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Soundscape mapping in urban context using GIS techniques

Case study area: 11th district, Budapest (Hungary)

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Contents

Abstract

Soundscape maps are based on the perception of sounds and are useful to describe an acoustic environment more accurately than using quantitative terms. I aimed to study soundscape perception, that is the collection of acoustic data in an urban environment and the analysis and visualization with GIS techniques to generate soundscape maps.

This research aims first to establish a method for representing soundscape through sound-related maps and secondly to correlate the sound source with the urban context in terms of specific activities. Soundscape data were collected in 137 points during 5 working days in two-time slots: 9:00 to12:00 in the morning and 2:00 to 5:00 in the afternoon. Afterwards, the soundscape variability (including technological, and natural or anthropic sounds was represented by maps using the Kriging interpolation technique.

GIS results show how spatial variation of a sound source in the urban soundscape is closely related to the urban context and activities.

The core of the thesis is formed by three parts: soundscape, urban context and online web application.

Focusing on the representation of soundscape and urban context using GIS technique. Based on the collected data, I created an online web application where we can find all the thematic Maps maid in this research I also created a sound map using Google My Maps, showing the location of 137 points of measurement with sound and pictures representing the selected places.

Keywords: soundscape, sound source, urban context, Web GIS, sound map.

Chapter 1 Introduction

Before beginning the presentation of my work, I introduce the main concepts of the soundscape and urban context.

Soundscape has recently been defined as an acoustic environment that is perceived or experienced. Such this definition is comparable (similar) to one given by the European landscape convention that defines landscape in similar terms, hence there is a general agreement that soundscape as well as landscape concerns to the human perception of the environment **[1]**.

Soundscape maps based on the perception of sound are necessary to describe an acoustic environment more accurately, Current is a study of soundscape perception which employs GIS techniques to generate soundscape maps in various urban settings including three categories of sounds (technological, anthropic, and natural sound). The definitions of those categories of sounds are: technological sounds are those generated by human activities in daily life (electro-mechanical, social communal and motorized transports) and this kind of sounds change between cities. Anthropic sound is also generated by humans and it increases in those places within the city, where the markets and commercial activities are located, These two categories of sounds (technological and anthropic), in determined by the population density and diversity of activities and has different effects in the cities. Finally, the last category is natural sounds. These sounds are not generated by human activities, it can be generated by nature (wind, rain, and water sound, etc) and by domesticated animals (dogs, cats, etc). This type of sound makes cities beautiful and helps human activities, unlike the two first categories **[2].**

An urban context can be defined broadly based on population density, or a group of spaces that possess formal and functional behaviour in a specific time. It can also be defined as the urban fabric of the city consisting of different layers of buildings and movement axes in different periods that reflect different urban and civilization values, determining the quality of urban life in the modern cities **[3].**

1.1 History of sound mapping

Scientists created an interactive map of all the emotional sounds that humans make, for example: those spontaneous sounds we make to express a pain (Aayy), elation (woohoo) or realization (oooh). In this framework a specific example is, an interactive sound map appeared for the first time in 2019 that produces more than 2000 sound for 24 groups expressing different feelings. The results were published online in the American Psychologist Journal and the interactive audio map is available at this link:

<https://s3-us-west-1.amazonaws.com/vocs/map.html#modal> **[4].**

Sound maps as we know it have some advantages: they help persons with low vision to reach their destination when they wish to visit any place. These types of maps are the maps for blind and visually impaired people. These maps constantly remind to get help from the detailed voice navigation to find the way **[5].**

The world is developing and currently, those kinds of maps are digital with access to Android and IOS devices and it can be activated by using a maps application and setting the navigation option, which is helped sounds. As we know, we can hear many different sounds in our cities and some of them have a different effect, The acoustic environmental of our cities are characterized by some categories of sounds which can be naturally represented by animals, voices and some natural elements like wind, rain and sound water, as well as human sounds generated by human beings or the period of their existence on the Earth, like human speech, human singing and human laughter. Another category is the technological sound, which is also generated by human activities, e.g the transport used by people in their daily life **[6].**

2.1 International experiences on sound maps

Mapping sounds is a way of placing sound data record into a map and evaluate the acoustic environment. It means that we can hear sounds recorded in different places. The sounds can be classified into categories (natural, anthropic and technological), and each of those categories represent different sound experiences, some of them are beautiful and fun. And others have negative effects too. Connecting different sounds to the map help understanding the world **[5].**

There are many experiences and projects presenting sound mapping and some case studies in cities. One example is the research project that is available at this link:
<https://www.researchgate.net/publication/322983533_Soundscape_mapping_in_environmental_noise_management_and_urban_planning_Case_studies_in_two_UK_cities>

In this project, the study area selected in Sheffield covers the inner city centre since it combines many different lands uses and can also be considered a typical example of a post-industrial average-sized European city. The area is characterized by different land-use, streets, the main road, and other infrastructures, The method of collecting data in the study area began with the selection of 90 points of measurement. The result was to create a sound map with three categories of sound sources (technological, anthropic and natural sounds), as it can be seen in Figure 1. Areas on the top left side are mainly covered by Universities buildings, parks and residencies. The author created a sound profile too **[7].**

as we can see in Figure 2, combining the three groups of sound sources (natural, anthropic and technological sounds). They classified and refer to the minimum and maximum values of each sound source by a different colour.

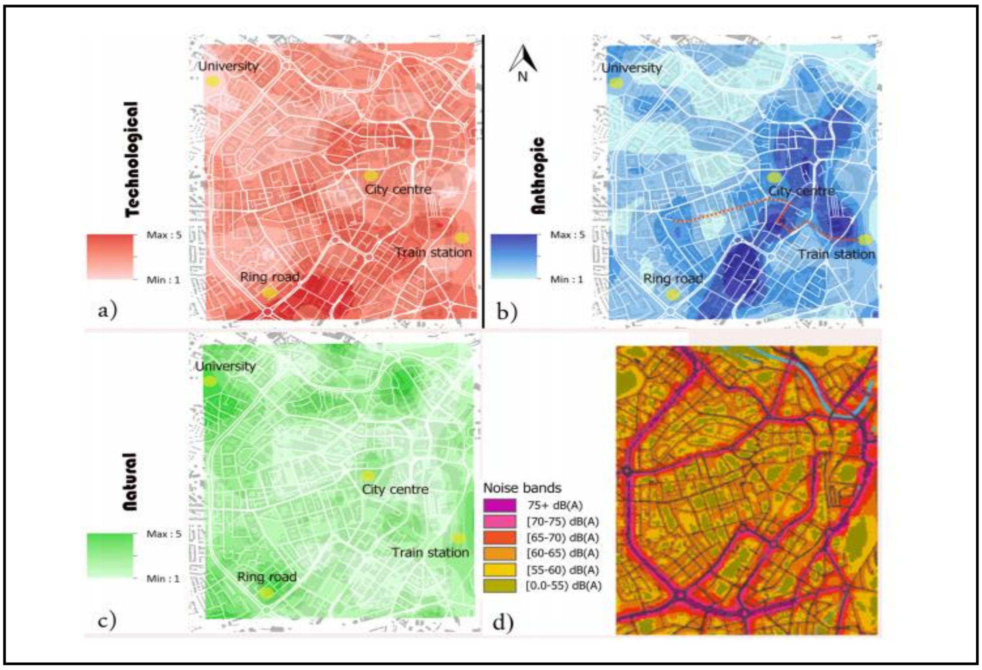


Figure 1: Representation of spatial variability of sound sources with three different categories of sound (natural, anthropic and technological)

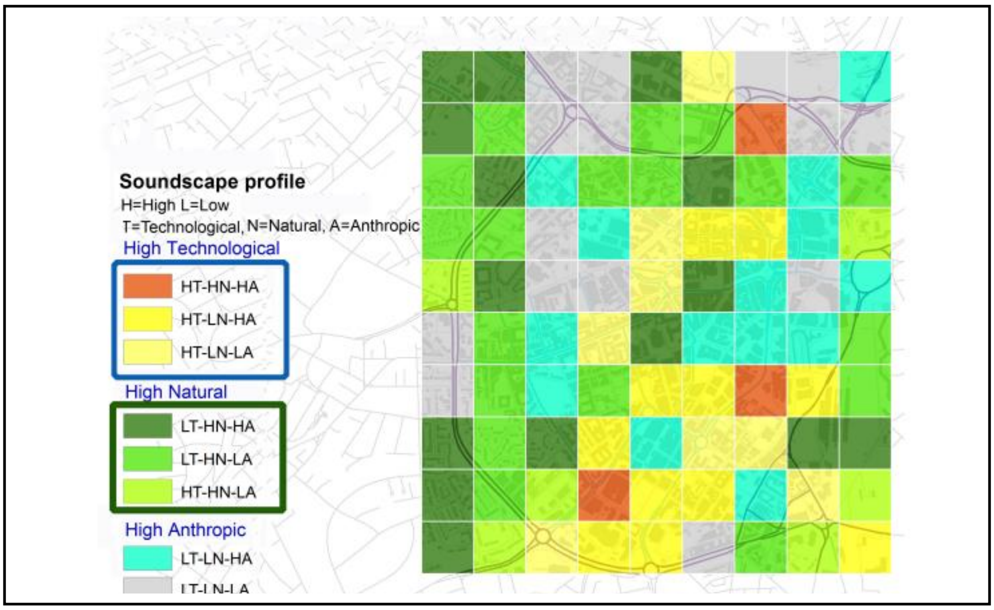


Figure 2:Soundscape profile representing High (H) and Low (L) profile sound of different categories of sound sources based on maximum level sound

Figures 1 and 2 are available in this article: <https://www.researchgate.net/publication/322983533_Soundscape_mapping_in_environmental_noise_management_and_urban_planning_Case_studies_in_two_UK_cities >

Chapter 2 Using a GIS and web application

2.1 Definition of GIS and web application

Geographical Information Systems (GIS) is a technology that provides the means to collect and analyse geographic data and visualize data and information related to a location on the surface of the Earth **[8].**

There are many different definitions for Geographic Information Systems, For example, GIS as a database system developed for georeferred data analysis and representation using mainly maps. In this case, GIS gives all the tools needed for data analysis and representation, as the use of map layers for the organization of data. As early as 1999, Martindale emphasize that GIS can be defined as an application that provides a visual interpolation of data stored in a database which can and then represent it visually in mapped format and can be used for communication **[9].**

A digital map is generally of much greater value than the same map printed on paper because the digital version can be combined with other sources of data for analyzing information with a graphical presentation. The advantage of GIS software makes it possible to synthesize a large amount of different data, combine different layers of information to manage and get back the data in a more useful method. For example, GIS can provide powerful means for scientists specialized on agriculture, to offer a better service to the farmers and farming community in helping and answering their queries, collaboration to take better decisions to implement planning activities for the development of agriculture. GIS software has also enabled users to see spatial data in a proper format, as well as Web GIS became a cheap and easy way to disseminate geospatial data and processing tools **[10].**

2.2 Functions

The functions of GIS describe the steps that have to be taken to implement a Geographic Information system, These steps have to be followed to obtain a systematic and efficient.

The steps involved five different stages working with GIS. (Diagram 1) **[11].**

1. Data capture: often comes from many sources, mainly from survey, digitization or scanning.
2. Data compilation: Stage following e.g the data digitization of the map. Users can complete the compilation phase connecting all spatial features to their attributes and cleaning up the errors of the data conversion process.
3. Data storage: once those data have been digitally completed, the data storage is based on a generic data model (raster or vector) that is used to convert a map data into digital form.

4. Data manipulation: Tools that can be used e.g for coordinate change, projection change and edge matching (allowing GIS to liminate irregularities between map layer and adjacent map sheets).
5. Data analysis: Joint use of spatial and non-spatial attributes for the study of different phenomena and processes in the real world. Results are represented graphically, mainly using maps.

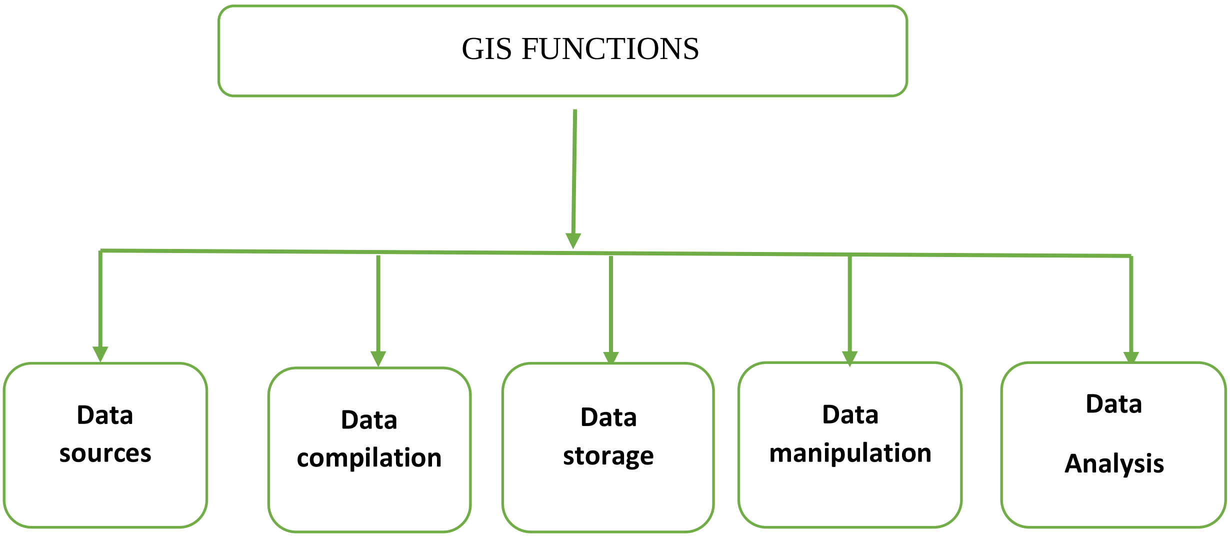


Diagram 1: Description of the steps that have to be taken to implement a GIS

2.3 Uses

Geographic Information systems (GIS) can be used in multiple and different fields, being present in almost all branches of the society (economic, social, etc). GIS can be also used in many different fields, I cite only some main, for examples as agriculture, urban planning, different sectors of business life and surveying **[12]:**

1. Agriculture: GIS can be used to create more effective and functional farming techniques, analyzing soil data to determine what is the best crop to be planted in the soil and how to do it for a higher benefit GIScan be also used for maintaining nutritional levels to achieve the best product for the type planted and this help to increase food production and to avoid a food crisis in the world.
2. Urban planning: GIS can be used for the analysis of urban population growth and ways of urbanization expansion, as well as for finding more appropriated places for urban development.

3. Business: GIS can be used for managing business information based on its location and it is used in many enterprises for the tracking of customers location, optimization of sales territories and others.
4. Surveying: GIS can be used to manage the planning aspect of a surveying project. GIS tools can be also used for the analysis of GNSS data and to estimate areas and make digital maps.

In this research, I focused on the use of Web GIS for the representation of collected data. Web GIS is used in fields that are similar to those in the most traditional GIS, some of them listed above.

Chapter 3 Urban contexts: creating the base map

3.1The urban section and elevation (topographic profile)

A topographic profile was created as we can see in Figure 3, which shows two cross-sections made in different places with DEM elevation.

The elevation data was collected using Garmin 62 GPS in 137 points of measurement as we can see in Figure 7 and Annexe 1. Elevation data was transferred to Arc Map version 10.6.1 to create a database. Using Arc Toolbox I created the DEM elevation profile for the case study area and later I made two cross-sections of different places.

The first section as shown in Figure 3a represents a higher elevation from the West area (Budapest Kelenföld) and it decreases going to the East (Danube river).

The second section as shown in Figure 3b represents a low elevation in the middle of the case study: it became higher on both sides North area (Citadella) and the South area (Kelenvölgy) where the residential area is located.

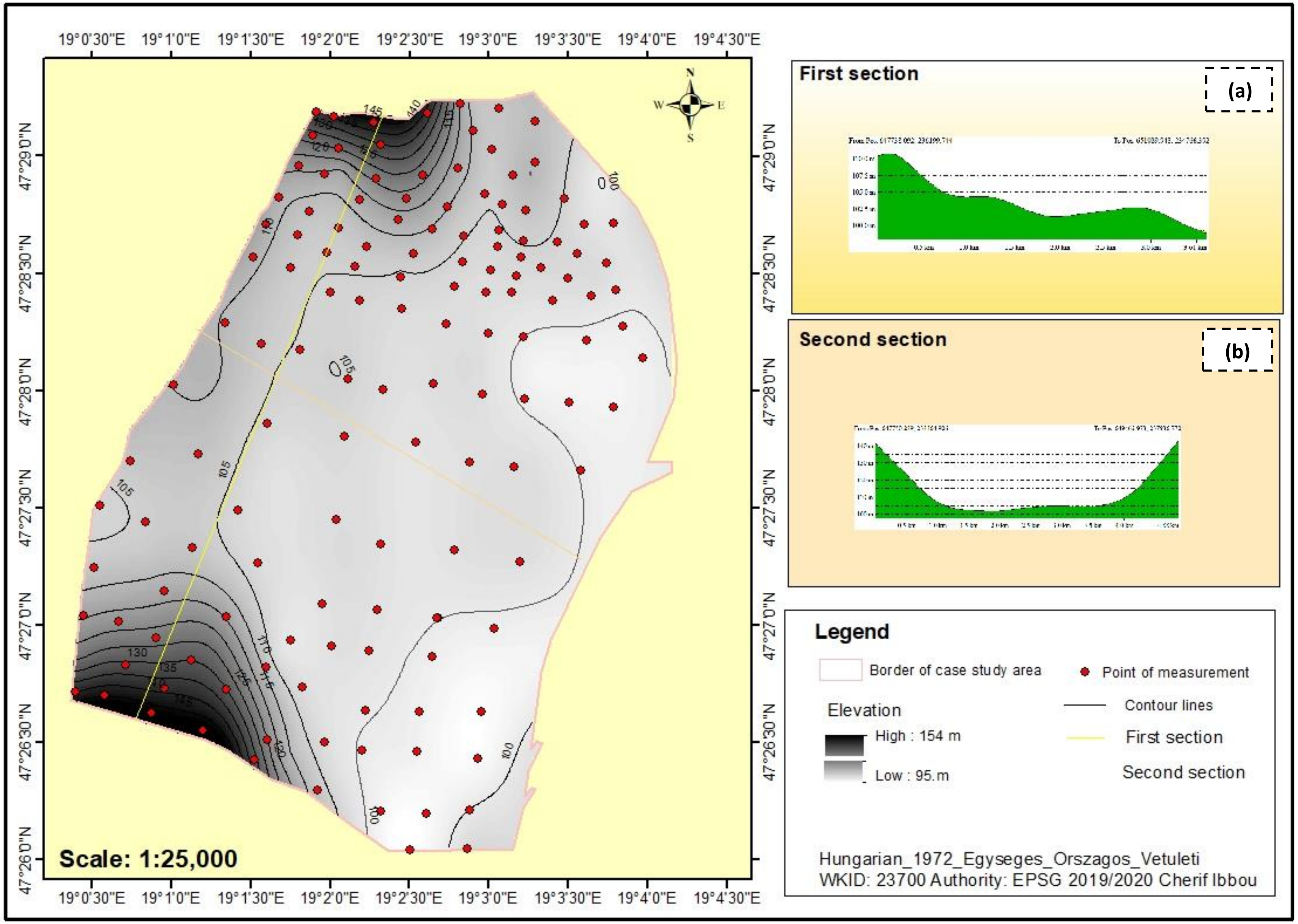
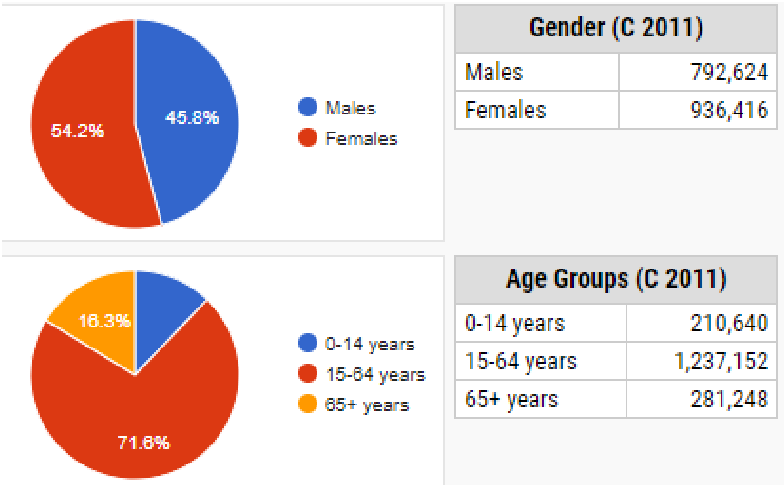


Figure 3: Map of topographic profile showing tow sections from different places (Derived from Arc Map 10.6.1 and Global Mapper)

3.2 Urban profile

Budapest's population is 1,768,073 inhabitants currently; while in 1950, the population of the city was 1,617,845. Budapest has grown by only 22,159 inhabitants since 2015, which represents a 0,25% annual change These population estimates and its projection come from the latest revision of UN World Urbanization prospects. At the same time, the city of Budapest covers ana area of 525,5 km^2. The population density comes to approximately 3,351 people living in a square kilometre **[13].**

The agglomeration of Budapest in addition to adjacent urban areas is as follows (figure 4) **[13].**

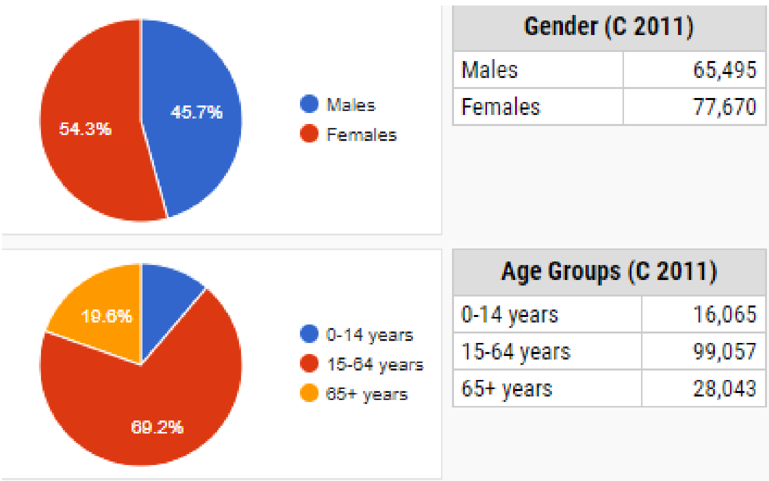


Gender (C 2011)	
Males	792,624
Females	936,416

Age Groups (C 2011)	
0-14 years	210,640
15-64 years	1,237,152
65+ years	281,248

Figure 4: Percentage of population in Budapest, Hungary, given by gender and age groups (Source: Hungarian Central Statistical Office http://www.ksh.hu/?lang=en)

The population in the 11th district of Budapest was estimated at 148,517 inhabitants in 2019 and covers an area of 33,5 km2 with a population density of 4,435 inhabitants km2 **[13].**



Gender (C 2011)	
Males	65,495
Females	77,670

Age Groups (C 2011)	
0-14 years	16,065
15-64 years	99,057
65+ years	28,043

Figure 5: Percentage population in the 11th district of Budapest by gender and age groups (Source: Hungarian Central Statistical Office http://www.ksh.hu/?lang=en>)

Figures 4 and 5 available here: <https://www.citypopulation.de/en/hungary/budapestcity/>

3.3 Case study area

A study area was selected in Budapest (Hungary), the 11th district, since it combines many different lands uses and can be considered a typical example of a post-industrial average-size European city, the study area spans a varied urban topography and areas, city streams, and squares. Furthermore, the area is characterized by a dense and varied network of the local and national level streets as well as its transport infrastructure (e.g. railway, buses, trams). The total area extends to 19km2. Figure 6b shows the 137 points of measurement, each point was selected considering the different land uses e.g. building, green area, road, residential area, train line, etc (Figure 6c).

(a) (b) (c)

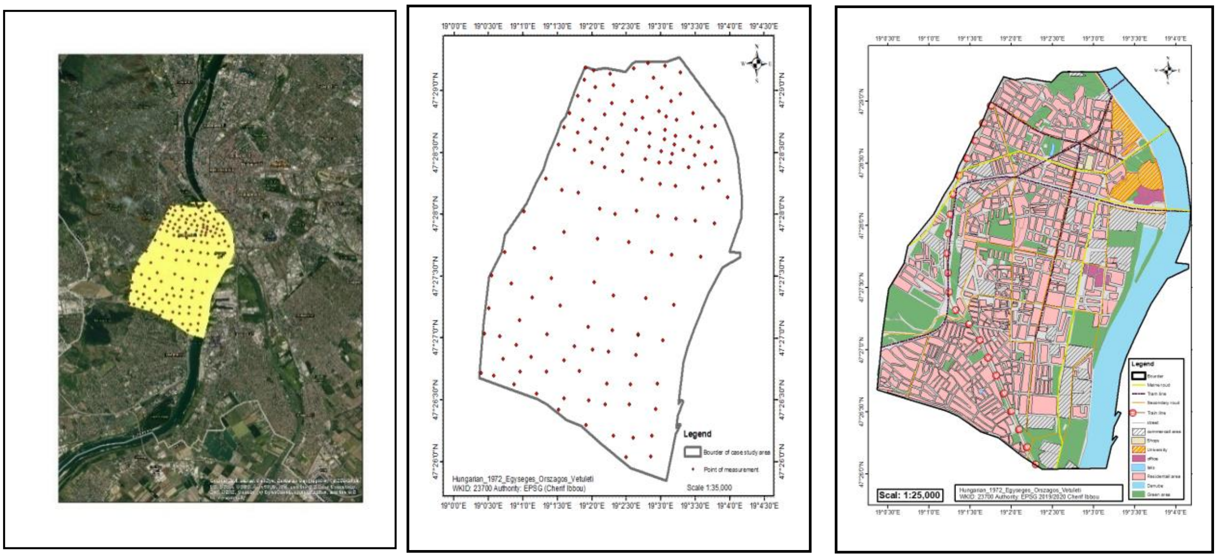


Figure 6: (a) Satellite image of the study area (Google Maps), (b) points of measurement (200x200m), and (c) land uses (derived from Arc Map 10.6.1)

3.4 Determination the points of measurement

Three maps with the points of measurement were created in the study area. Figure 7 shows the location of the137 points of measurement.

Previously I have created an imaginary grid in the case study area, considering two conditions: trying to keep the same distance between the points and selecting characteristic points in their immediate environment to measure as varied as possible different sound sources (natural, anthropic and technological).

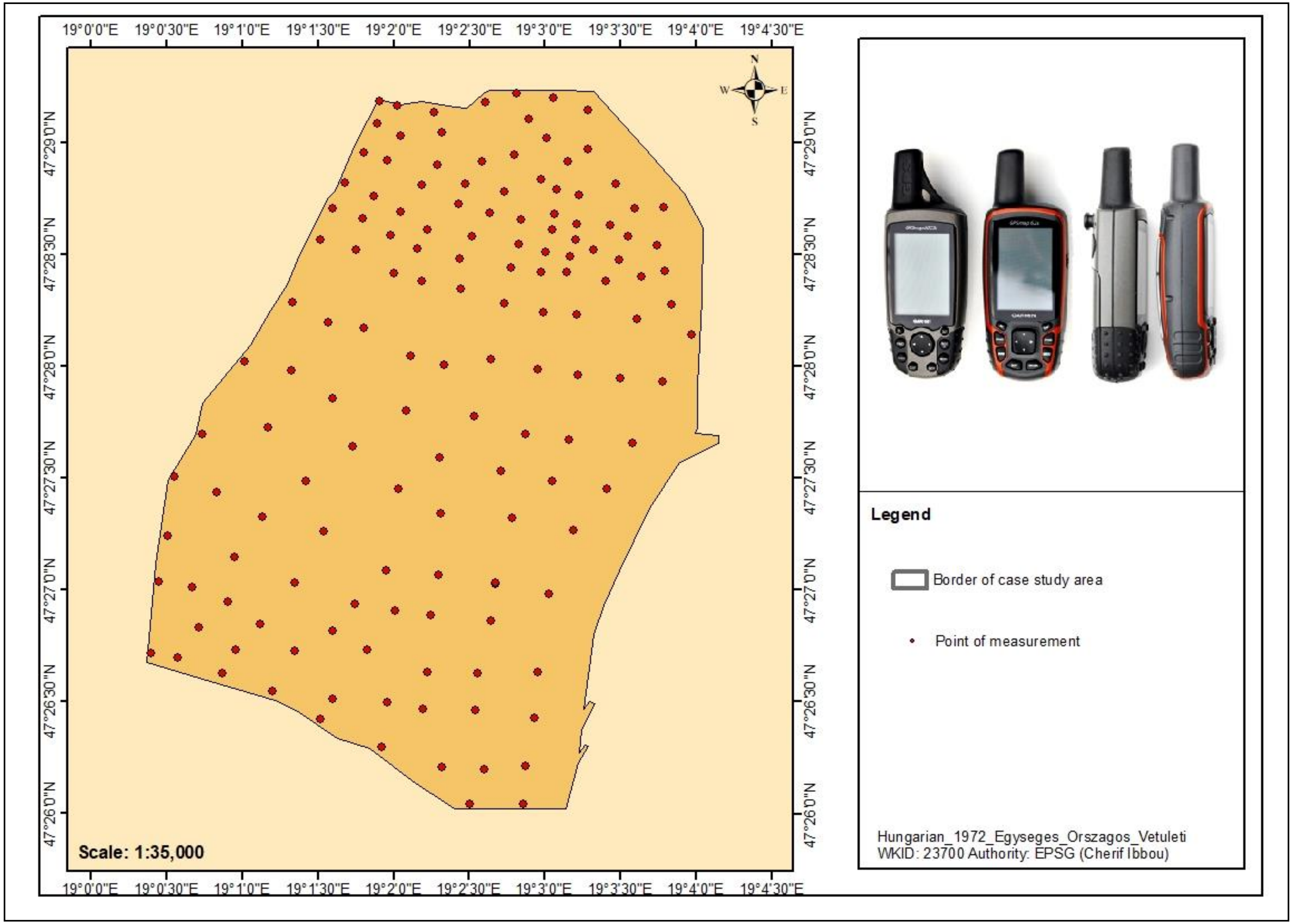


Figure 7: Map of the 137 points of measurement (derived from Arc Map 10.6.1)

3.6 Mapping tools

After the data collection was finalized, all the information related to the audible sound sources, annexe 1. Was transferred to the ArcGIS software (v. 10.6.1) for further processing. The audible source occurrences were aggregated per type and these values were averaged over morning and afternoon (after classifying them as technological, natural, and anthropic data). Then a prediction surface was created using the Kriging interpolation method for the technological, natural, and anthropic sound sources accordingly. The surfaces were created based on the Ordinary Kriging method and the spherical semivariogram model, considering all the 137 points of the study area.

Soundscape mapping depends on the use of interpolation tools, which can predict cell values in unknown locations based on the cells with known values in the study area.

3.7 Mapping content

Soundscape maps were created for the study area, Figure 8 shows spatial variability of audible natural, anthropic and technological sound source, as we can see in Figure 8, four maps containing different land uses (residential area, train line, offices, main road) were used as base maps to represent the collected thematic data: the different types of sounds as well as noise bands.

In Figure 8a can be seen an increased number of natural sources in specific areas near the Danube, Citadella and some places which constitute parks and residential areas. In the West and North side of the study area, the natural sound is higher because of the green space and playgrounds.

Anthropic sources are presented in Figure 8b, as we can see an increased number of sounds in the East and South of the study area, where more markets are located, with intense commercial activities, services and active social life in the day. Evident high values of anthropic presence can be seen also between the next two places: Szent Gellért tér and Móricz Zsigmond körtér. The presence of human sources is limited in the West area of the study area. I found it interesting that there is an extensive degree of intersection between high values of anthropic and technological sources, which can be justified by the commercial character of the study area.

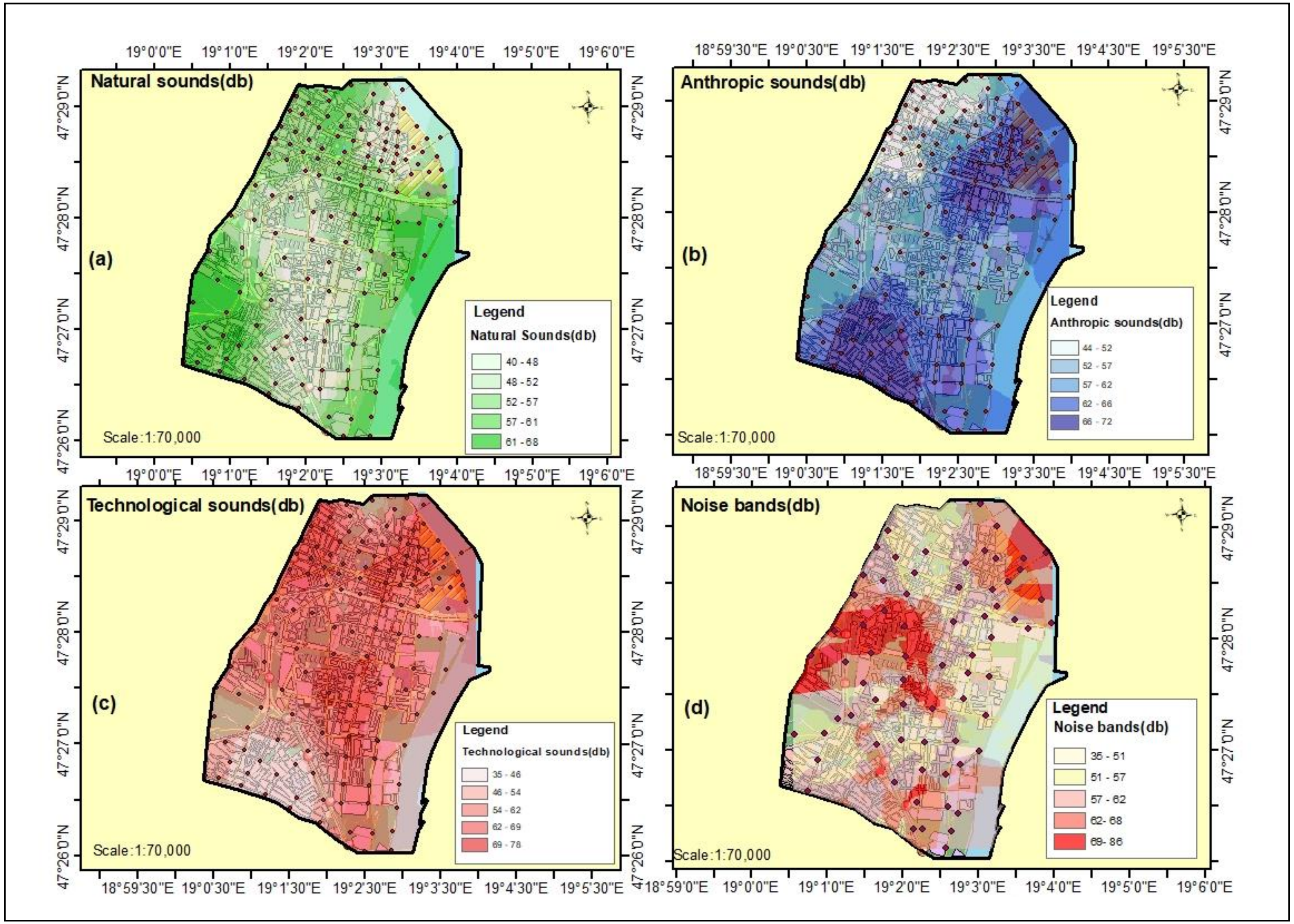


Figure 8: Spatial variability of the audible sound sources (natural, anthropic, technological and Noise bands). (Derived from Arc Map v. 10.6.1).

Figure 8c presents a low level of technological sounds, because is a purely residential area. The high technological sound was located close to the train station of Budapest-Kelenföld and along the railway line. The low level can be seen near to the Danube river and the highest number of technological sources are found in the central region of the study area, which is expected because of the heavier vehicle traffic.

Figure 8d presents noise bands based on 69 points selected by me near to the main roads, secondary roads and train lines. The sound was measured in decibels, each point presented an increase in the sound level near to the train station and main roads and a low level in the middle central region of the study area, where secondary roads are located.

Chapter 4 Creation of the sound map

4.1 Testing sound data and base map

Figure 9 shows the base map created for the study area, including points with natural, anthropic and technological data sounds that are shown on the base map and in a line chart.

I selected 69 of the 137 points in different places to test them on a base map of the study area. Natural, anthropic and technological sounds were recorded on each point and later I transferred the sound records to decibels (dB) and created a database on Arc Map v. 10.6.1.

The green line in Figure 9a represents natural sounds. We can see how the number of natural sounds is increased in some points, which are green areas, parks and playgrounds. We can also see a low number of sounds, which constitutes human life during the day, mainly in commercial areas and some related activities.

The blue line in Figure 9b represents anthropic (human) sounds. We can see a high number of sounds from points 14 to 26 and 38 to 52, which constitutes areas of social life and some related activities.

The red line in Figure 9c represents the technological sounds, showing an increased value of the sound sources from points 13 to 41, because of the vehicle traffic on the main roads and train line too.

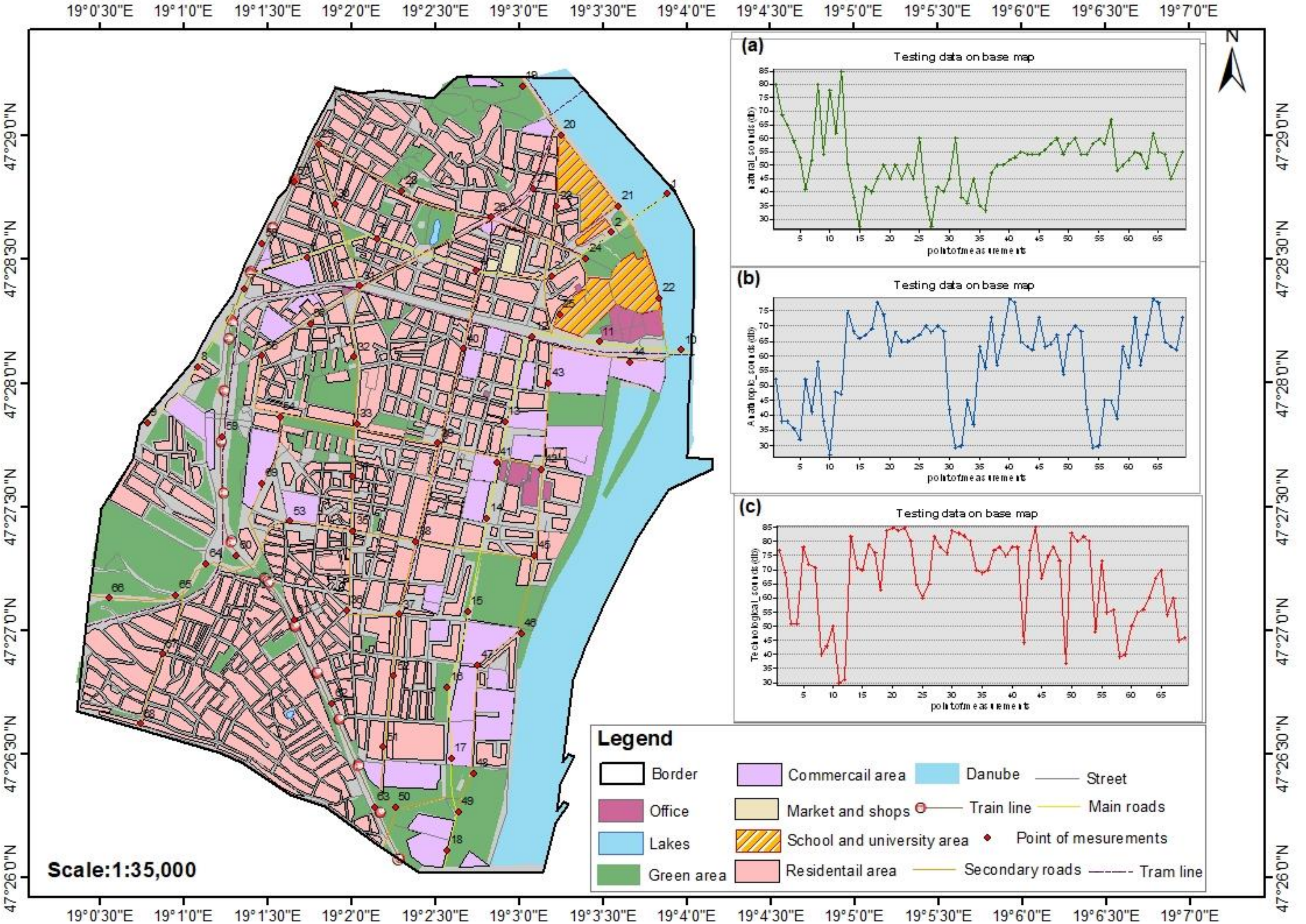


Figure 9: Maps representing testing data sounds (natural, anthropic and technological) and graphic line diagrams (derived from Arc Map v. 10.6.1).

4.2 Data collection

The thesis performed daily measurement in all 137 points as shown in Annexe 1. In 5 (five) working days the measurement period was divided into two time slots: morning (09:00-12:00 AM) and afternoon (2:00-5:00 PM). During this time, the sounds were recorded on each point. I also created a sound map in Gogol Maps using the application Google My Maps. The sound map includes the location of the recorded point completed with a picture of each point. I installed the Sound Meter Android application on my mobile phone with a Distance Calculator application to keep the same distance between points. The application was used to record the sound pressure levels at each point. The final data sound was averaged between the minimum and maximum sound level, Table 2 shows a list of sound sources found during the soundscape data collection and their classification to the three categories of sound sources (natural, anthropic and technological). I did not make a more detailed classification but in international projects, researchers can find that technological sounds are classified as motorised, electromechanical and social-communal, as well as within natural sounds we can find sounds emitted by domesticated animals or in nature **[7].**

Table 2: List of sound sources used during soundscape data collection.

Category	Sound sources		
Technological	Cars	Bicycles	Industries-fans
	Buses	Fireworks	Industries-Others Machines
	Trucks	Alarms	Construction
	Aeroplanes	Grass mowing	Domestic
	Recreation	Miscellaneous	
Natural	Thunder	Rain	Birds
	Water sounds	Wind	Miscellaneous
	Grass rusting	Insects	Forges
	Trees rusting	Doges	
Anthropic	Human speech	Church bells	Music-live
	Human singing	Footsteps	Music-records
	Human laughter	Roller-skating	Music-shops
	Crowd of people		

4.3 Soundscape profile (data analysis)

The map in Figure 10 shows a representation of a soundscape profile based on the High (H) and Low (L) sound levels of data collection in the study area.

The average between the minimum and maximum values of the sound source were used to create the High (H) and Low (L) soundscape profile.

The first group includes two classes with average sound from maximum and minimum values for natural sound as shown with two different green tones classified as High and Low Natural. The next group of anthropic sounds is also divided into two classes: High (H) and low (L), the average of the maximum and minimum sound values with two different blue tones. Finally, the last group of technological sound was also divided into two classes: High (H) and Low (L), and they are shown with two different tones.

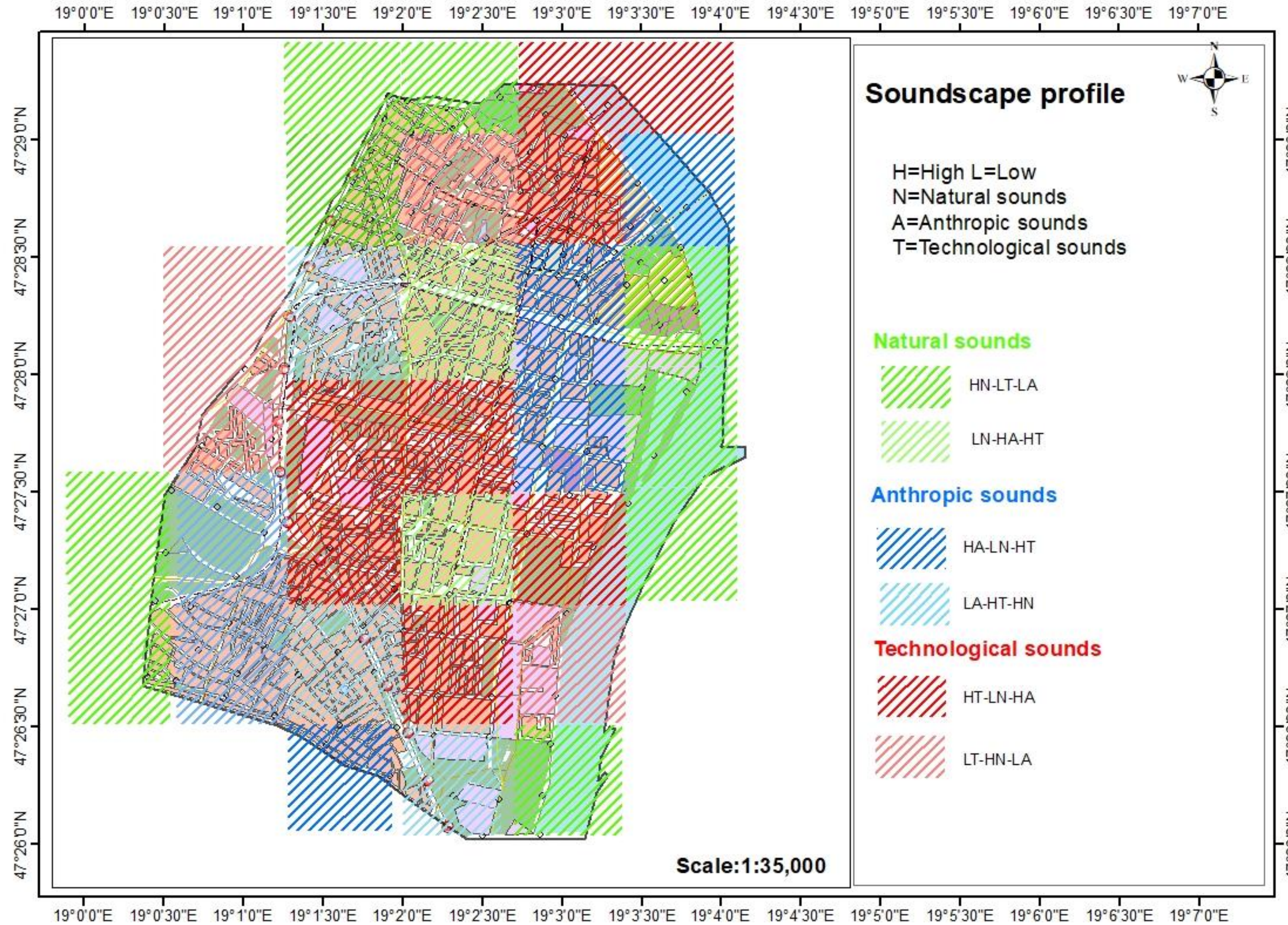


Figure 10: Representation of the soundscape profile based on high (H) and low (L) sound level of data in the study area (derived from Arc Map v. 10.6.1)

Chapter 5 Creation of the story map

5.1 ArcGIS Online

ArcGIS Online is a web-based GIS environment that makes geographic content and analysis accessible to a business company, a research institution, organization or the general public. The use of ArcGIS Online can be also considered a standalone solution for mapping and analytics needs. It also offers options that can be used to make a connection between people, locations, and data using interactive maps. Users can work with smart, data-driving and intuitive analysis tools that deliver map-based GIS solutions **[14].**

5.2 Content created on ArcGIS Online

The maps created in ArcGIS Online are listed in Figure 11. Firstly I made those maps in ArcMap 10.6.1. After that, I exported data to shapefile format, creating four files by each exported layer. After it, I zipped all the shapefiles related to each specific layer, because it is a condition asked by ArcGIS Online to visualize the layers. I imported them into ArcGIS Online to create different online map layers, which later I used to make the Story Maps series.

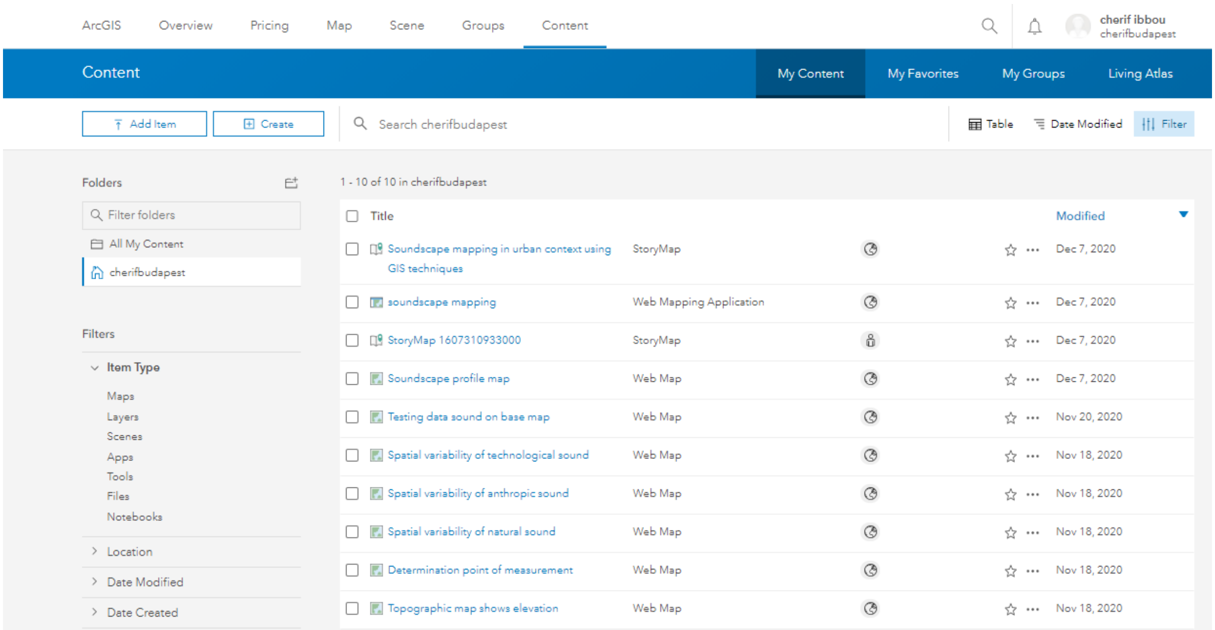


Figure 11: The list of map content used to create StoryMaps (screenshot from ArcGIS Online)

5.3 Creating a StoryMap series

StoryMaps are interactive presentations or narratives combining text, maps and other multimedia files (e.g. images and videos). ArcGIS Online offers 35 pre-defined StoryMaps, but users have also the opportunity to create their own types of StoryMaps combining different elements.

I selected the StoryMap Series because using it I can create an interactive web atlas formed by different maps related to the same them. The maps are presented using the same web environment and offering similar options to access more detailed data for the users.

Creating a Story Map series in ArcGIS Online implies some previous steps to be followed. Firstly I imported and edited the content of the maps that I want to include in the StoryMaps series (Figure 11). After choosing the first map to be added to the StoryMap series, ArcGIS Online offers two options: under the "Create a Web app" menu: Configurable Apps (using a template) and StoryMaps (create your own solution). I selected Configure Apps using the Story Map series (Figure 12).

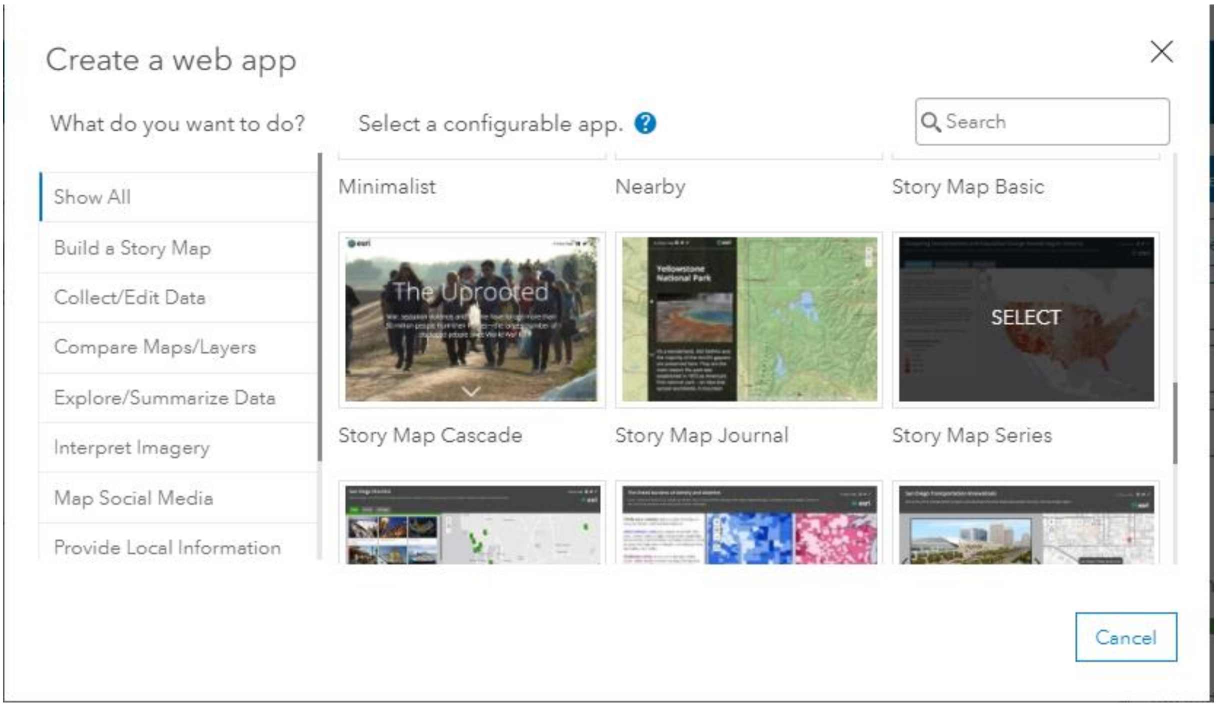


Figure 12: Starting page for the selection of a StoryMap (screenshot from ArcGIS StoryMaps)

Beginning the definition of a StoryMaps series I had to select the first map and to determine the different parameters needed for the visualization of the map(Figure 13). After giving the parameters, the first map is showed and the application offers me the option of adding new maps to the current series.

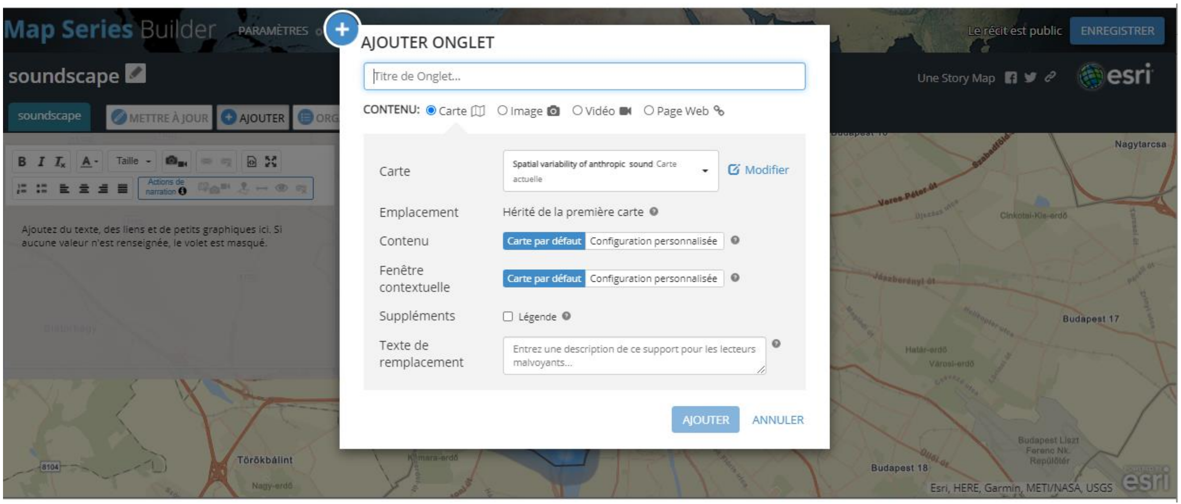


Figure13: Telling a StoryMap series with an icon (+) (screenshot from ArcGIS Maps series)

Resuming this chapter, I created a StoryMap making emphasis on the interactive presentation of the sound maps created me by during the research. The StoryMaps series can be viewed using any of the following addresses: https://arcg.is/1L8DvO or https://www.arcgis.com/apps/MapSeries/index.html?appid=a3308eaea6e44108bbb879ed418ae7bd

Conclusion

In this study, the sounds in 11^{th} of district of Budapest, Hungary have been recorded in 137 points of measurement during 5 (five) working days in the morning (9:00-12:00 AM) and afternoon (2:00-5:00 PM) and it is available on the sound map that I created with Google My Maps.

In conclusion, a soundscape map has been created for the study area, classifying sound data into three different categories (natural, anthropic and technological), The collected data was tested on a base map of the study area a topographic profile was created at the beginning of the collection of data because the method of collecting data was a sound walk in the case study area. After all, I have to know the elevation, highs and lows places.

At the end of the thesis, a map of soundscape profile was created to represent the results of the analyses of the data sound collected in the study area.

The results of my analysis were that a high number of natural sounds were expected in the green areas, parks and some places close to the Danube river, and also a high number of natural sounds were recorded in the Citadella and surrounds.

A high number of anthropic sound sources were detected close to the markets to the universities, as well as an increase of technological sound was measured in the main roads and near to the train line and some of the secondary roads.

Finally, I would like to highlight that I selected this theme because, according to other internationally recognized specialists working on this area, after the study of international bibliography can be noted a lack of studies in the field of soundscape mapping compared to noise mapping (e.g.[7]). Soundscape maps can be considered a novel research area also in Hungary because I did not find any previous work developed in the country. I expect that my maps can be considered a small contribution that can be used in the future development plans of the 11^{th} district, which is one of the largest districts in Budapest, Hungary, counting with a denser population and attracting more visitors due to the concentration of many services like shops, offices, parks, train stations and universities.

Acknowledgements

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List of Figures

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Annexe 1: Sounds data and elevation points of study area

Piont measurement	Natural Sounds (dB)	Anthropic Sounds (dB)	Technological Sounds (dB)	Elevation Data (m)
1	60	52	77	156
2	69	38	69	177
3	65	38	46	201
4	69	36	51	211
5	59	48	42	229
6	53	32	78	134
7	41	52	72	120
8	52	41	71	149
9	80	58	40	134
10	54	38	43	131
11	78	27	50	157
12	62	48	30	168
13	65	47	30	168
14	50	70	82	110
15	38	62	71	115
16	41	55	70	132
17	38	45	79	127
18	27	47	76	124
19	42	75	63	105
20	40	68	84	136
21	45	66	85	150
22	50	66	84	120
23	45	68	85	103
24	60	69	60	110
25	36	78	65	102
26	36	74	82	111
27	45	60	78	132
28	53	66	76	103
29	33	65	76	116

30	45	65	76	139
31	50	66	84	114
32	50	65	83	105
33	52	66	73	111
34	53	67	80	116
35	55	70	83	131
36	54	66	82	126
37	54	42	80	126
38	54	29	70	110
39	54	30	69	105
40	58	45	70	123
41	60	45	77	123
42	54	37	77	126
43	54	63	76	120
44	66	56	77	130
45	58	66	79	129
46	58	73	44	124
47	67	57	77	107
48	48	67	85	120
49	50	79	67	126
50	32	78	75	115
51	55	65	76	140
52	54	63	73	129
53	49	52	37	116
54	52	73	83	103
55	55	63	80	104
56	54	60	83	106
57	45	67	82	114
58	50	54	48	119
59	55	67	78	121
60	50	67	85	106
61	55	78	49	124
62	70	55	52	111

63	80	63	50	108
64	57	82	42	115
65	60	76	45	103
66	78	51	84	101
67	70	80	41	110
68	61	78	37	115
69	49	64	64	111
70	36	49	78	116
71	60	49	75	110
72	66	65	79	115
73	61	55	52	110
74	44	52	61	120
75	42	61	78	112
76	36	51	36	101
77	50	52	75	107
78	57	77	75	110
79	54	61	51	111
80	78	60	43	109
81	58	61	78	112
82	66	63	44	105
83	55	53	68	105
84	55	64	70	115
85	51	62	73	109
86	50	63	83	112
87	56	70	80	111
88	55	70	80	108
89	48	60	81	106
90	49	64	82	108
91	44	60	79	111
92	58	39	70	131
93	40	56	40	122
94	81	57	33	102
95	75	52	50	121

96	77	63	45	110
97	80	65	60	112
98	75	65	35	121
99	50	82	70	116
100	35	52	50	63
101	40	69	70	115
102	37	47	75	109
103	45	62	72	108
104	51	` 65	84	115
105	44	72	78	103
106	45	68	38	136
107	73	50	42	120
108	70	62	38	110
109	60	50	31	104
110	73	56	35	101
111	78	57	46	110
112	69	52	81	110
113	55	70	80	106
114	52	62	78	107
115	52	64	80	113
116	45	60	61	126
117	47	79	62	110
118	44	75	50	123
119	52	67	42	115
120	50	67	41	108
121	55	72	30	125
122	39	50	36	114
123	51	70	40	122
124	56	73	37	104
125	60	75	25	115
126	47	79	29	154
127	54	80	30	120
128	55	81	41	144

129	**49**	**59**	**80**	**138**
130	**50**	**60**	**80**	**105**
131	**80**	**64**	**45**	**128**
132	**45**	**65**	**44**	**120**
133	**50**	**69**	**38**	**136**
134	**79**	**55**	**78**	**130**
135	**55**	**80**	**78**	**133**
136	**79**	**50**	**38**	**135**
137	**50**	**55**	**69**	**107**

DECLARATION

I, undersigned **CHERIF IBBOU** (NEPTUN CODE: **JYHRF8**), declare that the present master's thesis is my original intellectual product in full and that I have not submitted any part or the whole of this work to any other institution. Permissions related to the use of copyrighted sources in this work are attached.

I AGREE to the publication of the accepted master's thesis in pdf form on the website of the Department of Cartography and Geoinformatics.

Budapest, 16, 11, 2020

CHERIF IBBOU

(signature of the student)