

Communicating data quality from citizen science: lessons learned from environmental monitoring studies

Jan Brus*

*^a Palacký University Olomouc, Faculty of Science, Department of Geoinformatics,
17. listopadu 50, 779 00 Olomouc, Czechia, jan.brus@upol.cz*

Keywords: citizen science, uncertainty visualization, data quality, geoparticipation, environmental monitoring, sustainable development

Abstract:

The global expansion of citizen science has fundamentally transformed environmental monitoring and conservation practices. While volunteer-contributed data offers unprecedented spatial and temporal coverage, it introduces significant challenges in data quality assessment and communication. This work presents methodological approaches and lessons learned from two long-term citizen science projects focused on environmental monitoring: (1) mosquito outbreak mapping in a protected landscape area in Czechia, and (2) international monitoring of honey bee colony losses through the COLOSS network. Both projects demonstrate the critical importance of visualizing and communicating data uncertainty to diverse stakeholder groups, from local communities to policymakers.

The Context of Sustainable Development

These citizen science initiatives support sustainable development by balancing ecological conservation with human well-being. Mosquito management requires protecting floodplain biodiversity while reducing community nuisance—biological control using Bti targets larvae specifically, but effective implementation needs both distribution data and community perceptions. Similarly, declining honey bee populations threaten food security; beekeepers' systematic knowledge provides colony health insights that complement official statistics. In both cases, citizen data enables evidence-based decisions addressing ecological and socio-economic concerns.

Methodology: From Data Collection to Uncertainty Visualization

Our approach follows a user-centered framework that treats uncertainty not as a problem to eliminate but as information to communicate transparently. This philosophy guides three key methodological components:

1. Geoparticipatory Data Collection In the Litovelské Pomoraví Protected Landscape Area, we developed an online questionnaire enabling 105 residents, cottage owners, and visitors to mark locations experiencing high mosquito activity for both spring and summer periods (Rypl et al., 2024). This approach explicitly captures subjective perception alongside spatial information—recognizing that nuisance is itself a subjective phenomenon that varies among individuals. For the COLOSS bee monitoring network, beekeepers across 40+ countries report winter colony losses through standardized questionnaires. The Czech implementation includes validation against official agricultural statistics, allowing quantification of sample representativeness and identification of systematic biases in volunteer-reported data.

2. Objectifying Subjective Information Raw citizen science data inherently contain uncertainty arising from multiple sources, including positional imprecision, temporal vagueness, and subjective interpretation. To address these challenges, the data were first aggregated by area and confidence level. Overlapping polygon submissions were unified and averaged to produce compromise values that reflect consensus among respondents. Next, citizen-reported mosquito hotspots were integrated with professionally mapped breeding site locations through buffered envelope zone weighted by predicted threat level. This process resulted in composite “active zone” maps that balanced subjective perceptions with objective environmental information. Finally, these active zones were overlaid with high-resolution population distribution grids—differentiating between daytime and nighttime populations—to quantify the number of people affected and to prioritize areas for targeted intervention.

3. Visualizing and Communicating Uncertainty Effective uncertainty visualization must balance technical accuracy with cognitive accessibility. Our designs evolved through iterative testing with target user groups: for local stakeholders: simplified categorical maps (low, medium, high activity zones) with clear visual hierarchies proved more effective than complex graduated symbology, for decision-makers: population threat maps combining mosquito activity with demographic data enabled evidence-based larvicide application prioritization, emphasizing actionable insights over comprehensive data display, for beekeepers: annual COLOSS reports explicitly state sample representativeness relative

to national statistics (e.g., "representing 18% of registered colonies in selected ZIP code area"), building trust through transparency about data limitations.

Results and Impact

The mosquito monitoring project successfully delineated active zones covering 92.5 km² and quantified threatened populations: approximately 16,700 people during daytime and 10,840 at night. Summer outbreaks affected larger areas (28.4 km²) and more people than spring outbreaks (2.4 km²), informing seasonal management strategies. Critically, visualizations combining citizen reports with breeding site locations shifted high-activity designations from residential areas toward floodplain interiors—redirecting larvicide applications to ecologically appropriate targets while minimizing chemical exposure to populated zones. The COLOSS monitoring network has documented winter losses across 13 years, revealing temporal trends and risk factors including operation size, queen replacement practices, and migration patterns. Czech data validation demonstrated that volunteer samples, while not perfectly representative, consistently captured relative trends matching official statistics. Explicit communication of sampling uncertainty transformed stakeholder perceptions: rather than dismissing citizen data as unreliable, policymakers now engage with qualified conclusions appropriately contextualized by data limitations.

Discussion: Lessons for Sustainable Environmental Management

1. Subjectivity as Information, Not Noise: In environmental management, human perception is often the phenomenon of interest. Mosquito "nuisance" cannot be objectively measured—it is inherently subjective and spatially variable. Rather than attempting to eliminate this subjectivity, we documented and mapped it systematically. Similarly, beekeepers' self-reported losses reflect operational realities that official statistics may miss. **2. Validation Builds Trust:** Transparency about data limitations paradoxically increases credibility. The Czech COLOSS approach of validating volunteer data against independent sources has become a model for other national networks. Explicitly quantified uncertainty enables users to make appropriately qualified decisions rather than uncritically accepting or rejecting citizen-contributed evidence. **3. Iterative Co-Design with Users:** Effective uncertainty visualization requires understanding target audiences' cognitive capabilities and decision-making contexts. Our eye-tracking studies revealed that cartographically sophisticated designs often failed with non-expert users. Simpler visualizations, co-developed through stakeholder workshops, achieved better comprehension and decision support. **4. Biological Control as Sustainable Practice:** The mosquito case study demonstrates how citizen science can enable targeted biological control, reducing reliance on broad-spectrum pesticides. By identifying precise breeding site locations and quantifying population exposure, larvicide applications minimize environmental impact while maximizing public health protection. This exemplifies the balance between human needs and ecological conservation central to sustainable development.

Conclusions

Citizen science offers transformative potential for environmental monitoring supporting sustainable development goals. However, realizing this potential requires systematic approaches to data quality assessment and uncertainty communication. Geoparticipatory tools have demonstrated the ability to systematically capture local ecological knowledge, transforming subjective perceptions into actionable spatial information. When uncertainty is visualized and communicated explicitly—rather than concealed—it enhances the credibility of citizen-contributed data and supports more informed decision-making. At the same time, user-centered design principles remain essential: effective visualizations must correspond to the cognitive capabilities and decision contexts of their target audiences, rather than focusing solely on technical sophistication. Finally, integrated approaches that combine citizen-generated observations with professional monitoring and objective environmental factors provide a more comprehensive understanding of environmental processes, yielding insights unattainable from either source alone. These lessons extend beyond mosquito control and beekeeping to broader applications in conservation planning, invasive species management, climate adaptation, and participatory landscape governance. As citizen science continues expanding into environmental decision-making, systematic frameworks for quality assessment and uncertainty communication will prove increasingly critical for achieving sustainable development outcomes.

Acknowledgments

This work was supported by The Ministry of Agriculture of the Czech Republic (QL24010241) and by the Ministry of Education, Youth and Sport of the Czech Republic through the Inter-Action grant LUAUS24085.

References

- Rypl, O., Burian, J., Pánek, J., & Brus, J. (2024). Geoparticipation as a tool for mapping calamities mosquito hotspots: A case study from Litovelske Pomoravi, Czechia. *Environmental and Sustainability Indicators*, 24. <https://doi.org/10.1016/j.indic.2024.100509>