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Reviewing 10 years of openSenseMap - the open environmental data platform for (GI)Science, Education and Participation

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Abstract. Since its launch in 2014, openSenseMap has become a widely used platform for citizen science and environmental sensing. Over the past decade, it has enabled real-time data collection, visualization, and analysis through an open sensor network. This paper reflects on its evolution, technical advancements, and impact on geospatial research. We discuss challenges in managing an open geospatial infrastructure at scale and introduce the next-generation openSenseMap, which enhances data quality, interoperability, and usability. By sharing lessons learned and future directions, we underscore its role in participatory environmental monitoring and geographic information science.

Submission Type. dataset, software, project, infrastructure

BoK Concepts. Web services, Geospatial citizenship, Data Collection

Keywords. open data, citizen science, environmental monitoring

1 Introduction

Open data, open-source, and free platforms have become essential in fulfilling the aims of citizen science, particularly in the realm of environmental monitoring. When Goodchild (2007) claimed the term 'Volunteered Geographic Information' in his widely cited work on "Citizens as Sensors" he not yet had in mind, that citizens will use real physical sensors to observe environmental change. But the advancements in the Citizen Science domain, developments in low-cost and open source microcontrollers and sensor technologies led to various citizen observatories and sensing projects and platforms e.g. in the context of air quality monitoring (Castell et al., 2013). Participatory sensing, which involves individuals contributing to (geographic) data collection efforts, has rapidly gained traction as a means to address critical environmental issues. These approaches not only broaden the scope of data collection but also foster greater public engagement and awareness in scientific processes, in particular in GIScience.

The openSenseMap was launched in 2014 as an open-data platform designed to facilitate real-time environmental data collection and sharing through a network of community-driven sensors (Pfeil et al., 2015). It enables environmental data from all domains to be uploaded, accessed, and visualized (see Figure 2). During the past decade, it has evolved into a widely used tool to support research, education, and citizen science. As openSenseMap reaches its ten-year milestone, this paper reflects on its evolution, technical advancements, and impact on GIScience. We highlight key developments, research applications, and lessons learned from maintaining an open geospatial data infrastructure, with a particular focus on the sustainability of such a system. In addition, we introduce the next-generation openSenseMap, which incorporates improved data quality mechanisms, improved interoperability, and new analytical tools. By reviewing the successes and challenges of the past decade, we contribute to the broader discourse on participatory GIS and the role of open geospatial platforms in environmental monitoring.

As openSenseMap progresses into its next phase, it remains committed to enhancing the accessibility, reliability, and usability of environmental data. The platform's ongoing development emphasizes the importance of community-driven data collection, with new features designed to foster collaboration and support a wider range of applications. By providing robust tools for data analysis, sharing, and visualization, openSenseMap continues to empower users — whether researchers, educators, or citizens — to actively participate in environmental GIscience. The future of openSenseMap holds exciting possibilities for advancing both citizen science and GIScience, driving innovation in environmental monitoring, and creating a more inclusive, data-driven approach to solving global environmental challenges.

2 Related Projects

Several initiatives and platforms have played a significant role in advancing the field of participatory sensing and open environmental data. An overview of some platforms that display citizen science data and information and collect relevant scientific outcomes from participatory environmental sensing can be found in Liu et al. (2021). Among the listed examples, sensor.community, HackAir and the Smart Citizen platform stand out as notable contributors to the democratization of environmental monitoring next to openSenseMap and will be introduced in the following sections.

Sensor.community (https://sensor.community) is a collaborative initiative that allows citizens to build, deploy, and share air quality monitoring sensors. Originally launched as luftdaten.info, it has grown into a global network of individuals and organizations engaged in collecting real-time environmental data. The platform encourages users to construct low-cost sensors, contribute to the data network, and access the resulting environmental measurements. Its sensors have been used extensively for air quality research and policy development (Hamm, 2020). While Sensor.community is limited to only a few environmental phenomena and stationary devices, openSenseMap, in comparison, allows for the measurement of an unlimited range of environmental phenomena and supports mobile devices. Since the devices' firmware enables submitting data to the openSenseMap as well, most users opt to do so.

HackAir (https://www.hackair.eu/) used low-cost hardware for air quality monitoring. Though its platform shut down post-funding, its devices remain accessible on openSenseMap.

Smart Citizen platform (https://smartcitizen.me/kits/) is another prominent project that focuses on enabling individuals to monitor their environment through the use of customizable sensor kits. The platform supports a wide range of sensors that measure various environmental parameters, such as air quality, noise, and temperature. These kits empower citizens to contribute to a global network of environmental data while also providing access to tools for data analysis and visualization (Camprodon et al., 2019).

3 openSenseMap - Impact across domains

As of 2024, openSenseMap hosts data from thousands of environmental sensors worldwide on a variety of environmental phenomena - for example weather, air quality or traffic. The platform has been widely adopted in scientific research, education, and urban monitoring.

3.1 Contributions to Scientific Research

openSenseMap has become an essential tool for various academic studies, particularly in environmental monitoring and geospatial research. Researchers have used its open application programming interface (API) for real-time data analysis, air quality assessments, and geospatial modeling, showing its relevance for data-driven environmental research.

Most recently, Feizizadeh and Omarzadeh (2025) utilized openSenseMap to analyze cycling discomfort and risk in Berlin, highlighting the platform's role in collecting volunteer geographic information (VGI). Beck et al. (2023) relied on openSenseMap's infrastructure to handle large datasets for indoor air quality monitoring, ensuring uninterrupted measurement storage. Additionally, in the context of tourism, a mobile application called LightBeam used openSenseMap to stream sensor data on light intensity, UV irradiance, and temperature, integrating this information into a mobile application for real-time touristic recommendations (Dionisio et al., 2017).

openSenseMap has also been recognized as a key resource in the broader context of open data and citizen science. Sanders and Liebig (2020) cited openSenseMap for its role in decentralized data collection, which supports distributed knowledge discovery in citizen science projects. Others mentioned the platform for its contribution to crowdsourced environmental data collection, which supports public health and urban planning research (Peters and Zeeb, 2022; Bill et al., 2022).

Since its introduction, openSenseMap has become increasingly recognized in academic research, especially within environmental and geospatial sciences. Using a Google Scholar search for the term 'openSenseMap', we identified publications that either reference or directly utilize the platform. Figure 1 shows the number of such studies between 2014 and 2024.

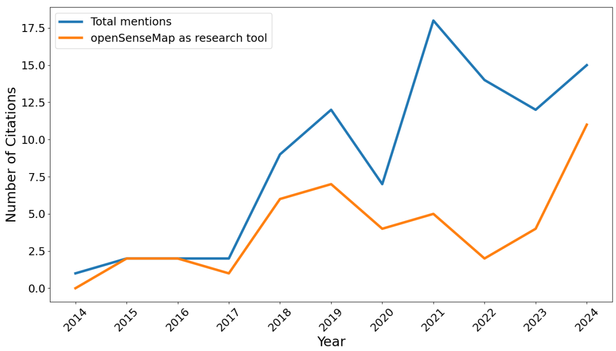

Figure 1. Number of academic publications mentioning openSenseMap and those using it as a research tool between 2014 and 2024, based on a Google Scholar keyword search for 'openSenseMap'.

3.2 Enhancing Educational Practices

openSenseMap has become an important tool in education, helping to foster data literacy, hands-on learning, and interdisciplinary projects. It is widely used in university courses and high school programs to teach students about environmental sensing, data analysis, and the principles of open science. As Bartoschek and Keßler (2012) explored, the use of participatory VGI applications is very motivating for learners, if they know that all their contributions (from collection and submission to use) makes sense and will be used for a good purpose. This is the case with openSenseMap.

Thapa et al. (2018) integrated openSenseMap into a high school project on agricultural monitoring, demonstrating its value in engaging students with sensor technology and geospatial analysis. Similarly, Hüsing et al. (2024) utilized openSenseMap data in a study on epistemic programming – a method that enables learners to explore personal interests through data-driven programming. In the aforementioned study Beck et al. (2023) used openSenseMap explicitly in a classroom setting, where students program and maintain sensors and connect them to the platform under scientific supervision.

Meng (2022) takes a look at the challenges and proliferation points of cartographic education and mentions the openSenseMap as an example for coopetition-oriented talent cultivation, a hub for visual analysis of thematic information and a shared interface for the collection of crowdsourced data.

In a joint Open Educational Resources (OER) project related to Spatial Data Infrastructures by three german universities (ORCA.nrw) the openSenseMap API is being used as a data source for Analyzing Streams of IoT Air Quality Data using Kafka and Jupyter Notebooks (Puri and Remke, 2024).

By providing access to real-world environmental data, openSenseMap enhances science, technology, engineering, and mathematics (STEM) education, encouraging students to develop analytical skills, engage in self-directed learning, and apply computational methods to real-world problems. This has been reflected in a variety of works in STEM didactics, e.g. by Penzlin and Marsch (2022), Georg (2023) or Becker and Riemann (2020).

3.3 Advancing Urban Monitoring and Decision-Making

Beyond academia, the platform provides accessible, community-driven data on environmental factors such as air quality and urban heat islands. These are used by municipalities and local organizations to inform decisions related to urban resilience and public health (Feizizadeh and Omarzadeh, 2025; Beck et al., 2023). By enabling real-time data collection and analysis, openSenseMap helps local authorities better understand environmental challenges and take targeted actions for improvement. Plenty official data visualisation platforms and dashboards rely on the openSenseMap API as source of live sensor data, e.g. the Smart City Dashboards of Bad Hersfeld (https://badhersfeld.urbanpulse.de/), Münster (https://dashboard.smartcity.ms/) or Bad Belzig (https://bad-belzig.klima-daten.de/wasser) in Germany.

3.4 Addressing Global Challenges

openSenseMap provides an infrastructure that contributes to addressing global challenges, particularly in climate change and environmental sustainability. With a constantly growing number of over 15.000 devices collecting environmental data from both mobile and stationary sources, the platform offers valuable insights into local and global conditions. This dataset can support research and decision-making related to climate change, providing real-time data on various environmental parameters.

The platform's role in the open data ecosystem has been recognized, such as with the Open Data Impact Award 2022 (Mühlenhoff and Traeger, 2023). The open accessibility of its data allows researchers and policymakers to use the information in efforts to improve sustainability practices and address climate-related issues. The platform's well-documented API and user-friendly interface further enable easy access to this data, promoting its use in climate research and solution development.

openSenseMap's educational applications align with the United Nations' Sustainable Development Goals (SDGs), particularly quality education (SDG 4) and climate action (SDG 13) (United-Nations, 2015). By involving students and communities in data collection, the platform supports the development of skills and knowledge necessary to address global challenges.
In summary, the openSenseMap infrastructure provides valuable data for addressing environmental challenges. Its continued development, along with the integration of educational initiatives and tools for data collection, offers opportunities for further engagement with climate and sustainability issues.

4 Technical Advancements

openSenseMap was launched in 2014 as part of the *senseBox* project at the Institute for Geoinformatics (ifgi) at the University of Muenster, Germany (Pfeil et al., 2015). From its beginning, the platform has followed open data principles, ensuring unrestricted access to environmental sensor data. The platform provides a public Representational State Transfer (REST) API that enables data retrieval in standard geospatial formats such as GeoJSON, enhancing compatibility with GIS applications. Over time, the API has been optimized to handle increasing request loads while maintaining response efficiency.

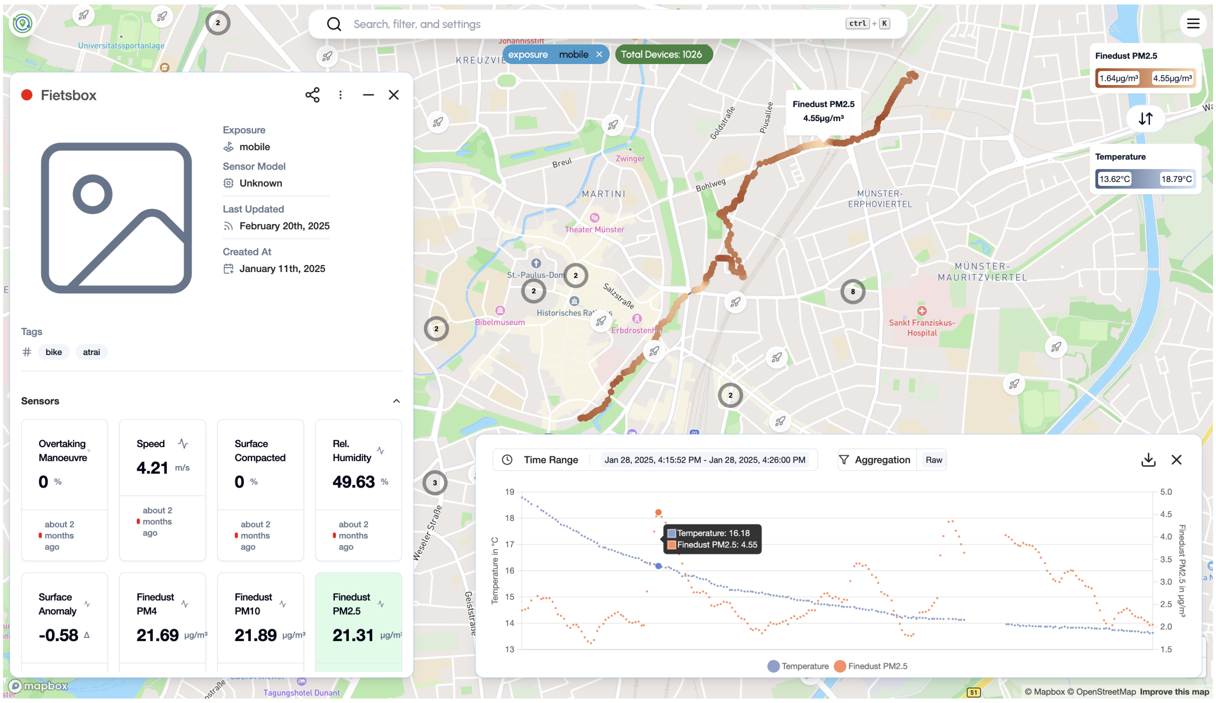

Figure 2. Example of a mobile sensor visualization. Two selected sensor measurements—temperature and fine dust (PM2.5)—are selectable on the map and both visualized as a time series graph. The map highlights the route taken by the device, while the graph below allows for detailed temporal comparison of the selected parameters during the specified time range.

To enhance scalability, interoperability, and usability, openSenseMap has undergone multiple technical improvements. Originally developed as part of a bachelor's thesis, the platform started with a monolithic architecture and has since transitioned to a containerized deployment, initially using Amazon Web Services and later moving to a OpenStack system. The distributed infrastructure allowed for improvement of system reliability and scalability.

Another enhancement was the extension of the data model and frontend to support mobile sensor data, enabling the integration of trajectory-based datasets, as visualized in Figure 2. This advancement broadened the capabilities of the platform, allowing for mobile environmental monitoring and real-time geospatial analysis.

Currently, openSenseMap is undergoing further improvements, including a migration from a NoSQL database (MongoDB) to a Timescale database (PostgreSQL with PostGIS extensions). This transition enhances data storage efficiency, query performance, and spatial data processing capabilities. Additionally, a comprehensive UI redesign is in progress to improve usability and accessibility. These updates ensure that openSenseMap remains a robust and scalable platform for open environmental data.

5 Expanding Community and User Base

Expanding the community and user base of openSenseMap requires understanding participant motivations. A first user study was conducted in 2018 with over 250 participants to find out users motivations taking part in a technology oriented citizen science project (Pesch and Bartoschek, 2019). According to this study, users were primarily driven by the open data principle and personal motives, while underrepresented groups may need tailored strategies to enhance participation. Most users used only basic features of openSenseMap such as viewing or downloading data. The issue of how to maintain user motivation for regular use of measurement devices had not yet been addressed.

A promising strategy to expand engagement is the integration of gamification elements (Alsawaier, 2018), such as digital badges. Gamification boosts motivation through rewards and competition. Open Badges, an open standard for digital micro-credentials (Badges), can incentivize participants by recognizing contributions like sensor data uploads or station setups. Integrating Open Badges with openSenseMap will automate badge issuance, further encouraging contributions and enhancing open data quality (Bruch et al., 2023). This functionality is realized in the upcoming version of openSenseMap through the API of Open Educational Badges[1].

Collaborative projects like Atrai Bikes and senseBox:bike (Bartoschek et al., 2024) also help expand the user base. Atrai Bikes incorporates citizen science into mobility studies, enabling participants to collect environmental and mobility data (Scharf et al., 2024). In Berlin, senseBox:bike allowed citizens to measure air quality, bike lane condi-

[1] https://openbadges.education

tions, and traffic data, contributing to both research and local policy on sustainable mobility.

To ease data collection, Blockly for senseBox[2] simplifies sensor programming through a visual, drag-and-drop interface, lowering the entry barrier to connect devices to the openSenseMap. The programming interface facilitates blocks for different data transmission technologies such as WiFi and LoRa and allows users to easily program and transfer data. Figure 3 illustrates a straightforward setup for programming a senseBox to upload live data to openSenseMap. Blockly for senseBox, openSenseMap and the senseBox hardware create a whole ecosystem as a learning suite for Computer-, Data- and Scientific Literacy. The tools enable non-technical users to contribute, while openSenseMap's platform provides data visualization (Pesch et al., 2022).

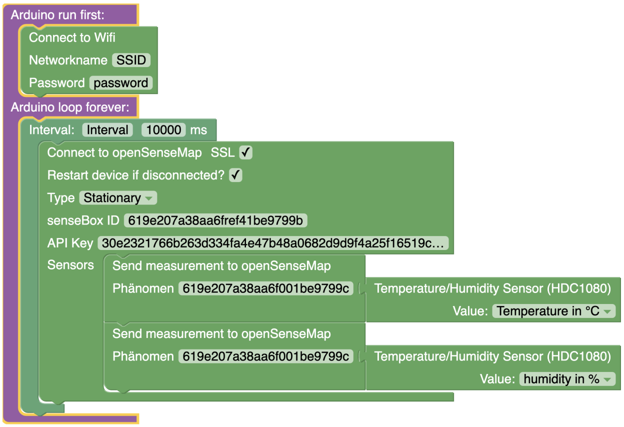

Figure 3. Simple setup to program a data upload sketch using blockly for senseBox.

6 Challenges and Lessons Learned

Maintaining an open geospatial infrastructure like openSenseMap has presented several challenges over the past decade, particularly in scalability, data quality, and long-term sustainability. Addressing these challenges has provided valuable insights into the management of open sensor platforms coming from the scientific domain.

6.1 Scalability and Performance

Scaling openSenseMap required database optimizations, time-series storage, and geospatial indexing to handle increasing data volumes efficiently. Currently, the database takes up 1TB of storage while the API is running on a server with 64GB of RAM and 8vCPUs, hosted on the cloud infrastructure by the University of Muenster, Germany (Vogl and Blank-Burian, 2025).

6.2 Data Quality and Semantic Challenges

Ensuring high-quality data within a citizen science network remains an ongoing challenge. A significant issue is the inconsistent or incorrect description of sensors and measured phenomena (Williams et al., 2018). Since sensor metadata on openSenseMap is user-generated, often by non-experts, semantic inconsistencies arise, reducing data quality and reusability. Similar challenges have been observed in other citizen science projects, where metadata ambiguity limits interoperability and integration with other datasets (Clements et al., 2017; Bastin et al., 2017). One potential solution to improve metadata quality is the use of semantic web technologies and ontologies (Berners-Lee et al., 2001) as for instance OGC's SSN and SOSA ontologies (Haller et al., 2018). However, these are often not easily comprehensible for non-expert users (i.e. citizen scientists).

To address the identified challenge in the given context, a light weight and extensible ontology for citizen science data has been proposed within the openSenseMap consortium. A corresponding web application named sensors.wiki[3] is currently under development and will allow users to extend the ontology in a crowd sourced approach. Users can add new sensors and devices and specify predefined relations to phenomena, domains and units. As part of openSenseMap's future improvements this tool will replace user generated text based metadata. The standardization of metadata facilitates data accessibility and interoperability of openSenseMap data.

6.3 Sustainability and Infrastructure

Ensuring long-term sustainability requires balancing infrastructure costs with an open and accessible data model. Transitioning to containerized deployments and distributed hosting has helped improve resilience and scalability. However, maintaining an active community of contributors and ensuring data reliability remain ongoing concerns that have not been solved yet. The transition from a volunteer initiative to a bachelor thesis project to a large funded research project and back to a platform running long-term on a university infrastructure was a major challenge. Hosting and maintaining a platform of this size and managing the community of >10000 users usually is not an effort of daily business in a research institution, if funding is not available. Taking this into account it was a matter of time to found a non-profit organisation (openSenseLab gGmbH) in 2021 that would take over these efforts being able to collect funds in a more efficient way.

These challenges and lessons have guided the ongoing development of openSenseMap, with a focus on enhancing scalability, improving metadata quality, and ensuring long-term sustainability. Future improvements will continue to address these issues, making openSenseMap a more re-

[2] https://blockly.sensebox.de

[3] https://sensors.wiki

liable and interoperable platform for citizen science and environmental monitoring.

For further information on data access and licenses, refer to the documentation available at https://docs.opensensemap.org.

7 Conclusion and Future Aspirations

openSenseMap has proven to be a valuable platform for citizen science, environmental monitoring, and geospatial research. By providing an open infrastructure for real-time data collection and visualization, it has empowered researchers, educators, and the public to engage in participatory sensing. The platform's integration into scientific research, educational initiatives, and urban decision-making highlights its broad impact across multiple domains.

Despite its success, openSenseMap has faced challenges in scalability, data quality, and sustainability. Technical advancements, such as improved database architectures and metadata standardization, will help to address these issues, ensuring the platform remains robust and accessible. Moving forward, efforts will focus on expanding community engagement, improving data interoperability, and enhancing long-term sustainability through collaborative initiatives and funding strategies.

To remain relevant in an evolving technological and scientific landscape, openSenseMap must continue to adapt. Future directions include leveraging machine learning for data validation, refining user-driven metadata contributions, and exploring new integrations with smart city initiatives and emerging environmental policies. By fostering stronger collaborations between researchers, policymakers, and citizen scientists, the platform can transition from a data collection tool to a dynamic system that actively informs and influences environmental decision-making.

Declaration of Generative AI in writing

The authors declare that they have used Generative AI tools in the preparation of this manuscript. Specifically, the AI tools were utilized for structuring sentences and paraphrasing but not for generating scientific content, or research data. All intellectual and creative work, including the analysis and interpretation of data, is original and has been conducted by the authors without AI assistance.

Data and Software Availability

The source code of both the openSenseMap platform[4] and API[5] is fully open and publicly accessible. The platform is licensed under MIT, and sensor data is available for both real-time and historical environmental measurements under the Open Data Commons Public Domain Dedication and License (PDDL).

[4]https://github.com/openSenseMap/frontend
[5]https://github.com/sensebox/openSenseMap-API

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