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Sound and Weather – A complex Relationship

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ABSTRACT

This paper presents a short study on the interrelationship of weather, landscape position and the metrically quantified sound environment in a public park in Gelsenkirchen, Germany, indicating that cloud coverage may have a significant influence on NDSI, AEI, and ADI values. The results inform the conclusion that dense low-hanging cloud coverage may influence the sound environment by dampening soundwaves and masking background anthrophonies, in a type of 'background noise absorber' effect, constituting a higher fidelity sound environment where avifauna and human noises are suppressed. Although the effect is purely physical, it may constitute a psychoacoustic effect in the human perception of soundscapes. The paper presents these results and invites further thinking around the idea of the 'background noise absorber' effect and the potential for quantification of other psychoacoustic effects of weather on soundscape perception.

Keywords: Sound, Weather

1. INTRODUCTION

Soundscape Ecology is an emerging field of research that tries to describe the complex relationship between an area's spatial structure, biotic structure and the resulting composition of sounds. One part of this composition are geophonic sounds that originate from the geophysical environment. These sounds can be temporarily static, like the constant rushing of a river, or dynamic like the sounds generated by fluctuating winds or rainstorms. Biological organisms are the source of biophonic sounds, for example the birds' chorus at dawn, but also human voices. However, sounds of human-made objects are called anthrophonic sounds. These sounds can be both static and dynamic. The constant background noise of a motorway or an air-conditioning unit can be static in an area whereas the sound of a rescue helicopter changes based on distance and movement. Hence, the soundscape of an area is defined as "the collection of biological, geophysical and anthropogenic sounds that emanate from a landscape and which vary over space and time reflecting important ecosystem processes and human activities"(1). (1,2)

Ecosystem processes as well as human activities are in the long-term determined by the general geophysical environment and human systems, which take shape in the natural and built environment (2). However, in the short term the sound of an area is determined by dynamic factors like the current weather and active human activities. Nevertheless, the sound environment of an area in the short term influence a person's perception of the area at a specific moment. It can be assumed that a public park has a much higher recreational potential when the actual sound environment is mainly influenced by biophonic sounds than a sound environment influenced by gardeners working with machines (3). The evaluation of different sound environments through influencing weather conditions in the same urban park is less obvious. It is unclear if, for example, a warmer day results in a more pleasant sound environment for humans than a colder day. The knowledge of such influences could be beneficial for the timing of annoying garden care, estimating the daily number of visitors in the morning for personnel planning or planning of recreation trips.

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2. Purpose and theoretical background

This study aims to explore the influence of the weather conditions on the sound environment in an urban park. Therefore, a field study with sound and temperature measurements as well as weather observations in a public park is conducted. Sound metrics, which are originally designed for sound environment quantification from the field of soundscape ecology, are applied in research on the sound environment in this study. Sound metric results are statistically analyzed against weather data and bird observations to answer the following research question:

What is the influence of weather conditions on the sound environment in a public park?

Weather conditions can influence the sound environment in different ways. Klein et al. states that the sound environment is determined by weather first through the influence of temperature, relative humidity and atmospheric pressure on sound frequency propagation in the air, and secondly through the sounds caused by weather events for example rain and third the influence of environmental conditions on sound produced by animals (4). Regarding to the first assumption, it holds that in general high-frequency ranges (which include biophonic sounds) are more strongly muffled during weather periods with more dense air (colder; higher humidity), than low frequency geophonic and anthrophonic sounds (5). Wind has an influence on the muffling of sound depending on speed and direction (5).

Sounds caused by weather events, for example rain falling on the ground or wind rustling through leaves, are low frequency geophonic sounds (2). Thus, on the one hand weather events influence the sound environment due to physical propagation of sound in the atmosphere and on the other hand weather may influence the behavior of animals and thus the sound environment (6,7,8). The author interprets the literature to mean that the physical influence of cold, humid, or rainy weather dampens both the propagation of high frequency biophonic sounds in the sound environment and the sound producing activity of animals, resulting in a sound environment with a higher proportion of low frequency sounds that travel more easily through dense air. Hence, cold and harsh weather conditions could lead to a sound environment that is different to conditions resulting from warmer weather in the same location and season.

3. Research Design and Methodology

To investigate the influence of weather on the sound environment, a case study method using hand measurement devices in an urban park was developed. Due to the short duration of the study, a single semester, and the necessity to keep the workload manageable, a single case within one season was analyzed. Given the small scale of the study, the author considers the study as an explorative case study.

3.1 Sample Design and Field Work

The *Nordsternpark* in Gelsenkirchen, Germany, a public park in the western part of the city and part of the *IBA Emscherpark*, was selected as the case study because the study aims to observe impacts of weather on recreation areas and because the location is in close proximity to the author's home which makes it easily accessible and keeps the necessary amount of time manageable. To ensure the study collected observations during different weather conditions and to eliminate sound environment variations that may occur due to land cover, six sound measurements points within Nordsternpark on mixed grassland/shrub land cover were identified using a fishnet with a cell size of 200m x 200m in ArcGIS. Measurements were taken only on Fridays and Mondays at the same time and in the same order from 16 November to 3 December, 2018. In total thirty measurements were taken in the *Nordsternpark* and a two-sided Kruskal-Wallis Test was enabled to be used to determine if the sound metrics in the group of recordings were statistically different from each other and if they correlated with weather observations. The sample design is displayed in Figure 1.

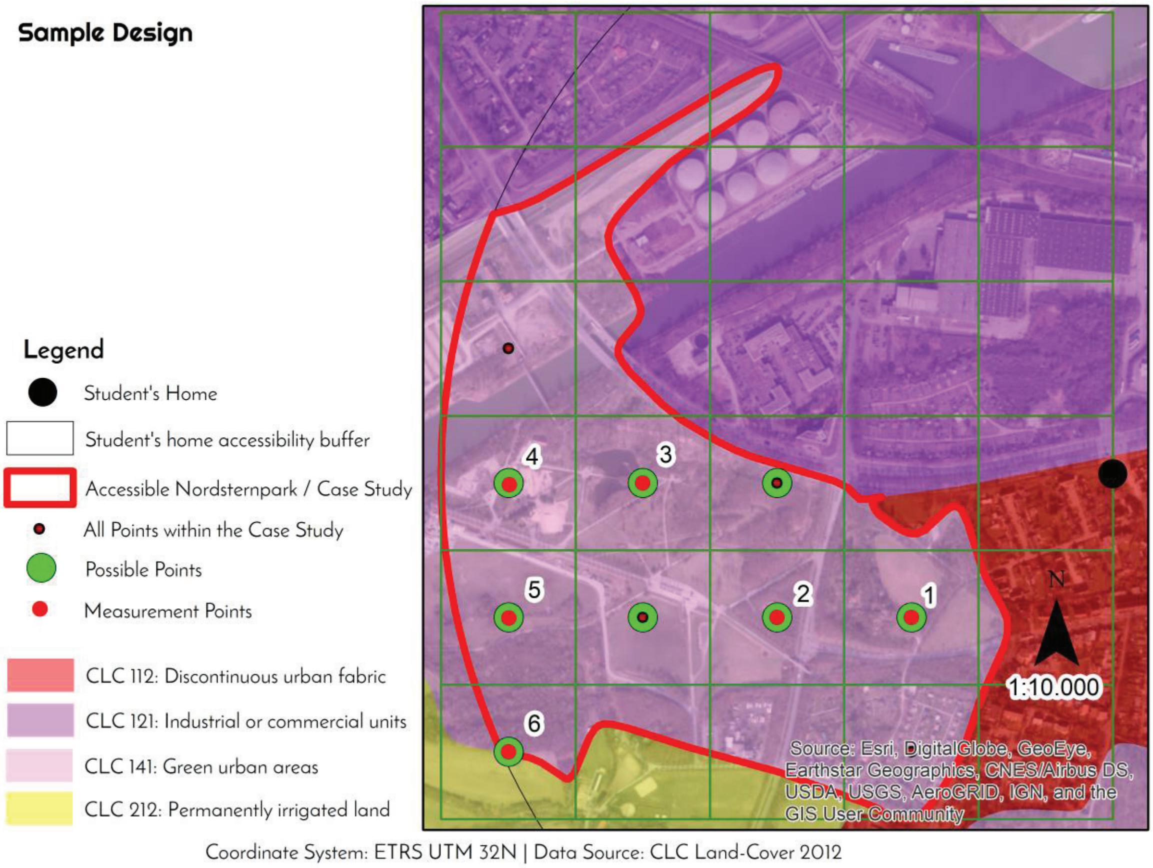


Figure 1: Sample Design

Sound was recorded for three minutes at each point to balance the amount of time per measurement and the quality of the measurements (see Joo et al. as an example using three-minute recordings (9)). Recordings were made with the *XL2 Audio and Acoustic Analyzer from NTi AUDIO*. The temperature was measured with an already available customary thermometer, but humidity and air pressure are left out because of a missing suitable measurement device. The weather was nominally ranked within three categories of cloudiness, windiness and raininess on a scale from zero to two. Whereas zero means sunny, no wind until breeze and no rain; one means some clouds, medium strength wind and light rain; two means sky completely covered by clouds, strong breeze and medium strength to heavy rain. The limits of the study are that the results only apply for the eastern part of the *Nordsternpark* and cannot be generalized on the park as whole or on other public parks, and that the results are only valid for the winter season. Even with limitations, the explorative case study enables initial insights to the topic and may serve as a basis for further research.

3.2 Soundscape Metrics

After field data collection, sound files were analysed with RStudio and the soundscape ecology package (10). Table 1 displays the calculated soundscape metrics and the set parameters. The soundscape ecology package metrics were selected because they are widely applied and cover different characteristics of a sound environment. The resulting data set is then merged with the collected weather data to prepare the dataset for further statistical analysis in RStudio.

3.3 Statistics

The first step of the statistical analysis is a data description to introduce the variables and identify possible errors in the dataset before data analysis. The cleaned dataset is used to investigate the relationship between weather and soundscape metrics. The Kolmogorov-Smirnov test was used to verify that the sound and weather datasets were at least partially non-normally distributed. Therefore, the main inferential statistical methods applied are the Kruskal-Wallis-Test and the calculation of

Table 1 – Soundscape Metrics

Soundscape Metric	Description	Value Range	Set parameters
Acoustic Complexity Index (ACI)	Assesses the complexity of the sound regarding to dB and Hz by computing the average absolute amplitude difference between points in time next to each other in each selected frequency bin.	0 to unlimited	Minimum frequency = 1000Hz Maximum frequency = 11500Hz Calculation distance = 5s
Normalized Difference Soundscape Index (NDSI)	Anthrophonic disturbance of soundscape. Computes the ratio of anthrophonic to biophonic acoustic components.	-1 to 1	Minimum Anthrophonic Frequency = 1000 Hz Maximum Anthrophonic Frequency = 2000 Hz Minimum Biophonic Frequency = 2000 Hz Maximum Biophonic Frequency = 11500 Hz
Acoustic Diversity Index (ADI)	Assesses the diversity of Hz by selecting the relative amplitude on a determined number of bins between two frequency levels and applying the Shannon entropy Index.	0 to 1	Maximum frequency = 11500Hz dB threshold = -50dB Frequency steps = 500 Hz
Acoustic Evenness Index (AEI)	Assesses the evenness of Hz by conducting the same steps as the ADI but applying the Gini coefficient for distribution inequality.	0 to 1	Maximum frequency = 11500Hz dB threshold = -50dB Frequency steps = 500 Hz
Bioacoustic Index (BI)	Assesses the relative avian abundance by computing the mean dB spectrum and calculating the area under the curve between two frequency levels.	0 to unlimited	Minimum frequency = 2000Hz Maximum frequency = 11500Hz

Table adapted from Sueur (11)

spearman's correlation coefficients, which both do not require normal distributed variables. (12) The Kruskal-Wallis test helps to decide if two or more independent population distributions are identical without assuming a normal distribution. The null hypothesis is thereby that the respective populations are identical which can be rejected if the resulting p-value is below 0.05. In this study the Kruskal-Wallis test is conducted for the soundscape metrics, temperature, cloudiness, windiness and raininess. Whereas the Kruskal-Wallis test only compares the distributions, a correlation analysis enables discovering a direction of the possible interrelationship between two variables. Hence, the

Spearman's correlation coefficients between the soundscape metrics, temperature and observed weather conditions are calculated, interpreted and appropriate plots are displayed. (12)

4. Results

The descriptive statistics of the different variables show that the overall aim of the measuring process, collecting sound data at different weather condition, is accomplished. Table 2 shows that the temperature has a range of roughly eight degrees, moreover measurements at different cloudiness, windiness and raininess levels are taken. Thereby the maximum value of raininess is one, thus the results are not biased by heavy rain. Furthermore, the soundscape metrics enable different interpretations. The ACI shows values in a relatively small range which implies a stable complexity of sounds in general. The mean and median NDSI values are below 0, thus the sound environment contains biophonic sound which are generally disturbed through anthrophonic sounds that could result from the nearby main streets and the motorway. The distribution of ADI and AEI mean values show that the sound environment in general is even, with a medium sized proportion of biophonic sounds, due to a medium sized mean BI.

Table 2 - Descriptive Statistics

Group	Variable	Mean	Median	Min	Max	Standard deviation	Distribution
Weather	Temperature	8.673	8.95	4.8	12.7	2.46	bimodal
	Cloudiness	/	2	0	2	/	/
	Windiness	/	1	0	2	/	/
	Raininess	/	0	0	1	/	/
Soundscape metrics	ACI	2476	2464	2399	2666	59.67	Normal distributed
	NDSI	-0.551	-0.590	-0.731	-0.038	0.16	Normal distributed
	ADI	0.33	0.02	0	1.62	0.55	Right-skewed
	AEI	0.94	0.96	0.82	0.96	0.04	Left-skewed
	BI	10.70	10.62	6.46	14.92	2.07	Normal distributed

n = 30

The second step of the analysis is the application of the Kruskal-Wallis-Test to investigate changes in the distributions of soundscape metrics under different weather conditions. Table 3 shows the *p*-values resulting from the Kruskal-Wallis Test of the soundscape metrics grouped by an indicator for the weather conditions. For only two cases, the null hypothesis can be rejected which is the ADI and AEI grouped by the cloudiness. Hence, it can be stated, that different cloudiness levels influence the diversity or evenness of the sound environment in Nordsternpark.

Table 3 - Kruskal-Wallis-Test

Soundscape metric grouped by	Temperature	Cloudiness	Windiness	Raininess
ACI	0.4199	0.4811	0.2087	0.1345
NDSI	0.6984	0.08975	0.0817	0.5060
ADI	0.5244	0.0027**	0.5677	0.2122
AEI	0.5140	0.0025**	0.5043	0.2120
BAI	0.5223	0.6709	0.3091	0.3184

Significance is indicated if *p*-value is below 0.05(*), below 0.01 (**) and below 0.001(***)

The results of the correlation analysis shown in Table 4 and Figure 2 give evidence about the direction of the relationship between the ADI, AEI and cloudiness. With a significant correlation coefficient of r = -0.61 and r = 0.61 respectively, it can be stated that the cloudier the sky is the more even or less diverse is the sound environment in the park. Moreover, a less strong but also significant correlation between the cloudiness and the NDSI is found (Figure 3). Thus, with an increasing level of cloudiness, the NDSI increases towards more biophonic sounds.

Table 4: Correlation Coefficients

	Temperature	Cloudiness	Windiness	Raininess
ACI	0.15	-0.12	-0.31	0.28
NDSI	0.15	0.36*	0.00	0.12
ADI	-0.20	-0.61***	-0.19	-0.23
AEI	0.20	0.61***	0.21	0.23
BAI	0.20	0.01	-0.22	-0.19

Significance is indicated if *p*-value is below 0.05(*), below 0.01 (**) and below 0.001(***)

Figure 2: ADI and AEI at different cloudiness levels

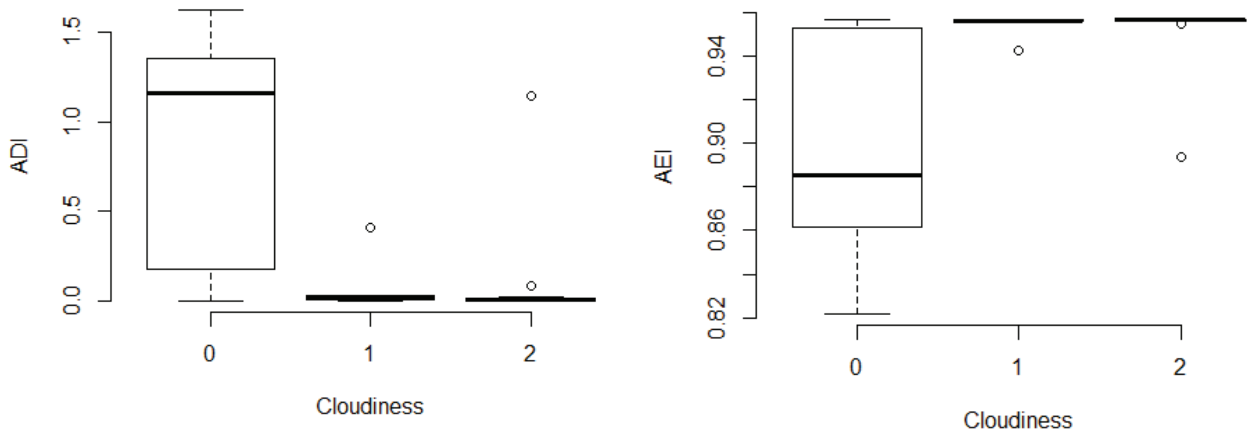
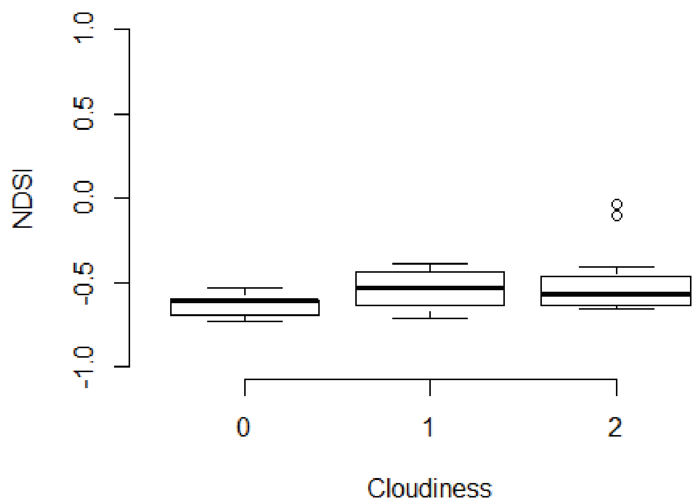


Figure 3: NDSI at different cloudiness levels



5. Discussion

The results may be interpreted together. If bird human activity in the park is less intense during cloudy weather conditions, the sound environment contains fewer biophonic sounds in the foreground, leaving anthrophonic road noise in the background. Hence, the sound composition is less diverse and more even. However, the positive correlation of NDSI and cloudiness indicates a less anthrophonic disturbed sound environment at higher cloudiness levels. Considering the fewer biophonic sounds at higher cloudiness levels, the remaining possibility of an increasing NDSI value is a ‘dampening’ of anthrophonic sounds. Thus, the ratio of biophonic and anthrophonic sounds is tilted slightly more towards biophonic sounds during cloudy conditions even though anthrophonic sounds still dominated the park. A possible explanation is that a dense low-hanging cloud coverage may influence the sound environment by dampening anthrophonic soundwaves and thus masking background anthrophonies. The greater cloud coverage may produce a type of ‘background noise absorber’ effect constituting a higher fidelity soundscape due to its physical characteristics.

The boxplots shown in Figure 2 and 3 illustrate the findings that the distribution of ADI and AEI values change strongly with different cloudiness levels. In sunny weather conditions in November, the sound environment in the Nordsternpark is slightly diverse and not fully even, but when the cloudiness reaches level one or two, the sound environment is almost totally even. The NDSI is higher with higher levels of cloudiness, however, the distribution at cloudiness level 1 is similar to level 2. Thus, the taken assumption that an even sound environment with only a few biophonic sounds can be less disturbed through stronger dampened anthrophonic sounds holds, when comparing the distribution of the soundscape metrics’ values at different cloudiness levels. One possible reason for not finding significant results between cloudiness and other metrics is the small sample size of 30 observations which reduces the potential to find significant correlations or p-values with the Kruskal-Wallis Test. Nevertheless, the results do not force rejecting the hypothesis of relations between the temperature, windiness, raininess and the sound environment; rather they give an outlook for possible future studies on the relation of weather and the sound environment. Thus, the general hypothesis that harsh weather conditions influence the sound environment in the short run still applies and must not be rejected. However further exploration is required to fully understand the results of this study.

6. Conclusion and Outlook

The study applied the calculation and statistical interpretation of soundscape metrics in combination with weather conditions on the actual sound environment in a public park and finds some significant results. Hence, the hypothesis of the negative interrelationship between weather conditions and the composition of sounds in a public park is not rejected. It is found that an increasing level of cloudiness results in a totally even sound environment in the eastern part of the *Nordsternpark*, Gelsenkirchen which either reduces animal activity or masks animal noises and results in a sound environment characterized by road noise from the nearby traffic corridors. However, background anthrophonies are apparently muffled by a possible `background noise absorber´ effect of dense cloud coverage. Although, these results may not be directly applicable on other case studies or able to fully substantiate the `noise absorber effect´ of denser cloud coverage due to the limited research design, the results give a first insight into the topic and can serve as basis for further research. Hence, to further prove the hypothesis a broader study must be conducted. Thereby, the sample size should be increased and the indicators for the weather conditions should be reported using more precise equipment such as a weather station. Moreover, the humidity and the air pressure as two major meteorological indicators should also be measured and analysed. Therefore, automated measuring devices are especially suitable. Another aspect worth investigating could be the possible differences in influences on the sound environment because elevation influenced temperature change due to convection or sun influenced temperature change due to solar irradiance. The understanding of the factors influencing the sound environment in the short run and the soundscape in the long run is essential for designing pleasant urban parks.

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