Artículo de investigación

Differences in geographical coordinates of minefields in Colombia according to their acquisition method

Diferencias en coordenadas geográficas de campos minados en Colombia según su método de adquisición

Diferenças nas coordenadas geográficas dos campos minados na Colômbia segundo seu método de aquisição

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ABSTRACT

The scourge of explosive devices such as landmines, improvised explosive devices and unexploded ordnance, a product of armed conflicts in several countries around the world, has set a great precedent in the violation of fundamental human rights. In Colombia, the efforts of the government and NGOs to reduce their effects have succeeded in clearing minefields of more than 8 million square metres and destroying more than 7000 explosive devices. The standards for finding and clearing minefields (Confirmed Hazardous Areas - CHAs) include the determination of geographical coordinates (Latitude and Longitude) based on DATUM WGS84. However, the precision or accuracy in the location of these coordinates according to their capture method has been little studied and analysed, so this research investigates three methods for capturing coordinates on a simulated minefield (CHAs), finding interesting results: (1) The static method with dual frequency GNSS receivers presented a standard deviation of 4 millimetres corroborating a high accuracy, by Stop and Go it ranged between 4 and 19 millimetres with respect to the mean showing also a high accuracy, control by simple radiation confirmed obtaining a mean positional difference of 4.62 centimetres, (2) the capture of coordinates obtained with navigator yielded a mean positional difference of 219.28 centimetres, very similar to that obtained with (3) azimuths and distances without correction for a magnetic declination of 235.73; However, when corrected for magnetic declination, it gave a positional mean with correction of 53. 32, which showed a reliability of the method as long as the declination correction is applied and starting from a point with sufficient coordinate accuracy.

Keywords: humanitarian demining, global positioning systems, minefield, confirmed hazardous areas, geographic coordinates.

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RESUMEN

El flagelo de artefactos explosivos como landmines, improvised explosive devices and unexploded ordnance, producto de conflictos armados en varios países del mundo ha marcado gran precedente en la violación de derechos humanos fundamentales. En Colombia los esfuerzos del Gobierno y NGOs para disminuir sus efectos han logrado despejar campos minados de más de 8 millones de metros cuadrados y destruir más de 7 mil artefactos explosivos. Los estándares de hallazgo y despeje de campos minados (Confirmed Hazardous Areas – CHAs) incluyen la determinación de las coordenadas geográficas (Latitud y Longitud) basadas en el DATUM WGS84. Sin embargo, la precisión o exactitud en la ubicación de estas coordenadas según su método de captura ha sido poco estudiada y analizada, por lo cual, en esta investigación indaga sobre tres métodos de captura de coordenadas sobre un campo minado simulado (CHAs), encontrando resultados interesantes: (1) El método estático con receptores GNSS de doble frecuencia presentó una desviación estándar de 4 milímetros corroborando una alta precisión, mediante *Stop and Go* osciló entre 4 y 19 milímetros respecto a la media mostrando también una alta precisión, su control realizado por radiación simple lo confirmó al obtener una diferencia media posicional de 4,62 centímetros, (2) la captura de coordenadas obtenidas con navegador arrojó una diferencia media posicional de 219,28 centímetros, muy semejante a la obtenida con (3) azimuts y distancias sin corrección por declinación magnética de 235,73; sin embargo, al realizar la corrección por declinación magnética arrojó una media posicional con corrección de 53.32, lo que mostró una confiabilidad del método siempre y cuando se aplique la corrección por declinación y se inicie desde un punto con suficiente precisión en coordenadas.

Palabras clave: desminado humanitario, sistemas de posicionamiento global, campo minado, zonas peligrosas confirmadas, coordenadas geográficas.

RESUMO

O flagelo dos artefatos explosivos, como minas terrestres, artefatos explosivos improvisados e material bélico não detonado, produto de conflitos armados em vários países do mundo, estabeleceu um precedente para a violação dos direitos humanos fundamentais. Na Colômbia, os esforços do governo e das organizações não governamentais para reduzir seus efeitos foram bem-sucedidos na limpeza de campos minados de mais de 8 milhões de metros quadrados e na destruição de mais de 7.000 dispositivos explosivos. Os padrões para encontrar e limpar campos minados (áreas de risco confirmado [CHAs, em inglês]) incluem a determinação de coordenadas geográficas (latitude e longitude) com base no DATUM WGS84. No entanto, a precisão ou exatidão na localização dessas coordenadas de acordo com o método de captura foi pouco estudada e analisada. Portanto, nesta pesquisa, são pesquisados três métodos de captura de coordenadas em um campo minado simulado (CHAs), encontrando resultados relevantes: (1) o método estático com receptores GNSS de dupla frequência apresentou um desvio-padrão de 4 milímetros, corroborando uma alta precisão pelo Stop and Go, e variou entre 4 e 19 milímetros em relação à média, demonstrando uma alta precisão; seu controle por radiação simples o confirmou ao obter uma diferença posicional média de 4,62 centímetros; (2) a captura de coordenadas obtidas com navegador produziu uma diferença posicional média de 219,28 centímetros, muito semelhante à obtida com (3) azimutes e distâncias sem correções por declinação magnética de 253,73; contudo, ao realizar a correção por declinação magnética, evidenciou-se uma média posicional com correção de 53,32, o que mostrou uma confiabilidade do método sempre que for aplicada a correção por declinação e iniciada desde um ponto com suficiente precisão em coordenadas.

Palavras-chave: desminagem humanitária, sistemas de posicionamento global, campo minado, áreas perigosas confirmadas, coordenadas geográficas.

Introduction

The objective of the action against antipersonnel mines is to eradicate the danger of these explosive devices for people who are not involved in the conflicts, whereby the first activity to be carried out within the territories is humanitarian demining, an activity that involves two main tasks; first carry out surveys in the territories to identify contaminated areas and second start cleaning them up, however, these tasks should not be carried out for military or commercial purposes (Paterson et al., 2013).

According to the International Campaign to Ban Landmines, during 2020, non-state illegal armed groups used antipersonnel mines in at least six countries; Afghanistan, Colombia,

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India, Libya, Myanmar, and Pakistan (CBL-CMC, 2020). In the case of Colombia, antipersonnel mines have affected more than three generations of people. Nonetheless, the official sources of information from the state are not clear in the determination of a starting date of their use by non-state illegal armed groups (Vega Uribe et al., 2020). On the other hand, the Colombian state has kept an inventory since 1990 with more than 22 thousand cases related to antipersonnel mines, either their deactivation or accidents that have caused injuries or deaths (Descontamina Colombia, 2021a). The main negative impacts produced by antipersonnel mines are associated with three main aspects; (a) The social aspect, since the rural community is isolated or confined from other communities, forcing them through fear to change their customs, their way of life, that is, the people who live there are psychologically affected, in certain cases the children cannot go to school, (b) economically speaking, rural communities, being confined, cannot trade their agricultural products normally with business centres or with other communities, which causes a loss of purchasing power, money flow, employment and therefore increased poverty, (c) the environmental contamination of natural resources occurs, such as the contamination of water sources by chemicals, soil contamination, the inability to collect forest fruits or the death of wild animals (Vega Uribe et al., 2020). This contamination of their territories is very effective since it alters the relationships between the actors who live there and build their landscapes, forbidding transit or use of spaces such as roads, fields for crops and animals, water sources, among others (Pardo Pedraza, 2020). Hence, the goal of humanitarian demining operations is to eliminate anti-personnel mines and improvised explosive devices, remove these minefields and return these free lands to local governments and farmers, which involves a series of actions such as non-technical survey to in order to locate the field, clean up the area as well as Mine Risk Education (M.R.E) and victim assistance (Kostelnick et al., 2008).

In Colombia, as in other countries that present this issue, defining suspected hazardous areas (SHA) is a basic task, considering that these are defined as those in which there is a reasonable suspicion of the presence of mines/explosive remnants of war (ERW) or contamination based on indirect evidence (Krtalić et al., 2019). This task is carried out in Colombia by different internationally recognised NGOs in humanitarian demining work such as NPA, The HALO Trust, DDG, HI and others from within the country such as; Humanitarian Demining Brigade (BRDEH), CCCM, among others. These organisations, according to official data from 2004 to date, February 2021, have located more than 2285 minefields (Confirmed Hazardous Areas - CHAs), clearing areas of more than 8 million square meters mined and destroyed more than 7 thousand explosive devices among landmines, improvised explosive devices and unexploded ordnance (Descontamina Colombia, 2021b).

These data collected in mine action, in the field as minefield records (point or polygon data) and SHA (point or polygon data) (Alegria et al., 2017), by the different NGOs, are stored and analysed by the state institution Descontamina Colombia, in the Information Management System for Mine Action (IMSMA), this being the leading alphanumeric and geographic information system for the collection, storage and mapping of minefields and other actions against mines (Kostelnick et al., 2008). Regarding the geographic information of the minefields, specifically the latitude and longitude coordinates of their turning points or vertices, Descontamina Colombia requires that it must be presented in the geographic coordinate system, in decimal degrees and using the DATUM WGS84, in addition to the azimuth, and the distance between vertices, information also required by the IMSMA system.

Notwithstanding, the uncertainty in the precision of the coordinates according to their capture method is not considered, nor have the differences between capture methods been studied according to their location. Therefore, depending largely on their capture method, the location, shape, and areas of the minefields (CHAs) do not correspond exactly to the real ones, on the contrary Khamis and ElGindy (2012) affirm that demining and robotics navigation systems must be very precise, since coordinates produce inaccuracies in the empty spaces that are not detected. The main objective of this research is the comparison of the geographical coordinates of the same vertices but captured with three different methods of

the Global Navigation Satellite System (GNSS); (a) dual frequency global positioning receivers, (b) navigating global positioning receivers and (c) azimuth and distance techniques, in order to know the differences. In addition to proposing an adjustment to the capture method used in the mine action sector, applying the obtaining of at least one vertex with GNSS and the others correcting the magnetic declination of the azimuth.

Therefore, the instruments used to capture the coordinates are described below in the materials section, later in the methods section a description is set forth of how the field measurements of the coordinates were made, to then identify the differences between the coordinates obtained for the same vertices but with different methods in instruments, which allows discussing the capture that is currently done in the field of action against mines.

Material and Method

Materials

Generally, Suspected Hazardous Areas (SHA) do not have an accurately defined perimeter. When a non-technical survey is deployed based on direct evidence, pivot points or vertices, coordinates, angles, and distances are clearly defined, turning an SHA into a Confirmed Hazardous Area (CHA) (Alegria et al., 2017). Therefore, during this project, a confirmed hazardous area is simulated with limits and vertices defined using wooden stakes painted red at the tip and danger tape (Descontamina Colombia, 2016b), using a marking system with eight vertices, denominated as shown on Table 1.

To carry out the topographic survey of the polygon that simulates the minefield, a Leica TC 605 Total Station was used, which, using rods with their respective prisms, electronically measures angles and distances. For the most part Global Navigation Satellite System receivers were used, which are constellations of satellites that orbit the earth belonging to different governments, calculating the location of the observer (Latitude, Longitude and Height), with millimetric precision up to more than three meters depending on the frequency (Kaiser

et al., 2003). For the present investigation, two Trimble 5700 L1 / L2 dual-frequency GNSS receivers were used to capture the coordinates of the eight vertices. Also, a GARMIN GPSMAP 64s navigator receiver, which has a GPS and GLONASS receiver, was used to capture the coordinates of the eight vertices.

Finally, the compass of the GPS navigator GARMIN GPSMAP 64s, which according to the manufacturer has three axes tilt-compensated (GARMIN, 2021) was used. Along with the 30 m tape measure to measure distances between vertices.

It should be mentioned that for the post-processing of the data captured with the GNSS L1/L2 Trimble 5700 antennas, Topcon Tools software was used; ArcGIS software was used to plot the coordinates of all the methods.

Method

As already mentioned previously, with the wooden stakes an irregular polygon of eight vertices was created, which looks like a minefield (Figure 1), discovered by vegetation or structures on it, seeking the greatest precision in capturing the coordinates of each vertex.

Table 1
Vertex name

	Ver
1	GPS 1
2	GPS 2
3	P-3
4	P-4
5	P-5
6	P-6
7	P-7
8	P-8

The first method of capturing the geographic coordinates was carried out by means of static survey, with the two GNSS dual-frequency receivers, determining two geodetic points (Georeferencing), GPS 1 and GPS 2, (Figure 2). The widespread use in cartography of dual-frequency receivers involves reducing ambiguity even in movement (Hasegawa & Yoshimura, 2003).

Figure 1

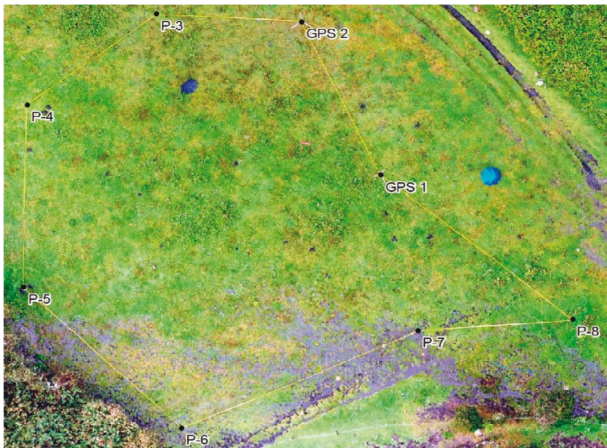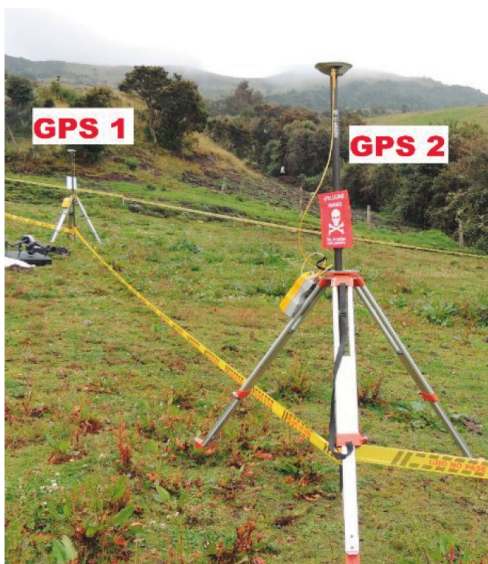*Eight vertex irregular minefield*

Figure 2

Trimble 5700 GNSS L1 / L2 at GPS 1 and GPS 2 vertices

The tracking time of the two antennas was 2 hours and 50 minutes, complying with the parameters for the capture of coordinates by differential static survey established by the IGAC, whose tracking time "t" for each point depends on the distance "d" in kilometers between the MAGNA-ECO network station and the point (IGAC, 2018), as follows in Equation (1):

$$t = 65min. + [3min. * (d - 10)] \qquad (1)$$

The maximum distance "d" for the case is approximately 33.74 km, to the farthest BOGA station of the MAGNA-ECO network,

which yields a minimum tracking time "t" of, as follows in Equation (2) and Equation (3):

$$t = 65min. + [3min. * (33.74 - 10)] \qquad (2)$$

$$t = 136.22min. \qquad (3)$$

In equation (2), minimum tracking time shown should be 136.22 minutes, equivalent to 2 hours, 16 minutes approximately. However, the measurement taken in the field using the first capture method resulted in 2 hours and 40 minutes. It means that the field measurement was higher in time than the theoretical formula expressed, showing 34 minutes more than necessary.

Correction of the geographic coordinates of the GPS 1 and GPS 2 vertices was performed using the corresponding RINEX files at the time of capture, generated by GNSS stations Continuous Operation BOGA and ABPD (SIRGAS, 2018) located in the city of Bogotá, state-owned stations belonging to the Geocentric Reference System for the Americas (SIRGAS). Due to scarcity in software related to GNSS topography and cartography data processing, a specialised software in post process coordinates should be used (Niu et al., 2015). For this case, Topcon Tools accept parameters such as RINEX files, precise cartesian coordinates, exact GNSS network ephemerides, instrumental antenna height (the absence of this measure may fail position (Meyer & Hiscox, 2005)). The use of this software determines whether there is overlapped tracking time between the continuous stations and the GNSS receptors (GPS 1 and GPS 2) that allow the generation of adjustment vectors to the relative position of two vertices. See Figure 3.

The second method of capturing the geographical coordinates was carried out by means of relative survey or better known as stop & go, this method is fast, efficient and allows the georeferencing of a succession of points with precision in centimeters (Wyloe & Featherstone, 1995). The GPS 1 base receiver remains static performing tracking, while the other Rover receiver is stationed on each of the vertices P-3, P-4, P-5, P-6, P-7 and P-8, for 5 minutes, as shown in the graph of overlapping time tracking and vector generation adjusted to each vertex in Figure 4.

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Figure 3

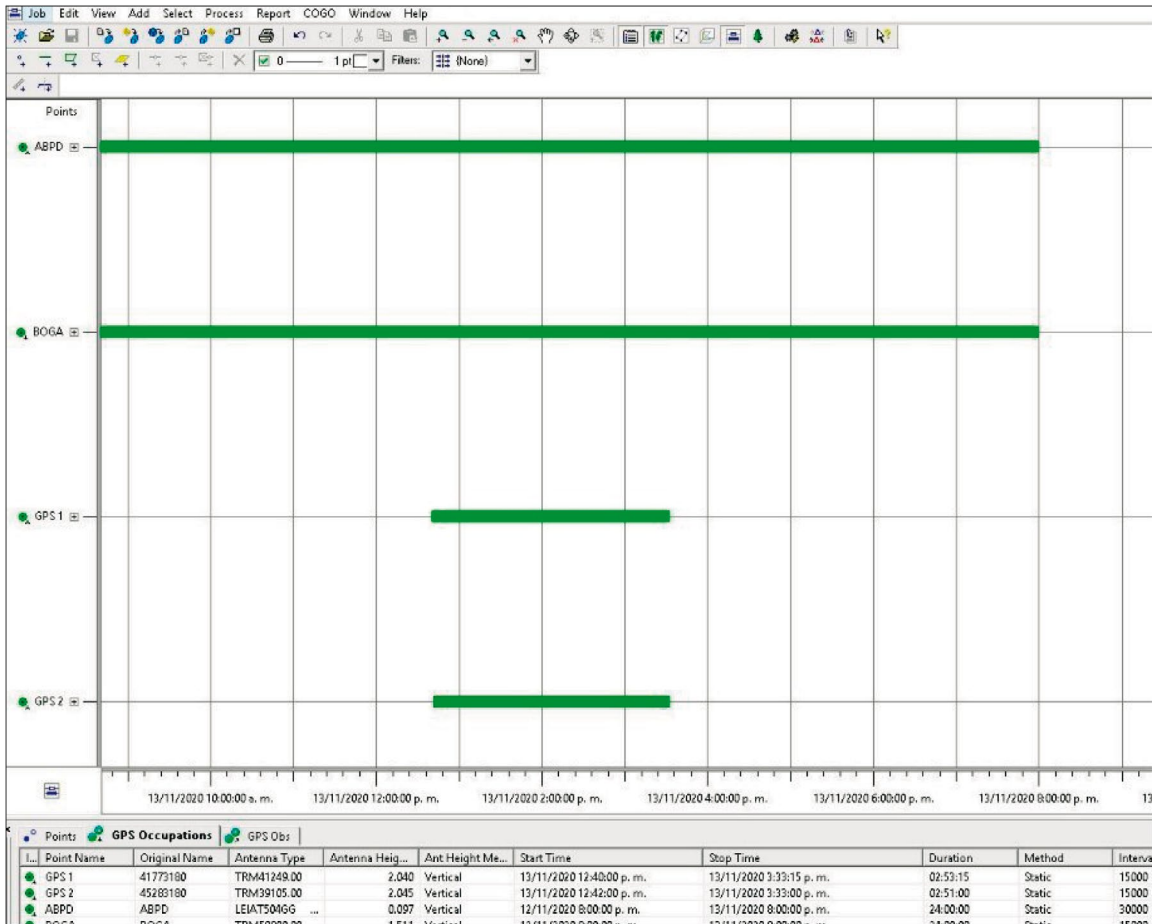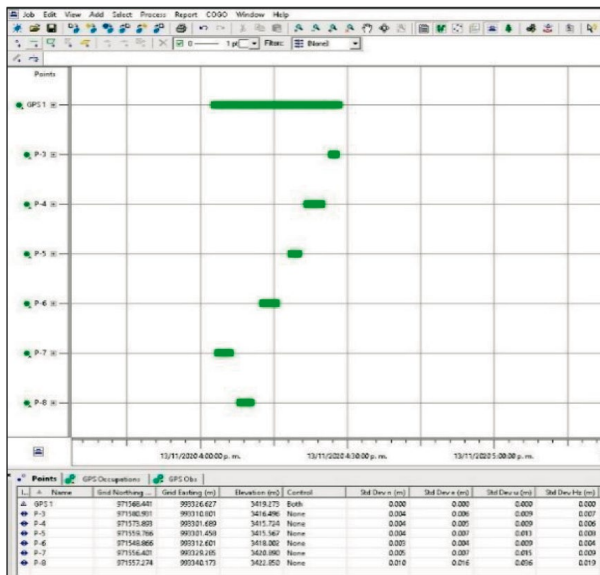*Tracking overlap time and vectors generated from BOGA and ABPD continuous stations*

Figure 4

Tracking overlap time between GPS base receiver 1 and the other vertices

The third method of capturing the geographical coordinates was carried outby means of topographic survey, by the simple radiation method, this method is the simplest system to measure a terrain (Torres & Villate, 2001), It consists of stationing at a known coordinates point from which the polar coordinates of the lifted points or vertices (angle, distance) are to be measured (López Cuervo, 1996) are measured based on the adjusted coordinates of the GPS 1 and GPS 2 vertices. The Leica TC 605 Total Station was located at the GPS 1 vertex and the horizontal angles were measured by setting 0 ° 0 '0" at the GPS 2 vertex, using a cane with its respective prism. From there, all the horizontal and vertical angles and distances to the vertices P-3, P-4, P-5, P-6, P-7 and P-8 were measured.

The fourth method of capturing the geographic coordinates was performed using a GARMIN

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GPSMAP 64s navigator receiver which was located on each of the vertices; GPS 1, GPS 2, P-3, P-4, P-5, P-6, P-7 and P-8 leaving a tracking time of three minutes and the geographic coordinate for each vertex was captured. The use of GPS navigational receivers is sufficiently useful for purposes in which horizontal position errors of up to 10 m are allowed, however, they are not recommended for topographic and cartographic surveys, even less when under the influence of peripheral obstruction, (Hasegawa & Yoshimura, 2003). Nonetheless, the polygon that simulates the minefield in this study is free of obstructions that may affect the signal, which encouraged the survey with this method.

The fifth method of capturing the geographical coordinates was carried out using a compass and tape measure, in this way an observer can obtain locations or coordinates of other points from their own location (Robinson et al., 2020). The measurement begins at the GPS 1 vertex, from there the azimuth is measured with the compass to the GPS 2 vertex and the distance with the tape measure. Then from the GPS 2 vertex the azimuth is measured with the compass to the P-3 vertex and the distance with the tape measure. This procedure is repeated for all vertices until the polygon is closed, it should be clarified that these azimuth data must be corrected by magnetic declination. Since the Middle Ages it has been known that there is a

difference between the geographic north and the magnetic north that the compass points to (Arneitz et al., 2014).

Results and Discussion

Results

Using the first capture method, static survey, with the two dual-frequency GNSS receivers, the latitude and longitude coordinates of the GPS 1 and GPS 2 vertices were determined, see Table 2. The GPS 1 vertex, after its respective post-processing, obtained a 95% confidence level and an average standard deviation for the two coordinates of 0.004 m. For the GPS 2 vertex, a 95% confidence level and an average standard deviation were obtained for the two coordinates of 0.004 m.

Using the second capture method, relative survey (stop & go). The GNSS receiver remained as a base at the GPS 1 vertex and the other receiver acted as Rover to acquire the coordinates of vertices P-3, P-4, P-5, P-6, P-7 and P-8, then of their respective post-processing. As can be seen on Table 3, a 95% confidence level was obtained and a standard deviation that varies between 0.004 m and 0.019 m depending on the point.

Table 2
GPS 1 and GPS 2 dual frequency GNSS coordinates

	Latitude	Longitude	Height	Std dev
GP	4°20'20,7	74°08'15,4	3419.2	0.004
GP	4°20'20,7	74°08'15,6	3419.8	0.004

Table 3
Coordinates determined with dual frequency GNSS receiver

	Latitude	Longitude	Height	Std dev
P	4°20'21,1	74°08'15,9	3416.4	0.007
P	4°20'20,8	74°08'16,2	3415.7	0.006
P	4°20'20,4	74°08'16,2	3415.5	0.008
P	4°20'20,0	74°08'15,9	3418.0	0.004
P	4°20'20,3	74°08'15,3	3420.8	0.009
P	4°20'20,3	74°08'15,0	3422.8	0.009

Using the third capture method, simple radiation surveying in which, as already mentioned, the horizontal and vertical angles and distances to the vertices are measured with the Total Station, from the GPS 1 vertex, as shown on Table 4. From the already known coordinates of GPS 1 and GPS 2, determined with the two GNSS dual-frequency receivers and the aforementioned data measured with the Total Station, it is possible to determine the geographical coordinates (Latitude and Longitude) of the vertices P-3, P-4, P-5, P- 6, P-7 and P-8, as shown on Table 5.

Table 4

Data measured with the Total Station

GPS	Horizontal	Vertical	Distance
GPS	0° 00″	95° 4953′	13.196
P-3	333° 28′59″	97° 36′04	20.36
P-4	307° 29′22″	97° 47′40	25.775
P-5	276° 19′73″	97° 49′27	26.962
P-6	240° 48′34″	92° 50′44	24.117
P-7	192° 37′34″	81° 59′59	12.499
P-8	154° 43′46″	78° 13′45	18.013

Table 5

Coordinates determined with simple radiation

	Latitude	Longitude
P	4° 20	74° 8′15,971
P	4° 20	74° 8′16,266
P	4° 20	74° 8′16,277
P	4° 20	74° 8′15,912
P	4° 20	74° 8′15,370
P	4° 20	74° 8′15,016

Using the fourth method, placing the GARMIN GPSMAP 64s navigator receiver, on each of the vertices, the respective geographic coordinates were obtained for each point, as shown on Table 6.

Table 6

Coordinates determined with navigator receiver

	Latitude	Longitude
P	4° 20′	74° 08′
P	4° 20′	74° 08′
P	4° 20′	74° 08′
P	4° 20′	74° 08′
P	4° 20′	74° 08′
P	4° 20′	74° 08′

By the fifth method, using the compass and the tape measure the azimuth and distance between each of the vertices was measured. It should be clarified that the starting point will be the GPS 1 vertex in the field, however, the starting coordinates to represent the angles and distances in the office were those determined with the navigator receiver for the GPS 1 vertex, since the objective of this the project was to recreate how measurements are currently made in Colombia and compare them with more precise methods. It is necessary to specify that the azimuth angle must be corrected by magnetic declination, which for this case because the location is -7 °, in the next section the comparison between the resulting data without correction and with correction will be made. The results of these measurements are shown on Table 7.

Table 7

Azimuth and distances measured by the fifth method

From	to	Azimuth	Magnetic decination	Distance m.
GPS	GPS	348°	341°	13.30
GPS	P-3	279°	272°	10.39
P-3	P-4	240°	233°	11.50
P-4	P-5	188°	181°	14.06
P-5	P-6	142°	135°	15.82
P-6	P-7	76°	69°	18.46
P-7	P-8	88°	81°	11.05
P-8	GPS	315°	308°	17.85

Table 8

Coordinates determined with azimuth and distance

	Latitude	Longitude	Latitude. Declination	Latitude. Declination
GPS	4° 20′	74° 08′	4° 20′	74° 08′15.500′
GPS	4° 20′	74° 08′	4° 20′	74° 08′15.640′
P-3	4° 20′	74° 08′	4° 20′	74° 08′15.977′
P-4	4° 20′	74° 08′	4° 20′	74° 08′15.275′
P-5	4° 20′	74° 08′	4° 20′	74° 08′15.283′
P-6	4° 20′	74° 08′	4° 20′	74° 08′15.920′
P-7	4° 20′	74° 08′	4° 20′	74° 08′15.361′
P-8	4° 20′	74° 08′	4° 20′	74° 08′15.007′

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After the graphical representation in the office of the azimuths, distances and known coordinate point (GPS 1), the coordinates of the resulting vertices can be determined, a pair of coordinates without correction due to magnetic declination and another pair of corrected coordinates, such as are shown on Table 8.

Discussion

As mentioned by Alegria et al. (2011), the development of decision systems based on the Geographic Information System, taking into account spatial and geographical aspects of mine action, has been of little importance for this community. In this sense, the precision of geographical coordinates has been a subject little studied and analysed, if considering that the minefields (CHAs) might be abandoned for different reasons such as an unfinished conflict or a global pandemic and as the coordinates are the only data stored/kept in the national authority or organisational databases, this will allow the minefield to be located again.

This means that all geographical information that allows the localisation and drafting of areas that determine the size of a minefield, as well as each of its vertices, must have the coordinates for latitude and longitude.

 For the Colombian case, the National Mine Action Authority in the document "National Standard of Non-Technical Survey", states in the section Mapping and Polygons Drafting, that all the georeferenced information of minefields must be stored in the geographic coordinates system, in decimal degrees and using the DATUM WSG84 (Descontamina Colombia, 2016). This means that all geographical information that allows the localisation and drafting of areas that determine the size of a minefield, as well as each of its vertices, must have the coordinates for latitude and longitude. More specifically in the report hazardous area and / or hazardous area confirmed document in which Descontamina Colombia collects detailed information on minefields, under section 9 (GEOGRAPHIC INFORMATION), there is a request to enter each vertex that makes up the polygon, in turn, its geographical coordinates (Latitude and Longitude) and the azimuth and the distance between vertices, see Figure 5 (Descontamina Colombia, 2018).

Figure 5

*Hazardous area report and / or confirmed hazardous area*

Currently in Colombia the geographic information referring to minefields is collected or captured basically by two combined methods; capture of the coordinates with commercial navigator GPS receivers and by using a compass and tape measure. Therefore, the main objective is to compare the spatial location and its differences with more precise techniques, as will be seen below by way of discussion.

Unquestionably the most accurate method is the first method by means of static survey, with the two dual-frequency GNSS receivers, where the two GPS 1 and GPS 2 points were determined, if the length between two receivers is not very long, and a majority of errors such as clock error, orbit error, atmospheric error, etc. can be eliminated through difference (Dong-feng et al., 2009). As mentioned by Correa Muñoz and Cerón-Calderón (2018), the static method allows greater precision in geodetic and topographic surveys using two receivers: one located in a control station with coordinates previously determined with high precision, and the other as a receiver at a point whose coordinates are to be determined, in this case two receivers to be determined GPS 1 and GPS 2. For these points, a precision of 4 mm was obtained in the Latitude and Longitude coordinates, as seen on Table 2. As for the other vertices (P-3, P-4, P-5, P-6, P-7 and P-8) with the second capture method, relative survey stop & go, the Latitude and Longitude coordinates were determined, with accuracies that vary between 4 mm and 1,9 cm, see Table 3. In this sense, these two methods are the ones that most accurately represent the polygon of the minefield, as shown see in Figure 6. From these coordinates the comparison with the other methods will be made.

Figure 6

Spatial location of the GNSS double frequency vertices
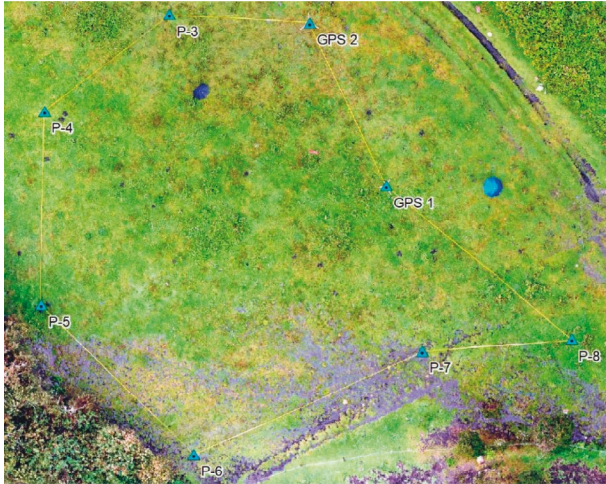
The coordinates obtained by the third method, topographic survey by simple radiation, are a control to the relative survey stop & go, since it was required to know the positional difference when tracking for a time of 5 minutes. As can be seen on Table 9, there is no positional difference between the coordinates of the GPS 1 and GPS 2 points, because the GNSS antennas and also the Total Station were located there. However, a difference is observed that varies between 2.82 cm, the smallest for P-6 and 12.29 cm, the largest for the P-5, thus guaranteeing that the stop & go method has an average of 4.62 cm of positional difference.

Table 9

Positional difference between GNSS and Station

GNSS	Difference	Station
GPS 1	0	GPS 1
GPS 2	0	GPS 2
P-3	3.26 cm	P-3
P-4	4.47 cm	P-4
P-5	12.29 cm	P-5
P-6	2.82 cm	P-6
P-7	5.99 cm	P-7
P-8	8.19 cm	P-8

Having said this, when comparing the coordinates obtained using the fourth method, several studies have identified the mean error of handheld GPS units from 95 cm to 760 cm

(Robinson et al., 2020). In this study using the GARMIN GPSMAP 64s navigator receiver, as shown on Table 10, the positional difference varies from 108.86 cm the smallest, to 406.24 cm the largest. Therefore, an average positional difference of 219.28 cm is obtained with this method.
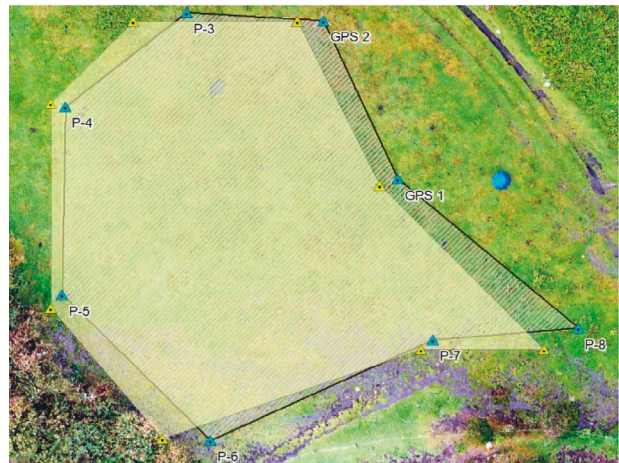
Table 10

Positional difference between GNSS and Navigator

GNSS	Navigator	Difference
GPS 1	GPS 1	141.22 cm
GPS 2	GPS 2	191.07 cm
P-3	P-3	406.24 cm
P-4	P-4	108.86 cm
P-5	P-5	129.97 cm
P-6	P-6	361.79 cm
P-7	P-7	115.27 cm
P-8	P-8	299.86 cm

Notwithstanding, it is worth mentioning that the technical specifications of the GARMIN GPSMAP 64s receiver have signal reception from two satellite constellations GPS and GLONASS (GARMIN, 2021), making the coordinates have greater precision, that is, in a receiver with a single constellation, as in the case of demining in Colombia, the precision tends to decrease. Figure 7 shows the positional differences between the vertices according to the GNSS (mark in blue) or Navigator method (mark in yellow), a difference that would increase if a receiver with several constellations is not used.

Figure 7

Positional difference between GNSS and Navigator

Differences in geographical coordinates of minefields in Colombia according to their acquisition method
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When comparing the coordinates obtained by the fifth method, using the compass and the tape measure, as shown on Table 11, the positional difference varies from 141.22 cm for the smallest to 336.52 cm for the largest. Having a positional difference of 235.73 cm on average. Figure 8 shows the positional differences between the vertices according to the GNSS (mark in blue) or Azimuth and Distance method (mark in red), data without magnetic declination corrections. The measured azimuth must be corrected for magnetic declination and deviation to obtain the true azimuth that is parallel to the geographic meridian (Iribar et al., 2014).

Table 11

Positional difference between GNSS and Azimuth & Distance

GNSS	Azimuth & Distance	Difference	Declination Difference
GPS 1	GPS 1	141.22 cm	141.22 cm
GPS 2	GPS 2	163.49 cm	24.9 cm
P-3	P-3	223.19 cm	22.27 cm
P-4	P-4	303.68 cm	31.29 cm
P-5	P-5	336.52 cm	35.5 cm
P-6	P-6	298.39 cm	28.80 cm
P-7	P-7	194.39 cm	106.98 cm
P-8	P-8	225.02 cm	35.63 cm

Figure 8

Positional difference between GNSS and Azimuth & Distance
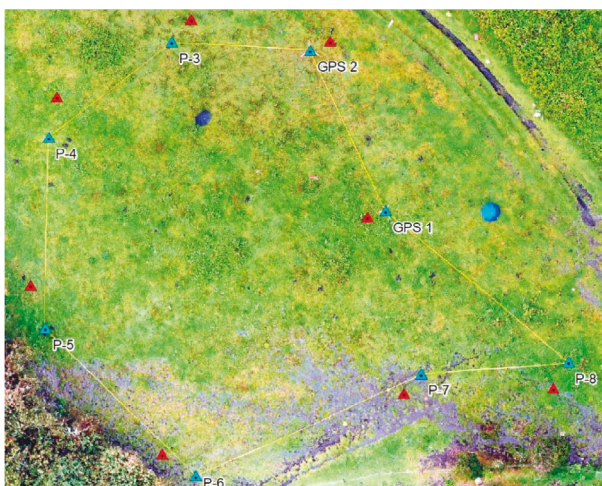
When comparing the coordinates obtained through the correction for magnetic declination, it can be observed that the positional difference compared to the most precise coordinates decreases notably in the order of 53.32 cm on average, with variations between 22.27 cm for the smallest and 141.22 cm for the greatest, remembering that the greatest difference is due to the fact that the starting point was the coordinate captured with the navigator receiver at the GPS-1 vertex, see Table 11. Figure 9 clearly shows a mark in purple for the reduction of the positional difference when performing the correction for magnetic declination, it can be seen more clearly when comparing with Figure 8, special emphasis is placed on this correction because demining organisations in Colombia do not perform the correction for magnetic declination, causing the geographic coordinates stored in the national IMSMA database to present a positional difference of 235.73 cm on average, per measured vertex.

Figure 9

Positional difference between GNSS and Azimuth & Distance with declination correction

Finally, it is important to review the differences in polygon areas found by the different methods, since humanitarian demining revolves around the cleared, decontaminated or cleaned square meters. Therefore, on Table 12 it can be seen that the most accurate GNSS method presents a difference of 3 square meters with the Total Station control method. In turn, the difference with the GPS receiver method is 6 m² and with the Azimuth & Distance method

it is 8 m². Despite this, as shown in Figure 10, Figure 11 and Figure 12, although the difference in area is greater, the positional accuracy of the Azimuth & Distances method makes it more suitable for simple use if and only if the respective magnetic declination correction is performed. With all this, it is recognised that there are several sources that influence the Earth's magnetic field and that affect the precision in the measurement of azimuths (Tomaštik & Tunák, 2015). It can also be concluded that the first vertex should be used with a GNSS receiver to have the best precision throughout the polygon.

Table 12

Areas of the polygon with the different methods

Method	Area m²
Station	713.58
GNSS	711.13
GPS	705.38
Azimuth	718.9016
Azimuth corrected	718.9014

Figure 10

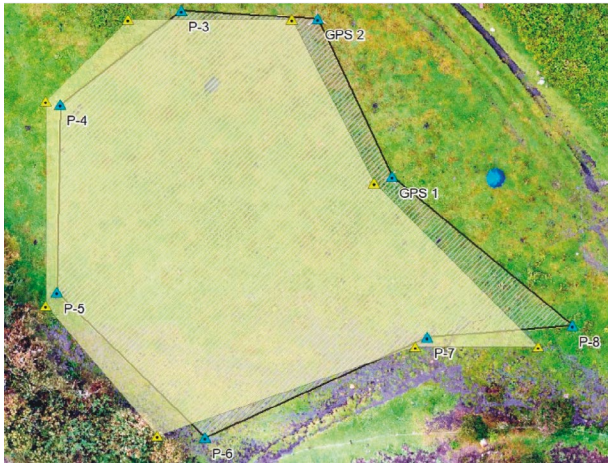*Positional difference areas between GNSS and Navigator*

Figure 11

Positional difference areas between GNSS and Azimuth & Distance
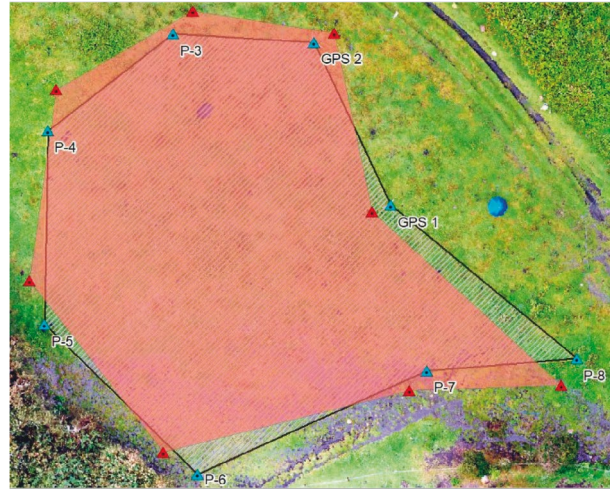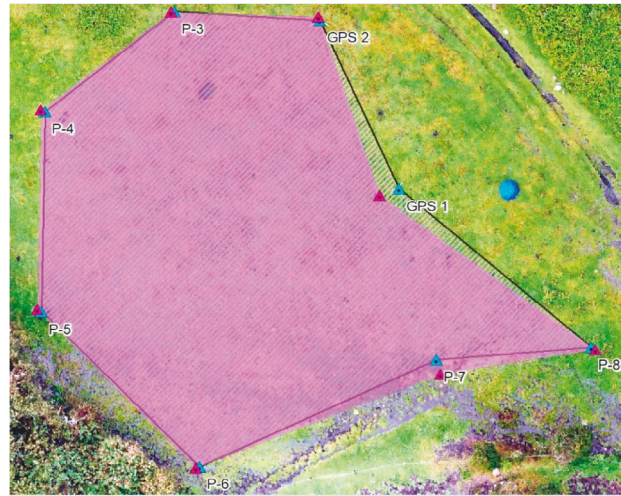

Figure 12

Positional difference areas between GNSS and Azimuth & Distance with declination correction

Conclusions

Currently, the collection of geographical coordinates of the minefields in Colombia is basically

done by a combination of methods between GPS navigator receivers for a starting point and compass (azimuth) and measuring tape (distance) for the remainder of the vertices that make up the minefield Confirmed Hazardous Areas – CHAs (Descontamina Colombia, 2016a). However, according to the results shown, for the starting points captured with commercial browsers, there can be more than 406.24 cm of difference with the real position on the ground of said vertex, propagating this error (Mikhail & Gracie, 2007) in subsequent azimuth and distance measurements. On the other hand, it is necessary to perform the magnetic declination correction to the azimuth measured with the compass, since this angle is measuring magnetic north, and the geographical coordinates are referred to the geographical north (O'Brien, 2009). The previous sections when performing the correction for magnetic declination the positional accuracy increases significantly, approaching in most of the measurements 30 cm from the real position, see Table 11. It should be noted that although to date there is no known accident within minefields derived from or as a consequence of inaccuracies in their delimitation, despite the ambiguity that this study shows regarding the shape and dimensions of the fields by not performing at least the correction for magnetic declination, in light of this reality that as a scientific contribution suggests that appropriate measures be taken to minimise the risk of accidents, this finding should induce the inclusion of a section within the general principles of non-technical demining studies in Colombia.

It is clear that the collection of coordinates in humanitarian demining must maintain the criteria of cost, speed and precision. Dual-frequency GNSS receivers are much more expensive and require specialised professionals in the field to post-process the data, this would raise the costs of the cleaning process of the CHAs. In addition, to capture all the vertices of the polygons of the CHAs, the antennas must be placed on them, a situation that is not possible in many cases, due to different factors such as dense vegetation or security strips due to suspicions of landmines, improvised explosive devices, among others, a situation in which only the points can be projected.

Hence, when the necessary tools are available, it is appropriate to capture the geographic coordinates of the CHAs starting point with dual frequency GNSS antennas, beginning at this point to start the polygon measurement, always correcting the magnetic declination of the data obtained with the compass, ensuring that the coordinates are referred to the geographic north. Finally, obtaining the geographic coordinates for the remainder of the vertices with a Geographical Information Systems (GIS) software. The usefulness of GIS as a strong analytical tool in assessing landmine risk in mine-impacted, should be further examined as means to help improving the quality of decision-making (Schultz et al., 2016).

For instance, one of the most renowned GIS software globally is ArcGIS, which the COGO tool can be used with, and allows plotting the respective azimuths in angles and the distance in meters (Esri, 2019). On the other hand, given that the history regarding the use of global positioning has warlike origins, which have mainly obeyed geopolitical interests, these could incite the reproduction of selective availability events (Laxminarayana et al., 2004) that as a consequence and by not making use of differential correction techniques or instruments to detect them such as GNSS antennas, could generate errors in the capture of coordinates (French, 1996). As a final remark, obtaining coordinates from minefields with higher precision and a further humanitarian demining process allows to transform the social development of rural communities. As a result, rural communities are able to go back to their rural daily lives after feeling threatened and enclosed. Thus, communities will commercialise their agricultural and cattle products in near-by markets, supporting the decrease in poverty. Added to this, natural resources will be recovered for further use in tourism or to improve the quality of life in these communities.

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