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Analysis on the Effect of Map Projection System for Area Calculation

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Abstract*—Map projection is required for modeling the earth from sphere into flat form. Out of so many types of projection systems, Universal Transverse Mercator (UTM) is the most common map projection system used in Indonesia. The concept of Mercator projection system is to maintain the angle but cause distortion on the area and distance. This will become problem if it is used for calculating an area that require minimum distortion, especially on a large scale. This study aims to find out the effect of the projection system for any scale to the area, and find out the best projections system in Indonesia. In this paper, the area was calculated using 72 projection systems with various scale using MATLAB software. The reference area that considered true was the polygon area of an ellipsoid so the difference between area of ellipsoid and projection can be known. The projection systems that give minimum distortion are the most optimum result. Based on the study, the most suitable projection system for calculating the area with minimal distortion is Collignon for 1: 250,000 scale and 1: 50,000, Eckert II projection system for 1: 25,000 scale and Equal-area Conic Albers Standard projection system for scale 1: 5,000.

Keywords*—Projection System, Polygon Area Of Ellipsoid, Distortion, Scale.

I. Introduction

The map is a model of the earth's surface in a flat form which produced through a particular projection process. Map projection is a systematic transformation of the latitude and longitude position of a point on the earth's surface into a flat form [1]. These transformation process from three into two dimensions cause distortion on the angle (conform), distant, and area. The projection system is distinguished by projection form as well as undistorted or defended elements. It can be a plane, cylinder, or cone.

There are now many known types of projection systems (Table 1). The projection of the map is designed for a specific purpose, for example a projection system is used for large-scale small areas while other projection systems are used for small-scale worldwide scopes [2]. The selection of the projection system needs to be adjusted to its needs and objectives whether to maintain shape, distance between points, or area. For example, maps created for navigation purposes generally use conformed projections to maintain angles. However, conformed projections provide great distortion in the extent of areas close to the poles. Greendland's area is one-eighth of South America's width, but on Mercator's projection map, Greenland actually looks bigger [3].

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So far, the map projection system commonly used in Indonesia is Universal Transverse Mercator (UTM). The UTM divides the earth's surface into several zones, with a zone width of six degrees, each mapped using the Transverse Mercator (TM) projection with the central meridian in the center of the zone. Minimal distortion in each zone is located in the central meridian. The further away from the central meridian, the greater the distortion. Mercator projection system is used to maintain the angle so that there will be distortion on the area and distance. This becomes a problem if these projections are used for calculation purposes that require minimum distortion, especially on large areas consisting of several zones on the map on a large scale. In relation to the UTM map projection system, Indonesia is divided into nine zones ranging from 46 to 54, both North and South. Snyder [4] recommends a cylindrical equal-area, equatorial lambert, and azimuthal equal-area projection system for the minimum distortion in Asia and Australia with an earth record assumed to be ellipsoid-shaped primarily for smaller areas or larger scales.

Based on these problems, this study is conducted to determine the effect of map projection system on the area of a region based on the map scale and what is the comparison of UTM projection result with other system. It is also to find out which projection system is suitable for Indonesia to produce minimum distortion.

II. Method

This study used samples in geodetic coordinates on the ellipsoid adjusted for its scale. The map scale used is 1: 250,000, 1: 50,000, 1: 25,000, and 1: 5,000 with dimensions as in Table 2. The sample location used was the west longitude position taken at longitude 102 o East and the latitude position is divided starting from the latitude 0o to 10o. This was done due to study the effect of distortion trough the location when it goes away from the equator. The flow of this research can be seen in Figure 1. The software used is Matlab R2014b. There are 72 projection systems used in this research (Table 3) with different forms and elements. It was used in this study by defining the earth on the ellipsoid shape. The reference ellipsoid used was WGS84 with the parameter of semi-major axis = 6378137 m, semi-minor axis = 6356752.3 m, and flattening = 1 / 298.257223560 [5].

The area calculations based on the projection system were then validated using the area of polygon of ellipsoid. Validation is conducted by calculating the residuals between the counting area and the polygon area in each area and scale specified. The optimum result was the minimum value of the sum of squares of the residue.

TABLE 1.
TYPE OF PROJECTION SYSTEMS

Projection System	Projection Field	Equal-Area	Conform	Equidistant
Balthasart	Cylindrical	•		
Behrmann	Cylindrical	•		
Bolshoi Sovietskii Atlas Mira	Cylindrical			
Braun Perspective	Cylindrical			
Cassini	Cylindrical			•
Central	Cylindrical			
Equal-Area Cylindrical	Cylindrical	•		
Equidistant Cylindrical	Cylindrical			•
Gall Isographic	Cylindrical			•
Gall Orthographic	Cylindrical	•		
Gall Stereographic	Cylindrical			
Lambert Equal-Area Cylindrical	Cylindrical	•		
Mercator	Cylindrical		•	
Miller	Cylindrical			
Plate Carrée	Cylindrical			•
Trystan Edwards	Cylindrical	•		
Universal Transverse Mercator (UTM)	Cylindrical		•	
Wetch	Cylindrical			
Apianus II	Pseudocylindrical			
Collignon	Pseudocylindrical	•		
Craster Parabolic	Pseudocylindrical	•		
Eckert I	Pseudocylindrical			
Eckert II	Pseudocylindrical	•		
Eckert III	Pseudocylindrical			
Eckert IV	Pseudocylindrical	•		
Eckert V	Pseudocylindrical			
Eckert VI	Pseudocylindrical	•		
Fournier	Pseudocylindrical	•		
Goode Homolosine	Pseudocylindrical	•		
Hatano Asymmetrical Equal-Area	Pseudocylindrical	•		
Kavraisky V	Pseudocylindrical	•		
Kavraisky VI	Pseudocylindrical	•		
Loximuthal	Pseudocylindrical			
McBryde-Thomas Flat-Polar Parabolic	Pseudocylindrical	•		
McBryde-Thomas Flat-Polar Quartic	Pseudocylindrical	•		
McBryde-Thomas Flat-Polar Sinusoidal	Pseudocylindrical	•		
Mollweide	Pseudocylindrical	•		
Putnins P5	Pseudocylindrical			
Quartic Authalic	Pseudocylindrical	•		
Robinson	Pseudocylindrical			
Sinusoidal	Pseudocylindrical	•		
Tissot Modified Sinusoidal	Pseudocylindrical	•		
Wagner IV	Pseudocylindrical	•		
Winkel I	Pseudocylindrical			
Albers Equal-Area Conic	Conic	•		
Equidistant Conic	Conic			•
Lambert Conformal Conic	Conic		•	
Murdoch I Conic	Conic			•
Murdoch III Minimum Error Conic	Conic			•
Bonne	Pseudoconic	•		
Werner	Pseudoconic	•		
Polyconic	Polyconic			
Van Der Grinten I	Polyconic			
Breusing Harmonic Mean	Azimuthal			
Equidistant Azimuthal	Azimuthal			•
Gnomonic	Azimuthal			
Lambert Azimuthal Equal-Area	Azimuthal	•		
Orthographic	Azimuthal			
Stereographic	Azimuthal		•	
Universal Polar Stereographic (UPS)	Azimuthal		•	
Vertical Perspective Azimuthal	Azimuthal			
Wiechel	Pseudoazimuthal	•		
Aitoff	Modified Azimuthal			
Briesemeister	Modified Azimuthal	•		
Hammer	Modified Azimuthal	•		
Globe	Spherical	•	•	•

Source : www.mathworks.com [6]

TABLE 2.
THE DIMENSIONS OF SPHERE FORM ON EACH SCALE

Scale	Dimensions of sphere form
1:250,000	1^{o} x $1,5^{o}$
1:50,000	15’ x 15’
1:25,000	7,5’ x 7,5’
1:5,000	1’ x 1’

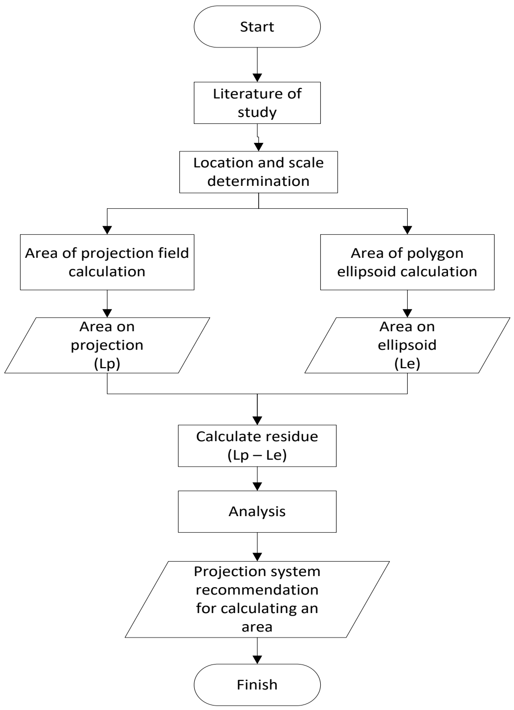

Figure 1. Research flow chart.

III. RESULT AND DISCUSSION

The result of the residual calculation of each projection system at each scale is presented in Table 3.

Based on these results (Table 3), there were eight projection systems with minimum residual values, i.e. rows with a darker color. It was found that there was no single projection system that was suitable for all locations. Each map scale had its own projection system that would provide the area minimum distortion. On a scale of 1: 250,000 and 1: 50,000, the best projection system was Collignon. The Eckert II projection system provides optimum results for wide calculations on a 1: 25,000 while Equal-area Conic (Albers) - Standard for a scale of 1: 5,000. These three projection systems used an equal-area type in which the system is designed to maintain a large area due to minimize the distortion. Collignon projection systems [7] and Eckert II [8] use pseudocylindrical projection fields while Equal-area Conic Albers Standard uses conical projection fields [4].

Comprehensively, UTM projection system has not been optimally used for area calculations because of considerable distortion compared to other projection systems. On a large scale (1: 5,000), the area of ellipsoid is about 3.401 km2. The distortion for one sheet map width with UTM projections reaches 6,525.401 m2. While for the same scale, the distortion in the Equal-area Conic (Albers) projection system - Standard is only 0.018 m2 or Collignon and Eckert II of 0.059 m2. On a small scale (1: 250,000), UTM provides a distortion of 15,074 km2 compared to the ellipsoid area of 18,353,375 km2. While projected Collignon, Trystan Edwards Cylindrical, Eckert II, Gall Orthographic [9], Balthasart Cylindrical, Cylindrical Equal Area, Lambert Cylindrical, and Behrmann Cylindrical [10] only distorted 320,327 m2. More about the distortion of projection systems on each scale can be seen in Table 4, with the area in the ellipsoid area shown in Table 5. Dark colors indicate distortion in the optimum projection systems at each scale.

For the UTM projection, the longitude position taken as the sample in this study was not in the central meridian but the furthest from the central meridian so the distortion is the maximum distortion that can be produced. After tested using the centroid meridian, which is in the longitude position 105^{o}, the distortion was still much larger than the other eight projections. However, from the percentage scale view (Table 5), the distortion in the UTM projection becomes less significant as the range was only range from 0.082% to 0.192% (larger scale, greater distortion) compared to the ellipsoid. For the other eight projections, the percentage is almost negligible.

The use of UTM as a projection system on a map divided into several map sheets numbers can be tolerated. However, if it is used to calculate the entire area of Indonesia, the UTM projection system needs to be reconsidered. As a rough idea, on a scale of 1: 250,000 Indonesia has 309 pieces of NLP. If it calculated roughly, then the distortion can reach to 25% of the total area of Indonesia on ellipsoid. Nevertheless, a scale of 1: 50,000, the total map sheet is 3,901 pieces so the distortion can be very large if the area is calculated using UTM projections. Instead, the other eight projections for the scale of 1: 250,000 produce a distortion of 5.393E-04% and for 1: 50,000 just reach 6.809E-03%.

The division of an area from latitude 0 to 10 degrees gives the information that as the greater distance from equator gives the smaller distortion projection for the Collignon, Eckert II, UTM, and Equal-area Conic (Albers) - Standard systems on each scale.

IV. CONCLUSIONS

Based on this study, for the calculation of Indonesia territory area, the minimum distortion on the 1: 5.000 scale map is the Equal-area Conic Albers Standard projection system. The effect of Equal-area Conic Albers Standard projection system of area distortion is 0,018 m^2 on ellipsoid area of 3,401 km^2. 1: 25,000 (medium scale) should use Eckert II projection system. The area distortion is 3,339 m^2 on ellipsoid area of 191,315 km2. While the optimum projection system for the scale of 1: 50,000 and 1: 250,000 are Collignon. Collignon's projection system has an area distortion of 13,355 m^2 on ellipsoid area of 765,186 km^2 for 1: 50,000 (medium scale). For 1: 250,000 (small scale), the area distortion is 320,327 m^2 on ellipsoid area of 18,353,375 km^2. UTM projections are still optimally used for each map sheet but not to calculate the area throughout Indonesia.

TABLE 3.
RESIDUAL CALCULATION OF PROJECTION AREA WITH THE AREA IN ELLIPSOID FIELD

Projection System	Residue (km^2)			
	250k	50k	25k	5k
Balthasart Cylindrical	0.000320327	1.33551E-05	3.3391E-06	5.93703E-08
Behrmann Cylindrical	0.000320327	1.33551E-05	3.33911E-06	5.93705E-08
Bolshoi Sovietskii Atlas Mira*	3287.696591	137.6443557	34.43698955	0.612606152
Braun Perspective Cylindrical*	291.9735329	11.46228416	2.837846439	0.050029925
Cassini Cylindrical-Standard	70197.53543	2869.091028	715.9043504	12.70615668
Cassini Cylindrical	649804.2768	103277.0221	51171.96804	6767.857709
Central Cylindrical*	466.4631851	17.99166443	4.441026255	0.07808854
Equal Area Cylindrical	0.000320327	1.33551E-05	3.3391E-06	5.937E-08
Equidistant Cylindrical	2348.064103	98.30640532	24.59514844	0.437528519
Gall Isographic	5274.125781	220.2241448	55.07452427	0.979383193
Gall Orthographic	0.000320327	1.33551E-05	3.3391E-06	5.93689E-08
Gall Stereographic*	7099.911749	296.4373655	74.13329952	1.318288857
Lambert Cylindrical	0.000320327	1.33551E-05	3.3391E-06	5.937E-08
Mercator Cylindrical	226.2377231	8.474633306	2.081143531	0.036428924
Miller Cylindrical*	308.1826596	12.06903552	2.986832023	0.052637567
Plate Carree	112.4945229	4.215611842	1.035306183	0.018123254
Transverse Mercator	640429.5115	25737.3986	6412.450662	113.6614628
Trystan Edwards Cylindrical	0.000320327	1.33551E-05	3.3391E-06	5.93712E-08
Universal Transverse Mercator (UTM)	15.07427536	1.309115319	0.348319649	0.006525401
Wetch Cylindrical*	13460929.38	2345428.932	1172917.526	156372.3377
Apianus II*	188.0922242	7.577432198	1.883911641	0.033332359
Collignon	0.000320327	1.33551E-05	3.33909E-06	5.9369E-08
Craster Parabolic	0.412519253	0.001086974	7.04421E-05	8.05779E-08
Eckert I*	3057.460265	126.4867699	31.58284906	0.560870143
Eckert II	0.000320327	1.33551E-05	3.33908E-06	5.93695E-08
Eckert III*	5114.098319	213.4774479	53.38481277	0.949298106
Eckert IV	0.186135247	0.000497376	3.36411E-05	7.22371E-08
Eckert V*	3936.970899	164.3096914	41.08822986	0.730622238
Eckert VI	0.379133201	0.001001403	6.51501E-05	8.22899E-08
Flat-Polar Parabolic	0.373783698	0.000986233	6.41471E-05	7.8588E-08
Flat-Polar Quartic	12.40080703	0.454243941	0.111415668	0.001949529
Flat-Polar Sinusoidal	0.434973774	0.00114668	7.42463E-05	8.35095E-08
Fournier	9232.428399	384.6754544	96.16874166	1.709665695
Goode Homolosine	0.462163516	0.001216767	7.85592E-05	8.31441E-08
Hatano Assymmetrical Equal Area	0.1432932	0.002138351	0.000636011	1.18978E-05
Kavraisky V	0.214614577	0.000570629	3.81609E-05	7.03727E-08
Kavraisky VI	7.988179363	0.319550543	0.079726539	0.001416494
Loximuthal*	196.3746985	7.886266139	1.959664922	0.034641959
Modified Sinusoidal (Tissot)*	1720.123433	71.73487338	17.93567364	0.318883782
Mollweide	0.2881839	0.000762841	5.02095E-05	7.64733E-08
Putnins P5*	596.1936069	24.99371382	6.253838701	0.111258852
Quartic Authalic	0.3498827	0.000923369	6.02119E-05	7.73424E-08
Robinson*	3227.171668	134.8055785	33.71464701	0.599598676
Sinusoidal	0.463139296	0.001219379	7.87334E-05	8.34503E-08
Wagner IV	0.169539038	0.002847551	0.000847957	1.58705E-05
Winkel I*	3200.681271	133.5758822	33.40266075	0.593958015
Equal Area Conic (Albers)-Standard	0.787951618	0.000912544	5.70394E-05	1.80284E-08
Equal Area Conic (Albers)	0.788271904	0.000925899	6.03786E-05	7.74002E-08
Equidistant Conic-Standard	1542.132944	67.20620138	16.92402232	0.302760647
Equidistant Conic	1542.132596	67.20618685	16.92401868	0.302760583
Lambert Conformal Conic-Standard	3987.839936	174.3117933	43.92025477	0.786095262
Lambert Conformal Conic	3987.839546	174.3117769	43.92025066	0.786095189
Murdoch I Conic*	3258.084224	138.9256931	34.86281794	0.621809558
Murdoch III Minimum Error Conic*	689.2170743	27.14397459	6.7198727	0.118442068
Polyconic-Standard	29247.42714	1206.763164	301.4288482	5.354640696
Polyconic	29247.42529	1206.763088	301.4288291	5.354640357
Van Der Grinten I*	665.8713145	25.79558304	6.372879113	0.112132486
Bonne	0.484771179	0.001392875	8.9566E-05	8.68715E-08
Werner	0.784688084	0.002443697	0.000155257	1.07636E-07
Breusing Harmonic Mean*	26453.09325	1080.984422	269.7367928	4.787466803
Equal Area Azimuthal (Lambert)	0.835580389	0.004129918	0.000259844	1.40226E-07
Equidistant Azimuthal*	15577.38261	637.7237891	159.1591333	2.825298395
Globe	16602.4384	697.1399225	174.5084486	3.105813138
Gnomonic*	1744427.008	83765.36694	21258.95116	382.9580603
Orthographic*	14301.29413	604.2913646	151.287445	2.692861141
Stereographic	102153.4988	4125.918587	1028.362605	18.23411015
Universal Polar Stereographic	42212.88031	1790.280543	448.8855982	8.000511803
Vertical Perspective*	18353.36422	765.1857129	191.3146521	3.4014259
Wiechel Equal Area*	120.290356	5.040321136	1.261443403	0.022439324
Aitoff*	2882.28725	118.5448589	29.59671142	0.525553479
Briesemeister*	120.5900058	5.043713523	1.261654517	0.02243939
Hammer*	120.2612392	5.043041754	1.261612531	0.022439377

TABLE 4.
DISTORTION ON EACH SCALE

Projection System	Distortion (m^2)			
	250k	**50k**	**25k**	**5k**
Equal Area Conic (Albers)-Standard	787951.61807	912.54368	57.03945	0.01803
Eckert II	320.32701	13.35506	3.33908	0.05937
Collignon	320.32696	13.35505	3.33909	0.05937
Trystan Edwards Cylindrical	320.32698	13.35509	3.33910	0.05937
Gall Orthographic	320.32703	13.35508	3.33910	0.05937
Balthasart Cylindrical	320.32706	13.35507	3.33910	0.05937
Equal Area Cylindrical	320.32711	13.35509	3.33910	0.05937
Lambert Cylindrical	320.32711	13.35509	3.33910	0.05937
Behrmann Cylindrical	320.32716	13.35510	3.33911	0.05937

TABLE 5.
PERCENTAGE OF AREA DISTORTION

Projection System	250k		50k		25k		5k	
	Le (km^2)	**% R**	**Le (km^2)**	**% R**	**Le (km^2)**	**% R**	**Le (km^2)**	**% R**
Eckert II	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
Collignon	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
Equal Area Cylindrical	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
Lambert Cylindrical	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
Balthasart Cylindrical	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
Gall Orthographic	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
Trystan Edwards Cylindrical	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
Behrmann Cylindrical	18353.375	1.745E-06	765.186	1.745E-06	191.315	1.745E-06	3.401	1.745E-06
UTM	18353.375	0.082	765.186	0.171	191.315	0.182	3.401	0.192
Description:	Le = Area in ellipsoid							
	%R = Percentage of residual (difference) between the area of ellipsoid and projection.							

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