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Area calculation based on GADM geographic information system database

Adi Setiawan[1], Eko Sediyono[2]
[1]Department of Mathematics, Faculty of Science and Mathematics, Universitas Kristen Satya Wacana, Indonesia
[2]Faculty of Information Technology, Universitas Kristen Satya Wacana, Indonesia

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ABSTRACT

This paper aims to provide an overview of the calculation of the area of Indonesia based on the boundaries of sub-district/village, district, regency/city. The circle approach method is proposed as a fast method for determining the land area of Indonesia. The total area of Indonesia can be obtained by adding up to 33 provinces or 502 regencies/cities or 6696 districts or 77474 sub-districts. Calculation of the area of the area using district boundaries is better used in the calculation of the area of Indonesia which is obtained 1,965,443.51 km^2. The results obtained are 2.53% bigger than the reference area.

Corresponding Author:

Adi Setiawan,
Department of Mathematics,
Faculty of Science and Mathematics,
Universitas Kristen Satya Wacana,
52-60 P. Diponegoro St., Salatiga 50711, Indonesia.
Email: adi.setiawan@uksw.edu

1. INTRODUCTION

The land area of Indonesia according to the Central Bureau of Statistics is 1,916,862.20 km^2 [1]. The area can be obtained by adding up the total land area of all provinces in Indonesia. GADM is a data base that contains administrative boundaries of both state administrative boundaries and smaller sub-divisions such as provinces, regencies/cities, districts and evenly sub-districts/villages. The latest version available is version 3.6 which is released May 8, 2018 (for more information about GADM, see [2-4]. Various methods can be used to calculate the area if the geographical coordinates of the area boundaries are known. One method that is widely used is the polygon method specifically proposed by Karney. More information about the Karney polygon method can be seen in the paper [5]. However, the Karney polygon method is not an easy method to understand. In this paper, a practical and easy-to-understand method is proposed to calculate the area.

2. THE PROPOSED METHOD

In Vincenty distance between two points on the surface of the earth can be referenced in Vincenty's paper [6]. Suppose we have the coordinates of point *A* (-1.293805, 111.367690) and point *P* (-1.764110, 111.425670) (in degree). Using the method proposed by Vincenty and the R program package i.e. *geosphere* and by utilizing

the command *distVincentyEllipsoid*, it can be found the distance between A and P is equal to s = 48564.436 meter or 48.564436 km. Further information about the geosphere package can be seen in the paper [7-9].

To give an illustration of how the circle approach method can be used, it is explained below. Table 1 presents the coordinates of the boundaries of the Lamandau Regency. The mass center of the Lamandau Regency area can be determined as the average of latitude coordinates and the average of longitude coordinates i.e. P (-1.764110, 111.425670). Table 2 presents the Vincenty distance for each point on the regency boundary with a mass center P. Furthermore, the circle radius is the average of the distance between mass center and the boundaries of Lamandau regency i.e. r = 48.564436 km. Thus, the area of Lamandau Regency can be approached by

$$L = \pi r^2 = 3.141593\ (48.564436)^2 = 7409.46$$

in km^2. The result is 15.53% more than the reference area.

Table 1. Latitude and longitude coordinate tables of the regional boundaries of Lamandau Regency, Central Kalimantan (in degree)

No.	Latitude	Longitude	No.	Latitude	Longitude
1	-1.293805	111.367690	20	-2.304035	111.480299
2	-1.336365	111.404768	21	-2.184651	111.388289
3	-1.389909	111.450087	22	-2.142109	111.364943
4	-1.409129	111.602522	23	-2.022712	111.299025
5	-1.451688	111.669814	24	-1.970558	111.971059
6	-1.491500	111.727492	25	-1.938991	111.079299
7	-1.543667	111.778304	26	-1.970558	111.036726
8	-1.583477	111.811263	27	-1.938991	110.976302
9	-1.615051	111.801649	28	-1.845658	110.974928
10	-1.672705	111.809889	29	-1.790754	111.005141
11	-1.749575	111.823622	30	-1.750948	111.009261
12	-1.807226	111.818129	31	-1.709768	111.002394
13	-1.903306	111.804396	32	-1.680941	110.880171
14	-1.960951	111.785170	33	-1.628778	110.844466
15	-2.007615	111.765944	34	-1.550531	110.965315
16	-2.122896	111.705519	35	-1.512092	111.113631
17	-2.154460	111.690413	36	-1.440705	111.136977
18	-2.187395	111.621748	37	-1.388536	111.279799
19	-2.245030	111.602522	38	-1.339111	111.326491

Table 2. Distance between mass center and the boundaries of Lamandau Regency (in km)

No.	Distance to the mass center	No.	Distance to the mass center
1	52.402713	20	60.011116
2	47.355091	21	46.687176
3	41.466425	22	42.339980
4	43.909102	23	31.878144
5	43.948800	24	64.832321
6	45.128909	25	43.117336
7	46.193590	26	48.926231
8	47.327061	27	53.606767
9	44.965439	28	50.955824
10	43.930447	29	46.883353
11	44.308297	30	46.355620
12	43.926760	31	47.479124
13	44.861186	32	61.390135
14	45.536987	33	66.379881
15	46.457252	34	56.407064
16	50.431346	35	44.521624
17	52.255071	36	48.070865
18	51.638891	37	44.588690
19	56.701080	38	48.272852

Figure 1 shows that the area of Lamandau Regency, the mass center P and the area the circle that is the approximation of area the Lamandau Regency based on the data in Table 1. The points on the circle are obtained from the center of the circle i.e. P(-1.764110, 111.425670) with the distance as far as r = 48.564436 km with the azimuth angle α_1 with the following steps. By using the *geosphere* program package and with the geodesic command, if given the coordinates of the center point mass P (-1.764110, 111.425670),

azimuth 0 degree and distance r will obtain the desired coordinates of the point on the circle. Furthermore, if the azimuth angle starts from 5, 10 to 360 degrees so that the points with geographic coordinates are obtained respectively (-1.3326582, 111.463702), (-1.331582, 111.501446) up to (-1.324911, 111.425670). The points are connected to form a circle. The area of this circle can be considered as an approximation of the concern area. This approach is done so that the calculation is done quickly if it is compared to other methods.

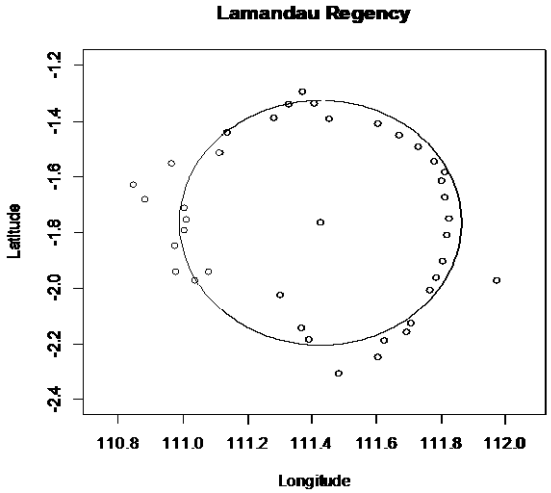

Figure 1. The area of Lamandau Regency and the circle with the center *P* and the radius which is an approximate of the area of Lamandau Regency, based on Table 1

Latitude and longitude coordinate data from regency/city boundaries in Central Kalimantan province obtained from GADM are used to calculate the area of Central Kalimantan province by using the circle approach method. Furthermore, based on latitude and longitude coordinate data from regency/city boundaries or district or sub-district/village boundaries, the area of each region can be determined. The total area of the provinces in Indonesia which is the sum of the area of the village/sub-districts, district area or regency/city area. Finally, the land area of Indonesia is the sum of the land area of each province in Indonesia. The results obtained are compared to the reference land area obtained from Central Bureau of Statistics.

3. RESULTS AND DISCUSSION

In this section, it is explained about the results obtained if the circle approach method is used in calculating the area of a regency/city in Kalimantan Tengah province. Furthermore, the method was also used in calculating the territory of the Indonesian provinces. Considering that GADM data still does not separate the provinces of Kalimantan Timur and Kalimantan Utara, this discussion is still united with the name of the province of Kalimantan Timur so that there are only 33 provinces in Indonesia.

If the polygon method and the circle method are used in determining the area of the regency/city in Kalimantan Tengah based on the GADM database of regency/city boundaries, the results are presented in Table 3. The percentage states the absolute difference with relative reference area. Using the circle approach method, Barito Selatan district results close to the reference area, which is only 0.81% with reference area. Figure 2 presents that the Lamandau Regency with geographic coordinates of the boundaries of the region was obtained from the GADM database, the mass center of the territory and the circle used as an aproximation of the Lamandau Regency area. With the circle method obtained the area of Lamandau Regency is 4347 km^2 i.e. 32.23% less than the reference area.

Table 4 presents the provinces in Indonesia and their reference area obtained from BPS. Furthermore, Table 4 also presents the number of regencies/cities, the number of districts and the number of sub-districts/villages for each province in Indonesia. Based on the GADM database, there are a total of 502 districts/cities throughout Indonesia and the total number of coordinate points to limit the districts or cities is 2,571,767 points. The provinces with the least number of regencies/cities are Sulawesi Barat and Daerah Istimewa Yogyakarta provinces each with 5 regencies/cities. The provinces with the most districts are

the provinces of East Java, which are 38 regencies/cities. The coordinate of the smallest latitude point is -11.007615° S (most South), while the coordinates of the largest latitude point are 6.076941° N. The coordinate of the smallest longitude is 95.009705° E (most West) while the coordinates of the largest longitude point are 141.019394° E (most East).

Table 3. Results of calculation of regency/city area (in km^2) in Kalimantan Tengah based on district boundary data

No.	Regency/City	Circle Method	%
1	Barito Selatan	8901.65	0.81
2	Barito Timur	1699.31	55.68
3	Barito Utara	9324.47	12.34
4	Gunung Mas	9519.58	11.90
5	Kapuas	29839.86	98.95
6	Katingan	43801.91	150.30
7	Kotawaringin Barat	9445.37	12.21
8	Kotawaringin Timur	17225.65	2.56
9	Lamandau	4347.21	32.22
10	Murung Raya	19715.34	16.81
11	Palangkaraya	3051.21	27.16
12	Pulang Pisau	16036.69	78.24
13	Seruyan	36125.05	120.22
14	Sukamara	3104.00	18.89

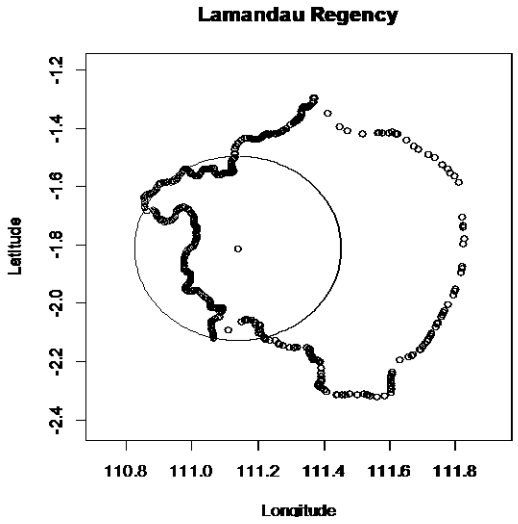

Figure 2. The Lamandau Regency area, the center of the circle *P*, which is an approximation of area of the Lamandau Regency based on geographic coordinates of the boundary region obtained from the GADM data base

If the circle method described above is used in determining the area of each province in Indonesia based on district boundary data, the results obtained as in Table 4. The area of Indonesia obtained by the circle method is 2,121,745.74 km^2 (10.88% more than the reference area). If the circle method described above is used in determining the area of each province in Indonesia based on subdistrict boundary data, the result is 1,965,443.51 km^2, which is 2.53% greater than the reference area. In the same way the results of the determination of the area of Indonesia can also be obtained based on village/kelurahan boundaries. The total area of Indonesia obtained by the circle method is 2,463,650.47 km^2 which is 28.75% more than the reference area.

The circle method gives relatively poor results compared to the polygon method proposed by Karney. However, in the polygon method, the theory used to understand the method is not easy compared to the circle method as shown paper [5]. Likewise, the circle method does not always yield good results, which is close to the reference area if the area determined is island territory, while the data used are not separated from one island region to another island area. That also applies to the calculation of the area if using the Karney polygon method. For this reason it is also necessary to compare the results obtained using other methods as proposed by the paper [10-27].

Table 4. Reference provincial area data and the number of regency/city, districts, sub-districts/villages based on the GADM database

No.	Province	Reference Area (in km^2)	Number of Regencies/Cities	Number of Districts	Number of Sub-districts/villages
1	Aceh	57956	23	277	6516
2	Bali	5780.06	9	59	712
3	Bangka Belitung	16424.06	7	43	362
4	Banten	9662.92	8	154	1535
5	Bengkulu	19919.33	10	124	1481
6	Gorontalo	11257.07	7	67	619
7	Jakarta Raya	664.01	6	47	268
8	Jambi	50058.16	11	131	1374
9	Jawa Barat	35377.76	27	628	5888
10	Jawa Tengah	32800.69	36	578	8580
11	Jawa Timur	47799.75	38	663	8580
12	Kalimantan Barat	147307	14	175	1894
13	Kalimantan Selatan	38744.23	13	151	1981
14	Kalimantan Tengah	153564.5	14	125	1511
15	Kalimantan Timur	204534.34	14	136	1435
16	Kepulauan Riau	8201.72	7	59	355
17	Lampung	34623.8	14	214	2430
18	Maluku	46914.03	11	73	906
19	Maluku Utara	31982.5	9	114	1097
20	Nusa Tenggara Barat	18572.32	10	116	969
21	Nusa Tenggara Timur	48718.1	21	287	2836
22	Papua	319036.05	29	385	3557
23	Papua Barat	99671.63	11	156	1372
24	Riau	87023.66	12	151	1644
25	Sulawesi Barat	16787.18	5	69	603
26	Sulawesi Selatan	46717.48	24	307	2970
27	Sulawesi Tengah	61841.29	11	155	1783
28	Sulawesi Tenggara	38067.7	12	201	2091
29	Sulawesi Utara	13851.64	15	159	1660
30	Sumatera Barat	42012.89	20	178	1018
31	Sumatera Selatan	91592.43	15	217	3157
32	Sumatera Utara	72981.23	34	419	5852
33	Yogyakarta	3133.15	5	78	438

Table 5. Results of calculation of province area (in km^2) in Indonesia based on regency/city boundaries

No.	Province	Circle Method	%
1	Aceh	59625.95	2.88
2	Bali	8927.52	54.45
3	Bangka Belitung	21183.57	28.98
4	Banten	11191.1	15.81
5	Bengkulu	22232.91	11.61
6	Gorontalo	10360.47	7.96
7	Jakarta Raya	1676.9	152.54
8	Jambi	44756.74	10.59
9	Jawa Barat	33681.19	4.80
10	Jawa Tengah	42223.17	28.73
11	Jawa Timur	72501.69	51.68
12	Kalimantan Barat	154994.93	5.22
13	Kalimantan Selatan	36534.84	5.70
14	Kalimantan Tengah	205418.47	33.77
15	Kalimantan Timur	147630.58	27.82
16	Kepulauan Riau	76579.12	833.70
17	Lampung	38964.85	12.54
18	Maluku	109441.51	133.28
19	Maluku Utara	58517.63	82.97
20	Nusa Tenggara Barat	22174.2	19.39
21	Nusa Tenggara Timur	49525.27	1.66
22	Papua	217803.56	31.73
23	Papua Barat	79962.94	19.77
24	Riau	78260.84	10.07
25	Sulawesi Barat	21060.29	25.45
26	Sulawesi Selatan	125065.49	167.71
27	Sulawesi Tengah	90633.99	46.56
28	Sulawesi Tenggara	39271.15	3.16
29	Sulawesi Utara	21583.3	55.82
30	Sumatera Barat	62598.58	49.00
31	Sumatera Selatan	77059.38	15.87
32	Sumatera Utara	77213.57	5.80
33	Yogyakarta	3090.04	1.38

4. CONCLUSION

In this paper, we have presented how to use the circle approach method to determine the land area of Indonesia based on the boundaries of regency/city or district or village/ sub-district from the GADM database. The best results obtained are when used the boundaries of the district is 1,965,443.51 km^2 which is 2.53% bigger than the reference area. The circle approach method can also be tested for other GADM databases, namely data on regional boundaries in other countries.

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REFERENCES

[1] BPS, "Statistik Indonesia 2018," Badan Pusat Statistik Indonesia, Jakarta, 2018.
[2] C. T. Lloyd, et al., "High resolution global gridded data for use in population Studies," *Scientific Data,* vol. 4, Jan. 2017.
[3] A. Sorichetta, et al., "Mapping internal connectivity through human migration in malaria endemic countries," *Scientific Data,* vol. 3, Aug 2016.
[4] K. Waha, et al., "An agricultural survey for more than 9,500 African households," *Scientific Data,* vol. 3, May 2016.
[5] C. F. F. Karney, "Algorithms for Geodesics," *Journal of Geodesy,* vol. 87, pp. 43-55, 2013.
[6] T. Vincenty, "Direct And Inverse Solutions of Geodesics on The Ellipsoid with Application of Nested Equations," *Survey Review,* vol. 23, no. 176, pp. 88-93, 1975.
[7] R. J. Hijmans, "Spherical data analysis with R," 2019. [Online]. Available: https://rspatial.org/sphere/sphere.pdf.
[8] G. Panou, et al., "Solving the geodesics on the ellipsoid as a boundary value problem," *Journal of Geodetic Science,* vol. 3, no. 1, pp. 40-47, March 2013.
[9] L. E. Sjöberg and M. Shirazian, "Solving the Direct and Inverse Geodetic Problems on the Ellipsoid by Numerical Integration," *Journal of Surveying Engineering,* vol. 138, no. 1, pp. 9-16, February 2012.
[10] 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.
[11] L. E. Sjoberg, "Determination of Area on The Plane Sphere and Ellipsoid," *Survey Review,* vol. 38, no. 301, pp. 583-593, 2006.
[12] A. Setiawan and E. Sediyono, "Using Google Maps and Spherical Quadrilateral Approach Method for Land Area Measurement," *Proceedings-2017 International Converence on Computer, Control, Informatics and its Applications: Emerging Trends In Computational Science and Engineering (IC3INA)*, pp. 85-88, 2017.
[13] K. A. Ahmed, et al., "Observing the rising and falling of water level in Mosul Dam Lake using remote sensing data and Geographical Information System," *Al-Rafidain Engineering,* vol. 20, no. 4, pp. 128-136, August 2012.
[14] M. M. Abu-Faraj and N. A. Ghatasheh, "Using Image Processing Functions to Determine the Edges of the Dead Sea and Calculate the Declining Rate," *IJCSI Intertional Journal of Computer Science Issues*, vol. 10, no. 6, pp. 97-101, November 2013.
[15] T. Kilic, et al., "Missing (ness) in Action: Selectivity Bias in GPS-Based Land Area Measurements," *Policy Research Working Paper No. 6490*, Jun 2013. Available: https://ssrn.com/abstract=2281015.
[16] H. DeGroote and O. Traore, "The Cost of Accuracy in Crop Area Estimation," *Agricultural Systems*, vol. 84, no. 1, pp. 21-38, April 2005.
[17] G. Carletto, et al., "Land Area Measurement in Household Surveys: A Guidebook," Washington DC: World Bank, 2016.
[18] I. Gillissen, "Area Computation of a Polygon on an Ellipsoid," *Survey Review*, vol. 32, no. 248, pp. 92-98, 1993.
[19] T. J. Lark, et al., "Measuring land-use and land-cover change using the U.S. department of agriculture's cropland data layer: cautions and recommendations," *International Journal of Applied Earth Observation and Geoinformation,* vol. 62, pp. 224-235, October 2017.
[20] W. Tong, et al., "Design of Digital Area Mapping Instrument Based on GPS," *AASRI Procedia,* vol. 1, pp. 261-266, 2012.
[21] Y. Nishiyama, "Measuring Areas: From Polygons to Land Maps," *International Journal of Pure and Applied Mathematics,* vol. 81, no. 1, pp. 91-99, 2012.
[22] D. Kaimaris and P. Patlas, "Identification and Area measurement of the Built-up Area with the Built-p Index (BUI)," *International Journal of Advanced Remote Sensing and GIS*, vol. 5, no. 6, pp. 1844-1858, 2016.
[23] R. Gaudensius, "Real estate cadastral data collection problems, imaging and works intensity in Lithuania," *Geodesy and Cartography,* vol. 40, no. 1, pp. 14-16, 2014.
[24] Y. Xiong, et al., "Digital Image Analysis of Old World Bluestem Cover to estimate Canopy Development," *Agronomy Journal-Crop Ecology and Physiology*, vol. 111, no. 3, pp. 1247-1253, 2019.
[25] C. Carletto, et al., "From Guestimates to GPStimates: Land Area Measurement and Implications for Agricultural Analysis," *Journal of African Economies*, vol. 24, no. 5, pp. 593-628, November 2015.
[26] T. Q. Hien, et al, "Techniques of Surveying and Cadastral Mapping in Vietnam," *International Journal of Scientific and Research Publications*, vol. 5, no. 2, pp. 1-7, February 2015.
[27] K. Zacharos, "Prevailing Educational Practices for Area Measurement and Students Failure in Measuring Areas," *The Journal of Mathematical Behavior*, vol. 25, no. 3, pp. 224-239, 2006.