

Comparison of the Karney Polygon Method and the Shoelace Method for Calculating Area

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ABSTRACT

In calculating the area of an area, latitude and longitude coordinates are based on data from Global Administrative Region Database and Google Earth can be used. The aim of this research is to calculate the area. This research uses the Karney and Shoelace method to determine its accuracy based on Median Absolute Percentage Error in calculating the area of an area. Median Absolute Percentage Error results use data based on Global Administration The Regional Database by applying the polygon method proposed by Karney is 18.73%, and the percentage is 18.19% by applying the Shoelace method. Based on Google Earth data, implementation the method proposed by Karney obtained a percentage of 19.14%, and the application of shoelaces method obtained a percentage of 19.72%. In this case, Karney polygons and the Shoelace method has good accuracy because the value is below 20%. The proposed Shoelace method is easier to perform understand compared to the Karney method for calculating land area because it uses the Universal Transverse Mercator coordinate system, which projects points on the Earth's surface onto a flat plane..

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1. INTRODUCTION

Data Utilization GADM and Google Earth can be used to obtain data in the form of regional boundaries such as latitude and longitude coordinate points so they can be used to calculate the area. Several methods can be used to calculate an area, such as the truncated cone method, the square method, the spherical method, the circular approach method, the Karney method, and the shoelace method. GADM is a big data that maps administrative areas in all countries containing coordinate points (latitude and longitude). Regional mapping in GADM is divided into four levels (provincial, district, sub-district, and village). GADM data can be accessed for free (<https://gadm.org>) and used for academic or non-commercial users. The services on Google Earth can show all map information covering the whole world and be accessed for free (<https://earth.google.com/web/>). Services can be used on Google Earth as KML files, which can be added to a placemark to create an area's boundaries. This placemark will make boundaries of one area with another by coordinating points (latitude and longitude). In this study, researchers would like to propose using the Karney polygon method and Shoelace method to calculate the area of villages divided into 19 sub-districts with a total number of 253 villages by utilizing data from GADM and Google Earth. The results obtained in the two methods were compared with the (Central Statistics Agency) BPS data. Several studies apply the polygon method proposed by Karney to calculate the extent of an area, such as research conducted by Karney [1], Windarni et al. [2], Yildirim et al. [3], and Windarni et al. [4]. In addition, the application of the Shoelace method can also be used to calculate the range of an area, such as research conducted by Setiawan et al. [5], Meng et al. [6], Stoeck [7], Kronenfeld et al. [8], Setiawan et al. [9], and Setiawan et al. [10].

The difference between this study and the previous research conducted by Setiawan et al. [10] is in area size. This study calculated the area of village land located in Semarang Regency (GADM level 4), whereas, in a previous study, this research calculated a wider area of land, namely the scope of the Regency/Province in Central Java Regency, West Java Regency, and Kalimantan. The novelty in this research is that the information used is more extensive or more detailed than previous research if the previous study only used the boundaries of the sub-district area and this study used village boundaries within the sub-district, which were then added together to obtain the district area. This research aims to determine the accuracy stated in the MdAPE in calculating village areas in the Semarang Regency by applying the shoelace method.

In this study, Chapter 2 contains research methods that explain the flowchart of research conducted by researchers. The first thing to do is look for data in the coordinates (latitude and longitude) points based on GADM and Google Earth data and calculate land area village using the Karney method and Shoelace. The final stage is to conduct an extensive analysis of the results, which will be compared with the Central Statistics Agency (BPS) data. Chapter 3 contains the results and analysis, and chapter 4 explains the conclusions.

2. RESEARCH METHOD

GADM data has four levels with coordinate boundaries in the form of provincial, district, sub-district, and village boundaries. Meanwhile, to get data on Google Earth in coordinate points, we need to create points according to regional boundaries, which then export the data in .kml form. The .kml data contains information about the coordinate points of the region that we have created. In this research, the Karney polygon and Shoelace methods will be used to find the village area, and both results will be compared with the actual data according to BPS. The flow of research carried out by researchers in this study can be seen in Figure 1.

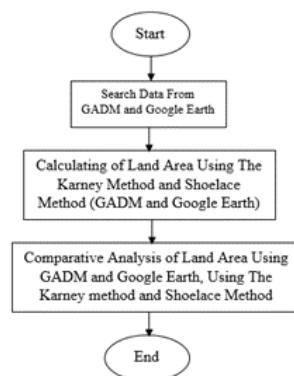


Figure 1. Research Flowchart

2.1. Data Search

Data search from GADM and Google Earth in latitude and longitude coordinates. The GADM data used is level 4 because the data covers land in the form of villages. When entering the GADM website, we can select maps or data, then we select data and download the data in the form of coordinate points based on the selected country. In this study, researchers chose the country of Indonesia.

2.2. Data Processing

After getting the coordinates based on GADM and Google Earth data, the next step is calculating the village area using the R application by applying the Karney polygon and the Shoelace method. However, the coordinate points must be converted to UTM to calculate the land area using the Shoelace method first.

Coordinate is a point based on the intersection of the latitude and longitude lines, which can describe the location in an area. For instance, a point on the earth's surface with coordinates (ϕ, λ) where ϕ represents latitude and λ represents longitude, so to calculate the distance between two points on the earth's surface, the coordinate system needs to be transformed into the UTM coordinate system with the following calculations (meters) [11], i.e., the east coordinates (Eastern):

$$x = E = E_0 + K_0 A(\eta' + \Sigma_j^3 = a_j \cos(2j\xi') \sinh(2j\eta')) \quad (1)$$

and the north coordinates (Northern) are:

$$y = N = N_0 + K_0 A(\xi^1 + \Sigma_j^3 = a_j \sin(2j\xi') \cosh(2j\eta')) \quad (2)$$

Where,

$$a = 6378137(\text{semi-majoraxis}), b = 6356752.314245(\text{semi-majoraxis}), k_0 = 0.9996,$$

$$f = (a - b)/a,$$

$$n = \frac{f}{2-f},$$

$$A = \frac{a}{1+n} \left(1 + \frac{n^2}{4} + \frac{n^2}{64} + \dots\right),$$

$$\alpha_1 = \frac{n}{2} - \frac{2n^2}{3} + \frac{5n^3}{16},$$

$$\alpha_2 = \frac{13n^2}{48} - \frac{3n^3}{5},$$

$$\alpha_3 = \frac{64n^3}{240}$$

$$t = \sinh \left(\tanh^{-1} \sin\phi - \frac{2\sqrt{n}}{1+n} \tanh^{-1} \left(\frac{2\sqrt{n}}{1+n} \sin\phi \right) \right), \quad (3)$$

$$\xi^1 = \tan^{-1} \left(\frac{t}{\cos(\lambda - \lambda_0)} \right) \quad (4)$$

$$\eta' = \tan^{-1} \left(\frac{\sin(\lambda - \lambda_0)}{\sqrt{1+t^2}} \right) \quad (5)$$

If $A1(-0.289287, 113.41617)$, then it can be converted to the Equation described in the previous study [10]. In this case, $a = 6378137$, $f = 1/298.2572235605$, so there will be obtained:

$$n = 0.0016792204,$$

$$a = 6367449.1458234154,$$

$$\alpha_1 = 0.0008377318,$$

$$\alpha_2 = 7.6084969587 \times 10^{-7},$$

$$\alpha_3 = 1.2034877876 \times 10^{-9},$$

$$t = -0.0050152533,$$

$$\xi = -0.0050196738,$$

$$\eta' = 0.0421820949$$

and to get the East coordinate = $E = 768936.0776497596$ 768936.08, the North coordinate = $N = 9967996.4484222736$ 9967996.45, and location at 49 M zone. Further information can be referred to a previous study by Eteje [11]. For example, the application of Equations (1), (2), (3), (4), and (5) will be applied to Pojoksari Village, where 8 latitude and longitude coordinate points have been

taken based on data from Google Earth, which can be seen in Figure 2. After obtaining the coordinate points, they will be converted into the UTM coordinate system using the R application, as in Figure 3, and the results of Easting or Northing can be seen in Table 1.

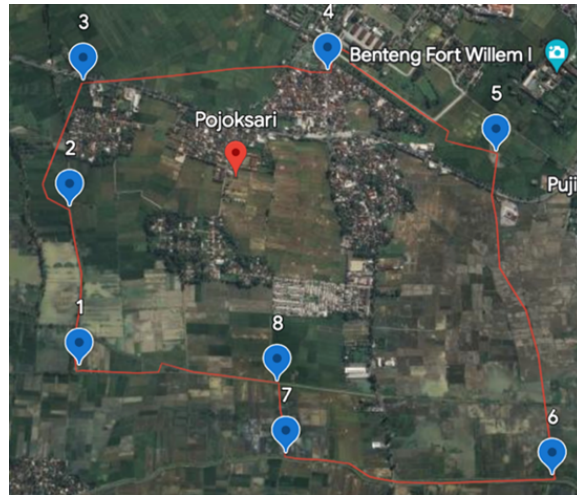


Figure 2. 8 Coordinate Points in Pojoksari Village

```

RGui (64-bit) - [R Console]
File Edit View Misc Packages Windows Help

>
> A =c(-7.275221061, 110.4032989)
> B =c(-7.275562799, 110.4012718)
> C =c(-7.273633836, 110.4022461)
> D =c(-7.271524352, 110.4044176)
> E =c(-7.268531103, 110.4078932)
> F =c(-7.279471224, 110.4115167)
> G =c(-7.278713364, 110.4065666)
> H =c(-7.277375871, 110.4020095)
>
>
> A1 = wgs2utm(A[1], A[2])
> B1 = wgs2utm(B[1], B[2])
> C1 = wgs2utm(C[1], C[2])
> D1 = wgs2utm(D[1], D[2])
> E1 = wgs2utm(E[1], E[2])
> F1 = wgs2utm(F[1], F[2])
> G1 = wgs2utm(G[1], G[2])
> H1 = wgs2utm(H[1], H[2])
>
> A1
[1] 434131.9606366928 9195782.7847744860 49.0000000000
> B1
[1] 433908.2372405779 9195744.7087317016 49.0000000000
> C1
[1] 434015.5092943637 9195958.1049658619 49.0000000000
> D1
[1] 434254.9170421395 9196191.6322014183 49.0000000000
> E1
[1] 434638.1617637002 9196523.0499273315 49.0000000000
> F1
[1] 435039.7415053768 9195314.1024202146 49.0000000000
> G1
[1] 434493.1913486496 9195397.1724364851 49.0000000000
> H1
[1] 433989.9375313822 9195544.3745831754 49.0000000000

```

Figure 3. The UTM Coordinate System Using R application in Pojoksari Village

Table 1. Coordinate Points of Pojoksari Village

No Point	Latitude Coordinates	Longitude Coordinates	Easting	Northing
1	-7.275221061	110.4032989	434131,96	9195782,78
2	-7.275562799	110.4012718	433908,23	9195744,70
3	-7.273633836	110.4022461	434015,50	9195958,10
4	-7.271524352	110.4044176	434254,91	9196191,63
5	-7.268531103	-7.268531103	434638,16	9196523,04
6	-7.279471224	110.4115167	435039,74	9195314,10
7	-7.278713364	110.4065666	434493,19	9195397,17
8	-7.277375871	110.4020095	433989,93	9195544,37

The Shoelace formula is commonly known as Gauss’s area formula and Surveyor’s formula [7]. The Shoelace formula is a mathematical algorithm used to determine a polygon’s area based on its coordinates’ angle. Meister and Gauss described this formula in 1769 and 1795. It divides a triangular polygon, for example ΔABC with vertices $A(x_1, y_1)$, $B(x_2, y_2)$, and $C(x_3, y_3)$, having areas defined as follows in Equation (6) and (7).

$$area(\Delta ABC) = \frac{1}{2} \left| \det \begin{bmatrix} x_1 & x_2 \\ y_1 & y_2 \end{bmatrix} + \det \begin{bmatrix} x_2 & x_3 \\ y_2 & y_3 \end{bmatrix} + \det \begin{bmatrix} x_3 & x_1 \\ y_3 & y_1 \end{bmatrix} \right| \tag{6}$$

where $|x|$ is the absolute value of x , thus the area can be written as follows:

$$\begin{aligned} area(\Delta ABC) &= \frac{1}{2} |x_1y_2 - x_2y_1 + x_2y_3 - x_3y_2 + x_3y_1 - x_1y_3| \\ &= \frac{1}{2} |x_1x_2 - x_2y_3 + x_3y_1) - (x_2y_1 + x_3y_2 - x_1y_3)|, \\ &= \frac{1}{2} \begin{bmatrix} x_1 & x_2 & x_3 & x_1 \\ y_1 & y_2 & y_3 & y_1 \end{bmatrix} \end{aligned} \tag{7}$$

In the Shoelace method, absolute bar values represent the difference between the sums of the diagonal products. To understand this formula, the first thing that has to be done is to explore the cross-product of vectors using triangles and rectangles. By applying the shoelace method, the UTM coordinate system can be used to find the area of Pojoksari Village; we get the following:

$$\begin{aligned} A &= \left(\frac{1}{2}\right) \left| \begin{array}{l} 434131,96 * 9195744,70 - 433908,23 * 9195782,78 \\ +433908,23 * 9195744,70 - 434015,50 * 9195744,70 \\ +434015,50 * 9196191,63 - 434254,91 * 9195958,10 \\ +434254,91 * 9196523,04 - 434638,16 * 9196191,63 \\ +434638,16 * 9195314,10 - 435039,74 * 9196523,04 \\ +435039,74 * 9195397,17 - 434493,19 * 9195314,10 \\ +434493,19 * 9195544,37 - 433989,93 * 9195397,17 \\ +433989,93 * 9195782,78 - 434131,96 * 9195544,37 \end{array} \right| \\ A &= \left(\frac{1}{2}\right) | - 1459650,15 | = 72,98250745 \end{aligned}$$

The resulting area of Pojoksari village is the same as 72,98250745 hectares (ha). The land area results for Pojoksari Village are different from the land area results presented in Table 5. The difference is that more points are used than in Table 1. Suppose the land area is calculated using the Karney method. In that case, the coordinate values based on the UTM system in Pojoksari Village will produce the same area as the shoelace method of 73,03291 hectares (ha), as seen in Figure 4. Further information can be referred to a previous study by Windarni et al. [12].

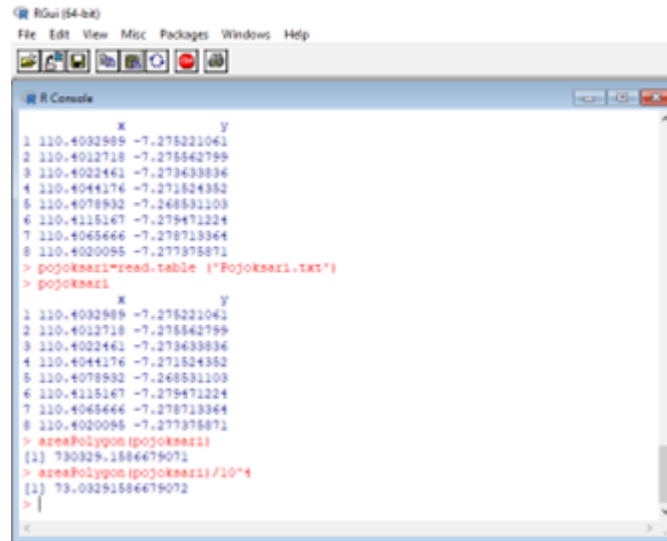


Figure 4. Pojoksari Village Land Area Results using the Karney method

2.3. Analysis

At this stage, the village area spread across the Semarang district is analyzed by applying the Karney polygon and the Shoelace method. Then, the results of these two methods will be compared with the data area according to BPS. So, the MdAPE value is obtained from the median of the values of APE (Absolute Percentage Error), which has the following Equation [13]:

$$APE_t = \left| \frac{\hat{Y}_t - Y_t}{Y_t} \right| \tag{8}$$

3. RESULT AND ANALYSIS

Semarang Regency is located at 110⁰ 14' 54.74" until 110⁰ 39' 3" East Longitude and 7⁰ 3' 57" until 7⁰ 30' 0" South Latitude. The total area of Semarang Regency is 1019.27 km², which is divided into 19 districts and 235 villages/sub-districts. The widest area is Pringapus District, with 84.27 km (8.27%), and the smallest is Ambarawa District, with 29.79 km (2.92%), as shown in Figure 5. The results for the area of all villages represented by each sub-district located in Semarang Regency can be seen in Table 2. The percentage results are obtained from the area of each village divided by 100%.

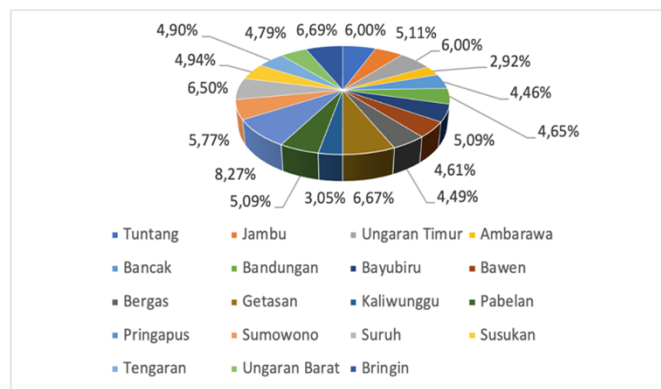
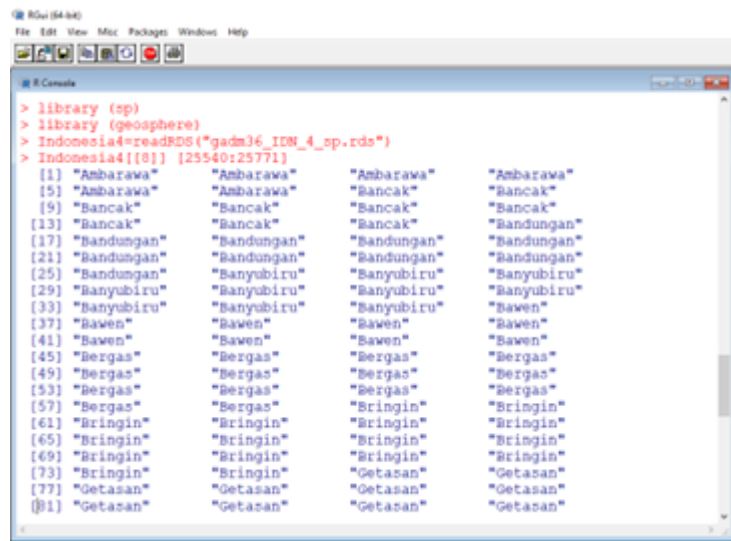


Figure 5. Percentage of Districts Area towards Semarang Regency Area

3.1. Data Search

Searching for data in the form of regional boundaries for each village in Semarang Regency was the first activity carried out in this research. Data search is done by looking for village area boundaries in coordinate points (GADM and Google Earth). In GADM big data, we only need to download the data that GADM has provided at level 4 because level 4 contains village/ subdistrict borderline data. After obtaining GADM data, the data can be exported into R software. R software can be used for data retrieval, management, and analysis purposes. Figure 6 shows all the names of sub-districts spread across the Semarang district with data taken from GADM using the R application. For example, if you want to see a village located in Jambu District, it will look like in Figure 7.

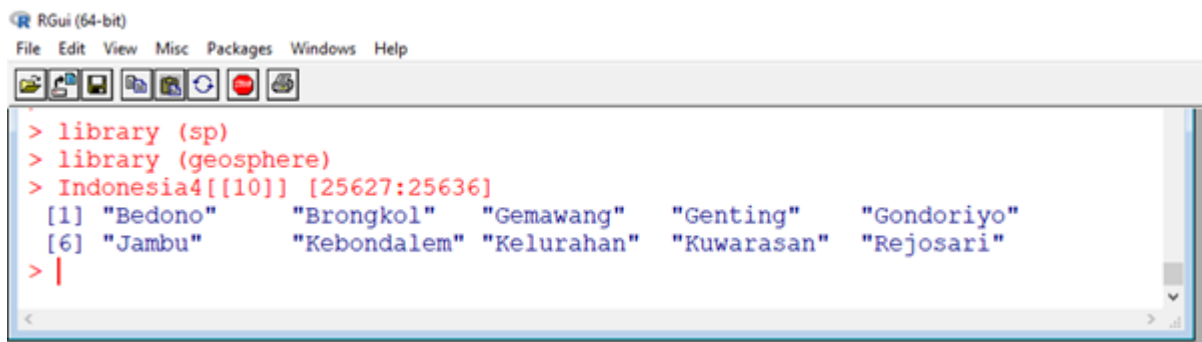


```

> library(sp)
> library(geosphere)
> Indonesia4=readRDS("gadm36_IDM_4_sp.rds")
> Indonesia4[[8]] [25540:25771]
 [1] "Ambarawa" "Ambarawa" "Ambarawa" "Ambarawa"
 [5] "Ambarawa" "Ambarawa" "Bancak" "Bancak"
 [9] "Bancak" "Bancak" "Bancak" "Bancak"
[13] "Bancak" "Bancak" "Bancak" "Bancak"
[17] "Bandungan" "Bandungan" "Bandungan" "Bandungan"
[21] "Bandungan" "Bandungan" "Bandungan" "Bandungan"
[25] "Bandungan" "Banyubiru" "Banyubiru" "Banyubiru"
[29] "Banyubiru" "Banyubiru" "Banyubiru" "Banyubiru"
[33] "Banyubiru" "Banyubiru" "Banyubiru" "Banyubiru"
[37] "Bawen" "Bawen" "Bawen" "Bawen"
[41] "Bawen" "Bawen" "Bawen" "Bawen"
[45] "Bergas" "Bergas" "Bergas" "Bergas"
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[53] "Bergas" "Bergas" "Bergas" "Bergas"
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[65] "Bringin" "Bringin" "Bringin" "Bringin"
[69] "Bringin" "Bringin" "Bringin" "Bringin"
[73] "Bringin" "Bringin" "Getasan" "Getasan"
[77] "Getasan" "Getasan" "Getasan" "Getasan"
[81] "Getasan" "Getasan" "Getasan" "Getasan"

```

Figure 6. Names of 19 Districts Based on GADM Data



```

> library(sp)
> library(geosphere)
> Indonesia4[[10]] [25627:25636]
 [1] "Bedono" "Brongkol" "Gemawang" "Genting" "Gondoriyo"
 [6] "Jambu" "Kebondalem" "Kelurahan" "Kuwarasan" "Rejosari"
> |

```

Figure 7. Village Located in Jambu District

3.2. Data Processing

The next step is to find the area of each village located in Semarang Regency based on GADM and Google Earth data using the polygon Karney and shoelace method. Table 2 shows the results of the area of each village represented by each sub-district based on the Karney method, shoelace method, and BPS. For example, for all villages located in Tuntang District, the results obtained were 5249 ha using the Karney method, 5246 ha using the shoelace method based on GADM data, and 4832 ha using the Karney method, 5474 ha using the shoelace method based on Google Earth data. Based on data obtained from BPS, the resulting area is 5824 ha.

Table 2. Results of Area Extent Based on Each District

Subdistrict	Village Area (Ha)				BPS
	GADM		Google Earth		
	Method Polygon Karney	Method Shoelace	Method Polygon Karney	Method Shoelace	
Tuntang	5249	5246	4832	5474	5624
Jambu	5422	5287	5298	5255	5163
Ungaran Timur	6336	6311	6299	6313	3799
Ambarawa	2757	2756	2666	2664	2821
Bancak	4699	4697	4704	4700	4380
Bandungan	4575	4571	4576	5559	4820
Bayubiru	5091	5087	4713	4709	5436
Bawen	4933	4911	6947	12346	4630
Bergas	4476	4476	4485	4482	4727
Getasan	6827	6822	6827	6754	6570
Kaliwunggu	2890	2886	2923	2933	2993
Pabelan	5197	5217	5181	5176	4793
Pringapus	7978	7973	8098	8092	7831
Sumowono	5431	5429	5431	5398	5553
Suruh	6894	6886	6839	6834	6394
Susukan	5257	5252	4674	4867	4880
Tengaran	4808	4806	4759	4765	4722
Ungaran Barat	3725	3723	7046	7039	3501
Bringin	6869	6875	6890	6922	6183

3.3. Analysis

The next thing to do at the analysis stage is to search for the Mean Absolute Percentage Error (MAPE) from the estimated village land area results according to GADM and Google Earth and then compare it with regional references from BPS. Table 3 shows the results of the percentage of village area represented by each sub-district located in Semarang Regency. For example, villages in the Tuntang sub-district have an area percentage according to data from GADM using the Karney polygon of 20.75% and the shoelace method of 20.73%. Based on data from Google Earth, using the Karney polygon method, the percentage obtained was 23.91%, and the Shoelace method was 29.68%.

Table 3. Village Area Results Based on Each District (%)

District	Percentage (%)			
	GADM		Google Earth	
	Method Polygon Karney	Method Shoelace	Method Polygon Karney	Method Shoelace
Tuntang	20.75	20.73	23.91	29.68
Jambu	14.46	9.46	9.64	10.19
Ungaran Timur	62.71	62.34	62.21	62.34
Ambarawa	29.24	29.19	29.93	30.73
Bancak	12.43	12.39	12.47	12.43
Bandungan	66.04	65.93	66	81.24
Bayubiru	10.67	10.67	16.75	16.74
Bawen	23.16	23.85	51.4	136.91
Bergas	19.78	19.78	19.81	19.86
Getasan	22.33	22.25	23.14	23.77
Kaliwunggu	13.56	13.54	15.5	13.44
Pabelan	18.73	18.19	18.48	18.49
Pringapus	23.91	23.91	25.24	25.22
Sumowono	19.14	19.15	19.14	19.72
Suruh	7.63	7.54	7.58	7.5
Susukan	13.27	13.22	17.45	17.87
Tengaran	12.78	12.72	12.95	12.75
Ungaran Barat	10.97	11	193.31	193
Bringin	15.93	15.97	16.12	16.6
MdAPE	18.73	18.19	19.14	19.72

Based on the percentage, MdAPE results using data based on GADM big data by applying the Karney polygon method is at 18.73%, and by applying the shoelace method, it has a percentage of 18.19%. Based on data from Google Earth, applying the method proposed by Karney obtained a percentage of 19.14%, and applying the shoelace method obtained a percentage of 19.72%. The results of MdAPE percentage based on GADM and Google Earth data can be seen in Table 3. In measuring the benefits of forecasting methods, we can use the Mean Absolute Percentage Error (MAPE) formula; the range of values is presented in Table 4 [14]. In this case, MdAPE is used as a substitute for MAPE because it is more robust against the emergence of extreme values.

Table 4. Mean Absolute Percentage Error (MAPE) Value Range

MAPE Range	Explanation
<10%	Very Good Forecasting Model Competition
10-20%	Good Forecasting Model Competition
20-50%	Competition Feasible Forecasting Models
>50%	Bad Forecasting Model Competition

We can see Bejalen Village in Ambarawa District as in Table 5. The area of Bejalen village was 156 ha using the Karney polygon and Shoelace method according to GADM data. According to Google Earth data, an area of 80 ha was obtained using the Karney polygon and the shoelace method. BPS results show that the area of Bejalen village is 471 ha. When viewed from the shape of the map between GADM in Figure 8, Google Earth in Figure 9, and BPS in Figure 10, the map of Bejalen Village has the same map shape.

Table 5. Village Area Located in Ambarawa District

Village Name	GADM		Google Earth		BPS (ha)
	Method	Method	Method	Method	
	Polygon Karney (ha)	Shoelace (ha)	Polygon Karney (ha)	Shoelace (ha)	
Baran	315	315	316	315	262
Bejalen	156	156	80	80	471
Kranggan	32	32	32	34	23
Kupang	270	270	269	269	189
Lodoyong	157	157	155	155	113
Ngampin	294	294	294	293	304
Panjang	241	240	241	241	209
Pasekan	840	840	841	840	759
Pojoksari	214	214	214	214	302
Tambakboyoy	238	238	224	223	189

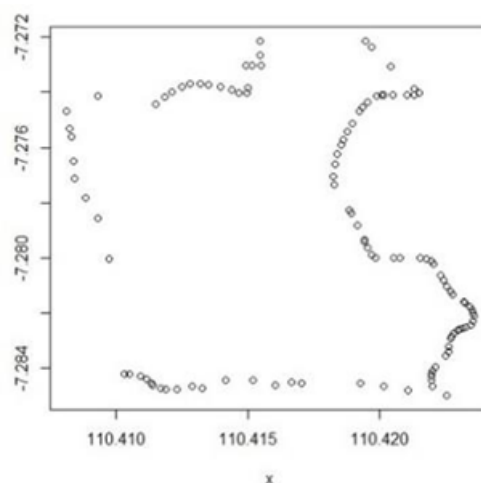


Figure 8. Bejalen Village Map in GADM

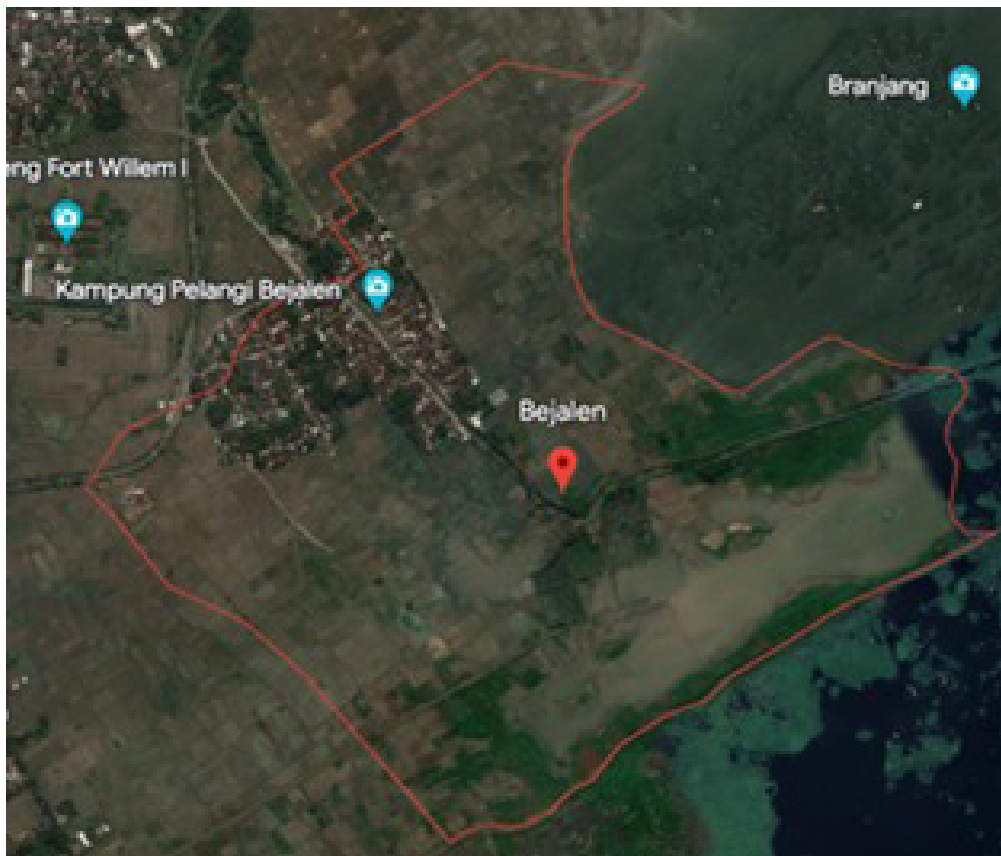


Figure 9. Bejalen Village Map in Google Earth

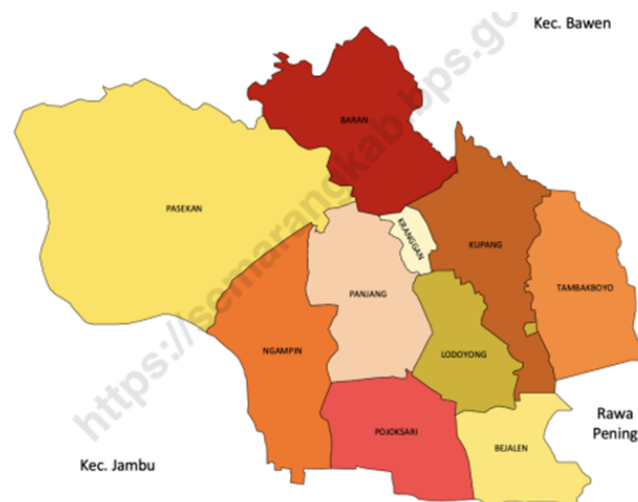


Figure 10. Bejalen Village Map in BPS

A map of an area should not be drawn haphazardly. The map's depiction has to be proportional or equivalent, which means that the ratio of the area on the map must be the same as the actual area. Looking at Figure 11 below, we can see ten villages in the Ambarawa District, which BPS maps. For example, Baran village is colored red, and Bejalen village is dark yellow. Looking

closely, it can be said that Baran Village should have a larger area than Bejalen Village. However, in reality, the area of Baran Village, according to BPS, is 262ha, and Bejalen Village has an area of 471 ha.



Figure 11. Village Map in Ambarawa District (BPS)

To create a map of an area using Google Earth, three things must be considered to make land boundary points (adding place-marks): (1) making land boundary points must be clockwise; (2) land boundary points are better close together, meaning that one point to another is better be closed because land shapes are not always straight and there are indentations; (3) the use of zoom in and zoom out also affects it, meaning that it is better to use zoom in to mark land boundaries because it will affect the accuracy of selecting points on the borderline of the area boundaries.

Applying the Karney and shoelace methods can be used to calculate the area of villages in the Semarang Regency because they have an accuracy rate below 20% compared to the application of the circle method to calculate the area of villages located in the Semarang Regency. The novelty obtained in this study is that both the Karney and Shoelace methods give relatively the same results. Still, the drawback of the Karney method is that the formula is difficult to understand, and when using the Shoelace method, the formula is relatively easier to understand. The two methods used above can also be compared with other methods proposed by Kin et al. [15], Lumban et al. [16], and Kin et al. [17].

4. CONCLUSION

The MdAPE results using GADM big data-based data with the application of the Karney polygon method obtained results of 18.73% and 18.19% for the Shoelace method. Based on Google Earth data, the application of the method proposed by Karney obtained a percentage of 19.14%, and the application of the shoelace method obtained a percentage of 19.72%. MdAPE result on GADM and Google Earth has a good level of accuracy because the value is below 20%. Suggestions for further research include calculating the area near the poles to determine whether the Shoelace method still gives relatively the same results as the Karney method.

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6. DECLARATIONS

AUTHOR CONTRIBUTION

This research was compiled by three writers who were divided into each task. Vikky Aprelia Windarni conducted data collection, analysis, and interpretation. Adi Setiawan conceptualized and designed the research, performed a critical review of the article, and granted final approval for publication. Atina Rahmatalia was responsible for preparing the articles.

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COMPETING INTEREST

I have no declaration under financial, general, and institutional competing interests.

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