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Full Length Research Paper

GIS analysis of the accuracy of Tomas Lopez´s historical cartography in the Canary Islands (1742 - 1746)

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The accuracy of Tomás López´s historical cartography of the Canary Islands included in the "Atlas Particular" of the Kingdoms of Spain, Portugal and Adjacent Islands" is analyzed. For this purpose, we propose a methodology based on Geographic Information Systems (GIS), a comparison of digitized historical cartography population centres with current ones. This study shows that the lineal error value is small for the smaller islands: Lanzarote, El Hierro, La Palma and La Gomera. In the large islands of Tenerife, Fuerteventura and Gran Canaria, the error is smaller in central zones but increases towards the coast. This indicates that Tomás López began his cartography starting from central island zones, accumulating errors due to lack of geodetic references as he moved toward the coast.

Key words: Canary Islands, Tomas Lopez, historical cartography, geographic information systems, accuracy.

INTRODUCTION

Historical maps are an important part of our cultural heritage (Jenny and Hurni, 2011). More than mere physical artefacts, they are also a potential source of information for the studies of historians and geographers who increasingly use maps as sources of geographical information used, for example, to trace the evolution of landscapes or traffic networks (Gregory and Ell et al., 2007; Knowles, 2002, 2008), geo-environmental analysis (Cremonini and Samonati, 2009) or the incorporation of historical data into GIS (Weir, 1997). Historical maps were produced on different scales, coordinate systems, projections, surveying and mapping techniques (Podobnikar, 2009). For example, the origins of cartographic projections could be based in Madrid, Teide, Paris, Rome, Greenwich, Ferro and local origins (Podobnikar, 2010). Considering that historical maps are typically less accurate than contemporary cartographic databases (Tucci and Giordano, 2011), it is not surprising that this is of particular concern in historical cartography studies and historical GIS applications (Plewe, 2003). Analysis of the accuracy of early maps is an important aspect in the study of the history of cartography. The accuracy of early maps has been a popular theme in the cartographic literature since the 1960s (Murphy, 1978). However, it seems that no standard methodology has been generally accepted (Hu, 2001). The distortion grid method is at least as old as the 1840s (Andrews, 1975) and has been used in several studies of the accuracy of early maps (Levin et al., 2010). Since the 1960s, with the rapid growth of computer technology, various experiments using computer-aided methods such as the coordinate method and the circle method have been conducted (Tobler, 1966; Ravenhill and Gilg, 1974; Ravenhill, 1976; Stone and Gemmell, 1977; Murphy, 1978; Lindsay, 1980; Mekenkamp, 1989; Livieratos et al., 1995).

The circle method analyzes the accuracy of an early map by displaying and interpreting patterns of standard inaccuracy circles on such a map. The radii of these circles are proportional to their deformation value, which is calculated from known coordinates of chosen points on an early map and those points' coordinates in a modern system (Mekenkamp, 1989). The coordinate method

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calculates the amount of correlation between two sets of map coordinates of points identified by modern latitudes and longitudes (Tobler, 1966). Another coordinate method involves recording point latitudes and longitudes shown on an early map and then converting them to a modern coordinate system through a computer program. These points can then be plotted on a modern map of the same area. In this way, the difference between these computer-generated points and corresponding points on the modern map can be displayed by vectors joining the two points to show direction and magnitude of errors (Ravenhill and Gilg, 1974; Ravenhill, 1976). This latter method involves a coordinate transformation from the old coordinate system to the new. The quality of a transformation or goodness of transformation parameters depend on the positional quality of the 2 sets of points used for the calculation of the parameters in a coordinate transformation between two sets of coordinates. Other authors try to geo-reference the historical map in order to overlay historical and current maps (Baiocchi and Lelo, 2010). The value of some early maps should not be judged only in terms of their accuracy because geodetic precision might not be the original intent of the map makers; the value of these maps shouldn´t be underestimated because of their positional inaccuracy (Hu, 2010). The interpretation of the accuracy of early maps should not be separated from their specific cultural context (Harley and Woodward 1987).

The Canary Islands were very important for European cartography, as their geographical position fixed the origin of geodetic longitude reference systems until the adoption of the Greenwich meridian in 1884 as the origin of longitudes (Sevilla, 1999). Tomas Lopez in his book "Principles Applied to the use of Geographical maps" (Lopez, 1795) refers to the use of a longitude origin in the Island of Hierro (page 2) “so determined the French on the board of the most famous mathematicians in Europe, convened by Cardinal Richelieu and confirmed by a decree of King Louis XIII, the day April 25, 1634”. He also refers to the adoption of the origin in the Peak Teyde (page 46 to 47) “Janson in his book “four parts of the World”, published in the year 1624, William Blaeu in his Atlas, Nicholas Vischer on his world map, and many Dutch, put the origin of longitude in Meridian Peak Teyde …. Call some of it the prime meridian, the Dutch meridian …” and justify its use, he says (page 92):

> “the convenience of using the origin of the Teyde with its advantages of visibility nautical in many Nautical charts and quarters of our pilots is adopted by the prime meridian which passes through the Peak Teyde; and it seems that all those who chose this meridian on their maps, among other reasons, had to be taller than the Peak, and the highest in the world, from whose summit is a large part of the sea, so I settled for just choice**”**.

One of the first cartographic representations of the Canary Islands was made by the cartographer Tomás (1731 to 1802) during the year 1779 and 1780. These representations were included as pages 58 to 61 of the “Atlas Particular of the Kingdoms of Spain, Portugal and Adjacent Islands” published in 1790 by the Royal Academy of History. This “Atlas Particular” was intended by the Academy to become a geographical-historical dictionary of Spain. Many of the maps that make up this ‘Atlas’ were created by Tomás López over a long period of time (1760 to 1788) and then delivered to the Academy. In turn, Tomás López was responsible for the composition of the ‘Atlas’ index which was the preamble to what would become his great work: The Geographic Atlas of Spain of 1804 (Lopez and Manso, 2006).

Lopez´s method - learned from his teacher D´Anville (Liter et al., 2002), who in turn learned it from F. Chevalier (Manzano-Agugliaro et al., 2005) - has been called “studio cartography” (San-Antonio-Gomez et al., 2011). He specialized in a compilatory methodology (Martin, 2001) that combined his talents for synthesizing and solving cartographic problems, although the method has been described as imprecise. Aware of the limitations of topographic mapping for accurate mapping (Liter et al., 2002), Lopez argued that it never could be used to represent large areas of land. So argued Chevalier himself, the master of D'Anville to justify the method of studio Cartography (Alinhac, 1965). Lopez has been criticized for dispensing with astronomical and geometric observations and for not doing field work to support the large volume of information he was able to gather (Matin, 2001; San-Antonio-Gomez et al., 2011). He created his maps from a collection of previously existing ones (Matin, 2001), but only by Spanish authors of maps of Spain, because he thought that foreign authors introduced intentional errors (Liter et al., 2002). His maps were supplemented with information from his “interrogations”. These “interrogations” consisted of a questionnaire, directed to those responsible for each diocese or parish, containing 15 questions about the most relevant data, varied in nature, pertaining to their communities (León, 2001). López also requested a small map of a three-league radius surrounding each territory, in which all of this information was to be included (Olarán, 2004). Lopez´s greatest achievement was to provide a global and complete image of the Canary Islands. This information was very valuable until the end of 16th century, as in 1875 the Spanish Geographic Institute began the publication of the National Topographic Map on a scale of 1:50,000 - a task completed in 1968 with the maps of the Canary Islands (Mújica, 2007).

Tomas Lopez, knowing that the Earth is not spherical felt that there was little distortion when using this spherical model approach. He knew of the ellipsoidal shape of the Earth and was in favour of Newton's theory that the earth was an ellipsoid-shaped "orange", flattened at the poles. Lopez (1795) wrote (page 2) “the purpose of

Table 1. Characteristics of the Canary Island pages studied.

Island	Year	Page	Scale (1/) (Lopez and Manso, 2006)
Tenerife	1779	58	285,100
Gran Canaria	1780	59	285,500
Fuerteventura	1779	60	289,000
Lanzarote	1779	61	287,700
El Hierro	1779	61	287,700
La Palma	1780	62	286,000
La Gomera	1780	62	286,000

geography is the explanation of the entire globe including land and water, and forming a single body called the 'terrestrial globe'. This large body is of spherical shape, a little flattened towards the poles, but very similar to the sphere as evidenced by the lunar eclipses circular shadow of the earth that is stamped on it"; we propose a method of systematic GIS analysis based on point-type graphical entities. Thanks to this novel methodology, it is possible to study all historical sites and their correspondence with current ones, in order to verify their accuracy and identify the cartographic procedure used in the creation of maps, through the spatial distribution of the errors obtained.

MATERIALS AND METHODS

In this paper, we analyze the maps of the Canary Islands included in Tomás López´s "Atlas Particular of the Kingdoms of Spain, Portugal and Adjacent Islands." Table 1 shows the identification characteristics for each of the maps studied, also listed in López and Manso´s work (Lopez and Manso, 2006) in which their scales were calculated. The maps analyzed are from the Digital Library of the Royal Academy of History of Spain (RAH, 2011) which are available on-line in digital format from a scanning of the original maps. The maps have a geo-referencing frame with a graduation of 5 min intervals, in both longitude and latitude. The origin of the longitude has two references: on one extreme, the Peak of Teide, and on the opposite extreme, Madrid. Because each page was designed using a frame of graduated geographical coordinates of latitude and longitude, it is possible to geo-reference it in space using a GIS. The software used in our work is ArcGIS 9 v.3 (Esri, 2011). The margins of the maps contain the representation of the graphic scale, expressed in 20 leagues per degree; Spanish geographical leagues and Castilian legal leagues. The geo-referencing of the islands is detailed in the texts included on the margins of each map, as well as the authors of the cartographic references on which they are based. In the case of Gran Canaria, the author was Manuel (1746), and for the rest of the islands, the authors were Antonio de Riviere (1742), Francisco (1746) and Capel and Tous (1998).

Although, uncertainty and inaccuracy are ontologically distinct concepts, in practice it is often difficult to measure the two separately. This is particularly true when dealing with historical maps. Technological advancements, changes in cartographic production techniques, and progress in the field of surveying contribute to blur the line between the two, as do the variety of map purposes, periods of creation and socio-cultural contexts in which maps are created. According to Buttenfield (1993) uncertainty is an ambiguous concept which arises from the imperfect understanding and modelling of the phenomenon under study, coupled with the use of imprecise, outdated and incomplete data (Harrower, 2003). As stated by Couclelis (2003), uncertainty occurs simply because part of the information is unknown or, as Fisher (1999) puts it, it cannot be known with precision. The problem of estimating the positional accuracy of an historical map has typically been tackled using spatial–analytical tools (Hessler, 2006; Livieratos, 2006). However, by employing methods for the evaluation of positional accuracy limited to the calculation of the root mean squared error (RMSE), for the entire map (Giordano and Nolan, 2007; Hsu, 1978; Pearson, 2005; Strang, 1998), previous studies have often neglected to systematically analyze and attempt to model how positional accuracy varies across the map.

Proposal of GIS analysis method

According to Hu (2010), application of GIS in assessing accuracy of early maps can be divided into four steps:

i) The first step is to identify locations of the points and features of an early map on a modern base map, that is, to find strictly comparable points and features between the early map and the modern base map. This modern base map with the identified points and features is used as the reference map to evaluate the accuracy of the early map.
ii) The second step is to digitize the original early paper map into GIS.
iii) The digitized early map is overlaid with the modern base map. At the stage of overlay, three conditions have to be met: first, the two maps must be on the same scale; secondly, the two maps must be in the same orientation; finally, two identical points on the two maps need to be selected as common control points for an overlay.
iv) The last step is to examine distortion of the early map based on the overlaid early map and the modern base map. The absolute distortion can be analyzed by the linear distance between the point on the early map and the identical point on the modern base map. In addition, distribution patterns and buffer regions around certain points on these two maps can also be analyzed using GIS.

In the analyzed maps, there is no guarantee of the existence of points more accurate than others, as the cartographer did not use the known coordinates of the cities for the preparation of maps; but instead, there is a framework of latitude and longitude with reference to a longitude origin. The proposed method is:

1) Check the scale of the maps; analyze the possible use of a spherical earth model.
2) Geo-reference of maps with latitude and longitude framework; move the historical longitude origin to the origin longitude of modern cartography.

Table 2. Distance scales and radius of the earth from Tomas Lopez (TL).

Reference	Type of league	League/1º	"vara"/1º	m/1º	Radius N-S (TL spherical) km
	De marina	20	132520	110654.20	6340.02
TL maps	Geografica	17.5	132510	110645.85	6339.54
	Legal	26.5	132500	110637.50	6339.06
TL book			132526	110659.21	6340.31

3) Digitize of all population settlements or cities.
4) Identify historic settlements or cities corresponding with current ones.
5) If the maps have the same orientation and scale, replace the coordinate transformation of historical settlements with a new one; by a translation in latitude and longitude equal to the calculated mean value of all ancient map points corresponding to the new; this translation in longitude ($\bar{\lambda}$) and latitude ($\bar{\varphi}$) is calculated by Equation 1:

$$\bar{\lambda} = \frac{\sum_{i=1}^{n} \lambda_{2i} - \lambda_{1i}}{n}, \quad \bar{\varphi} = \frac{\sum_{i=1}^{n} \varphi_{2i} - \varphi_{1i}}{n} \qquad (1)$$

Where:

λ_1 = longitude in the current cartography; f_1 = latitude in the current cartography; λ_2 = longitude in the historical cartography; f_1 = latitude in the historical cartography and n = number of matching cities. This avoids use of dubious quality points for the coordinate transformation and systematic displacement errors between the two maps, such as a shift of the origin of longitudes, or even a shift of tectonic plates, given the long time lapse between current and historical maps.
6) Calculation of absolute accuracy of the two maps, that is, the linear distance between the points of both maps, the linear error (LE) from Equation 2. This will be used for final rendering of map errors. Linear error (LE) is calculated in kilometers for each city:

$$Le = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad (2)$$

Where:

The linear coordinates in the historical map are: X_1 = longitude x cos (latitude) x 110.64585 km/º, Y_1 = latitude x 111.1775 x 110.64585 km/º and X_2, Y_2 are the coordinates in the current map with the same distance conversion.

RESULTS

Checking the scale and shape of the earth

Verification of the graphic scales on both X (longitude) and Y (latitude) axes shows that the 20-leagues-per-degree scale is identical in latitude but is reduced in longitude by a cosine factor of the angle of latitude. In the historical maps studied, a degree of latitude (N-S) expressed in several units of distance (Table 2) allows us to calculate the radius of the earth used. Given that a "vara" of Burgos measured 0.835 m before 1791 (Maier, 2005) and assuming a spherical earth, the average radius of the earth obtained for the three distance units tested was the same. Table 2 also contains the distance of one degree of latitude according to Tomas Lopez (Lopez, 1795) who wrote (page 94) "the degrees of latitude are all equal, assuming that the earth is spherical: each degree has 132526 Castilian varas of Burgos; and not being the earth spherical, the difference between both degrees is so small, it can be omitted without scruple to produce some effect in geography". Settlements were digitized from the island of Tenerife on the spherical earth model of Tomas Lopez, with the average radius of the 'earth' obtained earlier (TL spherical). On the other hand, settlement was also digitized on the current earth model for this area, the GRS80 ellipsoid system, both using the same origin of longitude.

Figure 1 exaggerates the size of GRS80 digitized cities in order to show the overlay spherical system. No appreciable difference between the two scans is observed as they are drawn in a concentric representation.

GEO-REFERENCING

TL maps have been geo-referenced on the GRS80 system; obtaining the RMS expressed in Table 3. Taking into account the equivalent distance for 1° of latitude, we obtain the root mean square (RMS) errors of geo-referencing in distance units. Then the origin of longitude was shifted from the Peak of Teyde to Greenwich meridian of -16.6409096611° east, for the digitization of historical maps and modern control maps, using the same origin of longitude. Table 3 shows the root mean square (RMS) errors in the geo-referencing of pages covering each of the Canary Islands. The largest error obtained is 209 m on the island of Gran Canaria; the smallest is 30 m on El Hierro with the average of 86 m for all the islands.

Digitizing and identification of locations

All cities on historical maps were digitized as shown in

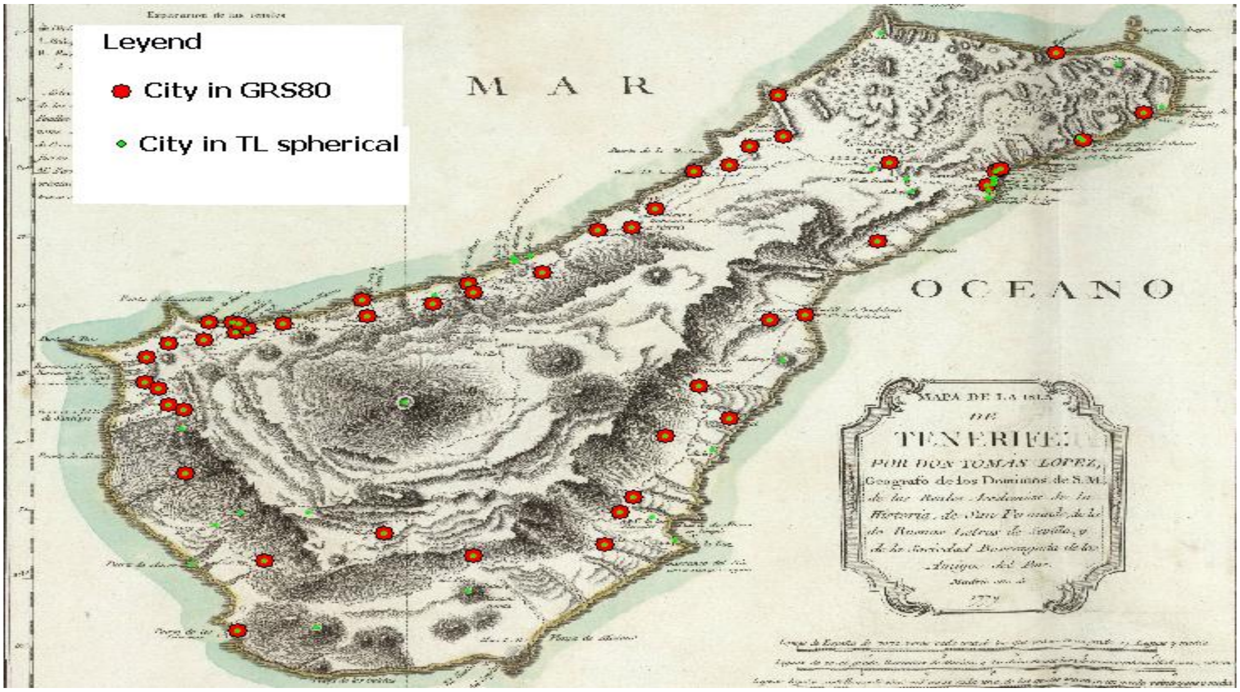

Figure 1. Example of digitizing for ellipsoidal (GRS80) and spherical Tomas Lopez (TL) earth model, Tenerife Island.

Table 3. Tomas Lopez´s cities (TL) and current population centres compared.

Island	RMS	T. L	Matching cities		Translation		Le	Scale
	(°) en SIG (grados)	n	n	%	$\bar{\lambda}$	$\bar{\varphi}$	km	1/
Tenerife	0.00053	58	48	82.8	-0.0379	0.0348	7.8691	3,934,5490 39,345,490 39,345,490
Gran Canaria	0.00189	52	24	46.1	0.1740	0.1212	9.6350	4,817,5162
Fuerteventura	0.00042	60	31	56.7	-0.7147	0.4303	7.3397	3,669,8608
Lanzarote	0.00075	99	34	34.3	-0.8276	0.2632	2.0799	1,039,9522
El Hierro	0.00027	16	9	56.2	-0.2479	0.0045	2.5301	1,265,0715
La Palma	0.00067	28	23	82.1	-0.2679	0.0289	3.7787	1,889,3510
La Gomera	0.00095	25	9	36.0	-0.0350	0.0138	4.1002	2,050,0976
Total		338	178					
Average (ABS)	0.00078			52.6	0.32928571	0.12810207	5.333	2,666,283

Table 4 which summarizes the number of cities or towns digitized for each island. We identified each city name with its corresponding current one as shown in the table of the number and percentage of matching cities. Of the 338 sites from the seven islands digitized, only 178 corresponded with their positions on current maps. Agreement varies from 34 to 82%. The maximum matching values are found on the islands of Tenerife and La Palma with very high values of about 82%; the lowest values were found in Lanzarote and La Gomera, with 34 and 36% respectively. The rest of the islands show values between 46 and 56%.

Translation of the historical map

The various population sites were digitized with the GIS and their geo-graphic coordinates - latitude and longitude were calculated. These coordinates were compared with those of current population sites (year 2005) and the group of coincident points, in order to avoid a possible systematic displacement error of the historical map. Table 3 shows the translation in longitude and latitude obtained for each historical island map. The absolute average is smaller for latitude than longitude and latitude is always positive.

Absolute accuracy of the two maps

Once the mean difference of longitudes and latitudes of all the matching cities was translated from the historical cartography, we proceeded to calculate the absolute accuracy of the two maps, the linear distance or linear error (LE) between the cities of both maps. Table 4 shows an example of LE obtained for the matching cities of Tenerife Island. Finally at this point, the LE of each city is represented in the GIS with respect to the historical cartography coordinates (Figures 2 to 8). The average linear error (LE) for each island and the scale (E = 1/M) associated with this error (obtained using 0.2 mm x M = LE) is shown in Table 3. Tomás López´s city locations are compared with their matching population centres. Figures 2 to 8 show error maps for each island. The colour gradation reflects the category of error distributed in 5 intervals from 0 to 20 km. The two ranges established for all of the islands are shown in the error maps. There is a central area of greatest accuracy decreasing radially toward the coast especially in the three larger islands. There is less fluctuation between extreme error values on the islands of Lanzarote and La Palma.

The result is not overly significant on the islands of La Gomera and El Hierro due to the smaller number of matching sites.

DISCUSSION

The proposed methodology allowed has to analyze ancient mapping without fixing precise points, in order to calculate the transformation parameters with respect to the current map. It has the limitation associated with the use of historical maps with their reference framework, their origin of longitudes and their not-necessarily-correct scale.

For small geographic areas such as the historic Canary Island maps analyzed, it was found that the approximation of a spherical earth and the small difference in the size of the earth used by Tomas Lopez did not influence the final map accuracy. According to the methodology presented in this paper, the results of matching cities vary from 34 to 82%; as a mean value, there is a 52% difference between Tomas Lopez´s city locations and the current population centres. Given the difficulty in comparing both cartographies, we observed that about half of López´s cities disappeared or changed names. The reasons may be diverse (Hu, 2010); first, some points or features on an historical map may have disappeared over time. Even though some of them still exist today, their names may be different from those indicated on the early map. Further difficulties are caused by place names which are the same as the old ones, but represent different features at the present time.

Translation of historical cartography reduced the absolute map error, allowing an estimation of the relative accuracy of the historical map while avoiding possible systematic errors such as: error in the frame of reference; lack of accuracy in the origin of longitudes or even the tectonic displacement of an island over the centuries. It is observed how the absolute average error is smaller for latitude than longitude, because at that time it was easy to measure the latitude with a sextant, while longitude was difficult to measure using a direct relationship between time and longitude since the Earth rotates at a steady rate of 360° per day or 15° per h in sidereal time. If the navigator knew the time at a fixed reference point when some event occurred at the ship's location, the difference between the reference time and the apparent local time would give the ship's position relative to the fixed location. Finding apparent local time is relatively easy. The problem; ultimately was the determination of the time at a distant reference point while on a ship. The absolute accuracy obtained is of great magnitude, as was that obtained by other authors (Baiocchi and Lelo, 2010) by comparing historical and current cartographies. Furthermore, our method allows us to quantify accuracy and to show it graphically in order to interpret the spatial distribution of errors in the historical cartography. The results of this study shows that Tomas Lopez´s maps have a cartographic accuracy on a scale of 1: 1,039,9522 to 1: 4,817,5162- much higher than that indicated by Lopez and Manso (2006) which was 1:285,000. Scales between 1 and 2 million for small islands and between 3.5 and 4 for large islands were found. It has been shown that the scale found is not homogeneous for all islands, 10 times more imprecise than suggested by other authors

Table 4. Linear error for matching cities of current and Tomas Lopez cartography (TL), Tenerife Island.

Current name	LON (º)	LAT (º)	TL name	LON (º)	LAT (º)	Le (km)
Adeje	-16.7258	28.1191	Adexe	-16.7632	28.0226	10.0497
Arafo	-16.4215	28.3371	Arafo	-16.3053	28.3160	7.8066
Arguayo	-16.8062	28.2661	Arguaio	-16.8364	28.2065	7.2046
Arico El Nuevo	-16.4780	28.1769	Arico	-16.4287	28.1000	4.7940
San Andres	-16.1906	28.5037	Bateria De S. Andres	-16.0222	28.5352	14.7212
San Antonio	-16.2859	28.4505	Bateria De S. Antonio	-16.1004	28.4972	17.0171
San Miguel De Gen	-16.3141	28.4626	Bateria De San Miguel	-16.0964	28.5004	19.3323
Buenavista Del No	-16.8505	28.3703	Buenavista	-16.8503	28.2877	6.4492
Caleta De Interia	-16.7912	28.3715	Caleta De Interian	-16.8137	28.3134	6.4521
Candelaria	-16.3697	28.3500	Candelaria	-16.2740	28.3225	5.7048
Carrizales (Los)	-16.8549	28.3158	Carrizal	-16.8696	28.2704	5.2848
Vilaflor	-16.6356	28.1539	Chasna O Villaflor	-16.6543	28.0549	9.0206
Daute	-16.8080	28.3617	Daute	-16.7916	28.3125	2.6475
Palmar (El)	-16.8439	28.3436	El Palmar	-16.8712	28.2399	9.9377
Rio (El)	-16.5215	28.1396	El Río	-16.4542	28.0418	7.5430
Sauzal	-16.4370	28.4761	El Sauzal	-16.3740	28.4976	6.6908
Tanque (El)	-16.7719	28.3621	El Tanque	-16.7890	28.3013	6.1057
Escobonal (El)	-16.4288	28.2562	Escobozal	-16.3415	28.1955	5.6194
Fasnia	-16.4422	28.2386	Fasnea	-16.3999	28.1744	3.2869
Guancha (La)	-16.6511	28.3703	Fuente de La Guancha	-16.6692	28.3205	5.7207
Granadilla De Abo	-16.5767	28.1211	Granadilla	-16.5740	28.0284	7.2822
Guia De Isora	-16.7784	28.2099	Guia Llamose Isora	-16.8350	28.1293	10.5452
Guimar	-16.4071	28.3134	Guimar	-16.3695	28.2348	4.8574
Icod El Alto	-16.6077	28.3847	Icod	-16.6096	28.3357	4.2050
Icod De Los Vinos	-16.7156	28.3659	Icod De Los Vinos	-16.7457	28.3108	7.0205
Caleta (La)	-16.7954	28.3725	La Culata	-16.7785	28.3059	4.0721
Victoria De Acent	-16.4658	28.4319	La Victoria	-16.4296	28.4295	3.5839
Lomo Oliva	-16.4591	28.2115	Lomo	-16.4413	28.0810	10.7915
Matanza De Acente	-16.4464	28.4490	Matanza, Lamose Acentejo	-16.4086	28.4513	4.1127
Orotava (La)	-16.5261	28.3851	Orotava	-16.5111	28.3737	3.4273
Garachico	-16.7603	28.3708	Puerto De Garachico	-16.7850	28.3119	6.6816
Cristianos (Los)	-16.7164	28.0503	Puerto De Los Cristianos	-16.7869	27.9358	13.8049
Realejo Bajo	-16.5866	28.3842	Realejo De Abaxo	-16.5782	28.3597	3.1116
Realejo Alto	-16.5834	28.3808	Realejo De Arriba	-16.5729	28.3499	2.7250
San Isidro	-16.3208	28.4138	S. Isidro	-16.2079	28.4125	8.2101
San Juan De La Ra	-16.6458	28.3929	S. Juan De La Rambla	-16.6749	28.3410	6.8224
San Cristobal De	-16.3174	28.4863	San Cristobal De La Laguna	-16.1969	28.5077	10.1972
Santa Cruz De Ten	-16.2589	28.4629	Santa Cruz	-16.1093	28.4809	12.3899
Santa Ursula	-16.4928	28.4230	Santa Ursula	-16.4606	28.4256	4.1763
Santiago Del Teid	-16.8134	28.2945	Santiago	-16.8586	28.2317	8.6988
Silos (Los)	-16.8154	28.3638	Silos	-16.8179	28.2914	5.7435
Tacoronte	-16.4114	28.4783	Tacoronte	-16.3421	28.5050	7.4691
Taganana	-16.2167	28.5592	Taganana	-16.0459	28.6419	18.3914
Tamaimo	-16.8178	28.2670	Tamaimo	-16.8494	28.2123	7.1461
Tejina	-16.3610	28.5319	Tegina	-16.2975	28.5912	10.7190
Tegueste	-16.3345	28.5229	Tegueste	-16.3230	28.5286	5.1740
Valle De Guerra	-16.3847	28.5197	Valle De Guerra	-16.2925	28.5402	8.0997
Igueste De San An	-16.1510	28.5235	Valle De Igueste	-15.9661	28.5686	16.8697

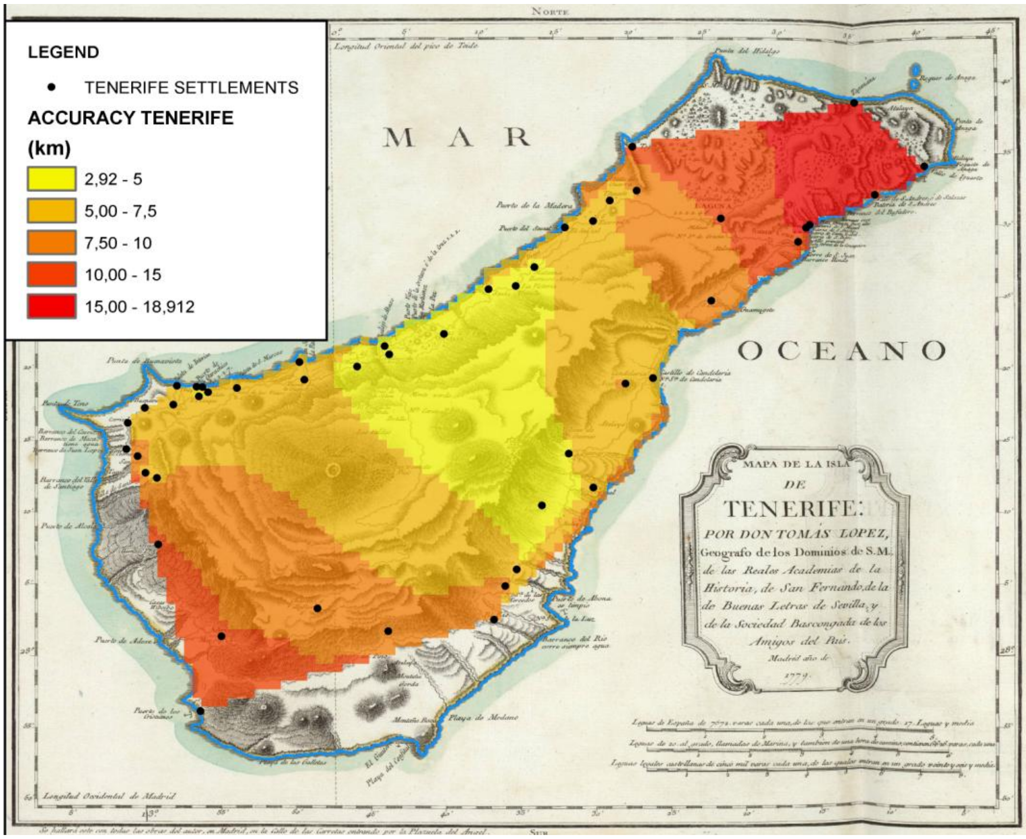

Figure 2. Lineal error map of Tomas Lopez´s Cities -Tenerife.

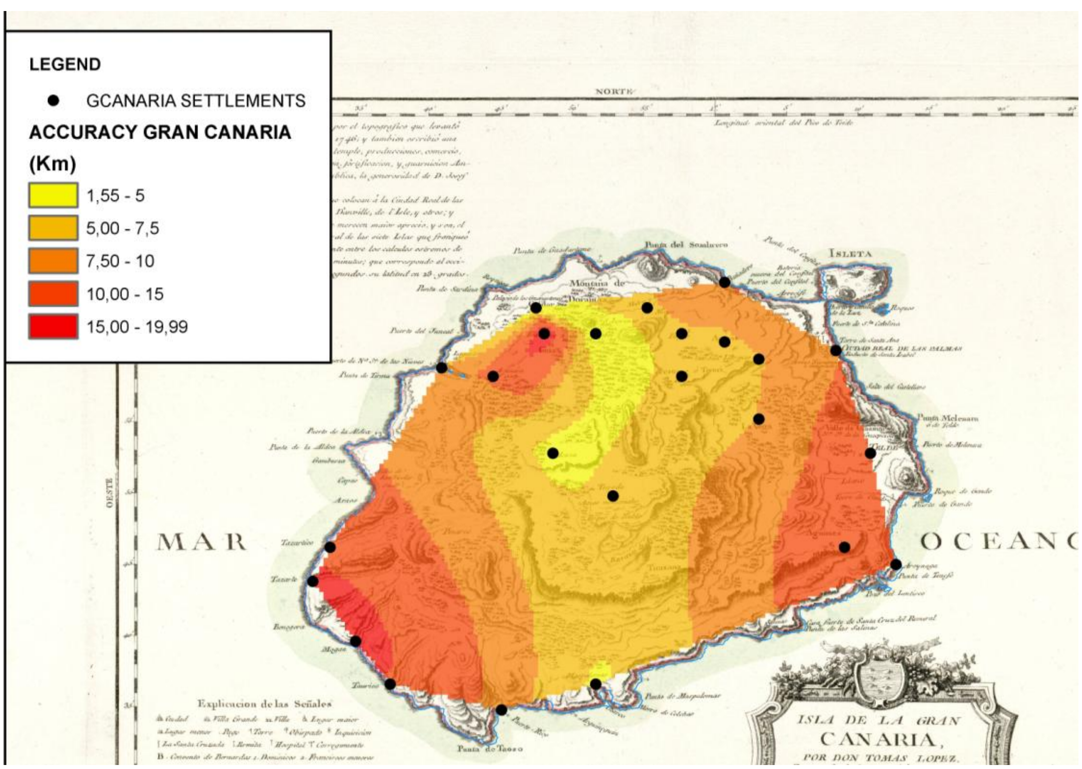

Figure 3. Error map of Tomás López´s Cities - Gran Canaria.

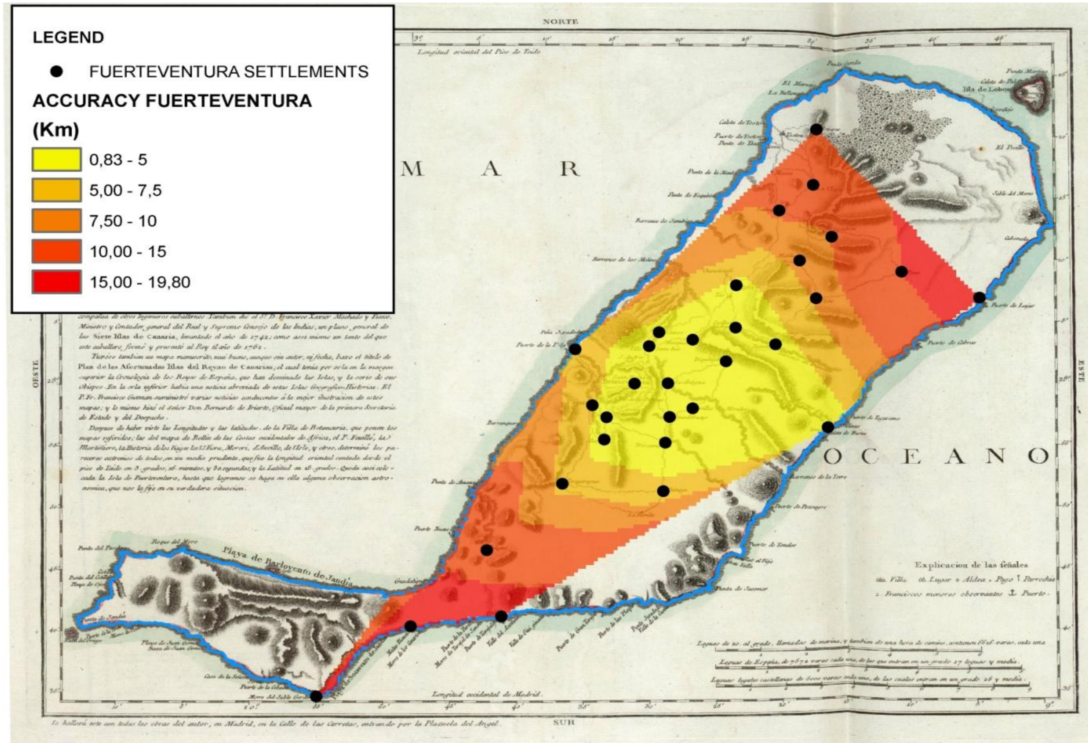

Figure 4. Error map of Tomás López´s Cities - Fuerteventura.

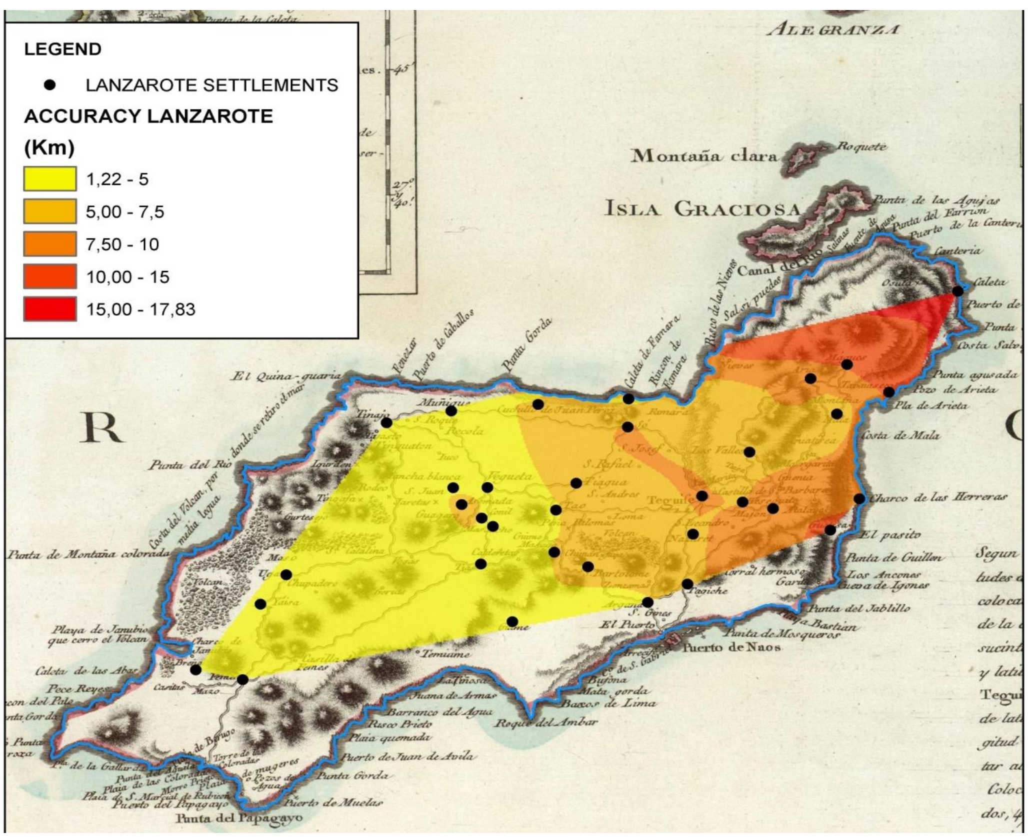

Figure 5. Error map of Tomás López´s Cities - Lanzarote.

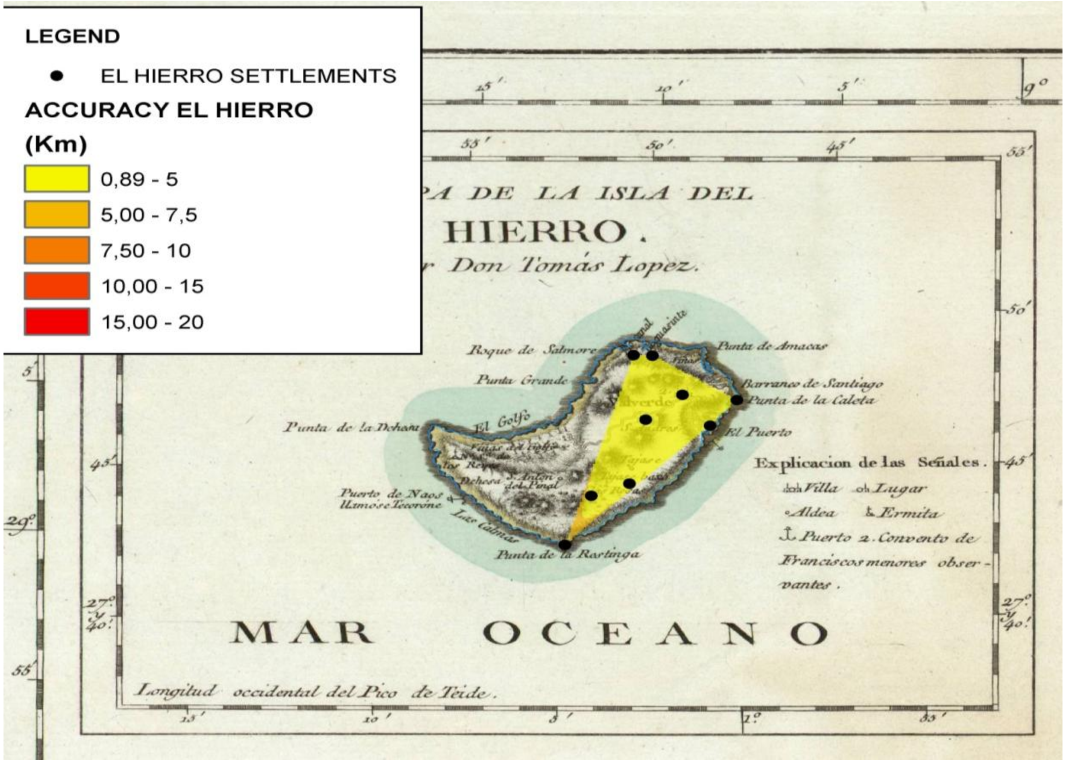

Figure 6. Error map of Tomás López´s Cities - El Hierro.

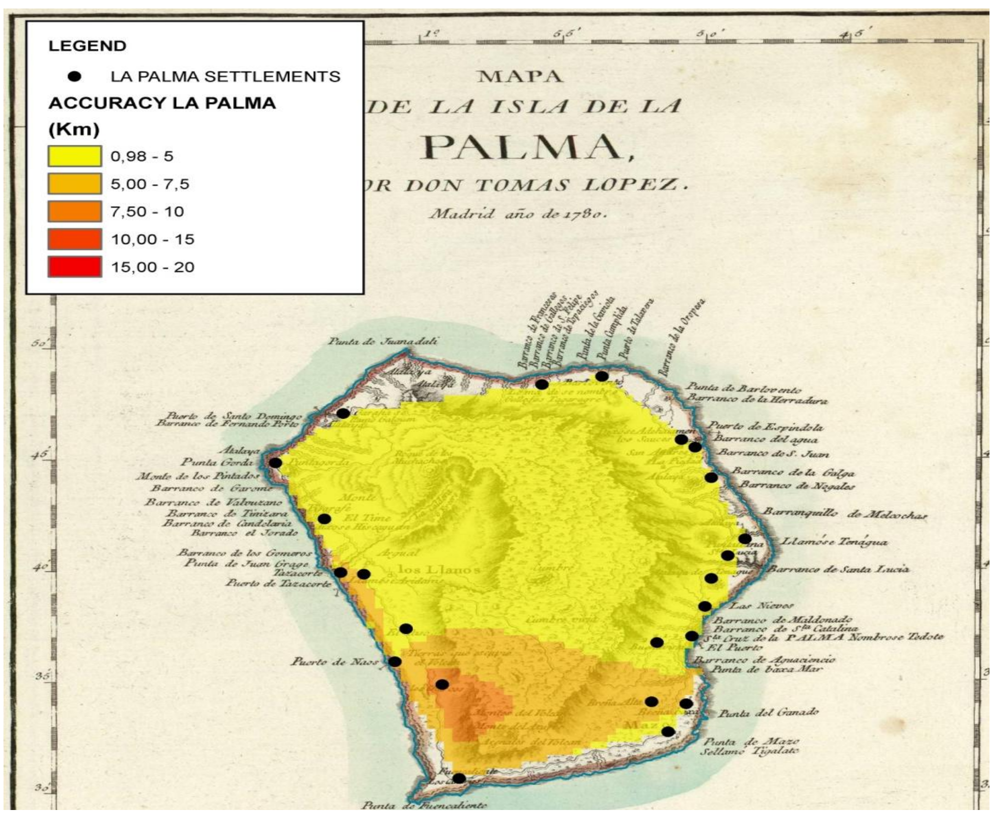

Figure 7. Error map of Tomás López´s Cities - La Palma.

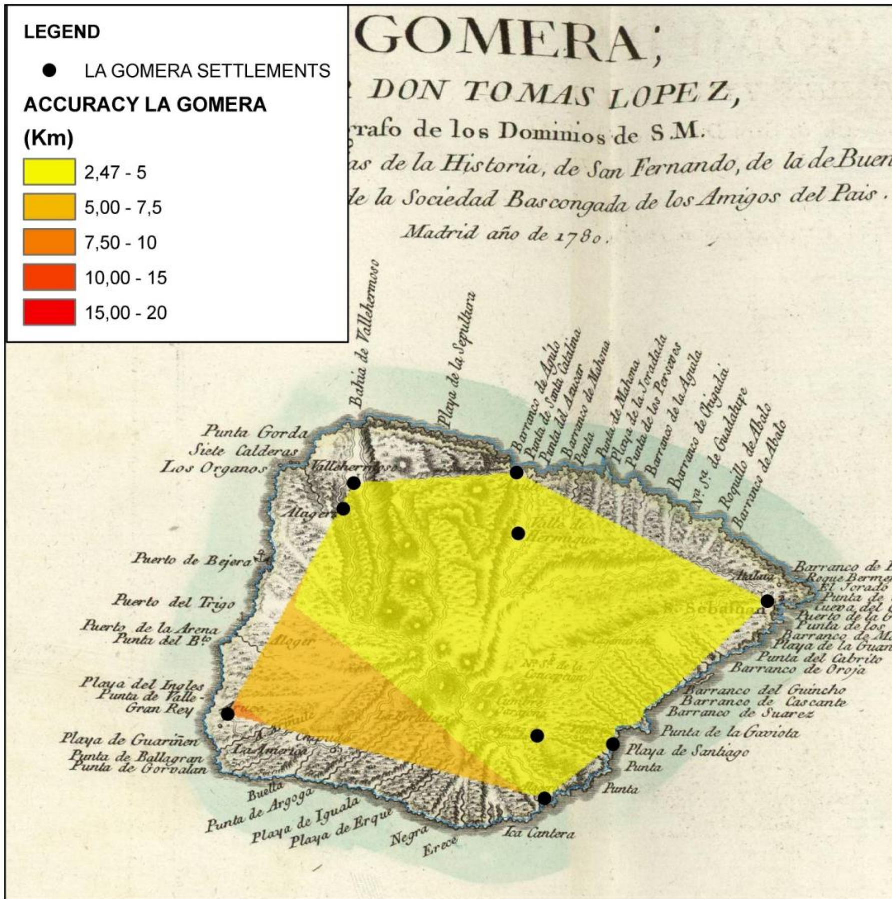

Figure 8. Error map of Tomás López´s Cities - La Gomera.

such as Lopez and Manso (2006), these authors have copied the scale that Tomás López wrote in his maps.

Gran Canaria, with a linear error (LE) of 9.6 km is the island with the highest error rate. This fact seems to be directly related to the origin of the baseline cartographic reference in Tomás López´s work which is different from that of the other islands that are based on Antonio de Riviere´s cartography (Capel and tous, 1998). We observed that the linear error value is small for the smaller islands: Lanzarote, El Hierro, La Palma and La Gomera - with an average error value of 3.1 km. The average linear error is 8.3 km for the higher-range group of islands: Tenerife, Fuerteventura and Gran Canaria. Also, in the large islands, the error is smaller in central zones and increases towards the coast.

Conclusions

The proposed method of systematic GIS analysis allows us to determine the accuracy of historical cartography and to calculate the equivalent scale for current cartography. It also enables the geographic location of population sites that existed in historical cartography and the comparison of the total number of population sites that overlap with current ones. This study has shown that errors increase from a central island zone toward the coast. This leads to the conclusion that Tomás López began his cartographic representation starting from central zones of the islands, accumulating errors as he moved away from them which is to be expected given that he did not have accurate geodetic references at his disposal.

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