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From Fields to Data Infrastructures: Citizen Science for Soil Monitoring in the Western Balkans

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Abstract: Reliable soil information systems remain underdeveloped across the Western Balkans, limiting the capacity of institutions to monitor environmental change, ensure sustainable land management, and align with EU legislation. This article presents a sociotechnical case study of the Soil Health Guards initiative in Serbia, the country's first citizen-science initiative dedicated to soil health assessment. Here, we analyze the design, implementation and governance implications of an integrated citizen-science framework that supports farmers, youth, and local communities in generating standardized soil-health data. Participants collected standardized measurements of ten biological, chemical, and physical soil indicators using structured toolkits, educational manuals, and digital communication channels, supported by iterative workshops and expert validation. Of 135 registered participants, 67 actively contributed at least one soil assessment, with retention decreasing from 54% to 40% over the project duration. Farmers sampled soils across a range of land-use types and soil classes, while youth conducted assessments in schoolyards, home gardens, and urban green spaces, with group activities involving over 150 children and adolescents. Participants valued structured guidance, with the instructional manual cited as the most useful resource. The project demonstrates that even low-level-technology-mediated citizen science can facilitate knowledge co-production, environmental literacy, and community stewardship, while generating reliable, decision-ready soil data compatible with institutional monitoring frameworks. By integrating hands-on learning, digital tools, and collaborative engagement, the initiative highlights the potential of citizen science to complement formal soil monitoring, support sustainable land management, and foster inclusive participation in environmental governance.

Keywords: citizen science, soil health, knowledge co-production, environmental monitoring, participatory learning, technology-mediated engagement

Introduction

Environmental data are inherently complex and heterogeneous, reflecting the diverse and interconnected nature of ecosystems (Thomas et al., 2025). Soil, as a vital, yet non-renewable resource, is the foundation for food production and environmental stability (De Corato et al., 2024). However, soil health is increasingly threatened by intensive land use, pollution, and climate change, highlighting the need for robust monitoring systems that detect degradation and guide sustainable management while protecting ecosystem functions for biodiversity and food security (Olsson et al., 2019; Hou, 2023;). However, such data remain limited across Serbia and the wider Western Balkan (WB) region, where systematic soil assessments have historically relied on outdated, fragmented and spatially sparse datasets (Zdruli et al., 2022).

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As a result, the true status of soil functionality, contamination and degradation is hindered, leaving national and regional efforts to design, update and implement effective soil-related policies without an adequate evidence base. Only in the past decade has Serbia initiated more consistent and harmonized data collection through designated monitoring sites, gradually establishing the foundations of a national soil-monitoring network. This work culminated in the release of the country's first centralized soil-information system in February 2025 (SEPA, 2025). While an important milestone, the system highlights the extent of historical data gaps and the need for complementary approaches that expand monitoring coverage, increase data diversity and strengthen public engagement in soil stewardship (Todd-Brown et al., 2022).

At the European level, the adoption of the first Directive on Soil Monitoring and Resilience (the Soil Health Law) in 2025 has further transformed expectations. For the first time, EU legislation sets common standards for soil-health assessment, harmonized monitoring requirements and EU-wide resilience targets (EP 2025). These developments place additional pressure on non-EU countries, particularly those in the EU accession process, to enhance their soil-information infrastructures and align with European reporting frameworks.

In this context, citizen science offers a promising complementary pathway. Citizen science is broadly defined as the involvement of non-expert participants in scientific, predominantly environmental research (ECSA, 2015; Haklay, et al., 2021), but this definition conceals the deeper mechanisms through which such projects operate. This participatory approach can be also seen as a sociotechnical ecosystem in which people, technologies and institutions work together to create, interpret and govern environmental information. Non-expert participants do not simply contribute observations, but they also engage with a carefully designed network of tools, like manuals, sampling kits, digital communication channels, photo-sharing platforms, and data templates, which altogether guide their actions and shape the resulting knowledge. These tools structure the information practices of participants: how they learn, how they measure, how they document, and how they make sense of their results (Vikström et al., 2025).

At the same time, citizen science infrastructures must align with broader institutional and policy frameworks. Data must be compatible with governance systems, meet standards for traceability and quality and be interpretable within formal monitoring programmes. The legitimacy of citizen-generated data therefore depends on transparent validation procedures, shared standards, and ongoing human–technology interactions that build trust among participants and institutions. From this perspective, citizen science is best understood as an emergent, distributed information infrastructure that connects everyday practices in the real life with national and European governance systems (Hansen et al., 2021).

Therefore, the lack of soil-health data in Serbia is not only a scientific limitation but a social and institutional problem. Fragmented institutional responsibilities, limited public awareness of soil degradation, constrained monitoring budgets and historically low engagement between scientists and agricultural communities have all contributed to the persistence of soil data gaps. Addressing these gaps requires approaches that are both technically robust and socially grounded.

The purpose of here presented case study is to examine the socio-informational system created through the first scalable, two-year long citizen science project of its kind in Serbia titled as Soil Health Guards (https://citizenscience.eu/project/525). This article analyses how this initiative selected and integrated tools, knowledge, communication channels, training practices and validation workflows into a functioning sociotechnical infrastructure that actively engaged farmers and youth to monitor key soil health indicator. By focusing on the infrastructural, informational and governance dimensions of the initiative, we explore how citizen science can contribute to building resilient, EU-aligned soil-information systems in the Western Balkans.

Materials and Methods

Recruitment and Participant Groups

Understanding how citizens engage with sampling instructions, online communication channels, data submission procedures, and feedback workflows is essential for designing sustainable and policy-relevant initiatives. The Soil Health Guards project provides an evidence-based case study through which these dynamics have been examined. This citizen science initiative was implemented in Vojvodina, Serbia's most intensively cultivated region characterized by highly productive chernozem soils (Kuzmanović et al., 2025). Because the project aimed to create an inclusive and realistic picture of local land-use practices, recruitment strategies of non-expert participants were diversified to reach general public with different levels of digital access, agricultural experience and familiarity with environmental monitoring. The project focused on engagement of farmers, as the first line of stewards for soil health and youth of various ages and educational backgrounds in collecting data on standardized soil health indicators.

Recruitment of adult farmers relied primarily on partnerships with local agricultural cooperatives, advisory services and community organizations. Project partners staff attended regional agricultural fairs, seminars and local meetings, where they distributed printed leaflets and held in-person conversations with potential participants. This face-to-face approach was essential for engaging individuals who seldom use digital communication channels and who often rely on trusted local networks for information. Outreach was further supplemented with online communication through an online application form on the project's website and active social media channels (Facebook, Instagram, LinkedIn and YouTube), which enabled broader visibility and attracted participants who were already digitally engaged.

Recruitment of youth participants, including preschool, primary and secondary school students, took place through collaborations with local educational institutions. Teachers played an important facilitating role by integrating soil health activities into classroom projects and schoolyard. This approach ensured that children could participate in a supervised and age-appropriate manner, either in groups within their schoolyards or individually at home gardens and small family plots.

Participation was voluntary, without restrictions on parcel size, agricultural production system or soil type. All participants signed informed-consent forms, and parental consent was required for minors. Personal-data processing followed Serbia's Law on Personal Data Protection (Službeni glasnik Republike Srbije, 87/2018) and the EU General Data Protection Regulation ((European Parliament & Council, 2016), ensuring transparent, lawful and ethical treatment of participant information. This emphasis on consent and data privacy supported trust building between scientific institutions and general public, an essential element of the sociotechnical system underpinning the project.

Co-Learning and Participant Support System

As most participants had no prior experience with soil assessment, the project established a comprehensive co-learning infrastructure that included free, standardized toolkits containing all necessary sampling and analysis materials, standardized educational manuals, iterative co-learning workshops, and a collaborative communication space where participants could openly and promptly exchange ideas, knowledge, and experiences via their preferred communication channel (email, Viber chat community, social networks, telephone). This framework was designed to support all engaged citizens at every stage of soil data collection. It was specifically tailored in terms of content complexity and language style for each contributing group, taking into account cultural sensitivities and ethical norms of local values and customs.

Educational manuals served as the central reference point for all measurement procedures. Each participant received a printed, 30-page educational manual written in Serbian and adapted for different age groups and backgrounds, along with standardized toolkits with all materials required (sampling tools, testing reagents and other materials) for successful execution of soil sampling and on-field measurements. The manual provided step-by-step explanations, illustrated sequences of actions, photographs showing correct and incorrect examples, and troubleshooting guidance to help participants identify and resolve common errors. Standardized templates for data recording were also included to promote uniformity and minimize mistakes. The manual was used both independently in the field and during guided training sessions.

To complement the educational manual, the project produced short instructional videos demonstrating each sampling and measurement technique. Videos were filmed in local fields and school gardens, making the procedures relatable and easier to imitate. Participants could access the videos at any time through the project's YouTube channel (https://www.youtube.com/@Cuvarizdravljazemljista) for ongoing, accessible support, enabling self-paced learning and repeated review before or after fieldwork.

Training of participants was delivered through a series of three workshops held throughout the project duration. The introductory workshop provided hands-on practice with soil sampling, pH testing, and visual assessments of soil structure. Participants received their toolkits and had opportunities to ask questions and clarify uncertainties. A second workshop, held after the first major sampling cycle, focused on sharing early experiences, addressing methodological difficulties and refining techniques based on common errors observed in submitted data. The final workshop served as a closing event where participants viewed preliminary results, learned about expert validation outcomes and discussed how their contributions fit into broader soil-governance efforts. These workshops created a shared learning space and fostered social cohesion, which proved essential for sustaining engagement.

Between workshops, participants were supported through a hybrid communication system that combined email, telephone correspondence and a dedicated Viber community. Viber was particularly effective because it allowed participants to share photos of their samples, seek immediate advice on unexpected field conditions and exchange experiences with peers. This combination of communication channels ensured that participants with differing levels of digital literacy could receive timely support and maintain confidence in their measurements.

Soil Health Indicators and Sampling

The choice of soil health indicators reflected scientific considerations, institutional compatibility and the practical real-life perspectives of participants. The indicators selection process was guided by their scientific, agronomic and ecological relevance, sensitivity to diverse farm management systems, and the capacity to detect meaningful changes within realistic monitoring timeframes, while being aligned with the national soil monitoring framework. The research team, partnering with agricultural non-governmental organisations and local cooperatives, collaboratively selected a suite of ten indicators that offered a holistic, but achievable assessment of soil biological, chemical and physical conditions.

Biological indicators focused on organic matter decomposition and soil biodiversity. Standardized assays using tea bags and cotton cloths (Hughes, 2021; Keuskamp et al., 2013) buried at fixed depths and later retrieved for laboratory analysis of mass loss, provided sensitive insight into microbial activity and nutrient cycling. Earthworm surveys were included because earthworms are widely recognized as bioindicators of soil ecological health (Stroud, 2019). Participants counted and photographed earthworms for classification into functional groups, enabling quality control by experts.

Chemical indicators assessed soil nutrient status and acidity using semi-quantitative colorimetric kits for pH, nitrate, phosphorus and potassium. These indicators were chosen because they are essential to agronomic decision-making and align with the national soil-monitoring framework.

Physical indicators addressed soil structure, texture and bulk density via standardized, yet simple approaches. Specifically, soil structure was evaluated using the Visual Evaluation of Soil Structure (VESS) method, which relies on carefully observing the morphology of aggregates, root distribution and porosity (AHDB, 2025). Texture was estimated using the tactile "texture-by-feel" method (USDA, 2001), and bulk density was measured using undisturbed soil cores collected with Kopecky cylinders. This combination provided complementary insights into compaction, water retention and aeration as critical properties for soil functioning.

Together, the selected indicators offered a scientifically robust yet user-friendly set of methods that enabled participants to meaningfully assess soil health while supporting comparability with institutional datasets.

Participants collected soil samples following the standardized procedures outlined in the manual and demonstrated during workshops, using only materials and reagents supplied in their distributed toolkits.

To streamline reporting and reduce errors, participants recorded all measurements and metadata, including GPS coordinates, crop type, land-use history and sampling date, using standardized provided template sheets. These templates ensured completeness and supported consistent interpretation during analysis.

Data Submission, Quality Assurance and Validation

In order to ensure the reliability of citizen-generated data, a structured, multi-layered quality-assurance process was implemented **(Figure 1)**. After receiving field data and soil samples, the research team undertook an initial screening to check for missing fields, inconsistent units or unclear notations in submitted templates. When ambiguities appeared, researchers contacted participants directly via phone or email to clarify entries, maintaining an open communication loop that reinforced participant learning and transparency.

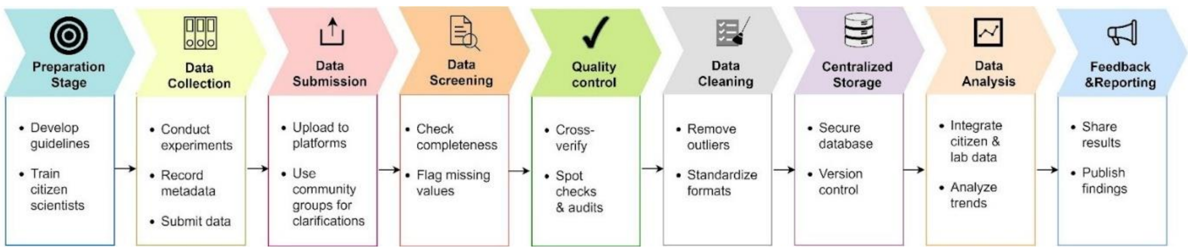

*Figure 1***.** Data quality assessment and validation flow chart. Workflow illustrating the data quality assessment and expert validation process for citizen-generated soil observations.

Spatial validation involved cross-checking submitted GPS coordinates against official cadastral parcel boundaries using the GeoSrbija platform (https://a3.geosrbija.rs/katastar). This step ensured that each measurement was accurately geolocated and associated with a correctly identified land parcel. Once verified, soil types were assigned based on the 1:50,000 Vojvodina soil map (Nejgebauer et al., 1971) and harmonized with the World Reference Base (WRB) classification system following the national-to-WRB conversion scheme (Knežević et al., 2011).

To evaluate the reliability of citizen-generated measurements, research scientists conducted field visits to parcels selected to represent different soil types, land uses and management systems. Soil at these locations was re-sampled using identical protocols, enabling direct comparison between participant data and expert measurements.

All datasets were securely stored on institutional servers with version control and routine backups, ensuring long-term data integrity and traceability, as key features for integrating citizen-generated datasets into national and EU-aligned soil governance systems.

Results

Between 2024 and 2025, from 135 registered individuals for the participation in Soil Health Guards citizen science project who received the necessary materials for soil health monitoring, 67 individuals (50%) actively contributed at least one assessment. Active participation was defined as completing and submitting at least one soil analysis with validated GPS coordinates and essential metadata, including sampling date, land use, and management practices, in line with the project manual.

Demographically, the participant pool comprised approximately 60% males and 40% females. Youth participants spanned ages 5 to 18 distributed across different educational levels, while farmers ranged broadly in age from 25 to 65 years. Their educational attainment varied, with over half having completed secondary education, thereby reflecting the region's general population trends (Statistical Office of the Republic of Serbia, 2023).

Retention declined slightly over time, from 54% in 2024 to 40% in 2025. Notably, one-third of active participants (23/67) completed all ten soil health indicator assessments over the two-year project duration.

Active participants included 46 adult farmers and 21 youth participants (ages 5–18). Farmers sampled soils across diverse soil types, at parcels ranging from 10 m² to 16.7 ha **(Table 1)**. Youth participants conducted individual assessments in schoolyards, home gardens, and urban green spaces, predominantly on chernozem soils. In addition, 45 group-based measurement activities engaged over 150 children and adolescents. These activities emphasized experiential learning, collaborative knowledge production, and soil literacy, rather than formal data collection.

Table 1. Participant demographics and sample distribution.

Participant Group	Number of participants (N)	Age Range	Soil Types Sampled (N)	Sample Context
Adult farmers	46	25–65	Chernozem (23), Fluvisol (4), Cambisol (5), Gleysol (3)	Agricultural parcels (size ranges: 0.1–16.7 ha)
Youth (individuals)	21	5–18	Chernozem (21)	Schoolyards, home gardens, urban green spaces
Youth (group)	150+	5–18	Mostly chernozem	Hands-on educational workshops

Participants' experiences, captured via a quick poll survey during the second workshop (n=18), illustrate the interplay between technology-mediated support, guidance materials, and participant engagement. The majority (61%) reported that performing experiments posed the greatest challenge, followed by express mail sample submission (33%), whereas registration for participation procdures were rarely cited as difficult (6%). In terms of perceived usefulness, the cotton cloth decomposition assay was most valued (33%), followed by earthworm counts and soil structure assessments (22% each), while tea bag decomposition was considered useful by 11%. Interestingly, participants relied heavily on instructional materials, with 72% citing the project manual as their primary support, 17% preferring video materials, and 6% indicating hands-on workshops as most beneficial. These findings highlight the centrality of clear, accessible guidance and digital facilitation for supporting participant learning, engagement, and confidence in data collection.

These results demonstrate that technology-mediated citizen science frameworks can successfully support both knowledge co-production and educational outcomes. Adult farmers and youth participants contributed complementary perspectives, producing a spatially and socially diverse dataset that reflects local agricultural practices and urban green space management. For youth, engagement in hands-on activities fostered practical skills, environmental literacy, and collaborative learning, exemplifying how citizen science can function as a tool for community empowerment and social learning, consistent with the aims of social informatics research. The project underscores the importance of combining digital tools (GPS-enabled data collection), structured instructional resources, and interactive guidance to maintain engagement, ensure data quality, and maximize the educational and societal impact of citizen science initiatives.

Discussion

In this case study, we demonstrate how citizen science can connect community engagement with soil health monitoring, generating actionable data on different ecosystem services, such as nutrient cycling, soil structure stability, and organic matter decomposition that are essential for Vojvodina's agricultural provisioning services. It demonstrates both the opportunities and challenges of implementing low technology-mediated citizen science initiatives in socio-ecologically diverse regions. While our participant pool included a broad age range, from schoolchildren to adult farmers, the observed demographic skew toward younger, urban participants highlights a commonly observed pattern in citizen science, whereby participants tend to cluster in socio-demographic groups with greater digital connectivity and access to engagement opportunities. Even with widespread internet access in Vojvodina (88% of households; Statistical Office of the Republic of Serbia, 2023), rural and older populations remain underrepresented. Such gaps can limit data coverage and the representativeness of collected information, as these groups often hold valuable historical and localized knowledge of soil management practices critical for sustaining crop yields, preventing erosion, and maintaining nutrient cycles. Similarly, the observed gender imbalance, favouring male participants, reflects global trends in citizen science participation, where cultural norms, differential access to resources, and time constraints influence recruitment and sustained engagement (Strasser et al., 2023; Ibrahim et al., 2021). Future outreach strategies should therefore prioritize inclusive engagement approaches, targeting rural, older, and female populations to ensure that citizen-generated data reflects the full diversity of experiences and knowledge across the region. Enhanced inclusion would not only improve ecological representativeness but also empower marginalized groups through the co-production of knowledge relevant to local land management and decision-making.

From an educational and social perspective, the project successfully fostered intergenerational learning and collaborative knowledge exchange. By engaging farmers and youth in complementary roles, the initiative created opportunities for experiential learning, skill development, and environmental literacy. Group-based activities for children and adolescents reinforced hands-on learning, while adult participants contributed practical agricultural expertise, resulting in a socially and spatially diverse dataset. These dynamics illustrate the capacity of citizen science to function as a platform for community stewardship, collaborative problem-solving, and knowledge co-production, aligning with social informatics principles that emphasize the interplay between people, technology, and information systems.

The project also highlights the potential for citizen-generated data to support environmental monitoring and policy-relevant initiatives. Standardized and replicable soil health assessment methods, combined with expert validation, enable participants to produce reliable, decision-ready data. Such practices align with broader European frameworks, including the EU Soil Strategy for 2030, the EU Mission “A Soil Deal for Europe,” and the EU Soil Observatory, which increasingly recognize participatory monitoring approaches as complementary to institutional capacities. It is reported that CS has the greatest policy influence when projects generate structured, decision-ready data, align their indicators with regulatory requirements, and proactively engage environmental authorities through policy briefs, validation processes, and early consultations (Turbé et al., 2019). CS initiatives such as ours directly support the EU legislative soil priorities by complementing institutional monitoring capacities and engaging communities in co-producing soil data relevant to climate resilience, biodiversity conservation, and sustainable agriculture. In this context, the Soil Health Guards project embodies many of the features identified as essential for effective policy integration: it offers standardized and replicable soil-health methods, includes expert validation to enhance credibility, engages both farmers and youth in data collection and learning, and targets soil health indicators where national monitoring capacity is still developing. While formal integration of citizen science into policy remains uneven, projects that offer structured protocols, clear guidance, and engagement with local authorities can help bridge this gap, demonstrating the societal and environmental relevance of community-collected data.

Importantly, the project's design, incorporating accessible and standardized methods, structured training, certain digital tools for data collection, and interactive guidance, illustrates a scalable model for regions with limited soil monitoring infrastructure. Beyond generating valuable ecological data, the initiative contributes to scientific literacy, environmental awareness, and community empowerment, opening pathways for the integration of local knowledge into agricultural and environmental governance. By combining practical data collection with participatory learning, the Soil Health Guards project highlights the transformative potential of citizen science: fostering stewardship, enhancing knowledge co-production, and sustaining soil functions and ecosystem services in contexts with persistent data gaps and governance challenges.

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