

## CALCULATION OF CENTRAL JAVA PROVINCE REGION AREA USING SHOELACE FORMULA BASED ON THE GADM DATABASE

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**Abstract.** This study proposes the use of the shoelace formula to determine the area of the regencies and towns/cities in the province of Central Java, which is based on the boundaries of the cities, regencies, (sub-) districts, and villages using the database from the GADM (Global Administrative Area). The results obtained are then compared with the Karney polygon method. With the shoelace formula, the area of Central Java province is 34365.40 km<sup>2</sup> (4.77% wider than the reference area), while the Karney polygon method yields 34379.48 km<sup>2</sup> (4.81% wider than the reference area). The area calculated using the boundaries of sub-districts is closer to the reference area if compared to using the boundaries of the regencies/cities and of villages. MdAPE values of 6.46 % and 6.54 % are obtained using the shoelace formula and the Karney polygon method respectively.

**Keywords:** Global Administrative Areas (GADM), MdAPE (Median Absolute Percentage Error), Shoelace Formula, Universal Transverse Mercator (UTM),

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## 1. INTRODUCTION

Genome-wide Various methods may be applied to determine the area on earth's surface, including the circular approach method [1], the rectangular method [2], the spherical quadratic approach method [3] and the polygon method proposed by Karney [4], [5]. The Karney polygon method is considered good for the purpose but is not an easy method to understand, while the circular approach method is a method that is easy to understand but gives unsatisfactory results.

Data available in a database is usually raw that needs analysis in order to obtain information that is crucial in decision making. Furthermore, considering the large size of data in the database, a special method is required for a reliable and fast data analysis. The GADM (Global Administrative Area) provides boundary coordinate data for each region (state, province, city, district, sub-district and village) in countries around the world. See [6] for further information on GADM.

The shoelace formula is widely used to determine the area of a polygon in a flat plane [7], [8], and [9]. On the other hand, the Universal Transverse Mercator (UTM) coordinate system is used to convert a curved geographic coordinate system (i.e. latitude-longitude) into a coordinate system on a flat plane, as such that the Euclidean distance and the shoelace formula can be applied [10], [11], and [12].

This paper proposes a shoelace formula based on the UTM coordinate system to determine the area of regencies and cities in Central Java based on the coordinates of the boundaries of the regencies, cities, districts, sub-districts, and villages. The results obtained are then compared to the ones using Karney polygon method, to determine the accuracy of the calculations. The boundaries are obtained from the GADM database.

## 2. RESEARCH METHODS

Discussed in this section are the latitude-longitude coordinate system, the UTM coordinate system, shoelace formula and its application in determining the area of a region.

The location of a point on the earth's surface can be expressed in a geographic coordinate system, namely the latitude and longitude coordinates. As an example, the office of Faculty of Science and Mathematics – Universitas Kristen Satya Wacana is at 7.319249° South latitude and 110.500090° East longitude. The latitude-longitude coordinates may also be expressed as 7° 19' 9.30" S and 110° 30' 0.324" E. As a convention the 7.319249° South latitude may be expressed as -7.319249° to denote the location is south of the equator, for locations that are north of the equator, the latitude coordinates are positive. Similarly, the 110.500090° East longitude may be expressed as +110.500090° denoting the location on the East longitude, while locations on the West longitude have negative coordinates. A coordinate of latitude and longitude gives exactly one point on the earth's surface that fulfils these properties.

For example, a point on the surface of the earth is at  $(\phi, \lambda)$  coordinates,  $\phi$  being the latitude coordinate and  $\lambda$  the longitude coordinate. The method commonly used to convert the geographic (latitude-longitude) coordinate system to the UTM coordinate system is proposed by [10]. Another method for converting latitude-longitude coordinates to UTM coordinates uses the following steps [11]:

$$a = 6378137 \text{ (semi-major axis),}$$

$$b = 6356752.314245 \text{ (semi-minor axis),}$$

$$k_0 = 0.9996,$$

$$f = (a-b)/a, \tag{1}$$

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

$$A = \frac{a}{1+n} \left( 1 + \frac{n^2}{4} + \frac{n^4}{64} + \dots \right), \tag{3}$$

$$\alpha_1 = \frac{n}{2} - \frac{2n^2}{3} + \frac{5n^3}{16}, \tag{4}$$

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

$$\alpha_3 = \frac{61n^3}{240}, \quad (6)$$

$$t = \sinh \left( \tanh^{-1} \sin \phi - \frac{2\sqrt{n}}{1+n} \tanh^{-1} \left( \frac{2\sqrt{n}}{1+n} \sin \phi \right) \right), \quad (7)$$

$$\xi' = \tan^{-1} \left( \frac{t}{\cos(\lambda - \lambda_0)} \right), \quad (8)$$

$$\eta' = \tanh^{-1} \left( \frac{\sin(\lambda - \lambda_0)}{\sqrt{1+t^2}} \right), \quad (9)$$

where  $\lambda_0$  is the reference longitude coordinates as such that the Easting coordinate is

$$x = E = E_0 + k_0 A \left( \eta' + \sum_{j=1}^3 \alpha_j \cos(2j \xi') \sinh(2j \eta') \right), \quad (10)$$

and the Northing coordinate is

$$y = N = N_0 + k_0 A \left( \xi' + \sum_{j=1}^3 \alpha_j \sin(2j \xi') \cosh(2j \eta') \right). \quad (11)$$

In this case,  $\lambda_0 = [\lambda/6]*6 + 3$  where  $[x]$  means the largest integer that is less than or equal to  $x$ . Here  $E_0 = 500000$  and  $N_0 = 10000000$  if the latitude  $< 0$  for locations which is south of the equator, and  $N_0 = 0$  if the latitude  $> 0$  for locations that are north of the equator. Measurements are in meters.

Using the method, the geographical coordinates of A (-8.357345; 116.081812) may be expressed using the UTM coordinate system to get

$$A = 6367449.1458234154,$$

$$\alpha_1 = 0.0008377318,$$

$$t = -0.1459231072,$$

$$\xi' = -0.1449187502,$$

$$\eta = -0.0158581127,$$

and to obtain Easting =  $x = 398902.32$  and Northing =  $y = 9076079.01$ , and the location of the point which is in the zone of 50 L. For more information about UTM, see paper [13].

To determine the area of a polygon shape on a flat plane with known coordinates of the vertices, the shoelace formula is used. This formula is used in the UTM coordinate system, and the following gives an idea of how it is used.

Suppose a triangle  $ABC$  has the coordinates  $A(x_1, y_1)$ ,  $B(x_2, y_2)$  dan  $C(x_3, y_3)$ . To find the area of triangle  $ABC$  using the shoelace formula:

$$\begin{aligned} A_{\Delta ABC} &= 0.5 |x_1 y_2 - x_2 y_1 + x_2 y_3 - x_3 y_2 + x_3 y_1 - x_1 y_3| \\ &= 0.5 |(x_1 y_2 + x_2 y_3 + x_3 y_1) - (x_2 y_1 + x_3 y_2 + x_1 y_3)|. \end{aligned} \quad (12)$$

where  $|x|$  is the absolute value of  $x$ . The formula can be extended to find the area of a rectangle  $ABCD$ . Suppose a square  $ABCD$  has the coordinates  $A(x_1, y_1)$ ,  $B(x_2, y_2)$ ,  $C(x_3, y_3)$  and  $D(x_4, y_4)$ . Using the shoelace formula to find the area of rectangle  $ABCD$ :

$$A_{ABCD} = 0.5 | x_1 y_2 - x_2 y_1 + x_2 y_3 - x_3 y_2 + x_3 y_4 - x_4 y_3 + x_4 y_1 - x_1 y_4 |$$

$$= 0.5 | (x_1 y_2 + x_2 y_3 + x_3 y_4 + x_4 y_1) - (x_2 y_1 + x_3 y_2 + x_4 y_3 + x_1 y_4) |. \quad (13)$$

Generally, suppose an  $n$ -side polygon has the coordinates  $A_1 (x_1, y_1)$ ,  $A_2 (x_2, y_2)$ ,  $A_3 (x_3, y_3)$ , ..., and  $A_n (x_n, y_n)$ , then using the shoelace formula to find the area:

$$A_{n\text{-sides polygon}} = 0.5 | x_1 y_2 - x_2 y_1 + x_2 y_3 - x_3 y_2 + x_3 y_4 - x_4 y_3 + \dots + x_{n-1} y_n - x_n y_{n-1} + x_n y_1 - x_1 y_n |$$

$$= 0.5 | (x_1 y_2 + x_2 y_3 + x_3 y_4 + \dots + x_{n-1} y_n + x_n y_1) - (x_2 y_1 + x_3 y_2 + x_4 y_3 + \dots + x_n y_{n-1} + x_1 y_n) |. \quad (14)$$

Consider the data of latitude and longitude coordinates of an island boundaries, the Gili Air island, obtained through Google Maps [1]. To obtain representative data, one center point was selected and 8 points were taken in accordance with the points of the compass. Based on this data, the area of the island will be determined using the shoelace formula and the Karney polygon method. Table 1 shows the eight coordinates and one center point used to find the area of the island, and Figure 1 represent the map of Gili Air island with points that are used to calculate the area of the island. Based on the shoelace formula and UTM coordinate (Easting dan Northing) system, we get:

$$A = \left(\frac{1}{2}\right) | 398902.31 \times 9076842.06 - 9076079.01 \times 398957.25 + 398957.25 \times 9076484.05$$

$$- 9076842.06 \times 398957.25 + 399440.07 \times 9076103.98$$

$$- 9076484.05 \times 399511.86 + 399511.86 \times 9075479.63$$

$$- 9076103.98 \times 399522.78 + 399522.78 \times 9075374.94$$

$$- 9075479.63 \times 398913.32 + 398913.32 \times 9075542.55$$

$$- 9075374.94 \times 398341.21 + 398341.21 \times 9076091.37$$

$$- 9075542.55 \times 398136.65 + 398136.65 \times 9076524.04$$

$$- 9076091.37 \times 398475.90 + 398475.90 \times 9076079.01$$

$$- 9076524.04 \times 398902.31 | = (1/2) | | - 2936565.3833 | = 1468283.$$

That is in  $m^2$ , so is equal to 146.8283 hectare (ha). The real area as officially recorded is 175 ha., so the calculated result is 16,10% narrower. This is due to the lack of area boundary points used in the calculation of area. The more points used to calculate the area, the closer the result to the actual area is. Using the same data, the Karney polygon method yields an area of 146.91 ha., or 16.05% smaller than the reference area. Based on the GADM data, on the other hand, applying the shoelace formula and the Karney polygon method yields an area of 179.2 ha. (2,30% larger than the reference area), and 179.11 ha. (2.35% larger than the reference area).

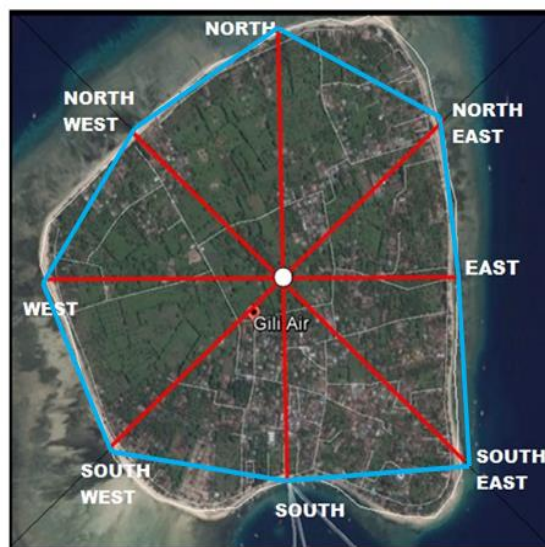


Figure 1. The Gili Air island with the points for the area calculation.

**Table 1. The latitude and longitude coordinates of the Gili Air island.**

No.	Directions	Latitude Coordinates	Longitude Coordinates	Easting	Northing
0	Center	-8.357345	116.081812	398902.32	9076079.01
1	North	-8.350445	116.082327	398957.25	9076842.06
2	North East	-8.353693	116.086704	399440.07	9076484.05
3	East	-8.357132	116.087348	399511.86	9076103.98
4	South-East	-8.362779	116.087434	399522.78	9075479.63
5	South	-8.363713	116.081897	398913.32	9075374.94
6	South-West	-8.362185	116.076705	398341.21	9075542.55
7	West	-8.357217	116.074859	398136.65	9076091.37
8	North West	-8.353311	116.077949	398475.90	9076524.04

The research is experimental using secondary data from the GADM, calculation results are compared to reference data from the Central Statistics Agency (BPS) [12]. The GADM data are geographical coordinates of the boundaries of regencies / cities, districts, and villages in Central Java, used to find the areas of regencies and cities based on their boundaries. The area of a district is calculated based on the boundaries of the district, and the area of a village is based on the village's boundaries. The shoelace formula and the Karney polygon method are applied to find the region's area, based on UTM coordinates resulted from the boundary coordinate conversion. Results from the two calculations are compared against the region areas from the Central Statistics Agency.

### 3. RESULTS AND DISCUSSION

The Central Java province consists of 35 regency/cities, districts and villages. Table 2 shows the detail of data obtained from the GADM database and data obtained from BPS. It shows that the least boundary points used to determine the boundaries of the area is 513, which is used to determine the boundaries of the city of Tegal. The largest number of points used to determine the boundary is 10168, that is to determine the boundaries of Boyolali Regency. A total of 168888 latitude and longitude coordinate points are needed to form the boundaries of the regencies / cities in the province. Based on BPS data, there are 573 districts and 8578 villages in Central Java, covering an area of 32800.60 km<sup>2</sup>.

By applying the shoelace formula and Karney method and using the regency/city boundaries, each of the regency / city area can be obtained as presented on Table 3. The resulted areas using the two methods are 34482.63 km<sup>2</sup> (5.13% greater than the reference area) and 34490.30 km<sup>2</sup> (5.15% greater than the reference area). Using the boundaries of districts, the shoelace formula and Karney method respectively yield a total area of 34365.40 km<sup>2</sup> (4.77% greater than the reference area) and 34379.48 km<sup>2</sup> (4.81% greater than the reference area). Next, Using the boundaries of villages, the two methods respectively yield a total area of 34511.11 km<sup>2</sup> (5.21% greater than the reference area) dan 34524.20 km<sup>2</sup> (5.25% greater than the reference area). Both the shoelace formula and Karney Polygon method give results which are closer to the reference area by using boundary coordinates of districts, but the results are farther from the reference area with boundary coordinates of regency / city and villages.

**Table 2. The number of boundary points, districts, villages The Central Java province, and reference area (km<sup>2</sup>).**

No.	Regency / City	No. of boundary points <sup>(1)</sup>	No. of districts <sup>(1)</sup>	No. of villages <sup>(1)</sup>	Ref. area <sup>(2)</sup>
1	Banjarnegara	5203	20	278	1023.73
2	Banyumas	4450	27	329	1335.30
3	Batang	3916	15	248	788.65
4	Blora	6277	16	295	1804.59
5	Boyolali	10168	19	267	1008.45
6	Brebes	6234	17	297	1902.37
7	Cilacap	6786	24	284	2124.47
8	Demak	4775	14	249	900.12
9	Purwodadi	7445	19	280	2013.86
10	Jepara	9759	16	194	1059.25
11	Karanganyar	5329	17	177	775.44

No.	Regency / City	No. of boundary points <sup>(1)</sup>	No. of districts <sup>(1)</sup>	No. of villages <sup>(1)</sup>	Ref. area <sup>(2)</sup>
12	Kebumen	4080	26	461	1211.74
13	Kendal	6233	20	285	1118.13
14	Klaten	4341	26	401	658.22
15	Kota Magelang	737	3	17	16.06
16	Kota Pekalongan	827	4	47	45.25
17	Kota Semarang	3411	16	177	373.78
18	Kota Tegal	513	4	27	39.68
19	Kudus	2718	9	132	425.15
20	Magelang	5827	21	373	1102.93
21	Pati	5955	21	406	1489.10
22	Pekalongan	4112	19	285	837
23	Pemalang	5056	14	222	1118.03
24	Purbalingga	3405	18	239	677.55
25	Purworejo	3565	16	494	1091.49
26	Rembang	4826	14	294	887.13
27	Salatiga	1123	4	22	57.36
28	Semarang	7312	19	237	950.21
29	Sragen	9959	20	208	941.54
30	Sukoharjo	4092	12	167	489.12
31	Surakarta	1044	5	51	46.01
32	Tegal	4271	18	287	876.10
33	Temanggung	4253	20	289	837.71
34	Wonogiri	6667	25	294	1793.67
35	Wonosobo	4219	15	265	981.41

Sources:(1) GADM, (2) BPS

The application of shoelace formula on UTM coordinates give relatively better results than that of the Karney method. However, this formula can only be used for areas that are all located in the same UTM zone (such as the province of Central Java), and cannot easily be used for provinces whose areas have UTM zone boundaries such as West Java, East Java and Central Kalimantan provinces.

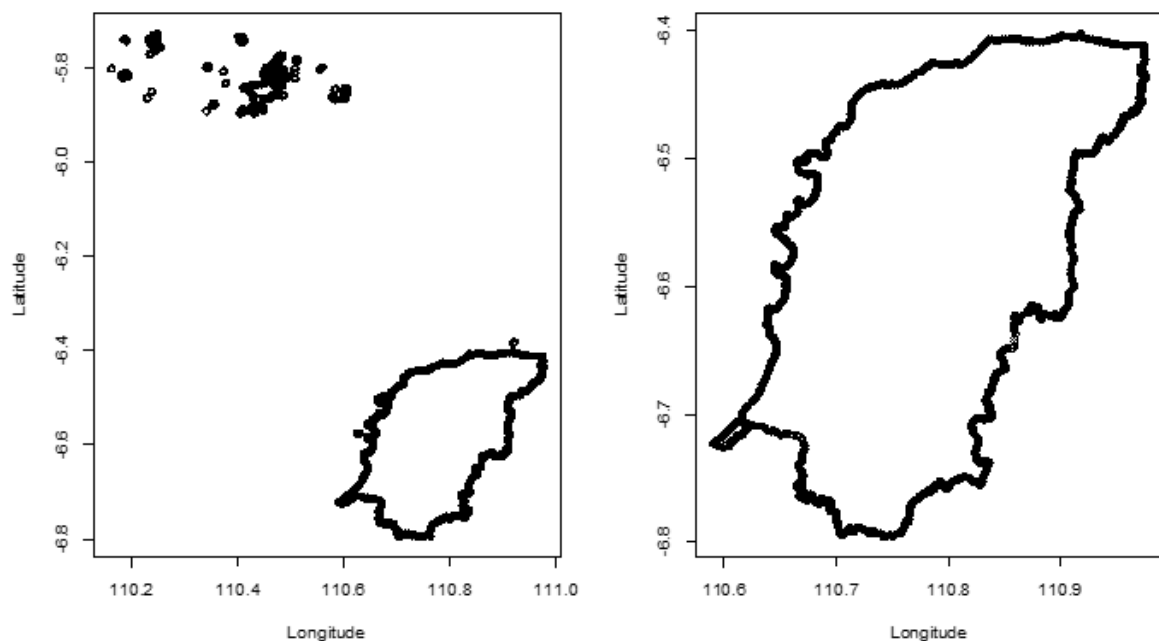
**Table 3. Results of Regency / City Area Calculation in sq.km. in the Province of Central Java based on Coordinates of the Region Boundaries.**

No.	Regency / City	Shoelace Formula	Karney Method
1	Banjarnegara	1148.89 (12.23 %)	1149.18 (12.25 %)
2	Banyumas	1390.10 (4.10 %)	1389.81 (4.08 %)
3	Batang	858.62 (8.87 %)	858.97 (8.92 %)
4	Blora	1947.30 (7.91 %)	1948.76 (7.99 %)
5	Boyolali	1076.36 (6.73 %)	1077.18 (6.82 %)
6	Brebes	1752.13 (7.90 %)	1751.25 (7.94 %)
7	Cilacap	2504.81 (17.90 %)	2503.45 (17.84 %)
8	Demak	999.1 (11.02 %)	1000.06 (11.10 %)
9	Grobogan	2028.67 (0.74 %)	2030.27 (0.81 %)
10	Jepara	976.84 (4.55 %)	977.60 (4.48 %)
11	Karanganyar	803.14 (3.57 %)	803.79 (3.66 %)
12	Kebumen	1331.32 (9.87 %)	1331.61 (9.89 %)
13	Kendal	595.20 (46.77 %)	595.54 (46.74 %)
14	Klaten	700.75 (6.46 %)	701.28 (6.54 %)
15	Kota Magelang	17.86 (11.21 %)	17.87 (11.27 %)
16	Kota Pekalongan	45.79 (1.19 %)	45.80 (1.22 %)
17	Kota Semarang	414.83 (10.98 %)	415.11 (11.06 %)
18	Kota Tegal	39.14 (1.36 %)	39.12 (1.41 %)
19	Kudus	435.18 (2.36 %)	435.52 (2.44 %)
20	Magelang	1136.77 (3.07 %)	1131.22 (2.56 %)
21	Pati	1582.24 (6.25 %)	1583.51 (6.34 %)
22	Pekalongan	892.64 (6.65 %)	892.84 (6.67 %)
23	Pemalang	1136.77 (1.68 %)	1136.79 (1.68 %)

No.	Regency / City	Shoelace Formula	Karney Method
24	Purbalingga	807.97 (19.25 %)	807.99 (19.25 %)
25	Purworejo	1089.36 (0.20 %)	1089.88 (0.15 %)
26	Rembang	1224.96 (38.08 %)	1225.87 (38.18 %)
27	Salatiga	53.05 (7.51 %)	53.08 (7.46 %)
28	Semarang	1221.97 (28.60 %)	1222.85 (28.69 %)
29	Sragen	915.09 (2.81 %)	915.82 (2.73 %)
30	Sukoharjo	493.16 (0.83 %)	493.55 (0.91 %)
31	Surakarta	46.23 (0.48 %)	46.27 (0.57 %)
32	Tegal	994.99 (13.57 %)	994.77 (13.55 %)
33	Temanggung	872.37 (4.14 %)	872.87 (4.20 %)
34	Wonogiri	1921.23 (7.11 %)	1922.76 (7.20 %)
35	Wonosobo	993.42 (1.22 %)	993.86 (1.27 %)

Applying the shoelace formula and Karney polygon method on the area calculation of regencies and cities based on the region boundaries, the results are MdAPE (Median Absolut Percentage Error) of 6.65% and 6.67%, respectively. The calculations that are based on district boundaries give MdAPE values of 6.46% and 6.54%, respectively. Similarly, the calculations that are based on village boundaries using the two methods respectively give MdAPE values of 6.67% and 6.67%. Based on the three cases, the shoelace formula appears to have relatively smaller MdAPE value than that of the Karney polygon method.

Both the shoelace formula and the Karney polygon method cannot easily be applied on certain cases such as the following. Jepara Regency consists of the mainland on Java Island and small islands in the Karimunjawa. If the shoelace formula and the Karney polygon method are immediately applied to calculate the area using the GADM database on Jepara district boundaries, it will give results that are very much different from the reference area. Figure 2 shows plots of the region of Jepara Regency including Karimunjawa District on the left, and excluding Karimunjawa District on the right. Excluding Karimunjawa District from the area calculation using the shoelace formula and the Karney polygon method, it respectively yields 976.84 km<sup>2</sup> and 977.60 km<sup>2</sup>. Due to the many islands of Karimunjawa District, the area calculation of the land of the region is not straight forward, every island needs to be separately calculated. Using the boundaries of districts and excluding Karimunjawa District from the area calculation of Jepara Regency using the shoelace formula and the Karney polygon method, it respectively yields 977.19 km<sup>2</sup> and 977.96 km<sup>2</sup>.



**Figure 2. Region of Jepara Regency including Karimunjawa District (left), and excluding Karimunjawa District (right).**

The boundaries of the Semarang Regency are not completely outside of the region, as there are boundaries of the city of Salatiga within that region. For this reason, the area is calculated from the area with the outer boundary minus the inner area, which is the area of the city of Salatiga. Applying the shoelace

formula and the Karney polygon method on the outer boundaries of Semarang regency, the calculated area is 1221.97 km<sup>2</sup> and 1222.85 km<sup>2</sup>, respectively. Subtracting the area of the city of Salatiga which is 53.05 km<sup>2</sup> and 53.08 km<sup>2</sup>, respectively from that area, we get 1168.92 km<sup>2</sup> (23.02% greater than the reference area) and 1168.77 km<sup>2</sup> (23.00% greater than the reference area). The difference between the calculated area and the reference area becomes smaller when the boundaries of the district and village are used.

Various methods that have previously been used such as the circle approach method, the rectangular approach method, as well as the spherical quadric approach method [1], [2], and [3] may be applied to the calculation of the region area, but the time needed to complete the data analysis based on the GADM database should also be considered. In this case of the area of Central Java province, the rectangular method and the spherical quadric approach method respectively yield 34667.79 sq.km. (6.51% greater than the reference area) and 34978.49 sq.km. (7.47% greater than the reference area).

**Table 4. Calculation Results of Regency / City Area (km<sup>2</sup>) in Central Java Province based on the Coordinates of District Boundaries (Shoelace Formula I and Karney Polygon Method I), and on the Coordinates of Village Boundaries (Shoelace Formula II and Karney Polygon Method II).**

No.	Regency/City	Shoelace Formula I	Metode Poligon Karney I	Shoelace Formula II	Metode Poligon Karney II
1	Banjarnegara	1148.89 (12.23%)	1149.18 (12.25 %)	1149.89 (12.32 %)	1149.18 (12.25 %)
2	Banyumas	1390.10 (4.10 %)	1389.81 (4.08 %)	1390.10 (4.10 %)	1389.81 (4.08 %)
3	Batang	858.62 (8.87 %)	858.97 (8.92 %)	858.62 (8.87 %)	858.97 (8.92 %)
4	Blora	1947.30 (7.91 %)	1948.76 (7.99 %)	1950.52 (8.09 %)	1951.98 (8.17 %)
5	Boyolali	1083.12 (7.40 %)	1083.94 (7.49 %)	1086.61 (7.75 %)	1087.43 (7.83 %)
6	Brebes	1762.74 (7.34 %)	1761.86 (7.39 %)	1751.38 (7.94 %)	1750.50 (7.98 %)
7	Cilacap	2300.61 (8.29 %)	2299.34 (8.23 %)	2305.58 (8.52 %)	2304.31 (8.47 %)
8	Demak	999.30 (11.02 %)	1000.06 (11.10 %)	998.02 (10.88 %)	998.77 (10.96 %)
9	Grobogan	2028.67 (0.74 %)	2030.27 (0.81 %)	2029.93 (0.80 %)	2031.54 (0.88 %)
10	Jepara	1092.74 (3.16 %)	1093.58 (3.24 %)	1171.75 (10.62 %)	1172.64 (10.70 %)
11	Karanganyar	803.14 (3.57 %)	803.79 (3.66 %)	803.14 (3.57 %)	803.79 (3.66 %)
12	Kebumen	1332.57 (9.97 %)	1332.87 (10.00 %)	1331.25 (9.86 %)	1331.54 (9.89 %)
13	Kendal	990.13 (11.45 %)	990.70 (11.40 %)	1004.33 (10.18 %)	1004.91 (10.13 %)
14	Klaten	700.75 (6.46 %)	701.28 (6.54 %)	701.12 (6.52 %)	701.65 (6.60 %)
15	Kota Magelang	17.86 (11.21 %)	17.87 (11.27 %)	17.86 (11.21 %)	17.87 (11.27 %)
16	Kota Pekalongan	45.79 (1.19 %)	45.80 (1.22 %)	46.27 (2.25 %)	46.28 (2.28 %)
17	Kota Semarang	386.10 (3.30 %)	386.37 (3.37 %)	385.90 (3.24 %)	386.16 (3.31 %)
18	Kota Tegal	39.14 (1.36 %)	39.12 (1.41 %)	39.14 (1.36 %)	39.12 (1.41 %)
19	Kudus	435.18 (2.36 %)	435.52 (2.44 %)	435.25 (2.38 %)	435.60 (2.46 %)
20	Magelang	1130.51 (2.50 %)	1131.29 (2.57 %)	1130.51 (2.50 %)	1131.22 (2.56 %)
21	Pati	1582.24 (6.25 %)	1583.51 (6.34 %)	1580.65 (6.34 %)	1581.91 (6.23 %)
22	Pekalongan	892.64 (6.65 %)	892.84 (6.67 %)	892.82 (6.67 %)	893.02 (6.69 %)
23	Pemalang	1136.77 (1.68 %)	1136.79 (1.68 %)	1136.48 (1.65 %)	1136.50 (1.65 %)
24	Purbalingga	807.97 (19.25 %)	807.99 (19.25 %)	807.97 (19.25 %)	807.99 (19.25 %)
25	Purworejo	1070.53 (1.92 %)	1071.04 (1.87 %)	1089.36 (0.20 %)	1089.88 (0.15 %)
26	Rembang	990.07 11.60 %)	990.79 (11.68 %)	1043.71 (17.65 %)	1044.47 (17.74 %)
27	Salatiga	53.05 (7.51 %)	53.08 (7.51 %)	53.05 (7.51 %)	53.08 (7.46 %)
28	Semarang	1046.82 (10.17 %)	1047.57 (10.25 %)	1023.36 (7.70 %)	1024.09 (7.78 %)
29	Sragen	971.31 (3.16 %)	972.09 (3.24 %)	976.84 (3.75 %)	977.62 (3.83 %)
30	Sukoharjo	493.16 (0.83 %)	493.55 (0.91 %)	493.16 (0.83 %)	493.55 (0.91 %)
31	Surakarta	46.23 (0.48 %)	46.27 (0.57 %)	46.23 (0.48 %)	46.27 (0.57 %)
32	Tegal	994.91 (13.56 %)	994.68 (13.53 %)	993.87 (13.44 %)	993.65 (13.42 %)
33	Temanggung	871.78 (4.07 %)	872.28 (4.13 %)	872.37 (4.14 %)	872.87 (4.20 %)
34	Wonogiri	1921.23 (7.11 %)	1922.76 (7.20 %)	1921.23 (7.11 %)	1922.76 (7.20 %)
35	Wonosobo	993.43 (1.22 %)	993.86 (1.27 %)	992.84 (1.16 %)	993.27 (1.21 %)

The shoelace formula applied to the UTM coordinate system is relatively better than the circular approach method, the rectangular method, the spherical quadratic approach method, or even the Karney polygon method. The UTM coordinates are to be selected, which should be located in a single zone, so that the shoelace formula can be applied. The circular approach method has also been applied to the case of areas that are not within one UTM zone [1]. Using the R program package made by Karney will indeed be more practical and quicker without selecting the coordinates of the boundaries of the area, but Karney polygon



method is not an easy-to-understand method for determining area. The two methods used above can also be compared with other methods proposed in [14], [15], [16], [17], [18], [19], [20], and [21].

#### 4. CONCLUSION

This paper has showed that:

1. The shoelace formula can be used to determine the area of regencies / cities in Central Java based on the boundaries of regency / city, district, and village.
2. The shoelace formula applied on the UTM coordinates of a region boundaries yields smaller difference from the reference area if compared to the Karney polygon method, but can only be used for determining areas that are in one UTM coordinate zone.
3. The Karney polygon method is relatively faster and more practical without the need to change the latitude-longitude coordinate system into a UTM coordinate system.

The research can be expanded to find a way to able to apply the shoelace formula in determining the area that is in different UTM coordinate zones. Also, it may be extended to determine the area of all provinces of Indonesia by using region boundaries of regency / city, district, or village.

#### REFERENCES

- [1] A. Setiawan and E. Sedyono, "The Use of Google Maps and Universal Transverse Mercator (UTM) Coordinate in Land Measurement of Region in Different Zone," *Journal of Theoretical and Applied Information Technology*, vol. 96, no. 23, pp. 8071–8080, 2018.
- [2] A. Setiawan and E. Sedyono, "A New Determination of Regional Area by Utilizing Rectangular Approach Method and Google Maps," in *2017 2nd International Conferences on Information Technology, Information Systems and Electrical Engineering (ICITISEE)*, 2017, pp. 417–420.
- [3] A. Setiawan and E. Sedyono, "Using Google Maps and Spherical Quadrilateral Approach Method for Land Area Measurement," in *2017 International Conference on Computer, Control, Informatics and its Applications: Emerging Trends In Computational Science and Engineering (IC3INA)*, 2017, pp. 85–88.
- [4] C. F. F. Karney, "Algorithms for Geodesics," *Journal of Geodesy*, vol. 87, no. 1, pp. 43–55, 2012.
- [5] C. F. F. Karney, "GeographicLib 1.49," 2017. <https://geographiclib.sourceforge.io/1.49/> (accessed Feb. 22, 2022).
- [6] GADM, "GADM maps and data," 2021. <https://gadm.org/> (accessed Feb. 22, 2022).
- [7] Y. Lee and W. Lim, "Connecting the Area of a Polygon and the Vector Cross Product," *The Mathematics Teacher*, vol. 110, no. 8, pp. 631–636, 2017.
- [8] Y. Lee and W. Lim, "Shoelace Formula: Connecting the Area of a Polygon and the Vector Cross Product," *The Mathematics Teacher*, vol. 110, no. 8, pp. 631–636, 2017.
- [9] K. R. Wijeweera and S. R. Kodituwakku, "A Simple Algorithm for Calculating The Area of an Arbitrary Polygon," *Ruhuna Journal of Science*, vol. 8, pp. 67–75, 2017.
- [10] J. P. Snyder, "Map Projections - A Working Manual," 1987.
- [11] K. KAWASE, "Concise Derivation of Extensive Coordinate Conversion Formulae in the Gauss-Krüger Projection," *Bulletin of the Geospatial Information Authority of Japan*, vol. 60, 2013.
- [12] Bidang Integrasi Pengolahan dan Diseminasi Statistik, *Provinsi Jawa Tengah dalam Angka 2021*. Badan Pusat Statistik Provinsi Jawa Tengah, 2021.
- [13] Tarek M. Awwad, "Relationship of ETM and UTM Projection Scale Factors in Egypt," *International Journal of Civil Engineering (IJCE)*, vol. 5, no. 6, pp. 57–68, 2016.
- [14] P. Pędzich and M. Kuźma, "Application of Methods for Area Calculation of Geodesic Polygons on Polish Administrative Units," *Geodesy and Cartography*, vol. 61, no. 2, pp. 105–115, 2012.
- [15] S. Z. Bolbol, K. M. Zaky, and A. A. Ghonem, "Non Iterative Formulae for Direct Geodetic Problem," *Australian Journal of Basic and Applied Sciences*, vol. 12, no. 9, pp. 131–134, 2018.
- [16] Y. Lumban-Gaol, A. N. Safi'i, P. Hartanto, and T. R. N. Rachma, "Analysis on the Effect of Map Projection System for Area Calculation," *IPTEK Journal of Proceedings Series*, no. 2, pp. 69–72, 2019.
- [17] D. Kin and Y. Karpinskyi, "Ontology of Geodetic, Cartometric and Morphometric Methods in The Geoinformation Environment," 2021.
- [18] F. Yildirim and F. Kadi, "Determining The Area Corrections Affecting The Map Areas in GIS Applications," *Reports on Geodesy and Geoinformatics*, vol. 112, pp. 9–17, 2021.
- [19] S. N. Kundu and B. Pradhan, "Surface Area Processing in GIS," 2004.
- [20] I. A. of O. & G. P. (OGP), "OGP Surveying and Positioning Guidance Note number," 7, 2009.
- [21] J. Dozier, *Improved Algorithm for Calculation of UTM and Geodetic Coordinates*. National Oceanic and Atmospheric Administration, 1980.

