Geospatial Analysis of Diabetes Type 2 and Hypertension in South Sulawesi, Indonesia

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Abstract

The spatial variation of type 2 diabetes mellitus (T2DM) and hypertension and their potential linkage were explored in South Sulawesi Province, Indonesia. The Local Moran's I, the Getis-Ord, and regression analysis were applied to identify the characteristics involved. The methods were performed based on T2DM and hypertension data from 2017 and 2018. The spatial variation of T2DM and Hypertension showed that the prevalence rate of T2DM tends to form a cluster hotspot and there is no cold spot and spatial outlier. Meanwhile, the prevalence rate of hypertension tends to occur randomly. In analyzing the relationship between T2DM and Hypertension, we utilized the Generalized poisson regression analysis and the result showed that there is a significant relationship between T2DM and hypertension (p-value = 1.695e-10). This research could help policymakers to plan and support projects with the aim of overcoming the risk of T2DM and hypertension.

Introduction

Non-communicable diseases (NCD) are one of the health problems of national and global concern at this time. Data from the World Health Organization (WHO) showed that out of the 57 million deaths that year. 41 million almost two-thirds of the total were caused by NCD [1]. In countries with low to middle economic levels, 29% of deaths in people less than 60 years old are caused by NCD [1]. Diabetes mellitus is one of four NCD priorities because of linked affections, such as blindness, heart attack, stroke, kidney and leg amputation [1]. The prevalence of diabetes mellitus worldwide reached 415 million people in 2015 and it is estimated that by 2040 the number of people with diabetes mellitus will amount to 642 million. Blood sugar levels greater than optimal value (normal fasting blood glucose concentration are between 70 mg/dL (3.9 mmol/L) and 100 mg/dL (5.6 mmol/L) resulted in an additional 2.2 million deaths, mainly through the increased risk for cardiovascular and other linked diseases [1].

In the last few decades, Indonesia has faced the problem of a triple-burden as infectious diseases and re-emerging other diseases remain, while new diseases continue to emerge frequently. Importantly, the prevalence of NCD has also increased with the prevalence of diabetes mellitus recently rising from 6.9−8.5% and hypertension from 25.8% percent to 34.1% [2]. Indeed, there may be a link as diabetic patients can experience an increase in blood pressure and 40−60% of diabetic cases often show high blood pressure, while diabetes or hypertension can cause a variety of complications without symptoms [3]. The interaction between hypertension and diabetes can lead to the development of stroke and myocardial infarction [3].

One of the important controls and prevention strategies for diabetes mellitus and hypertension would be to apply spatial analysis to find areas with a high risk of both diseases and make early prevention efforts. Spatial analysis gives more information about risk based on spatial variation making prediction more accurate. Knowledge about the risk of diabetes mellitus and hypertension in each district or city area can help health agencies carry out activities to prevent these two diseases effectively [4].

This study aimed to determine the level of risk of diabetes mellitus and hypertension in each district or city area in South-Sulawesi Province, which can be done by identifying spatial cluster in the number of people with the disease, carrying out geospatial analysis and applying a Generalized Poisson Regression (GPR) model to determine the potential effect of diabetes mellitus on hypertension.

Materials And Methods

Ethics approval and availability of data and material

This study was reviewed and approved by Ethics Committee of Medical Research of Faculty of Medicine Hasanuddin University (556/UN4.6.4.5.31/PP36/2021). This study was performed in accordance with the Helsinki declaration. Informed consent was waived by the Ethics Committee of Medical Research of Faculty of Medicine Hasanuddin University.   The dataset in the current study was acquired from national health assurance board (BPJS Kesehatan) and are available from the corresponding author on reasonable request.

Study area

South Sulawesi Province is one of the provinces in Indonesia with a high population number. The total population in 2020 was around 9 million people [5]. The total area covers about 46.717 km^2. Figure 1 shows the location of the research area. which coincides with South Sulawesi Province.

Figure 1 about here

Data utilized

The data used in this study refer to health insurance participants who suffer from T2DM and hypertension for the period January 2017 to December 2018 in the South Sulawesi Province. The data came from for the Social Health Insurance Administration Body. an authorized government body established to provide health insurance programmes for the Indonesian people. This data source provided all population data for each district and city and we used those related to T2DM and hypertension. The population data were obtained from the Central Bureau of Statistics of South Sulawesi Province. locally known as Badan Pusat Statistik (BPS) which is a non-departmental government institute in Indonesia responsible for conducting statistical surveys. The daily data of the health insurance participants were accumulated by month and the prevalence rate calculated per 100.000 people.

The daily data for T2DM and hypertension used in this study were processed based on the prevalence rate data for the occurrences of the two diseases. The prevalence rate was calculated for every 100.000 population by the formula:

$$\text{Prevalence rate } (i) = \frac{\text{The number of infected at distric} - i}{\text{The number of Population at district} - i} \; x \; 100.000$$

The prevalence rate was calculated annually and the prevalence rate for the 2017-2018 period is the average value for both 2017 and 2018 time periods in each district/city.

Statistical analysis

In this paper, we utilized Spatial Regression Model and GPR model to examine the relationship between hypertension and T2DM. The model was fitted using the maximum likelihood method to assess associations of the number of hypertension cases as the dependent variable and the number of TD2M cases as the independent variable. The inference procedure from the Generalized Poisson regression models is performed using the coefficients of the T2DM variable and their standard errors. If the interval of estimated coefficients (estimated coefficients value - standard error, estimated coefficients value + standard error) contains zero value then the independent variable does not significantly affect the dependent variable. Otherwise, the independent variable has a significant effect on the dependent variable.

The inference procedure also is done by calculating the probability value (p-value). If the p-value is less than the significance level (0.05) then the independent variable has a significant influence on the dependent variable. Otherwise, independent variables have a significant influence on a dependent variable. All the statistical analyses were performed using a 5% significance level and R-Studio version 1.2.5033 as a computation tool.

Natural Break Classification Method

The natural break method is a measurable procedure to identify cluster of values that are characteristic in data distribution. The natural break method using an algorithm that reduces the variance within classes and maximizes variances between classes. The natural break algorithm results may be expressed in a map of colors in graduation.

Spatial Cluster Analysis

Generally, to identify spatial clusters of disease is used Local Moran's I statistics and Getis-Ord Gi*. Local Moran's I is a local spatial autocorrelation statistics that identified local clusters and local outliers. Getis-Ord Gi* is a statistical tool that can be used to indicate whether high or low values are concentrated over the study area.

We used Local Morans *I* and Getis-Ord Gi* [6,7] to determine areas characterized as hotspots (concentrations) and coldspots (absence) with regard to T2DM and hypertension. This classifies the spatial patterns into clusters and outliers where the former can either be positive (hotspots) or negative (coldspots), while the latter are spatial objects whose attribute values are distinctly different from those of their spatial neighbours.

Regressions Models

We measured the effect of T2DM on hypertension using the spatial regression model [6] and the GPR model [8]. In this study, we want to assess the relationship between the number of T2DM cases and the number of hypertension cases using the spatial regression analysis as well as the Generalized Poisson regression model, where T2DM is set as independent variables and Hypertension is the dependent variable. The independent variable thought affects variables dependent through a hypothesis. The hypothetical tests are made to make a valid conclusion as to whether independent variables affect that dependent variable or not. The Spatial regression model is used to see if there are spatial contributions to hypertension. The Generalized Poisson regression used to the dependent variable as count. It matches the number of hypertensive cases in the form of count. The spatial regression model is a regression model with spatial dependence through response variables (Spatial Lag Model/SLM) or in the components of random error (Spatial Error Model/SEM). In contrast. the classic regression model (equation 1) has no spatial dependency. The spatial lag model is stated in equation 2 and the spatial error model is stated in equation 3 as follows:

$$Y = \rho WY + X\beta + \varepsilon \qquad \text{(Eq. 2)}$$

$$Y = X\beta + (I\text{-}W\lambda)^{-1}u \qquad \text{(Eq. 3)}$$

where

$u = Wu + \varepsilon$, Y the response variable, X the predictor variable, W the matrices of normalized weight spatial, β the coefficient of the predictor variable, ε a random error component, I the identity matrices, u a spatial random error, ρ the spatial effect of SLM, and λ the spatial effect of SEM. If ρ or λ is not significantly different from zero (p-value > 0.05) then there is no spatial dependency.

The Generalized Poisson Regression Model

Let Y_i be a count respon variable that followed the GPR distribution. The probability function of Y_i denoted as

$$f(y_i, \mu_i, \alpha) = \left(\frac{\mu_i}{1+\alpha\mu_i}\right)\frac{(1+\alpha y_i)^{y_i-1}}{y_i!}exp\left[\frac{-\mu_i(1+\alpha y_i)}{(1+\alpha\mu_i)}\right]$$

where

$y_i = 0, 1, 2, ...,$ and $\mu_i = exp(x_i\beta)$,

x_i is a (p-1) dimensional vector of covariates and β is a p-dimensional vector of coefficient of covariate or parameters, α is a parameter of GPR, p is a positive integer. Means and variance of GPR distribution are

$E(Y_i|x_i) = \mu_i$ and $Var(Y_i|x_i) = m_i(1 + am_i)^2$ respectively. If a = 0 then GPR model reduce to the Poisson regression model.

Inference procedures through regression models are done by estimating parameters values based on available observational data. The parameters estimation methods for both spatial regression and the GPR models using the maximum likelihood method. After obtaining the regression model results from the estimate parameters. The next step is to evaluate the regression model using the anova table. The anova table provide information about levels of variability within a regression model and form a basis for tests of significance. anova calculations are shown in the analysis of variance table. The anova table contains the F test statistic for testing the hypothesis that $\beta \neq 0$ against the null hypothesis that $\beta = 0$. The F test is defined as the ratio of the mean square model and the means square error. If the ratio is large than there is evidence against the null hypothesis.

Results

The comparison of the prevalence rate values of T2DM in each district/city in the 2017−2018 period is shown in Table 1 and Visualized in 5 groups as shown in Fig. 2 as follows:

Table 1
The prevalence rate of T2DM and Hypertension for the 2017 to 2018 period in South Sulawesi Province. Indonesia

No	district/City	T2DM	Hypertension
1	Bantaeng	0.93	4.32
2	Barru	2.71	2.60
3	Bone	0.21	1.38
4	Bulukumba	3.05	4.97
5	Enrekang	0.80	2.06
6	Gowa	1.65	1.82
7	Jeneponto	0.73	1.62
8	Luwu	2.20	6.27
9	Luwu Timur	0.00	0.00
10	Luwu Utara	0.32	3.07
11	Makassar	1.56	4.20
12	Maros	0.83	3.48
13	Palopo	1.09	5.43
14	Pangkep	0.72	3.47
15	Pare-Pare	1.84	3.96
16	Pinrang	0.46	2.56
17	Selayar	2.06	4.55
18	Sidenreng Rapppang	3.72	2.97
19	Sinjai	1.65	4.19
20	Soppeng	0.81	6.58
21	Takalar	1.30	1.24
22	Toraja	0.00	0.00
23	Toraja Utara	0.58	3.38
24	Wajo	0.41	5.62

Table 1 **about here**

Figure 2 **about here**

Table 1 revealed that the prevalence rate of T2DM for the 2017−2018 period is generally around the value of 1−2 cases for every 100.000 population in a district/City. South-Sulawesi Province. The number of cases equal to three or more T2DM cases can occur in Bulukumba and Sidenreng Rappang district (3−4 cases).

The prevalence rate of hypertension for the 2017−2018 period in each district/city is shown in Fig. 3 as follows:

Figure 3 **about here**

In general, the prevalence rate of hypertension cases for the 2017−2018 period is 2−3 cases for every 100.000 population. Wajo, Luwu, and Palopo city represents areas with a prevalence rate of 5 to 7 cases for every 100.000 population.

The results of the spatial pattern analysis using Global Moran's *I* to see the global spatial pattern in the study area showed a score = 0.25 for the prevalence rate of T2DM and a score = -0.04 for the prevalence of hypertension. This shows that the prevalence of many T2DM cases registered under BPJS Kesehatan coverage tends to form clusters. As for the prevalence of the number of hypertension cases, it tends to occur randomly. This is different from what happened with regard to the prevalence of T2DM.

Based on the results of the spatial correlation test above then followed up on hotspot and coldspot clusters, especially with regard to the prevalence of T2DM cases. The prevalence of hypertension cases did not need to be further analyzed because their prevalence tended to occur randomly.

Analysis of the spatial cluster of T2DM in the South-Sulawesi Province is conducted using Local Morans I and Getis-Ord methods. The result of the spatial cluster analysis reveals that the two methods used show the same results. There is only one hotspot of T2DM from 2017 to 2018 in the South-Sulawesi Province and there is no coldspot and spatial outlier occurred. The hotspot is centered in the Pare-Pare municipality with neighboring Barru, Soppeng, Sidrap, and Pinrang (Fig. 4).

In analyzing the effect of T2DM on hypertension, we utilized two model approaches: spatial regression model (SEM and SLM) and non-spatial regression model (GPR Model). The estimation parameter on the spatial regression model is shown in Table 2 as follows:

Table 2
The Parameter Estimation of SLM and SEM.

Model	Estimated Value							
	β_0 (p-value)	Std. Error	β_1 (Std. Error)	Std. Error	ρ (p-value)	λ (p-value)	AIC	R-Square
SLM	109.28	72.14	1.93* (0.00)	(0.26)	0.05 (0.80)	NA	316.62	0.70
SEM	123.78	35. 98	1.95* (0.00)	(0.25)	NA	-0.16 (0.58)	314.44	0.71
* denotes significance at a 95% level of confidence (*p-value* < 0.05).								

Table 2 **about here**

The estimated value of spatial effects of λ on SEM is -0.16 and the standard deviation is 0.58. The estimated ρ value on SLM is 0.05 and the standard deviation is 0.80. Meanwhile, the p-value for λ by 0.78 and ρ by 0.99. Both p-value for λ and ρ greater than 0.05, indicates that spatial effects on both models are not significant. Because spatial models do not show a significant impact in determining the effects of T2DM on hypertension, analysis is followed by a non-spatial approach using the GPR model.

Table 3 shows the results of the value of the estimated parameters in the Poisson regression model.

Table 3
The Anova of Poisson Regression Model

Variable	Coefficient	Std.Error	z-value	p-value	Conclusion
Intercept	5.22	0.14	36.82	$< 2 \times 10^{-16}$	Significant
T2DM	0.004	0.0005	7.56	4.07×10^{-14}	Significant
Residual deviance: 1772.8 on 22 degrees of freedom					

Table 3 **about here**

The estimated value of the coefficient of T2DM is 0.005, the standard of deviation is 0.0007347, and the p-value is 1.69e-10. However, the residual deviance is 1772.8 divided by 22 degrees of freedom earns more than one. It indicates an overdispersion of the models. For that matter, it further used a GPR model approach to overcome the overdispersion problem above. The estimated parameter of the GPR is shown in the Anova Table 4.

Table 4
The Anova of Generalized Poisson Regression Model

Variable	Coefficient	Std.Error	z-value	p-value	Conclusion
Intercept 1	2.16	0.17	36.82	$< 2 \times 10^{-16}$	Significant
Intercept 2	**2.77**	**0.28**	**9.89**	$< 2 \times 10^{-16}$	Significant
T2DM	0.005	0.0007	6.39	1.69×10^{-10}	Significant

Table 4 **about here**

The GPR parameter estimation produced a coefficient estimate value of 0.005 and a p-value of 1.695e-10 < 0.05. It shows that there is a significant impact between the number of T2DM cases on the number of hypertension cases.

Discussion

Diabetes mellitus and hypertension are two initial diseases on developing severe illness and often have no obvious symptoms. Some studies showed that diabetes mellitus and hypertension associated with single nucleotide polymorphisms (SNPs) genetic mutations and being known as closely related to genetics. Therefore, it might be mapped in family clusters or territorial clusters to detect diabetes mellitus and hypertension [9].

By study conducted in Taiwan on 922 participants. 30 novel single nucleotide polymorphisms (SNPs) were associated with co-morbid hypertension with diabetes mellitus adjusted for age and body mass index (p-value $< 1 \times 10^{-4}$). A cumulative genetic risk score consisting of 14 of the 38 SNPs is important for hypertension an increased propensity for systolic blood pressure and may contribute to hypertension in diabetes mellitus in Taiwan (Cheng CF et al. 2021). Another study conducted in Malaysia involving 320 volunteers divided based on hypertension (163) and normotensive (157) groups. The TT genotype/T allele of the WNK4 gene resulted in a close relationship between hypertension and diabetes mellitus [10].

In our study, we used sample data from patients who were visited health care facilities which was registered by Social Security Administrator for Health (BPJS) in the 2017–2018 period. Our study shows that the prevalence of Diabetes mellitus and hypertension in South Sulawesi Province was 1–2 patients for every 100.000 population and 2–3 patients for every 100.000 people in hypertension is higher respectively. These values are slightly lower than the national average of 2% and 8.4% for diabetes mellitus and hypertension in the same period. The prevalence of than Diabetes mellitus due to it is not a single causal disease. Various factors contribute to the prevalence of hypertension and diabetes mellitus as one of the causes. Blood pressure increases usually have no symptoms. Thus, the hypertension called as the silent killer. This result is associated with a study conducted by Tsimihodimos et al. in Mexico City for seven years showed that 16–46% of subjects were experiencing hypertensive; among participants the

prevalence of diabetes mellitus is around 20%-39%. Therefore. the prevalence of hypertension increases significantly as by diabetes mellitus disease [11].

By using spatial analysis. we found that the distribution of T2DM and hypertension had different patterns. Likewise, the trend analysis in diabetes mellitus and hypertension 2017–2018 tends to increase from year to year. The characteristics of the districts/cities in South Sulawesi Province are almost equal terms in the human development index community characteristics and health facilities. Therefore, it expects the distribution pattern of T2DM and hypertension is closely related to genetics and lifestyle.

Spatial regression analysis and classical regression found that the regression model of 70% and71% could explain the variation of this research data. The results of the ANOVA table show that T2DM with a coefficient of 1.95 has a p-value of < 0.05. This indicates that T2DM has a significant linear relationship to increased hypertension. This is associated with the research conducted by Akalu and Yitayeh. 2020 on entire T2DM patients at the Ethiopian Debre Tabor Hospital that the prevalence of hypertension in T2DM patients was 59.5% [12]. Research conducted in Benghazi also explained that 85.6%. 54.2%. and 56.3% prevalence of hypertension among DM patients [13]. Patients with diabetes mellitus have increased peripheral arterial resistance caused by vascular remodeling and increased body fluid volume associated with hyperinsulinemia and insulin resistance-induced hyperglycemia. Both mechanisms increase systemic blood pressure [12].

The factors of hypertension in T2DM patients are age, genetics, smoking behaviour, high BMI (≥ 25kg/m2). The age group was associated (p < 0.05) with hypertension prevalence among Benghazi DM patients. The association of BMI with hypertension is because obesity increases sodium and water reabsorption in the kidneys by activating mineralocorticoid receptors directly. This leads to an increase in blood volume and hypertension occurs. Therefore, the prevalence of diabetes mellitus expects to increase hypertension in the future [13].

This study needs further research since the data was sourced from secondary data and released by BPJS. It is based on patient visitation and needs more description to primary characteristics, especially patients who do not join in the national health insurance scheme or did not visit health care facilities. This data expects not to be recorded because diabetes mellitus and hypertension are asymptomatic in the early stages of the disease. so people do not visit health care facilities.

Conclusions

A geospatial analysis of patients with T2DM and hypertension has been carried out in this study. There are four geospatial analyzes carried out, namely: trend analysis in each district/city in South Sulawesi Province, global spatial pattern analysis hotspot, and coldspot analysis and spatial regression analysis. The results show that the district of Selayar. Bulukumba, Takalar, Soppeng, Barru, and Luwu have a tendency to increase the number of cases for both T2DM and Hypertension. Meanwhile, Bantaeng district has a decreasing number of people with T2DM and Hypertension. Globally, the number of T2DM cases

registered with *BPJS Kesehatan* occurs in groups and the number of people with hypertension tends to occur randomly. Hotspots for T2DM occurred in Makassar City, Barru, Takalar. Jeneponto, Bantaeng, and Bulukumba district. Cold spot areas occur in Maros, Gowa, Sinjai, Bone, and Soppeng district. The results of the spatial regression analysis show that the prevalence of T2DM can increase the number hypertension in the South Sulawesi Province.

Furthermore, the T2DM and hypertension prevention programs in South Sulawesi Province need comprehensive monitoring and evaluation. The districts have the same characteristics but have different patterns in the distribution of T2DM and hypertension in South Sulawesi.

Declarations

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

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Consent for publication

This manuscript has been approved by all authors and is solely the work of the authors named.

Authors' contributions

Data curation, conceptualization: AAZ, AR. Validation, Methodology: AR, SR. Conceptualization, writing – original draft: AAZ. Reviewing and editing: HR, HD, AAA.

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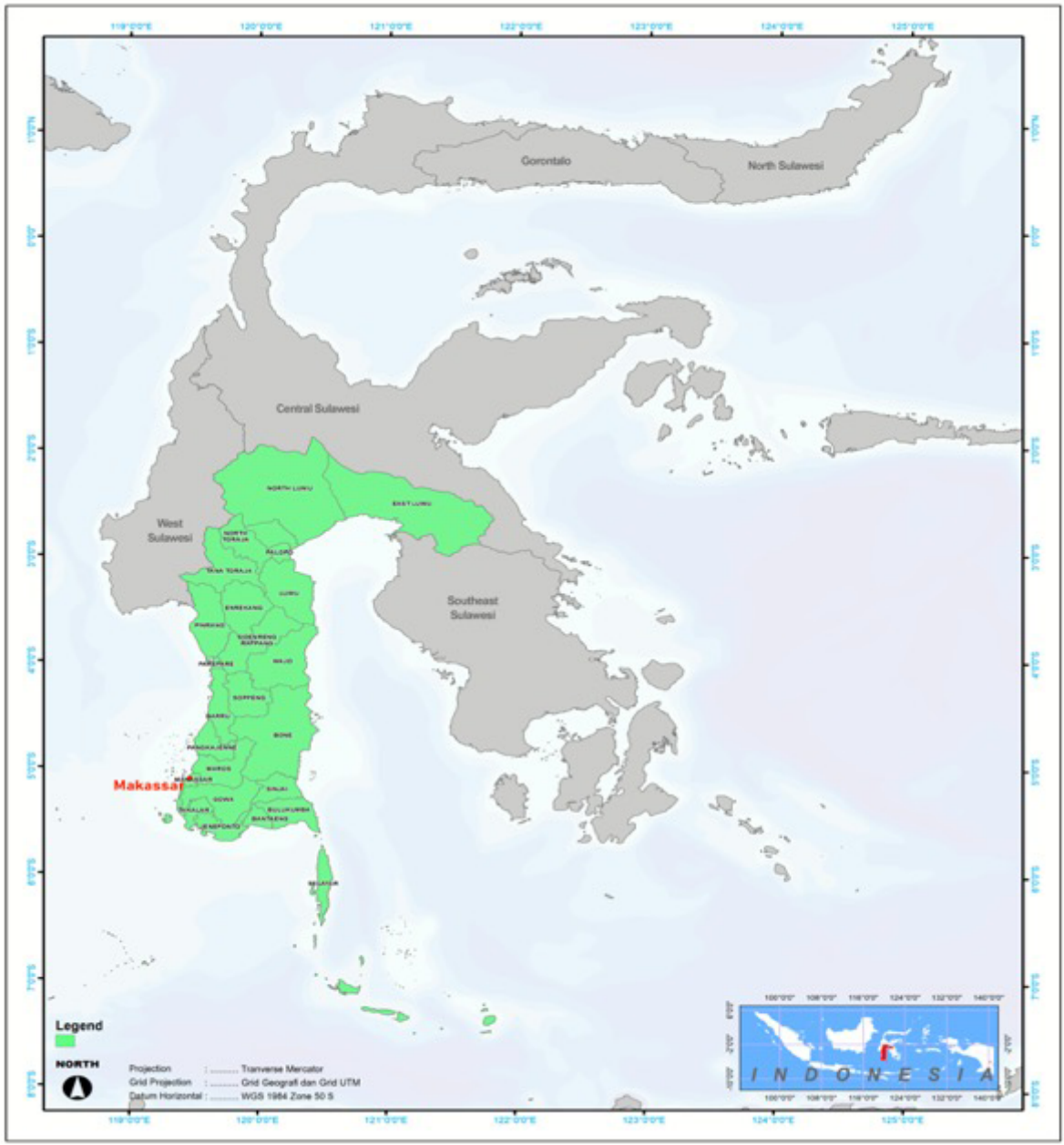
Figures

Figure 1

The map of the research area. The green area indicated the South Sulawesi Province where the study was conducted.
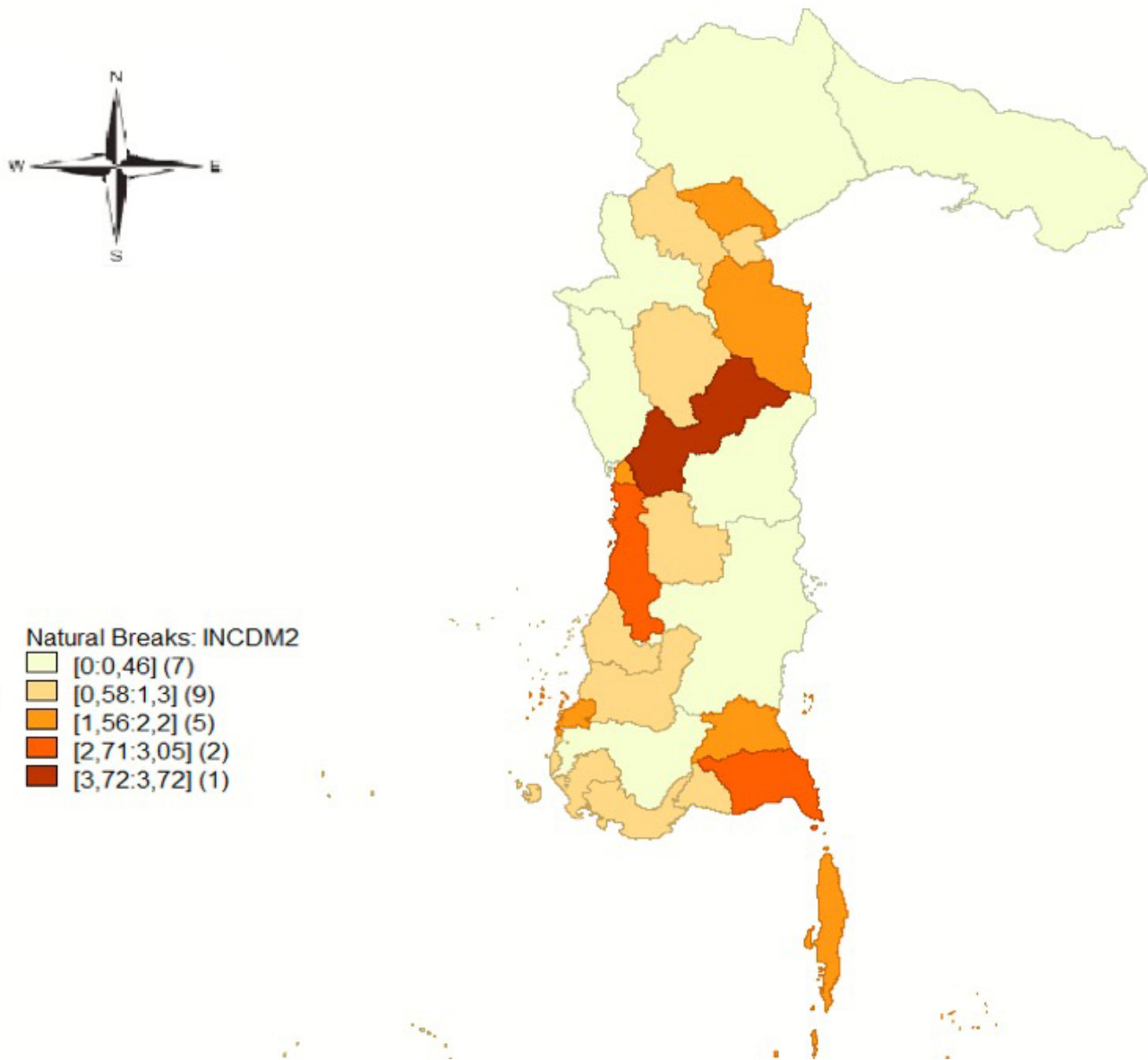
Figure 2

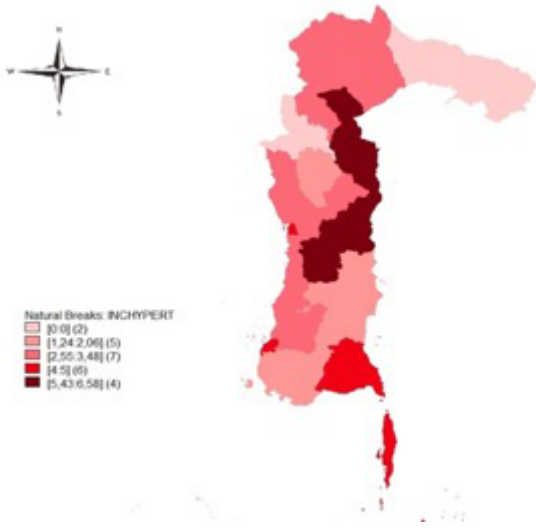Prevalence rate of T2DM for the 2017-2018 period in South Sulawesi Province.

Figure 3

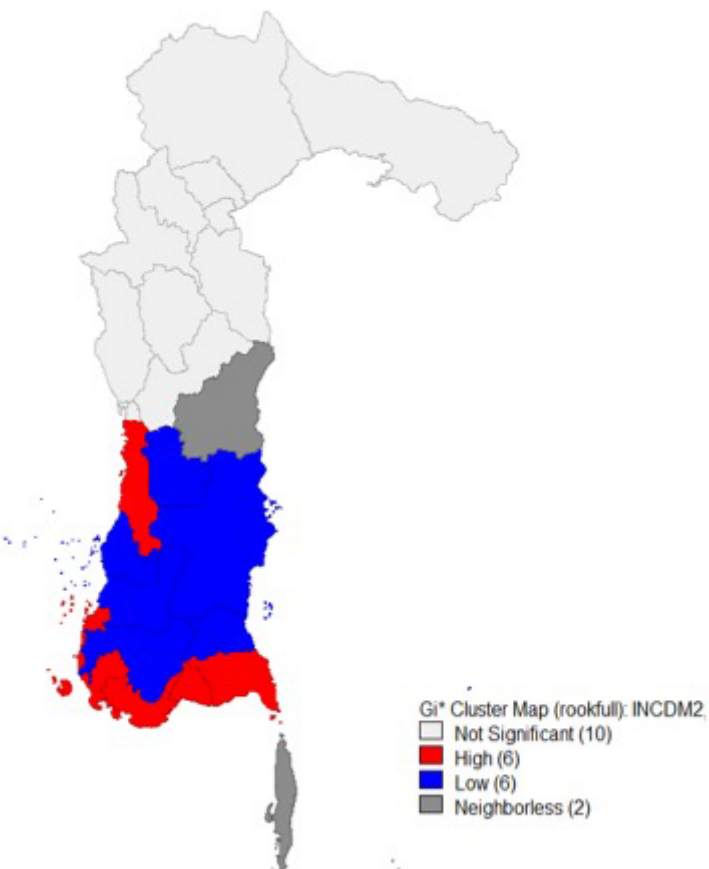Prevalence rate of Hhypertension in the 2017-2018 period in South Sulawesi Province.

Figure 4

The Hotspot Cluster of T2DM for the 2017-2018 period