Identification of areas and elevated structures with the greatest amount of lightning impacts (Hotspots)

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***Abstract*—This work presents a methodology to determine the sites with the greatest amount of lightning impacts or strokes (hotspots) in cities such as Medellín, Barranquilla, Barrancabermeja, and Pereira. Starting from the identification and location of the highest structures and possible event places, 600m polygons were located on their surface, in this way, using the information of lightning activity (cloud to ground CG strokes) provided by the Colombian Total Lightning Detection Network with LINET technology during the years 2016, 2017 and 2018, the number of impacts per polygon was determined, which allowed to identify the hotspots in each of the study areas. Among the obtained results, it was found that the places where the elevated structures are located do not always correspond to the sites with the highest incidence of lightning and that these are primarily found in forested areas.**

Keywords-Lightning impacts, strokes, Ground Flash Density (GFD), keraunic level (NK), elevated structures, hotspots, LINET network.

I. INTRODUCTION

Studies show that of the 500 places with the highest lightning flash rate density globally (FRD), 283 are located in Africa, 87 in Asia, 67 in South America, 53 in North America, and 10 in Oceania. However, the site with the highest number of flashes per square kilometer per year is located on Lake Maracaibo to the north of Venezuela, where are recorded in total 233 Flashes/km^2/Year [1], followed by the hotspot previously found in The Congo Basin with a total of 205 Flashes/km^2/year [2]-[4].

Seven of the ten places with the highest lightning flash rate density in South America are in Colombia since its territory is located in the intertropical convergence zone where the southeast and northeast trade winds converge. The three mountain ranges that cross the country's surface serve as a natural barrier [1], which favors the formation of electrical storms between the Magdalena River Valley and the Catatumbo. In this way, it has been possible to conclude that there are around 8 million cloud-ground flashes per year [5].

Lightning flashes make the devices installed in elevated structures vulnerable and directly affect different aviation systems, telecommunication towers, transmission lines, sports spaces, or scenarios with high concentrations of people [6]. That is why understanding this natural phenomenon and its characterization is of utmost importance since they allow the design of more robust protection systems and the elaboration of plans oriented to protecting human lives and mitigating material damages and economic losses.

This paper determines the places with the greatest amount of lightning strokes in specific cities of the country like Medellin, Barranquilla, Barrancabermeja, and Pereira based on information provided by the Colombian Total Lightning Detection Network with LINET technology, starting from the location of possible lightning event places such as elevated structures, public places, and open spaces. It is proposed that the areas where the highest structures are located in each study city correspond to the sites with the highest incidence of lightning.

II. ANTECEDENTS OF THE STUDY OF LIGHTNING FLASHES IN COLOMBIA

A. Keraunic Level (NK) and Ground Flash Density (GFD)

The first characterization of lightning parameters was made between 1974 and 1988 with the implementation of the first map that indicates the keraunic level (KN) [5], which measures the number of stormy days per year in a given region but is not very useful in determining the places with the highest lightning activity. For this, the parameter of Ground Flash Density GFD is used, which measures lightning flashes per square kilometer per year as in (1).

$$GFD = k \times KN^{a} \quad (1)$$

Where **k** and **a** are valid constants for the places where they were developed. This parameter has been determined through direct measurements with lightning counting equipment or locators and empirical equations that related the Ground Flash Density with the keraunic level [5].

B. Colombian Total Lightning Detection Network with LINET technology

In September 2011, the lightning detection and location network (LINET) came into operation. This is a system made up of magnetic field antennas that operate in the low frequency (LF) and very low frequency (VLF) ranges and offers location errors below 300 m and detection efficiencies above 90% [6]. This technology provides for each stroke parameter such as the time of occurrence, latitude, longitude, the amplitude of the return current, polarity, and type (cloud to ground or intracloud) using arrival time techniques [7]. To obtain these data, more than 30 sensors were located in strategic places in the national territory where the separation between sensors varies between 120 to 420 km [7]. With this network, it has been possible to build updated maps of the Ground Flash Density (GFD) in Colombia, and important studies have been made in which the variation of GFD is related to the topography, showing that the sites with the highest lightning activity coincide with the foot of mountains and valleys [8].

III. METHODOLOGY

A. Selection of the departments and their respective cities of analysis

In Colombia, the narrow mountain ranges, mainly the Oriental (Northwest of Cundinamarca and Southwest of Boyacá) and Central (Northeast of Caldas, Southeast of Antioquia), and winds that approach them, mark the primary influence on the Ground Flash Density. Therefore, the first criterion taken into account to choose the cities under study was their geographical location, evaluating variables such as height above sea level, proximity to mountain ranges, and terrain topography.

According to the methodology proposed by NTC 4552-2 [9], three types of damage appear due to lightning flashes: injuries to living beings, physical damage, and failures in electrical and electronic systems. Considering the above, information on damages related to lightning flashes by department between 2010 and 2015, presented in [10], was analyzed, which served as the second evaluation criterion.

As a third criterion, the population and built area were taken into account since the hypothesis is that the sites where elevated structures are found correspond to the places with the highest incidence of lightning. By the above, Table I presents the chosen cities: Barranquilla, Medellín, Pereira, and Barrancabermeja.

TABLE I. CITIES WITH A POPULATION GREATER THAN 200,000 INHABITANTS FOR THE YEAR 2018. COORDINATES GEOGRAPHIC, HEIGHT ABOVE SEA LEVEL, GROUND FLASH DENSITY GFD, BUILT AREA IN KM^2 AND NEARBY AIRPORT.

City	B /quilla	Medellín	Pereira	B / bermeja
Latitude	10.99	6.25	4.81	7.30
Longitude	-74.8	-75.58	-75.70	-73.5
Population	1.232.766	2.508.452	476.660	201.616
Altitude	18	1495	1411	75
GFD	2.8	11.3	4	2.5
Area [km^2]	35	86	16	15
Airport	1	1	1	1

B. Selection of elevated structures and event locations, classification and geographic location

According to the occurrence, three large groups of lightning events are considered, impacts in elevated structures, public and open spaces. The events that affected tall structures occur in: houses and buildings, airports, and others. Public places correspond to the public highway, stadiums, beaches, parks, and cemeteries. Finally, the events in open spaces like farms, rivers, seas, and lagoons are based on the classification in [9].

Consequently, the highest structures were selected in the cities under study, where they are buildings, stadiums, hospitals, telecommunication towers, transmission structures, refineries, and airports, since, due to their height, they could be vulnerable to lightning impacts that can cause damage to the electrical systems that these structures possess.

C. List of impact data from the LINET network and geographic location using the QGIS software

The LINET network has records of cloud-to-ground lightning strokes in the national territory from 2011 to 2019. For this work, the years 2016, 2017, and 2018 were taken into account. Since the information provided covered a larger perimeter than the area of the city under study, those impacts that did not affect the analysis area were discarded using the (clip) tool of the QGIS program, which allows an overlay between the city map layer and the lightning strokes layer. In this way, the program allows spatially locating each lightning stroke on the study surface.

D. Location of 600-meter polygons in the municipalities to be analyzed

To characterize the areas with the highest incidence of cloud to ground lightning flashes, rectangular polygons with vertical and horizontal spacings of 600 meters were created over the municipality of interest. These measurements were taken because the LINET location network has a location error of 250 meters radius in which lightning strokes a specific area.

The location of these rectangular polygons was made using the (Create Grid) function that the QGIS program has, which allows the superposition between the grid layer and the city map layer. For the correct location of this tool, it was necessary to establish a city centroid. It should be noted that initially, a layer with circumferences of 300 meters in radius was implemented, resulting in errors in the characterization of lightning in the structures under study since they did not wholly record the number of impacts.

E. Obtaining the total impacts by Grid

Using the point analysis tool of the QGIS program, which allows each rectangular polygon to be enumerated and the number of impacts to be individualized, it was possible to locate the Hotspot areas and identify the number of lightning strokes at these sites.

Likewise, the number of strokes located within the 600-meter coverage of the rectangular polygon, where elevated structures located received impacts considered direct due to the network location error, was determined.

IV. Results

A. Barranquilla

Barranquilla is a coastal city located in the north of the country and has a keraunic level of 84.5 stormy days per year and a Ground Flash Density of 2.77 flashes per square kilometer per year. It is the city with the highest incidence of lightning recorded in the structures under study. Table II shows the highest structures in the city with their respective characteristics of latitude, altitude, height above sea level (HASL), and height of the structure. It is noteworthy that the Ground Flash Density in Barranquilla shows a particular behavior not observed in other cities.

TABLE II. Elevated structures analyzed in the city of Barranquilla with their respective latitude, longitude, height above sea level (HASL), and height H in meters.

Structure	Latitude	Longitude	HASL	H
Luxe Tower	11° 0'26.76"N	74°48'39.95"O	80	175
Mirage 57	11°0'29.21"N	74°48'33.18"O	78	163
Grattacielo	11°0'30.76"N	74°48'34.06"O	71	154
The Icon	11°0'25.09"N	74°48'20.31"O	55	148
Illuminatta	11°0'29.65"N	74°48'35.14"O	71	145
Solara Tower	11°0'28.50"N	74°48'34.14"O	73	142
Green Tower	11°0'21.98"N	74°48'11.13"O	50	101
Hotel B / keel	11°0'13.10"N	74°48'40.39"O	80	92
Malibu	11°0'12.14"N	74°48'44.80"O	90	80
Metrop. Stadium	10°55'36.93"N	74°48'2.37"O	51	43

Indeed, Barranquilla registered the highest incidence of lightning in the studied structures since it has high periods of rain due to movements in the different layers of the atmosphere. Additionally, this city is conditioned by its location, in an intermediate zone between two climatic extremes: the arid north (La Guajira desert) and the humid region to the south that begins in the middle Magdalena valley and is influenced by the Caribbean Sea., which favors a cyclonic movement and temperature [10]. This phenomenon causes the ocean to be charged with energy opposite the concentrated electrical charge in the clouds, generating lightning impacts that randomly affect the entire city (see Table III).

TABLE III. Elevated structures and specific sites with the highest incidence of lightning in the city of Barranquilla. The bold sites correspond to the highest structures. The amounts in parentheses correspond to the number of floors .

Pos	Type of area	Imp	Coordinate	H (m)
1	Commercial Zone	384	10.96 °, -74.87 °	5
2	Wooded zone	352	10.96 °, -74.87 °	-
3	Transmission struct.	291	10.96 °, -74.86 °	45
4	Transmission struct.	264	10.94 °, -74.83 °	45
5	Telecom. tower	213	10.94 °, -74.84 °	35
6	Urbanization (6)	207	10.95 °, -74.85 °	18
7	Commercial area	188	10.94 °, -74.83 °	10
8	Transmission struct.	188	10.94 °, -74.83 °	45
9	Urbanization (10)	176	10.99 °, -74.81 °	30
10	Pumarejo Bridge	176	10.95 °, -74.75 °	16
11	Urbanization (14)	167	10.99 °, -74.82 °	42
12	Urbanization (16)	136	10.99 °, -74.81 °	48
13	**Hotel B / keel (30)**	**107**	**11.00 °, -74.81°**	**92**
14	Urbanization (13)	103	10.99 °, -74 .81 °	39
15	**-Green Towers (34)** **-The Icon (50)**	**76**	**11.00 °, -74.80 °** **11.00 °, -74.80 °**	**101** **148**
16	**Grattacielo (52)** **-Mirage 57** **-Iluminatta** **-Solara Tower** **- Luxe Tower** **-Malibu Building**	**71**	**11.00 °, -74.80 °** **11.00 °, -74.80 °** **11.00 °, -74.80 °** **11.00 °, -74.80 °** **11.00 °, -74.81 °** **11.00 °, -74.81 °**	**154** **163** **145** **142** **175** **80**
17	**Metrop. Stadium**	**67**	**10.92 °, -74.80 °**	**43**
18	Urbanization	50	10.94 °, -74 °	-

With geographical coordinates 10.96°, -74.87°, Villa Celia has the highest incidence of lightning strokes, with 384 impacts. Likewise, transmission structures and communication towers are structures of a high incidence of lightning. In Barranquilla, two urban structures are highlighted: the Pumarejo Bridge and the Barranquilla Plaza Hotel since they presented a high amount of impacts of 176 and 107, respectively. The area known as Platanal El Peludo is a place with many buildings, such as Transmission Structures (items 3 and 4) and Telecommunication Tower (item 5), registering that they receive a large number of impacts of 291, 264, and 213, respectively. Compared with the structures under study (see the ones in bold) that have a higher height, it is evident that in this case, the amount of lightning strokes does not increase with the height of the structures.

Fig. 1 shows the geographical location of the elevated structures and hotspots of the city of Barranquilla. The number in the box means the position in the elevated structure table. The elevated structures and specific sites found are located by colors, study structures (purple color), forested areas (green color), buildings (blue color), urbanizations (orange color), transmission structures (red color), refineries (color coffee) and telecommunication towers (pink), respectively.

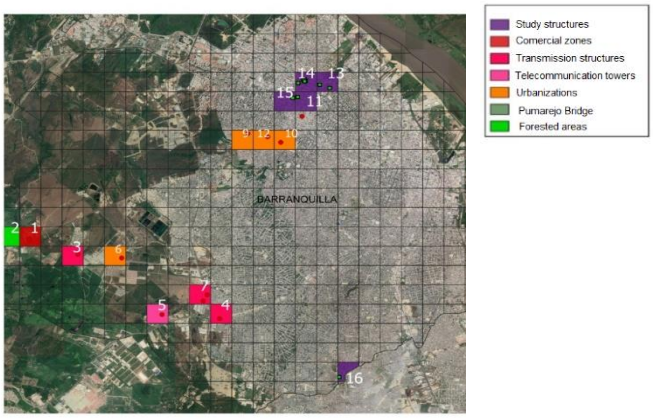

Fig. 1. Geographic location of elevated structures and specific sites with the highest incidence of lightning in the city of Barranquilla.

B. Medellín

Medellín is a city located in the northeast of the country. It has 158 stormy days per year and a Ground Flash Density of 11.3 flashes per square kilometer per year.

Medellín is the city with the highest incidence of lightning strokes in Colombia, considering its particular geography

facilitates this type of phenomenon. It is located in the geographical center of the Aburrá Valley. Additionally, the mountain ranges that enclose the city give rise to the formation of various microclimates. Indeed, being in the middle of mountains causes daytime warming to occur that favors the development of large cumulus clouds vertical [11].

This phenomenon generates more significant internal movement within the clouds, which have negative and positive charges, generating instability and producing two interrelated elements: lightning flashes and thunder. Based on the above, Table IV shows the tallest structures in Medellin, located towards the city center.

TABLE IV. ELEVATED STRUCTURES ANALYZED IN THE CITY OF MEDELLÍN WITH THEIR RESPECTIVE LATITUDE, LONGITUDE, HEIGHT ABOVE SEA LEVEL (HASL), AND HEIGHT H IN METERS.

Structure	Latitude	Longitude	HASL	H
Coltejer Building	6 °14'59.76"N	75°33'58.44"O	1492	175
Torre del Café	6 °14'55.60"N	75°34'7.52"O	1495	160
Cámara de comercio	6 °14'59.11"N	75°33'49.76"O	1505	139
Veracruz Tower	6 °11'2.13"N	75°33'40.80"O	1742	121
Q Concept Tower	6 °10'57"N	75°33'55.19"O	1721	111
La Libertad Tower	6 °14'3.25"N	75°34'29.03"O	1470	105
Popular Bank	6 °14'58.09"N	75°34'3.19"O	1494	102
Business Center Square	6 °12'26.03"N	75°34'19.28"O	1527	100
Colseguros Building	6 °15'2.20"N	75°33'48.60"O	1498	97
Atanasio Girardot Stadium	6 °15'24.31"N	75°35'25.56"O	1488	42

Table V shows the specific places where the highest incidence of lightning is evident in Medellín. The areas with the greatest amount of lightning impact are not located in the city's urban area. The mountainous areas have the most significant affectation because the city is the center of the Aburrá Valley, surrounded by mountainous areas where these phenomena occur. This area is known as Padre Amaya hill with geographic coordinates 6.27°; -75.68° and 417 impacts, where television, radio, military, and civil communications antennas are observed. See Fig. 2.

Additionally, other structures found during the investigation, as Towers Santa Helena and San Miguel and Prado, have lower heights than the structures under study (see the ones in bold), but they registered a large number of strikes: 95. In contrast, the Popular bank, with a height of 102 m, was struck by 72 impacts. A tower of the Metro Cable system with coordinates 6.277289 °, -75.531284 ° was found within the structures. Due to its geographical location in the mountainous area, it presented 65 lightning strikes, being the seventh zone with the highest lightning activity.

TABLE V. ELEVATED STRUCTURES AND SPECIFIC SITES WITH THE HIGHEST INCIDENCE OF LIGHTNING IN THE CITY OF MEDELLÍN.

Pos	Type of zone	Imp	Coordinate	H (m)
1	Padre Amaya hill	417	6.27 °, -75.68 °	30-45
2	Mountainous zone	365	6.27 °, -75.68 °	-
3	Wooded area	260	6.28 °, -75.68 °	-
4	Wooded area	100	6.28 °, -75.69 °	-
5	- Santa Helena Tower (21) -San Miguel Tower (15) -Prado Tower (21)	95	6.25 °, -75.55 ° 6.25 °, -75.56 ° 6.25 °, -75.55 °	60-65 45-50 62-65
6	**Popular bank**	**72**	**6.24 °, -75.56 °**	**102**
7	-Building under construction (18) - Metrocable tower	65	6.18, -75.65 6.27 °, -75.53 °	50-55 -
8	Nuevo Naranjal Tower (22)	54	6.25 °, -75.58 °	50-55
9	El conquistador (11)	53	6.24 °, -75.58 °	27-33
10	Torres de Compostela (12)	50	6.22 °, -75.60 °	33-36
11	**-Coltejer Building -Cámara de comercio -Colseguros Building**	**49**	**6.24 °, -75.56 ° 6.24 °, -75.56 ° 6.25 °, -75.56 °**	**175 139 97**
12	**Business center Square**	**33**	**6.20 °, -75.57 °**	**100**
13	**Veracruz Tower**	**31**	**6.18 °, -75.56 °**	**121**
14	**Q concept Building**	**30**	**6.18 °, -75.56 °**	**111**
15	**Torre del café Building**	**26**	**6.24 °, -75.56 °**	**160**
16	**Atanasio Girardot Stadium**	**24**	**6.25 °, -75.59 °**	**42**
17	**La libertad Tower**	**22**	**6.24 °, -75.57 °**	**105**

Fig. 2. shows the geographical location of the elevated structures and hotspots in Medellín.

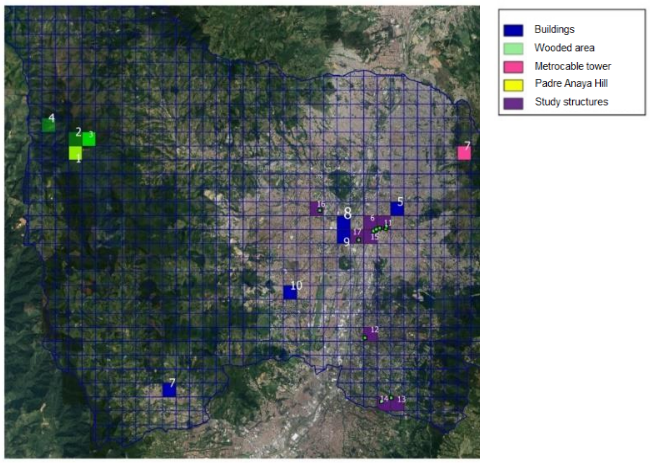

Fig. 2. Geographic location of elevated structures and specific places with the highest incidence of lightning in Medellín.

C. *Pereira*

Pereira is a city in mountainous Colombia's coffee region of western Colombia with a keraunic level of 84.5 stormy days per year and a Ground Flash Density of 4 flashes/km^2/year.

For the analysis of this city, ten elevated structures were taken into account: the Matecaña International Airport, the Hernán Ramírez Villegas Stadium, and buildings considered elevated structures in the city. See Table VI.

TABLE VI. ELEVATED STRUCTURES ANALYZED IN THE CITY OF PEREIRA WITH THEIR RESPECTIVE LATITUDE, LONGITUDE, HEIGHT ABOVE SEA LEVEL (HASL), AND HEIGHT H IN METERS

Structure	Latitude	Longitude	HASL	H
El Otún newspaper	4 °48'44.53"N	75°41'41.01"O	1415	95
Pinares de Alameda Building	4°48'3.83"N	75°41'8.86"O	1428	90
Pinamar E / C Building	4°48'9.63"N	75°41'5.33"O	1423	80
Comercio Bank	4°48'48.66"N	75°41'38.68"O	1413	75
E / C Trilogy	4°48'0.98"N	75°41'33.96"O	1424	65
Perla del Otún Building	4°48'44.94"N	75°41'41.12"O	1418	63
Pinares Campestre Building	4°48'2.45"N	75°41'5.73"O	1438	63
Parque Bolívar Building	4°48'55.15"N	75°41'40.09"O	1425	60
Villegas Stadium	4°48'16.82"N	75°45'8.77"O	1269	26
Matecaña Int Airport.	4°48'54.40"N	75°44'10.90"O	1343	28

Table VII presents the study of the zones with the greatest amount of lightning impacts like urbanizations, banks, telecommunication towers, transmission structures, the Hernán Ramírez Villegas Stadium, the Matecaña International Airport, and forested areas. As we can see, the area with the highest amount of lightning strokes is a wooded area called Pueblo Nuevo with 100 impacts. This is far from the city with geographic coordinates of 4.84°, -75.72°. The same behavior is seen for the first three positions of table VII, which allows us to conclude that in this city, the sites with the greatest amount of lightning impacts do not correspond to the ones where elevated structures are located. Additionally, it was possible to identify a transmission tower with 43 impacts.

TABLE VII. ELEVATED STRUCTURES AND SPECIFIC SITES WITH THE HIGHEST INCIDENCE OF LIGHTNING IN PEREIRA.

Pos	Type of zone	Imp	Coordinate	H (m)
1	Wooded area	100	4.84 °, -75.72 °	-
2	Wooded area	66	4.73 °, -75.60 °	-
3	Wooded area	60	4.78 °, -75.70 °	-
4	Building (11)	60	4.80 °, -75.68 °	33
5	Núcleo Tower (8)	60	4.80 °, -75.68 °	24
6	**Pinares de alameda**	**51**	**4.80 °, -75.684 °**	**90**
7	Building (8)	50	4.80 °, -75.680 °	24
8	Telecom. tower	48	4.81 °, -75.76 °	40
9	Building (7)	46	4.80 °, -75.72 °	21
10	Building (9)	44	4.80 °, -75.69 °	27
11	Transmission Tower	43	4.79 °, -75.67 °	40-45
12	Building (21)	43	4.82 °, -75.69 °	63
13	**Pinares campestre**	**43**	**4.80°, -75.68°**	**63**
14	**-Perla del Otún** **-Triología** **-Comercio Bank** **-Parque Bolívar**	**41**	**4.81 °, -75.69 °** **4.80 °, -75.69 °** **4.81 °, -75.69 °** **4.81 °, -75.69 °**	**63** **65** **75** **60**
15	**Pinamar Building**	**27**	**4.80, -75.68°**	**80**
16	**-El Otún newspaper** **-Villegas Stadium** **-Matecaña Airport**	**25**	4.81 °, -75.693 ° **4.81 °, -75.69 °** **4.81 °, 4.81 °**	60 **95** **60**

Fig. 3. shows the geographical location of the elevated structures and hotspots in the city of Pereira.

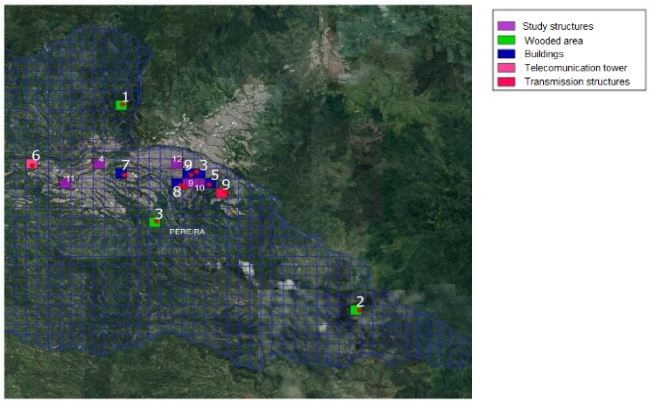

Fig. 3. Geographic location of elevated structures and specific sites with the highest incidence of lightning in Pereira.

D. *Barrancabermeja*

Barrancabermeja is a city located on the shore of the Magdalena River in the west of the department of Santander. It has a keraunic level of 84.4 stormy days per year and a Ground Flash Density of 10 flashes/km^2/year. Table VIII shows the elevated structures in Barrancabermeja.

TABLE VIII. ELEVATED STRUCTURES ANALYZED IN BARRANCABERMEJA WITH THEIR RESPECTIVE LATITUDE, LONGITUDE, HEIGHT ABOVE SEA LEVEL (HASL), AND HEIGHT H IN METERS.

Structure	Latitude	Longitude	HASL	H
Super Star Hotel	7°3'37.62"N	73°52'9.40"W	88	48
Terzetto Living	7°3'37.59"N	73°52'3.06"W	84	43
Portobello Cond	7°3'51.33"N	73°51'16.83"W	85	43
Plaza San Pedro	7°4'17.51"N	73°51'26.26"O	81	43
Barvento	7°3'39.24"N	73°51'36.93"O	85	41
Park 48	7°3'31.63"N	73°51'18.62"O	84	40
Palmetto Cond.	7°4'32.33"N	73°51'3.27"O	86	37
San Francisco Towers	7°3'38.29"N	73°50'54.16"O	80	33
Vivero Club	7°2'26.71"N	73°50 ' 6.48"W	96	33
San Silvestre Shopping Mall	7°4'1.65"N	73°51'28.27"W	83	27

From the data analysis of elevated structures, it was determined that the place with the greatest amount of lightning impacts is a wooded area with 99 strokes. This area is called Chinchorrera and is located in the limits of Yondó and on the banks of the Magdalena River. In this area, a high density of forested areas is concentrated, it was called this way since it is not possible to determine the existence of structures in this site and the abundance of vegetation is visible since the exploration through Google Street View does not allow to see more in detail the terrain.

Table IX shows the areas with the highest lightning activity in the municipality organized from highest to lowest, highlighting the areas with the elevated structures again in bold. From the obtained results, it can be seen that the San Francisco Tower was the structure with the highest amount of lightning impacts of the structures under analysis with 62 strokes. However, it does not correspond to the highest structure of those analyzed, such as the 48-meter high Super Star Hotel, which presents 46 impacts. This shows that the tallest structures are not always those with the highest incidence of lightning, presenting a behavior similar to that of the city of Pereira.

TABLE IX. ELEVATED STRUCTURES AND SPECIFIC SITES WITH THE HIGHEST INCIDENCE OF LIGHTNING IN THE CITY OF BARRANCABERMEJA.

Pos	Type of area	Imp	Coordinate	H (m)
1	Wooded area	99	6.87 °, -74.06 °	-
2	Wooded area	90	6.91 °, -74.02 °	-
3	Wooded area	85	6.91 °, -74.01 °	-
4	Wooded area	80	6.90 °, -74.00 °	-
5	Transmission Tower	76	7.08 °, -73.89 °	40-45
6	Urbanization	76	7.05 °, -73.81 °	10
7	Wooded area	65	7.07 °, -73.83 °	20
8	Wooded area	63	7.10 °, -73.84 °	-
9	-Transmission Tower **-San Francisco Tower** -Telecom. Tower -Building (8) -Refinery	62	7.07°, -73.89 ° **07.06 °, -73.84 °** 07.06 °, -73.84 ° 07.06 °, -73.84 ° 7.07 °, -73.88 °	40-45 33 40 24 -
10	Urbanization	58	7.07 °, -73.85 °	-
11	-Building (5) **-Plaza San Pedro**	55	7.07 °, -73.85 ° **7.06 °, -73.84 °**	15 **43**
12	**-Barvento Building** **-Palmetto Cond** **- San Silvestre SM**	**52**	**7.06 °, -73.86 °** **7.07 °, -73.85 °** **7.06 °, -73.85 °**	**41** **37** **27**
13	Urbanization (5)	50	7.06 °, -73.86 °	15
14	**Super Star Hotel**	**46**	**07.06 °, -73.86 °**	**48**
15	**Terzetto Living**	**44**	**7.06, -73.86 °**	**43**
16	Transmission Tower	43	7.08 °, -73.90 °	40-45
17	**-Portobello Cond** **-Vivero Club**	**38**	**7.06 °, ° -73.85** **7.04°, -73.83 °**	**43** **33**
18	**48Park**	**38**	**7.05 °, -73.85 °**	**40**

Fig. 4. shows the geographical location of the elevated structures and hotspots of Barrancabermeja.

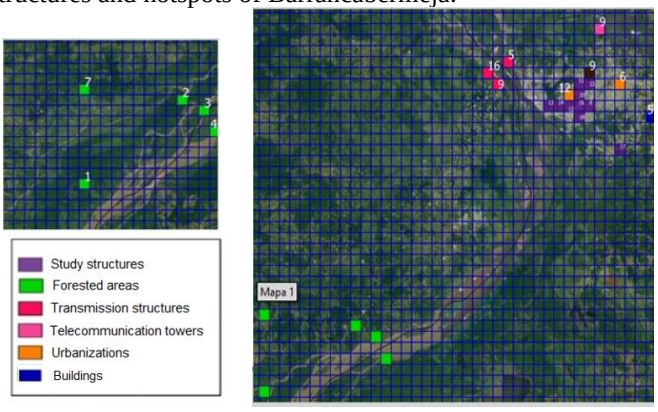

Fig. 4. Geographic location of elevated structures and specific sites with the highest incidence of lightning in Barrancabermeja.

V. CONCLUSIONS

With the lightning information sources provided by the LINET network, it was possible to verify that the tallest structures do not always correspond to the sites with the greatest lightning activity. Also, although the first hotspots in the study cities are far from the urban area, as observed in Medellín, Pereira, and Barrancabermeja, there is a marked influence of urban planning in determining the sites of high lightning activity, which allows us to infer that urban planning and the presence of elevated structures increase lightning activity.

From the areas under study, Medellín has the highest activity of cloud to ground lightning flashes in the periods 2016, 2017, 2018, with 417 impacts. This site is called Cerro Padre Amaya, with geographic coordinates of 6.27°, -75.68°. Considering that it is a city with geography that facilitates this type of phenomenon, it is located in the geographical center of the Aburrá Valley and is surrounded by high mountains. This city presents a particular behavior since its first four hotspots are located in the same area.

The elevated structures with the highest amount of lightning impacts belong to Barranquilla, specifically the Barranquilla Plaza Hotel with 107. In this city, the transmission and telecom structures have the highest impacts compared to the other cities' understudy. They are attributing this result to the fact that the city is a semi-arid area where the northeast trade winds blow parallel to the coast, absorbing moisture, pushing it towards the interior of the Caribbean Region to the foothills of the Andes mountain range, where produce abundant rainfall.

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