8 (0.58-11.82)
	2023	3.841±2.132	3.505 (1.31-10.6)

Variables	Years	Descriptive Statistics	
		Mean±SD	Median (Min - Max)
Human Development Index	2020	70.527±4.01	69.45 (64.26-82.25)
	2021	70.877±3.994	69.885 (64.56-82.66)
	2022	71.435±3.945	70.435 (65.13-83.12)
	2023	72.15±3.843	71.285 (65.9-83.52)
Life Expectancy at Birth	2020	69.485±1.985	69.63 (66.39-73.39)
	2021	69.577±1.961	69.79 (66.49-73.41)
	2022	69.889±1.938	70.175 (66.81-73.72)
	2023	70.134±1.928	70.495 (66.99-73.99)

this trend at the district and cities level in South Sulawesi.

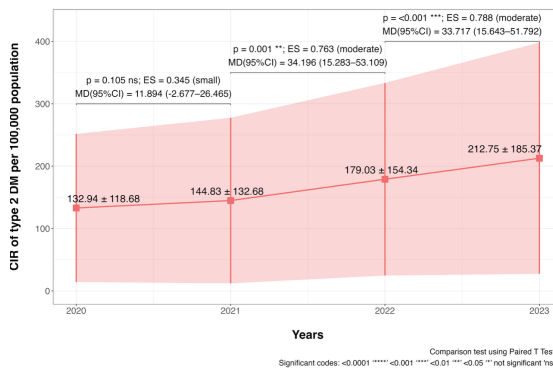


Figure 1. Comparison test with Paired T Test.

The spatial classification of CIR of type 2 DM across 24 districts and cities in South Sulawesi Province using the Natural Breaks (Jenks) method revealed distinct and evolving vulnerability patterns throughout the 2020–2023 observation period. The complete classification of each district and cities by CIR class for each study year is presented in Supplementary Table S2. In the first class (33.914–101.161), the areas that consistently fell into this group were Pinrang, Sidenreng Rappang, Sinjai, and Soppeng Regencies. This reflects a relatively low and stable CIR of type 2 DM in these areas, suggesting that adequate socioeconomic factors are likely the main determinants of maintaining a low incidence of the disease (L. Wang et al., 2021). In the second class (101.161–186.981), areas that consistently fell into this category included Bantaeng, Barru, Selayar Islands, Luwu, and East Luwu. These regions showed a moderate but generally stable disease burden during the observation period. This highlights the ongoing challenges in disease control efforts, although they are not as severe as those in other areas (Joseph & Yusuf, 2023). Meanwhile, in the third class (186.981–322.560),

North Luwu District was recorded as the region that consistently remained in this class for four consecutive years. This indicates that North Luwu experiences a relatively high disease burden, thus requiring more intensive and focused efforts to reduce the CIR of type 2 DM in this region (Pearson, 2019).

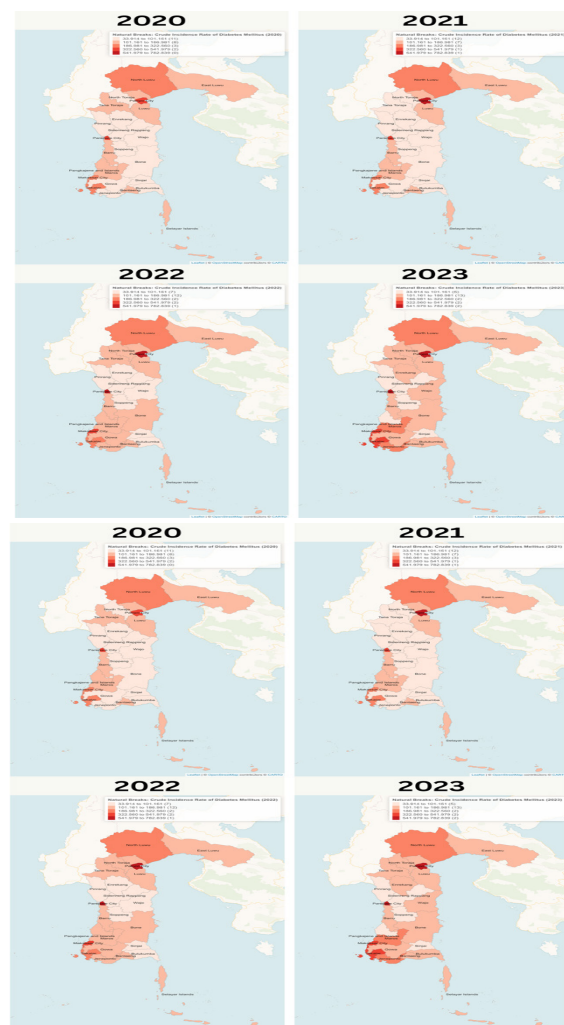


Figure 2. Map of district and cities distribution based on the CIR.

In addition to the consistency of regions within certain groups, visible spatial dynamics were observed in other areas. Most regencies such as Bone, Bulukumba, Enrekang, Gowa, Jeneponto, and Wajo, which were initially in the first class, began to shift to the second or third class in subsequent years, which may indicate an increase in the CIR of type 2 DM in these regions. This shift suggests a rise in the CIR of type 2 DM in these areas, which deserves greater attention. This phenomenon could be caused by various factors, such as lifestyle changes, increased incidence of risk factors such as obesity and lack of physical activity, and improved access to healthcare services, allowing for more cases to be detected (Mehdad et al., 2020). In contrast, urban areas such as Makassar and Parepare City experienced an increase in class from medium to upper-medium, whereas Palopo City consistently remained in the highest class (541,979–782,839) for four years. The combination of rapid urbanization, lifestyle transitions, a higher proportion of high-risk populations, and effective case detection makes Palopo City the region with the highest CIR of type 2 DM in South Sulawesi, even though it is not the most populous city in the province (Tobey et al., 2019). This condition underscores the need for region-based intervention strategies that consider the local socioeconomic context and community behavior, not merely based on population size (Ren et al., 2019).

Geospatial analysis using the Global Moran's I test was conducted to evaluate the presence or absence of spatial autocorrelation in the distribution of the CIR of type 2 DM across 24 district and cities in South Sulawesi Province from 2020 to 2023 (Zainuddin et al., 2025). Moran's I values were consistently negative and close to zero across all study years, recorded at -0.096 ($p = 0.907$) in 2021, -0.099 ($p = 0.914$) in 2022, -0.097 ($p = 0.912$) in 2023, and -0.098 ($p = 0.919$) in 2024. All values were statistically non-significant ($p > 0.05$), indicating the absence of significant spatial autocorrelation in the CIR distribution across districts and cities during the observation period (Supplementary Table S3). Nevertheless, the absence of significant Global Moran's I does not preclude the presence of local spatial variation in the relationships between socioeconomic factors and CIR. Global Moran's I evaluates the overall spatial pattern of the outcome variable, whereas GTWR is designed to capture varying relationships across space and time by estimating local regression coefficients for each location and time point (Fotheringham et al., 2015; Z. Wang et al., 2023). As a result, GTWR approach was em-

ployed to reveal location-specific socioeconomic effects that may not be detected by previous global spatial statistics.

To further substantiate the application of GTWR relative to global regression approaches, goodness-of-fit diagnostics were compared across GTWR and four global regression models, namely OLS, panel pooled, panel random effects, and panel fixed effects, as presented in Supplementary Table S4. GTWR demonstrated a markedly superior model fit, with the highest R^2 (0.8782) and Adjusted R^2 (0.8134) among all models compared, together with the lowest corrected Akaike Information Criterion ($AICc = 1117.599$). The difference in $AICc$ ($\Delta AICc$) between GTWR and the global models ranged from 32.89 (versus OLS) to 99.48 (versus the fixed-effects panel model), far exceeding the threshold of $\Delta AICc > 3$ conventionally used to indicate substantially stronger model support (Anderson & Burnham, 2002; Burnham & Anderson, 2004). These results provide statistical justification for the use of GTWR, confirming that the local spatiotemporal model offers a meaningfully better fit to the data than global regression approaches, independent of the non-significant Global Moran's I result.

Bivariate Pearson correlation analyses were conducted between the CIR of type 2 DM and each of the ten socioeconomic indicators across all study years (2020–2023), with the results presented in Figure 3. Of the ten candidate variables, six indicators Gini Ratio, Poverty Rate, Economic Growth Rate, Gross Regional Domestic Product, Labor Force Participation Rate, and Life Expectancy at Birth did not demonstrate statistically significant correlations with CIR in any of the study years ($p > 0.05$), with correlation strengths ranging from very low to low across the observation period. Therefore, these variables were therefore excluded from subsequent modeling, as they were considered to contribute insufficient explanatory power to the spatial variation of the CIR (Darvishi et al., 2024).

Four indicators demonstrated statistically significant and consistent positive correlations with CIR across all four study years ($p < 0.05$) and were retained for further analysis. Mean Years of Schooling exhibited the strongest and most consistent correlation, with Pearson r values ranging from 0.740 to 0.789 ($p < 0.0001$) across 2020–2023, classified as strong in all years. The Human Development Index also showed a strong and consistent positive correlation throughout the observation period ($r = 0.682$ – 0.749 ; $p < 0.0001$), reflecting a persistent association between overall human development levels and

type 2 DM burden at the district level. The Open Unemployment Rate demonstrated a strong positive correlation with CIR across all study years ($r = 0.644\text{--}0.693$; $p < 0.0001$), suggesting that district and cities with higher unemployment rates consistently exhibited higher disease burden. Per Capita Expenditure showed a significant positive correlation of moderate-to-strong magnitude across the observation period ($r = 0.542\text{--}0.612$; $p < 0.01$), with the strongest association observed in 2020 ($r = 0.612$), and a moderate but significant relationship was maintained from 2021 to 2023.

The direction and pattern of these correlations indicate that district and cities with higher levels of educational attainment, human development, unemployment, and per capita expenditure tended to record higher CIR of type 2 DM throughout the study period. In developing countries, diabetes prevalence has been shown to be positively correlated with HDI, a pattern that may partly reflect enhanced disease detection capacity and greater healthcare utilization in more developed areas rather than solely a true increase in disease burden (Xu et al., 2017). Furthermore, per capita income has been shown to be positively associated with diabetes prevalence at the country level, as higher income facilitates lifestyle and dietary transitions including increased consumption of processed foods and reduced physical activity that are well-established risk factors for type 2 DM (Richards et al., 2022). With respect to unemployment, higher Open Unemployment Rates may reflect broader socioeconomic deprivation within a region, which can influence dietary quality, access to healthcare services, and opportunities for healthy lifestyles (Aretz et al., 2024; Helmeczi, 2024; Milicic & DeCicca, 2017). These findings confirm that Per Capita Expenditure, Mean Years of Schooling, Open Unemployment Rate, and Human Development Index were the four socioeconomic indicators with consistent, statistically significant associations with CIR across all observation years and were therefore selected as independent variables for the subsequent GTWR modeling.

Advanced modeling using the Geographically and Temporally Weighted Regression (GTWR) approach strengthens the correlation findings and simultaneously reveals the existence of spatio-temporal variation in the influence of these four variables. The GTWR results indicate that areas consistently showing a significant influence of all four variables throughout the 2020 to 2023 period include Makassar City, Palopo City, Parepare City, Luwu, East Luwu,

North Luwu, Maros, Pinrang, Sidenreng Rappang, Takalar, and North Toraja (Table 3). This demonstrates that in these regions, the four socioeconomic factors play a significant role in explaining the spatio-temporal variation in the CIR of type 2 DM. Therefore, socioeconomic factors, such as education and income, may become important determinants in the management and prevention of type 2 DM (Allen & Mcfarland, 2019).



Figure 3. Correlation Matrix of Type 2 Diabetes CIR and Socioeconomic Factors.

In addition, Gowa Regency exhibited a dynamic pattern in 2020, with only three variables (Mean Years of Schooling, per capita expenditure, and Human Development Index) having a significant influence; however, from 2021 to 2023, all four variables consistently showed a significant effect. This indicates a change in socioeconomic conditions that has affected the increase in the CIR of type 2 DM in the region. In this context, socioeconomic changes occurring within a certain period can significantly affect public health (Susilowati et al., 2020). Therefore, policies responsive to these dynamics are crucial for addressing the rising CIR of diseases. However, there are areas that consistently do not show a significant influence from the four variables, namely Bantaeng, Enrekang, and Wajo. This indicates that although socioeconomic factors do not have a direct impact in these regions, there may be other factors that play a greater role in the CIR of type 2 DM, such as dietary patterns, limited access to healthcare services, or unmeasured environmental factors (Mutmainnah & Arifin, 2025). This suggests that a more holistic and integrated approach is needed to understand and address the issue of type 2 DM in these regions.

Table 2. GTWR Results of Significant Socioeconomic factors.

District and cities	2020	2021	2022	2023
Bantaeng	NS	NS	NS	NS
Barru	A,B,C,D	A,B,C,D	NS	NS
Bone	A,B,C,D	A,B,C,D	A,B,C,D	NS
Bulukumba	B	NS	NS	NS
Enrekang	NS	NS	NS	NS
Gowa	A,B,D	A,B,C,D	A,B,C,D	A,B,C,D
Jeneponto	B	A,B,C,D	B	NS
Selayar Islands	A,B,C,D	NS	NS	NS
Makassar City	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Palopo City	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Parepare City	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Luwu	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
East Luwu	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
North Luwu	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Maros	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Pangkajene and Islands	A,B,C,D	NS	NS	NS
Pinrang	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Sidenreng Rappang	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Sinjai	NS	A,B,C,D	NS	NS
Soppeng	NS	B	B	B
Takalar	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Tana Toraja	NS	B	B	A,B,C,D
North Toraja	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Wajo	NS	NS	NS	NS

NS: Non-significant; A: Mean Years of Schooling; B: Per Capita Expenditure; C: Open Unemployment Rate; D: Human Development Index

(Fedorenko et al., 2021). Therefore, further research is needed to identify other factors that may contribute to the high CIR of type 2 DM in these areas.

There are also regions that experienced changes in significance between years, such as the Selayar Islands and Pangkajene and Islands, which in 2020 showed a significant influence from all variables, but from 2021 to 2023, did not show any meaningful effect. A similar situation occurred in Bulukumba, which initially only showed a significant influence from Per Capita Expenditure in 2020, but did not show significance in subsequent years. This spatio-temporal variation reflects that socioeconomic factors can play a major role in explaining the differences in the CIR of type 2 DM in certain regions but may not be relevant in other areas or during certain periods (Herzallah et al., 2019). These results highlight the importance of the dynamic monitoring

of socio-economic factors and how these factors can play different roles in each region and time period (Sinitsyn et al., 2020). This means that socioeconomic factors relevant at a certain time or in a certain region do not always remain applicable in the following years, indicating that data-based health policies must be flexible and responsive to change (Naja et al., 2023). Therefore, interventions designed to reduce the CIR of type 2 DM must be adaptable to dynamic socioeconomic conditions and evolving local circumstances.

This study had several limitations. First, although the use of national data from BPJS Kesehatan provides comprehensive coverage for Indonesia's population, this study is inherently limited to individuals registered as participants in this insurance program. The exclusion of individuals without insurance or those who do not use insurance may result in an incomplete representation of the true burden of type 2 DM in South Su-

lawesi. Additionally, some BPJS participants may not utilize their insurance benefits for healthcare services, which further contributes to the potential underreporting of disease incidence in the study.

Second, it is important to note that CIR in this study was derived from FKRTL referral claims, which may not fully capture the true community-level incidence of type 2 DM. Case ascertainment through this pathway can be influenced by factors such as individual health-seeking behavior, the availability of advanced health facilities, and the efficiency of the referral pathway from FKTP to FKRTL. As such, variation in detection capacity and healthcare accessibility across districts/cities may partly contribute to the spatial patterns observed in this study, in addition to true differences in disease burden. This limitation is commonly acknowledged in claims-based epidemiological studies and is noted here to guide appropriate interpretation of the findings.

Third, reliance on population-level data from BPJS Kesehatan and BPS can lead to reporting bias or inaccuracies, particularly in areas with limited access to healthcare services or incomplete medical records. These disparities can affect spatial grouping and the estimation of incidence. Furthermore, although geospatial methods identify significant patterns and clusters, the influence of unmeasured socioeconomic, environmental, or genetic factors on disease incidence cannot be fully accounted for in the analysis (Hill-Briggs et al., 2021). These unmeasured variables may obscure the observed spatial relationships and limit the generalizability of our findings.

Fourth, the analysis was conducted at the district and cities level, which limits understanding of deeper socio-economic variations at a more micro level, such as villages or urban neighborhoods. The use of aggregate data at this level may not fully reflect the more specific and dynamic local conditions, especially regarding socioeconomic disparities within smaller areas. This limitation does not hinder the research's ability to identify regions with significant incidence rates, but it leaves room for further studies that could explore more detailed dynamics at smaller levels (Nasim et al., 2020). Thus, although the analysis results are aggregated at the district and cities level, these findings still provide a strong foundation for developing more specific health policies at the regional level (Tua & Mahi, 2023).

CONCLUSION

The results of this study indicate that the CIR of type 2 DM in South Sulawesi Province experienced a significant increase from 2020 to

2023, particularly since 2021, with a persistent concentration of high disease burden in urban areas. Although no significant spatial autocorrelation was identified, correlation analysis and GTWR modeling revealed that socioeconomic factors, including Mean Years of Schooling, Open Unemployment Rate, Human Development Index, and Per Capita Expenditure were significant contributors to the spatio-temporal variation of this disease. The results also showed that their influence was most consistently observed in metropolitan and urban centers as well as several surrounding districts in the province, highlighting geographic heterogeneity in the determinants of disease burden and underscoring the need for geographically targeted public health interventions and equitable socioeconomic policies to reduce disparities across South Sulawesi.

Based on the results of this study, it is recommended that local governments, particularly in districts and cities with a persistently high CIR, should strengthen community-based intervention programs that focus on health education, improve nutrition literacy, and promote healthy lifestyles. These efforts should be combined with more inclusive socioeconomic development policies, such as creating job opportunities to reduce open unemployment, expanding access to education, and improving the quality of healthcare services. This study also recommends that policymakers in the health and social development sectors routinely use spatio-temporal analysis approaches in planning so that intervention strategies can be more targeted and sustainable. In addition, future researchers should explore other unmeasured factors, such as dietary patterns, physical activity, and environmental factors, to provide a more comprehensive picture of the determinants of type 2 DM in South Sulawesi.

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DECLARATION OF GENERATIVE AI

This manuscript received limited assistance from an AI-based language tool (Quillbot and

ChatGPT) for language refinement and grammar checking. The authors critically reviewed and finalized all content and accept full responsibility for the published work. No AI tools were used in data analysis or the interpretation of findings.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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