Low-cost noise monitoring: STEM education as a medium to collect population based noise exposure data

Luc Dekoninck[1]

[1]Waves, Department of Information Technology, Ghent University, Belgium
luc.dekoninck@ugent.be

Abstract
Low-cost monitoring and citizen science are natural allies but the citizen's initiatives have also some downsides. The chosen measurement locations are in most cases dedicated to local initiatives. In this publication, the standard citizen science data collection is compared with an approach using an educational package which includes noise monitoring at the dwellings of the pupils. By design the educational package results in a random sample of dwellings with a wide variation of traffic condition.

Keywords: citizen science, noise monitoring, population based exposure, education.

1 Introduction

Environmental noise exposure is acknowledged as a relevant component in the burden of disease. A recent update of the WHO Environmental noise guidelines summarizes the evidence and provides new dose-effect relationships based on the most recent literature [1]. Most evaluations of the expo-sure of the population are based on modelling. At the European level, the choice to use noise modelling is standardized within the framework of the Environmental Noise Directive [2]. Within the con-text of the current Internet-of-Things and Smart City developments, the potential of including measured noise exposure into the 'noise impact assessment portfolio' is growing rapidly [3]. Integrating these noise monitoring projects into policy and into population exposure assessments is, however, challenging due to the high cost and relative low numbers of noise monitoring stations in most projects. The way forward is to build noise monitoring networks with low-cost noise monitors. This path is explored extensively in multiple projects [4, 5, 6, 7, 8, 9, 10]. A high-quality noise assessment with low-cost equipment is technically within reach [6, 11],yet, the hardware of a typical low-cost noise monitor, with a long-term qualitative microphone and wind screen, long-term logging capabilities, network connectivity and spectral analysis still costs about 200 Euros, more than sensors in similar projects for air pollution monitoring [12, 13]. Moreover, the huge data volume required for noise evaluations considerably contributes to the complexity of the measurement data collection, while the cost of the sensor deployment itself is a significant cost and thus a significant obstacle in noise research.
In parallel with these technological developments, the general public increasingly became an important driver in collecting environmental data to trigger legislative pressure and increase their impact on policy makers and hence reduce their own health risks. These projects, are commonly referred to as Citizen Sensing [14, 15] and are considered a subcategory of citizen science. The latter has been defined as participatory scientific research, with lay people volunteering in science activities like data gathering, data analysis, or even all steps in the scientific process. It is often considered a novel pathway that helps scientists to gather data in a more efficient way [16, 17, 18, 19]. The added value, the discussions on data quality, pitfalls, remediation and successes are increasingly represented in literature [20, 21, 22, 23, 24, 25, 26]. Within the noise context, only few citizen science projects have been implemented [4, 9, 15, 27], mainly due to the relative high cost of the relative high quality low-cost monitoring systems.
Both citizen science and data based governance are instigated by recent exponential technological advancements. The transformation of the society into a tech- and data-driven ecosystem urges our

educational systems to adapt accordingly. In response to this urge, education programs in Flanders, Belgium, are increasingly aiming to orient and prepare our ‘citizens of the future’ towards technology and science related jobs. Science and Technology, Engineering, Mathematics in education is commonly referred to as STEM. During STEM-courses, students get introduced to the scientific process and improve their mathematical and technological skills, often through interdisciplinary teaching modules. The content of this education package is available in [27]. In this publication, the focus is not on the content of the educational package, but different types of measurement campaigns are compared and evaluated.

2 Noise data collection: campaign design, applications and shortcomings

The basic approach in noise monitoring is performing high quality noise measurements with a specific and mostly project specific goal in mind. With the acoustical engineering field, this implies that a wide range of conditions are to be met, matching the regional legislation on the subject at hand. The typical application is the evaluation of industrial plants, noise control engineering actions, outdoor activities etc. The noise source under investigation is in most cases not traffic and when the traffic is evaluated, the industrial plant in general adds a significant contribution to the normal situation. All of these reasons result in the fact that these measurement locations don’t fit typical traffic exposure for the general population. For airports, noise monitoring networks are in place, but again the selection of the measurement locations is organized through the designated ISO standards and are the locations selected to perform qualitative ‘aircraft-only’ events. These types of locations can add value due to their high quality equipment and long-term (years) of data but the post-processing is not focusing on other applications. When these arguments can be refuted, the data is mostly proprietary and thus inaccessible for secondary applications. Within research projects, more freedom is allowed but the measurement locations are selected to match the specific scientific goals. If those goals do not include population based sampling, this data is also not directly applicable to perform population based exposure assessments. In all of the prior cases, the number of measurement locations is rather low.

In the past, large population based sample have been collected. In Flanders a repeated short-term sampling of 15 minutes in 250 measurement locations was performed between 1996, 2001 and 2009 [28]. This program was abandoned due to the high cost but the short-term sampling was intrinsically an important restriction on the applicability of the dataset. This approach was rejected in a recent evaluation of the environmental noise indicators in Flanders due to the lack of diurnal patterns [29]. In a large study performed in 2000/2001 in England and Wales, 24 hour noise measurements were collected at 1020 locations. The data is available as hourly results for a small set of statistical levels (L_{A01}, L_{A10}, L_{A50}, L_{A90}, L_{A95}, L_{Aeq} and L_{Amax}). The GPS-locations are not made available due to privacy reasons. In parallel a Noise Annoyance Survey (NAS) is performed on a different set of the population and no spatial relation can be built between the two datasets [10]. Linking actual exposure to annoyance reports is not possible in that setup.

In summary, population based noise monitoring is rare and expensive. When data is available, many restrictions apply for the applicability and use –cases of the data. As a result, current monitoring strategies don’t provide the required information to extend the current knowledge on noise exposure and by consequence, can’t improve the current state of the art towards noise annoyance assessments, health effects and trends in the exposure.

3 Standard Citizen Science campaigns

3.1 Gentbrugge – evaluation of a highway viaduct

The initiation of citizen science projects -especially in the noise exposure context- is strongly linked to local conflicts of interest. Highways and quality of green areas in urban settings are typical examples. Within the IDEA-project, the Ghent University collected data at in-city parks, some of the parks are close to a major highway and supported other measurements campaigns as example cases. One of the setups is initiated in the PhD of the author: the viaduct of the E40 in Gentbrugge, a suburban area at the south of the city of Ghent, Belgium. The same citizens asked to monitor during a refurbishment project of the viaduct, started just before the COVID pandemic. In Figure 1, the reference measurement and two month windows of measurements at a dwelling 300 m from the viaduct are made available. The refurbishment includes the replacement of the available screens, renewal of the road surface resulting in changing active lanes on the viaduct, a speed reduction during the traffic works, a reduction of traffic volume due to traffic diversions during the traffic works, and affected by the traffic changes due to the pandemic. Once the situation in normalized, an in-depth analysis can be performed to map the changes to the different stages of the viaduct refurbishment. At the time of publication, night-time traffic is still affected by the pandemic measures, but is a first evaluation shows a significant drop of the noise levels and a larger decrease during the night-time compared to the day-time. The data collection continues and more detailed analysis are necessary as soon as the traffic returns to the pre-pandemic situation.

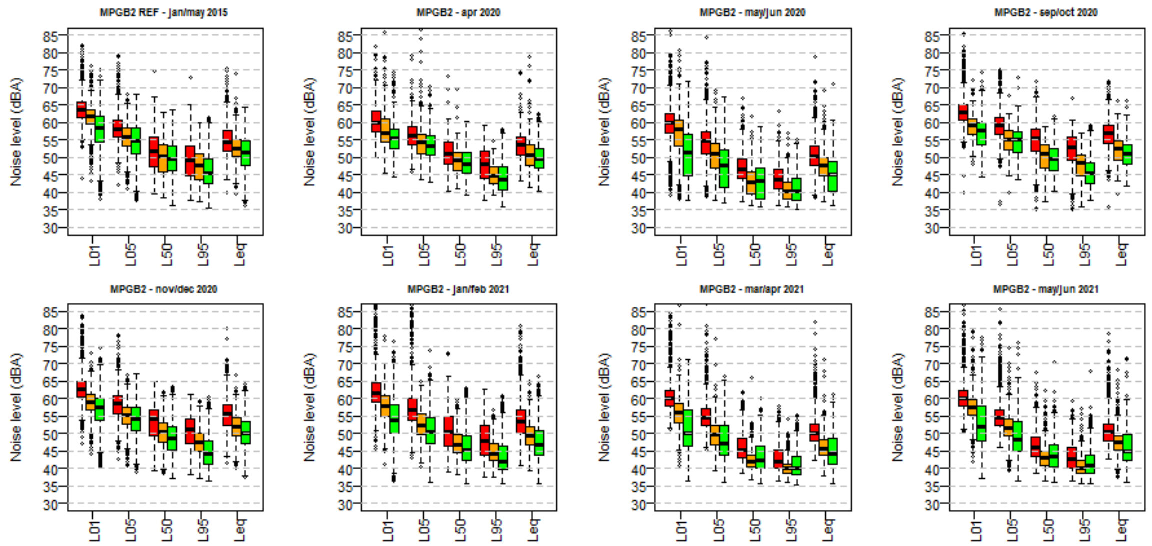

Figure 1 – Diurnal evaluation of the 15 minute statistical level at a measurement location at 300 m from a highway on a viaduct: reference measurement in 2015 (top-left) and time windows of one or two month during road works, screen replacement and noise control measures of the joints during the pandemic.

3.2 'Meet Mee Mechelen' – evaluation of a highway

A second example of standard citizen science application is the measurements performed in the wake of an H2020 project https://mechelen.meetmee.be/ focusing on air pollution. The local people insisted to include noise in the evaluation of the environmental quality. UGent contributed to a workshop on noise and as a result, the citizen started to measure noise with the low-cost system. The concept there was to shift a noise monitoring among the volunteers of the local action group. The results are shown in Figure 2. The citizen focused on the highway and some exits of the highway in their neighborhood. Five measurement locations were chosen but the low-cost equipment partially failed and the campaign continued with only one measurement unit (MP3-water in the box). An important feature is relevant here. At the first location (plots 1, 2 and 3), the measurements are repeated in the wake of the pandemic in the garden and an additional measurement is performed at the front façade. The results illustrate the impact of the pandemic in the garden and show the high peak values at day-time at the façade due to the local traffic. Background levels at the facade show the shielding of the façade measurement from the highway. More important, the citizen complains about the highway, not the local traffic in front of his dwelling. L_{Aeq} at the front façade is not the sole indicator to evaluate subjective annoyance responses. This subjective information is rarely included in current noise annoyance assessments and requires further attention.

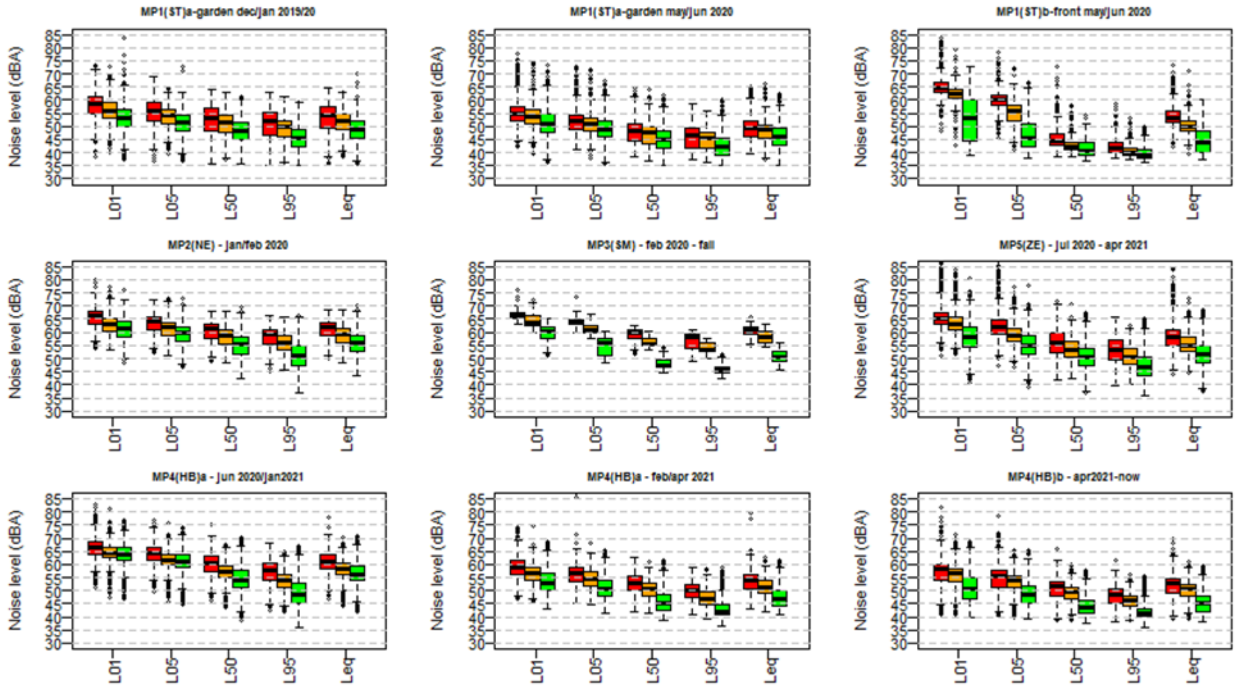

Figure 2 – Diurnal evaluation of the 15 min statistical level at five measurement locations chosen by local citizens between 50 and 500 m from a highway, split by measurement set.

At MP4, (plots on bottom row), repeated measurements are performed. The results differ significantly over the three sets. For the last sequence (from half of April 2021), the measurement location is moved 1.5m but that doesn't seem to account for the detected change.

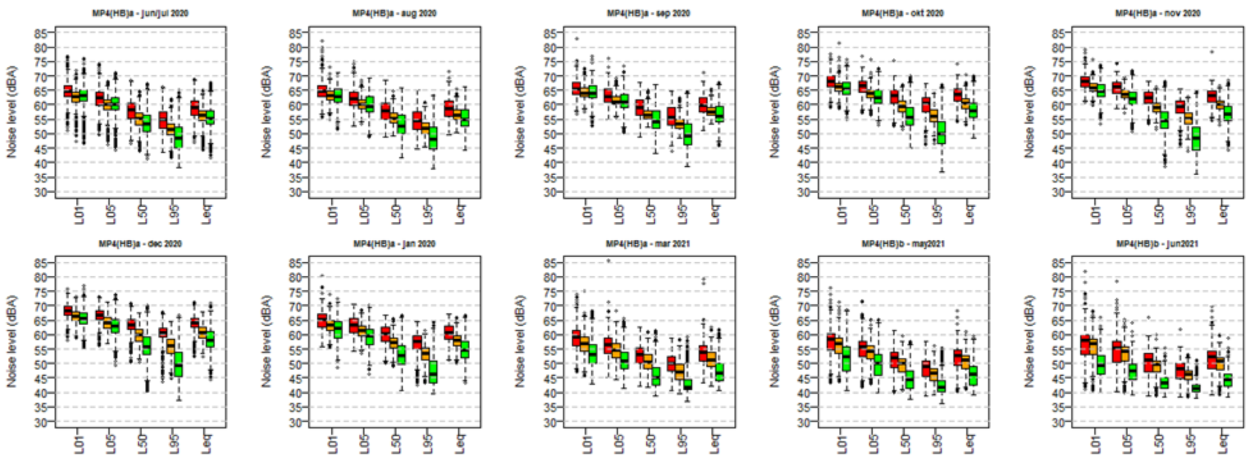

Figure 3 – Diurnal evaluation of the 15 minute statistical level at MP4 by month. Notice the significant change between December 2020 and March 2021.

In Figure 3, the data collected at MP4 (HB) are presented by month. The change is occurring between December 2020 and March 2021. The changing diurnal profiles suggest that it is not a calibration issue. When the equipment is retrieved, a validation of the calibration will be required. The origin of this change is not known yet. Further analysis for both the impact of meteorological conditions and/or changes in traffic are planned. The measurements are definitively impacted by the traffic changes related to the pandemic. Disentangling the effects of the pandemic is difficult but –evidently- highly relevant for future evaluation of (planned) interventions. Detailed (and funded) evaluation is planned through the environmental working group of the local city Mechelen.

4 Population based through STEM educational projects

It is evident that citizen based initiatives are highly relevant to gain knowledge on high exposed dwellings but these initiatives lack the potential to assess the general exposure of the population.

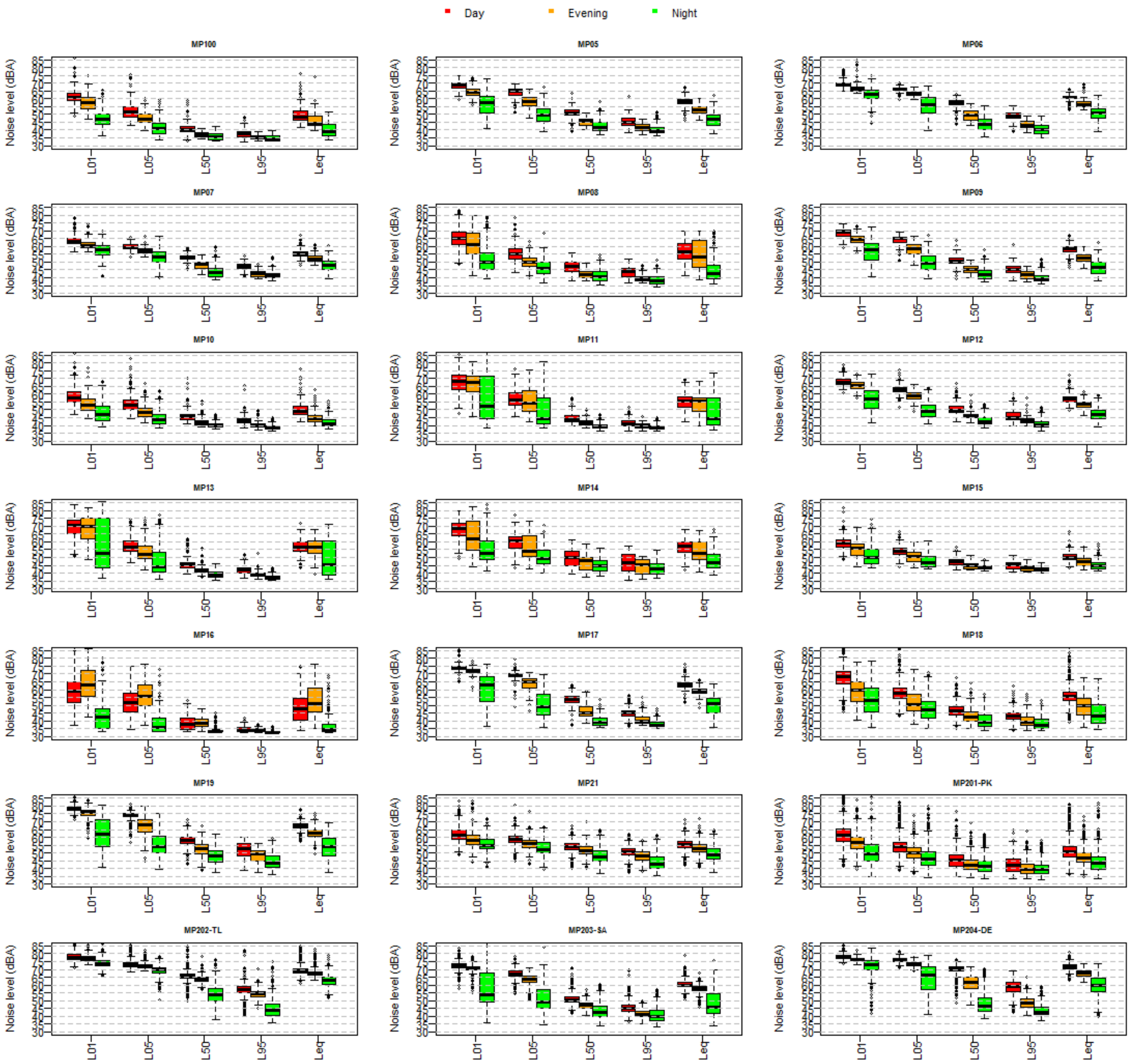

Figure 4 – Diurnal evaluation of the 15 minute statistical of the data collected in one group of pupils, extended with four other citizen science measurements (PK: suburb local street; TL: in-city narrow secondary road with bus line; SA: in-city wide local road with tram; DE: primary road at city edge).

To accommodate this missing information, the author suggest to focus on citizen science applications in schools and integrate the data collection in an educational package. The focus is science education but the resulting measurements provide a unique resource for population based noise assessments. The content of the educational package is presented in prior work [27]. Here we focus on the use of the data. In Figure 4, the educational dataset is shown, extended with some additional low-cost noise monitoring locations (long-term at a low exposure location (PK), a secondary road in a city with busses (TL), an in-city local road with a tram line and a primary road during the pandemic (DK). The additional data points are included to illustrate some extreme exposure situation for different settings. Noise exposure along bus or tram facilities is significant. The variation ranges for day, evening and night differ and provide insights in the traffic densities on the nearby road.

5 Discussion

Understanding the real-life exposure variation in the general population is difficult to assess due to the high operational cost of noise measurements. The introduction of low-cost noise monitoring with a quality comparable to at least type 2 noise equipment enables larger measurement campaigns. Decreasing the operational cost can be achieved by including citizen science approaches. Motivating citizens to measure noise without local noise issues is difficult. The trajectory as an educational package for schools delivers opportunities to collect population based exposure samples.

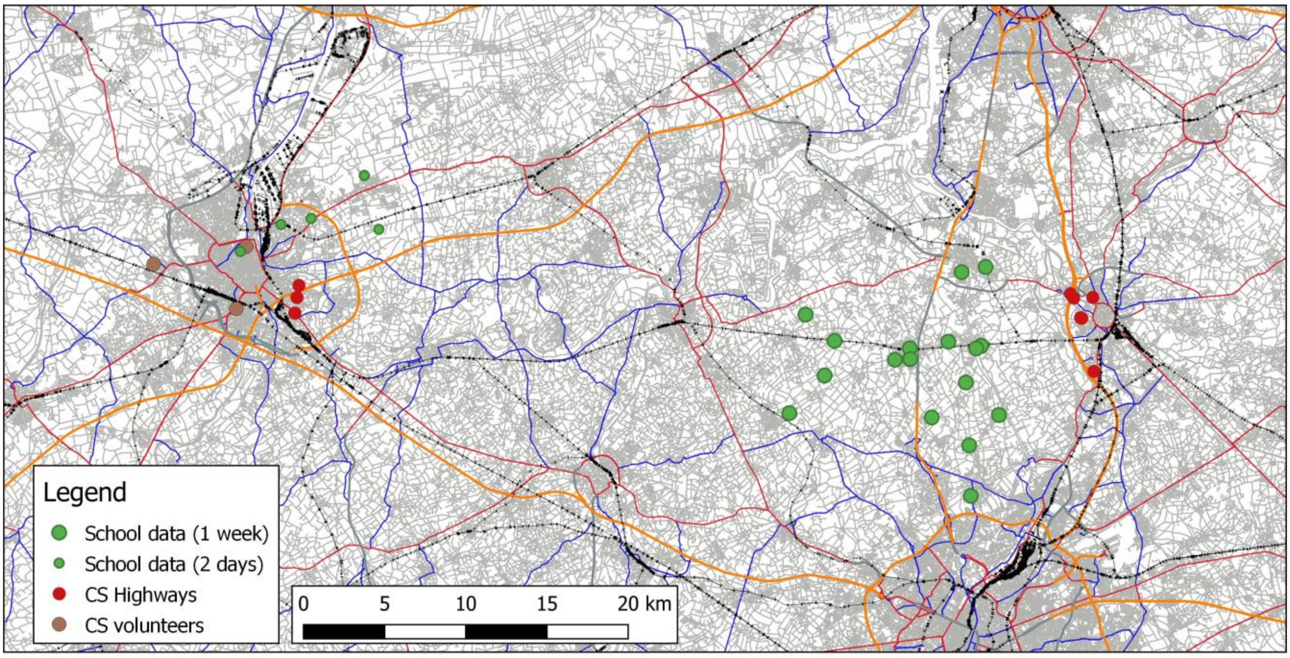

Figure 5 – Spatial overview of the citizen science data collection..

The sampling is significantly different compared to standard citizen campaigns. The type of output is completely different: the main goal of the educational package is to give insight in the scientific processes, the multi-disciplinarity of doing science, the mathematical component and most relevant, the meta-data collection. The educational package itself is extensively discussed in prior work [27]. The main benefit is the synergy between teachers and scientists. The teachers benefit from the predesigned project and their overview and evaluation of the work of the pupils in the project enhance the quality of both the measurements and the collected metadata.
In this practical out roll, some lessons can be drawn to improve the communication and data collection. The most important missing tool, is a structured method to collect the meta-data for the measurements. Especially

moving the equipment from location to location has to be well documents and a more generalized set of locations based parameters is required. A non-exhaustive list would be: on-façade or not, distance to façade, distance to curb-side, local street oriented or not, height of the noise monitor etc.
The pupils also collected traffic counts for short episodes in parallel with the measurements at their dwelling façade. They use it in an exercise to detect events in the detailed noise measurement sequence. This type of information might be provided to the scientists as well.
In Figure 5, the spatial extent of the citizens' science measurement locations is shown. It is evident that the highway related locations are case specific, while the other data is distributed. The school who took part in the campaign were not located in major cities. The current sample collected in the pilot is –evidently- not valid for the Flemish population yet but the pilot does show the potential to cover all potential noise exposure situations on a regional scale.
Organizing this in a higher level is necessary due to the restrictions on collecting data and metadata in the framework of the DGPR regulations. The Flemish government is progressing in an out roll for more structured environmental monitoring. Including the potential of the education package based noise monitoring in this initiative would result in significant synergies and doing so, accelerate, structure and integrate the population based data collection in the environmental policy related goals.

6 Conclusions

Noise measurements become more available and more affordable. Large-scale monitoring can add value to understanding of overall noise annoyance response in the general population. Citizen science can reduce the cost for collecting data significantly. The type of citizen campaign do affects the potential applications. The typical trigger for citizen campaigns is high exposure to specific situations and neighbourhoods. To assess population based exposure, the typical citizen projects fail.
The educational approach illustrates that the noise measurement locations cover all relevant variability in various noise climates. The educational package is creating a win-win situation for (1) the pupils learning about science and becoming part of real data collection, (2) the teachers working with a state-of-the-art tools in a field that is rarely targeted by citizen science, (3) the scientists retrieving valuable data for their research and (4) the governments add value to their environmental reporting. An additional benefit is the increased visibility of the environmental noise discipline as a relevant scientific field. It is just a matter of time that when of our future employees will grab our attention by mentioned their introduction to our field of expertise by similar initiatives.

Acknowledgements

I want to acknowledge the volunteering teachers who included the educational package into their program. The communication between the teachers and the scientist was initiated within the BRITEC project [27].

References

[1] World Health Organization. (2018). Environmental noise guidelines for the European region.

[2] DIRECTIVE 2002/49/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 June 2002 relating to the assessment and management of environmental noise

[3] Alías, Francesc, and Rosa Ma Alsina-Pagès. "Review of Wireless Acoustic Sensor Networks for Environmental Noise Monitoring in Smart Cities." Journal of sensors 2019 (2019).10

[4] Maisonneuve, Nicolas, Matthias Stevens, Maria E. Niessen, Peter Hanappe, and Luc Steels. "Citizen noise pollution monitoring." (2009).

[5] Botteldooren, Dick, Timothy Van Renterghem, Damiano Oldoni, Dauwe Samuel, Luc Dekoninck, Pieter Thomas, Weigang Wei et al. "The internet of sound observatories." In Proceedings of Meetings on Acoustics ICA2013, vol. 19, no. 1, p. 040140. Acoustical Society of America, 2013.

[6] http://idea.intec.ugent.be/en/

[7] Farrés, Júlia Camps. "Barcelona noise monitoring network." In Proceedings of the Euronoise, pp. 218-220. 2015.

[8] Mietlicki, Fanny, Christophe Mietlicki, and Matthieu Sineau. "An Innovative Approach for long term environmental noise measurement: RUMEUR Network in the Paris Region." In Proceedings of the EuroNoise. 2015.

[9] Bello, Juan P., Claudio Silva, Oded Nov, R. Luke Dubois, Anish Arora, Justin Salamon, Charles Mydlarz, and Harish Doraiswamy. "Sonyc: A system for monitoring, analyzing, and mitigating urban noise pollution." Communications of the ACM 62, no. 2 (2019): 68-77.

[10] Salvo, David, Gema Piñero, Pau Arce, and Alberto Gonzalez. "A Low-cost Wireless Acoustic Sensor Network for the Classification of Urban Sounds." In Proceedings of the 17th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks, pp. 49-55. 2020.

[11] Picaut, Judicaël, Arnaud Can, Nicolas Fortin, Jeremy Ardouin, and Mathieu Lagrange. "Low-Cost Sensors for Urban Noise Monitoring Networks—A Literature Review." Sensors 20, no. 8 (2020): 2256.

[12] McKercher, Grant R., Jennifer A. Salmond, and Jennifer K. Vanos. "Characteristics and applications of small, portable gaseous air pollution monitors." Environmental Pollution 223 (2017): 102-110.

[13] Rai, Aakash C., Prashant Kumar, Francesco Pilla, Andreas N. Skouloudis, Silvana Di Sabatino, Carlo Ratti, Ansar Yasar, and David Rickerby. "End-user perspective of low-cost sensors for outdoor air pollution monitoring." Science of The Total Environment 607 (2017): 691-705.

[14] Sheth, Amit. "Citizen Sensing, Social Signals, and Enriching Human Experience", Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences 370 [1958], (2009): 176-197. DOI:10.1098/rsta.2011.0244.

[15] Berti Suman, Anna & Marina van Geenhuizen (2020) "Not just noise monitoring:rethinking citizen sensing for risk-related problem-solving", Journal of Environmental Planning and Management, 63:3 (2020): 546-567. DOI: 10.1080/09640568.2019.1598852

[16] Bonney, Rick, Jennifer L. Shirk, Tina B. Phillips, Andrea Wiggins, Heidi L. Ballard, Abraham J. Miller-Rushing, and Julia K. Parrish. "Next steps for citizen science." Science 343, no. 6178 (2014): 1436-1437.

[17] Conrad, Cathy C., and Krista G. Hilchey. "A review of citizen science and community-based environmental monitoring: issues and opportunities." Environmental monitoring and assessment 176, no. 1 (2011): 273-291.

[18] Bonney, Rick, Caren B. Cooper, Janis Dickinson, Steve Kelling, Tina Phillips, Kenneth V. Rosenberg, and Jennifer Shirk. "Citizen science: a developing tool for expanding science knowledge and scientific literacy." BioScience 59, no. 11 (2009): 977-984.

[19] Newman, Greg, Andrea Wiggins, Alycia Crall, Eric Graham, Sarah Newman, and Kevin Crowston. "The future of citizen science: emerging technologies and shifting paradigms." Frontiers in Ecology and the Environment 10, no. 6 (2012): 298-304.

[20] Ottinger, Gwen. "Buckets of resistance: Standards and the effectiveness of citizen science." Science, Technology, & Human Values 35, no. 2 (2010): 244-270.

[21] Aceves-Bueno E., Adeleye A.S., Feraud M., Huang Y., Tao M., Yang Y., Anderson S.E. 2017. The accuracy of Citizen Science Data: A quantitative review. Bulletin of the Ecological Society of America, vol. 98 (4), 278-290.

[22] Cox J., Oh E.Y., Simmons B., Lintott C., Masters K., Graham G., Greenhill A., Holmes K. 2015. How is success defined and measured in online citizen science? A case study of Zooniverse projects. Computing in Science and Engineering, vol. 17 (4), p. 28-41.

[23] Riesch, H. & Potter, C. (2013). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. Public Understanding of Science, 0963662513497324.

[24] Westreicher F., Cieslinkski M., Ernst M., Frigerio D., Heinisch B., Hübner T., Rüdisser J. 2020. Recognizing failures in citizen science projects: Lessons learned. Proceedings of the Austrian Citizen Science Conference ACSC 2020. 14-16 September 2020. Vienna, Austria. 9 pp. https://pos.sissa.it/393/007/pdf

[25] Kelling, Steve, Alison Johnston, Aletta Bonn, Daniel Fink, Viviana Ruiz-Gutierrez, Rick Bonney, Miguel Fernandez, Wesley M. Hochachka, Romain Julliard, Roland Kraemer, Robert Guralnick. “Improving Citizen Science Data for Monitoring Biodiversity”. BioScience 69 (2019): 170-179.

[26] Brossard, Dominique, Bruce Lewenstein, and Rick Bonney. "Scientific knowledge and attitude change: The impact of a citizen science project." International Journal of Science Education 27, no. 9 (2005): 1099-1121.27. Berti Suman, Anna (2018) “Challenging risk governance patterns through citizensensing: the Schiphol Airport case”, International Review of Law, Computers & Technology, 32:1 (2018): 155-173. DOI: 10.1080/13600869.2018.1429186

[27] Dekoninck Luc, Van Buggenhout, Wim, Sterken, Mieke, (2021), Merging Science Education, Citizen Science and General Population Noise Exposure data collection in the battle against noise pollution, submitted to InterNoise 2021, 1-5 august 2021.

[28] Van Renterghem, Timothy, Dick Botteldooren, and Luc Dekoninck. "Evolution of building façade road traffic noise levels in Flanders." Journal of Environmental Monitoring 14, no. 2 (2012): 677-686.

[29] Dekoninck, Luc, and Dick Botteldooren. "Regional environmental noise indicators: SWOT analysis and future developments." In e-Forum Acusticum 2020, pp. 1663-1665. 2020.

[30] DEFRA. (2002) The UK National Noise Incidence Study 2000/01. London, Department for Environment, Food and Rural Affairs. http://www.defra.gov.uk/environment/noise/nis0001

[31] MeetMeeMechelen citizen science project: https://vito.be/en/do-business/government/towns-and-cities/meet-mee-mechelen