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TOWARDS LARGE-SCALE ENVIRONMENTAL NOISE MAPPING IN EUROPE'S NATURAL AREAS

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ABSTRACT

Sound propagation outdoors involves complex physics, posing significant challenges for accurate computational modelling and environmental noise mapping in natural areas. This study uses the advanced Harmonoise point-to-point sound propagation model, which incorporates key features for natural environments, such as acoustically soft surfaces, terrain variations, meteorological effects, and their interactions. Considering the model requirements, the study leverages remotely sensed data featuring high spatial and temporal resolution. Relevant datasets such as elevation, land use and meteorological parameters are integrated into the modelling framework, allowing to produce detailed exposure level maps. Standard noise emission spectra for anthropogenic traffic sources such as roads, railways and aircrafts, together with wind turbine and mining activities, are of interest. By utilizing open input data only, the study ensures applicability over various countries to arrive at the challenging task of producing anthropogenic noise exposure maps in all of Europe's natural areas. In this paper, focus is on road traffic noise, where traffic parameters are based on road categorization, and an update of the progress is reported.

Keywords: *noise mapping, road traffic noise, analytical harmonoise point-to-point model, environmental noise*

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1. INTRODUCTION

Environmental noise is increasingly recognized as a significant pollutant with adverse effects not only on human health but also on wildlife and biodiversity in natural areas. Following the Environmental Noise Directive (END) [1] and other European policies, there have been crucial efforts for human-centric large-scale noise mapping, consequently focusing on urban areas. However, natural regions-many of which fall under the Natura2000 network-remain underrepresented in these assessments.

Noise propagation in natural environments is influenced by factors such as undulated terrain, varying ground cover types, and dynamic meteorological conditions [2]. In remote areas, sources of noise, such as road traffic, wind turbines, railways or mining operations are often located at a distance from the natura2000 sites, i.e., away from the biodiverse habitat, necessitating models that accurately capture long-range sound propagation.

This study addresses these gaps by developing a methodology for large-scale environmental noise mapping across Europe's natural areas using exclusively open data sources. To simulate sound propagation with physical realism, the advanced analytical Harmonoise point-to-point model [2], [3] is employed. Unlike simpler methods, Harmonoise incorporates detailed ground characterization, impedance discontinuities, and terrain diffraction effects, which are critical for accurately estimating noise levels in complex natural environments, while keeping computing times within reason.

Ultimately, this work aims to contribute to the development of comprehensive, biodiversity-conscious noise mapping strategies that can inform environmental management and policy decisions across Europe.

2. DATA

This study uses open data sources, primarily derived from remote sensing. The key inputs to the model include ground cover, elevation (digital terrain model), meteorological datasets, and road traffic networks, each obtained from distinct sources.

For ground cover information, the study utilizes the Dynamic World land cover dataset. This dataset provides a spatial resolution of 10 meters across Europe, with a temporal resolution of 2 to 5 days, depending on the location [4]. The dataset delineates different types of ground cover class efficiently.

For large-scale environmental noise modeling across Europe, an essential input is accurate elevation data in the form of a digital terrain model (DTM), which represents the bare-earth surface without vegetation, buildings, or other surface features. While the EEA-10 dataset provided by the European Environment Agency [5] offers pan-European coverage at 10-meter resolution, it represents a digital surface model (DSM) rather than a true terrain model and is therefore less suitable for precise noise propagation modeling.

Ongoing research is exploring the derivation of DTMs from Sentinel-1 SAR data, which could potentially enable consistent terrain modeling across the continent. However, for the purpose of this study, a high-resolution regional DTM from the Flemish government (DHMV II) was used [6]. This dataset, based on LiDAR data, collected between 2013 and 2015, offers 1-meter spatial resolution and accurately captures ground elevation. While this limits the geographic scope of the current case study, it provides a robust testbed for assessing modeling methodologies with high-quality elevation inputs.

In this study the focus is on road traffic noise. The road network is obtained from the Open Street Map (OSM). OSM road data is categorized into different types to which appropriate traffic parameters were assigned. [7].

3. METHODOLOGY

The analytical Harmonoise point-to-point model (HP2P) was implemented in Python 3 [2]. Taking advantage of the available versatile geospatial manipulation libraries, such as the rasterio, osmnx, and shapely, the data processing and preparation were streamlined to serve as efficient inputs to the model. In this paper, as an example, a natura2000 site with coordinates 50.98° N 4.42° E in the Flemish province of Brabant, in Belgium, is chosen.

The study area is a relatively flat ground terrain with elevation varying between 9 m and 14 m above sea level. The site under observation is a mixture of ground cover, with dominant ground cover types forest floor, grass, shrub and scrub. Figure 1 and figure 2 shows ground cover and elevation maps in the study area, respectively.

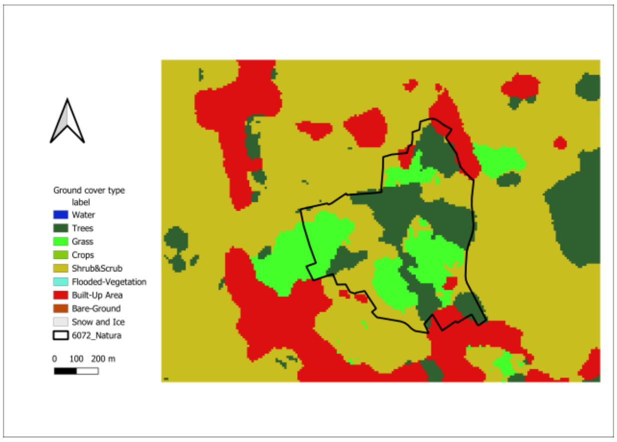

Figure 1. Ground cover map of the natura2000 site under study.

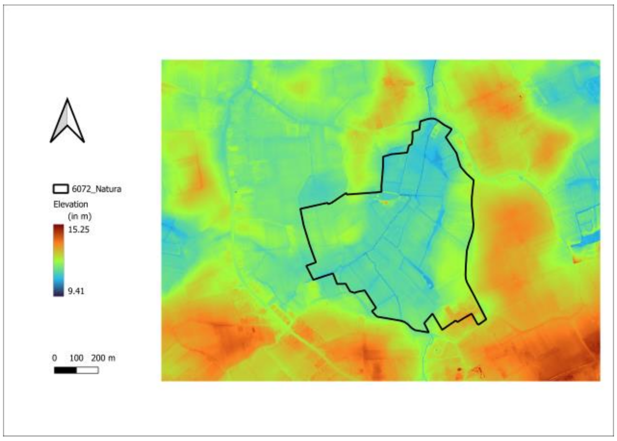

Figure 2. Elevation map of the natura2000 site under study.

3.1 Spatial ETL (Extract, Transform & Load) Pipeline

A buffer of 3.2 km is created around the Natura2000 site, i.e., the study area. Within this buffer, the existing road networks are downloaded. This network is then used to calculate the betweenness centrality [8] of each edge, assigning a corresponding value to each road segment.

Each road is then assigned a traffic intensity, vehicle speed and share of heavy vehicles based on the OSM category

(e.g., motorway, primary, secondary), as well as additional attributes such as the presence of tunnels, the number of lanes, and max speed. The constants linking road categories to traffic parameters are derived from observed traffic patterns in the Flanders region in Belgium. The betweenness values and assigned traffic intensity levels are combined to generate a final traffic-weighted road network.
Since we focus on Natura 2000 sites, we often don't find major road networks that pass through these areas. The following map (fig. 3) shows the road network. Most of the roads here belong to the tertiary or residential category.
Around the current Natura 2000 site, a grid of receiver points is generated at a resolution of 10 × 10 meters. The density of these points was decreased with increasing distance from the major road network (i.e., motorway, primary, secondary and tertiary) to optimize computational efficiency. Indeed, further away from the road, spatial variations in exposure levels become limited.
From each receiver point, cross-sections are drawn to the nearby road segments. The receiver points are divided into groups based on their distance to the road. For each group, a different discretisation of the roads segments in source points is applied. For example, as shown in the figure 3 below, the group of points closest to the major road have been assigned source separations along the road segments of 10 m, while the points furthest away 90 m. This approach strongly increases computational efficiency.

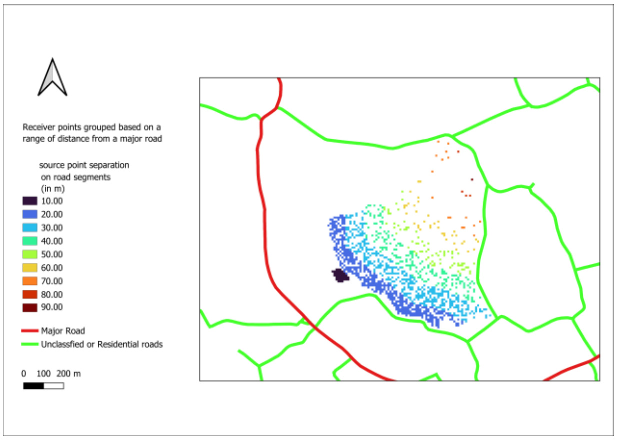

Figure 3. The solid black lines indicate the roads, the red region is the natura2000 site (study area) and the green dots are the receiver points, where the sound pressure levels are computed.

For a given receiver, only those road segments falling within four times the distance from the nearest line source are selected for generating the cross-sections.

The cross-sections are then used for sampling the elevation and ground cover values at a fine spatial resolution of 1 meter. Each of these cross-sections were then subject to the Douglas-Pecker algorithm for simplification to linear segments. With an allowed maximum deviation set at 0.1 m, the profiles preserve the topological features that are relevant for the sound propagation.
Therefore, the final simplified profile carries information on elevation, ground cover type, and the distance from the source. While preserving the topological structure of the profile, it is also essential to retain the exact positions where ground cover transitions occur. These points are explicitly included in the profile, along with the updated ground cover type. This ensures that the Harmonoise model correctly accounts for ground impedance discontinuities by assigning the appropriate acoustic parameters—such as porosity and flow resistivity—on a segment-wise basis. Including these transitions enables accurate Fresnel-zone-based weighting and avoids unrealistic attenuation estimates that could arise from assuming uniform ground conditions along the propagation path. The table 1 below summarizes different ground cover classes available in the ground cover dataset [4] and their associated effective porosity and flow resistivity values.

Table 1. Different types of ground cover and the associated effective flow resistivity and porosity values for using the Zwikker and Kosten ground impedance model [9]

Ground cover type	Flow resistivity (kPas/m^{2})	Porosity
Water	10^7	10^{-7}
Forest-floor	20	0.5
Grass	300	0.75
Crops	200	0.9
Shrub & Scrub	100	0.45
Flooded Vegetation	10^7	10^{-7}
Built – Up Area	10^7	10^{-7}
Bare Ground	450	0.35

Figure 4. The solid black lines indicate the roads, the red region is the natura2000 site (study area) and the green dots are the receiver points, where the sound pressure levels are computed.

3.2 Computing Sound Pressure Levels at receiver points

The sound pressure levels (SPL) are computed for 1/3 octave bands with center frequencies ranging from 25 Hz till 10 kHz.

Table 2. Input parameters used to run the Harmonoise propagation model

Parameters	Values
Air temperature	15 ° C
Relative Humidity	70%
Atmospheric Pressure	101.325 kPa
Speed of Sound	340 (ms^{-1})
Turbulence scattering strength	5e-6
Source Height	0.03 (m)
Receiver Height	2 (m)

Following the Harmonoise/IMAGINE source power level model [3], [10], the sound pressure level at each receiver location is computed by first determining the source power level based on the traffic parameters (more precisely : traffic intensity, share of heavy and light vehicle, and vehicle speeds) for each road segment.
As the analytical model provides sound pressure levels relative to free field sound propagation, the geometrical spreading term is added afterwards to calculate the total attenuation towards a receiver. Additionally, an A-weighting correction is applied. Future research should explore alternative weighting schemes to better capture the effects on wildlife and biodiversity.
To look at the impacts of elevation and ground cover on the final sound pressure levels, the simulations were run with different simplifications. Test cases involve free field sound propagation only, neglecting terrain elevation by using a fixed elevation, and using a fixed ground cover. All other parameters remain the same as mentioned in Table 1. For simplicity, no refraction was considered in any noise map in this paper, although the Harmonoise analytical point-to-point model is able to model this accurately and efficiently.

4. RESULTS

The sound pressure levels are stored as a feature of the receiver points and are used in creating the noise maps. The outputs are stored as a separate vector files for each test case. The vector shape files are converted to raster pixels with a pixel size of 10 m in the georeferenced units, in our case it is EPSG:3035. The simulations for 4 different test cases are discussed below with fixed level axes. In a first step, interpolation is not applied and only the locations with actual calculations are shown (raw sound pressure level maps).

4.1 Case 1: Free field propagation

The simplest map, only accounting for free field propagation, is depicted in Fig. 5.

Figure 5. Sound pressure level map under free field propagation for the natura2000 site.

4.2 Case 2: Elevation and ground cover is kept constant

In this case, the elevation is kept at a constant value throughout the sampling locations. The ground cover is taken as forest floor, which was assigned a flow resistivity value of 20 kPas/m^2 and porosity value of 0.5 (From table 1).

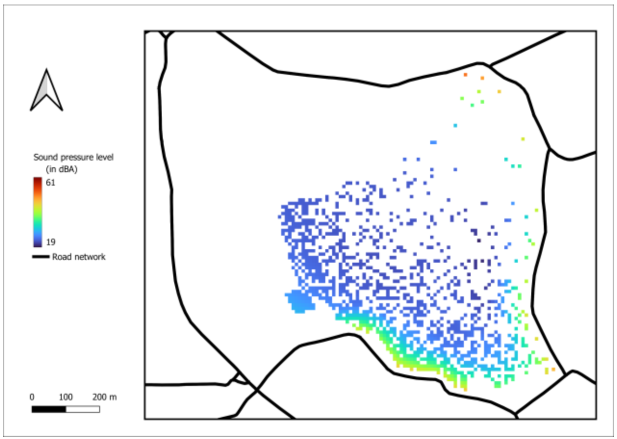

Figure 6. Sound pressure level map for flat forest floor ground

4.3 Case 3: Flat terrain with actual ground cover

Here, the actual ground cover from the dynamic world dataset [4] was used in case of flat terrain.

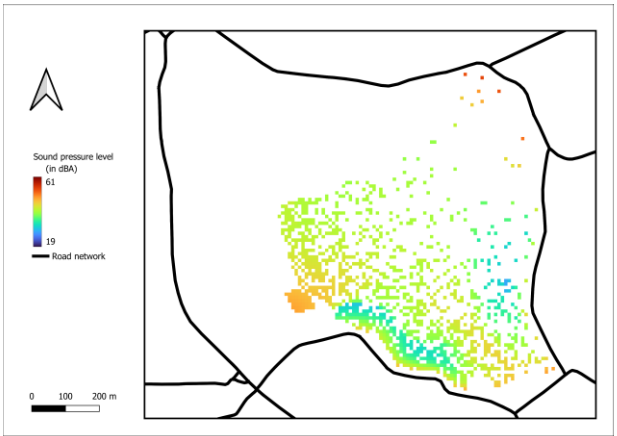

Figure 7. Sound pressure level map for constant elevation and actual ground cover values. The solid black lines indicate the roads

4.4 Case 4: Actual ground cover and actual elevation

In the final test case, actual elevation and ground cover are used, and represents the most accurate map.

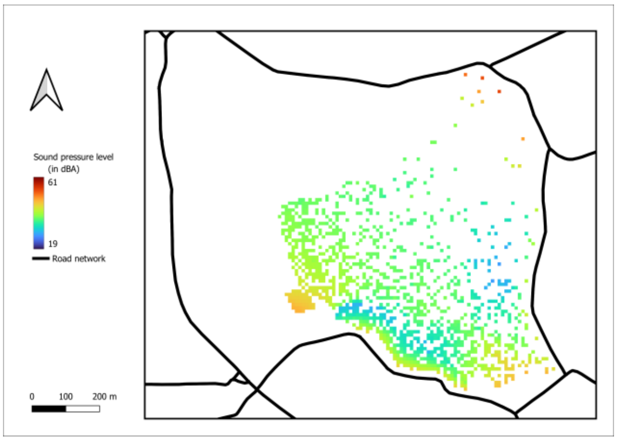

Figure 8. Sound pressure level map for actual ground cover and elevation values. The solid black lines indicate the roads.

4.5 Comparison map

Along with these 4 simulation cases, the difference map between the most simple free field propagation map and the most detailed one, including actual ground cover and elevation, is presented in fig. 9.

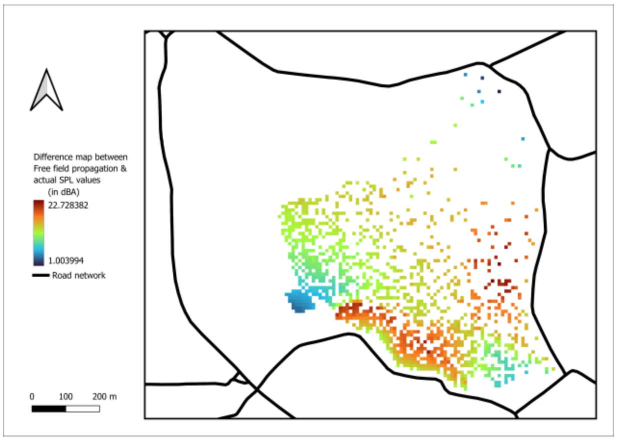

Figure 9. The difference map between the free field propagation and actual sound pressure level.

5. DISCUSSION

From the simulation test cases, it is found that both elevation and ground cover significantly affect the exposure levels. Table 3 summarizes the average differences and standard deviations in sound pressure levels.

Table 3. Average difference between the first three test cases and the final detailed exposure levels

Test case	Average difference (dBA)	Standard deviation (dBA)
Case 1: Free Field	13.5	3.5
Case 2: Flat terrain + forest-floor	10.8	5.4
Case 3: Flat terrain + actual ground cover	2.9	1.8

These variations highlight that ground-related excess attenuation is not merely an additive correction but a dominant propagation mechanism in vegetated and uneven terrain. Notably, the largest attenuation was seen in the final scenario, where both actual elevation and ground cover were used, suggesting synergistic attenuation effects between soft ground and terrain diffraction. Figure 9 illustrates that terrain and ground effects become increasingly important at greater distances, implying that simplified free-field approximations may severely overpredict noise exposure, thereby limiting the practical usefulness of noise mapping efforts. Free field maps, although they might seem attractive from a computational point of view, will not provide meaningful noise maps, with limited use in biodiversity studies.
The Harmonoise model's ability to account for ground attenuation and diffraction proves to be a critical advantage over simpler models like ISO 9613-2 or CNOSSOS - EU, which may underpredict attenuation in soft, vegetated environments [11].

6. FUTURE WORK

Future work will focus on reducing computational time through parallel processing, machine learning, and interpolation strategies. Parallel processing and machine learning methods can improve computational efficiency by optimizing noise modeling workflows, while interpolation techniques will help identify the minimum number of receiver points required to accurately estimate noise exposure across larger areas. These methods will be systematically tested by comparing their results against full calculations across a wider set of input parameters and scenarios, ultimately supporting more efficient large-scale environmental noise mapping for Europe's natural areas.

ACKNOWLEDGMENTS

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