Received: 25 September 2023 | Revised: 16 February 2024 | Accepted: 28 February 2024

DOI: 10.1111/1440-1703.12465

SPECIAL FEATURE

Ecosystem Responses and Behaviors Under Changing Pressures of Air Pollutants

ECOLOGICAL RESEARCH WILEY

Citizen-participatory nationwide survey of mountain streamwater chemistry in Japan in 2022: Comparison of nitrate concentrations with the 2003 survey

Soyoka Makino[1,2] | **Naoko Tokuchi**[2] | **Daisuke Akaishi**[2,3] | **Lina A. Koyama**[4] | **Yukio Komai**[2] | **Yoshimi Itaya**[4] | **Nay Lin Maung**[5] | **Kanae Ishimaru**[6] | **Tomoki Oda**[7] | **Rei Shibata**[8] | **Shinya Numamoto**[9]

[1]Research Institute for Humanity and Nature, Kyoto, Kyoto, Japan

[2]Field Science Education and Research Center, Kyoto University, Kyoto, Kyoto, Japan

[3]Faculty of Design Technology, Osaka Sangyo University, Osaka, Japan

[4]Graduate School of Informatics, Kyoto University, Kyoto, Kyoto, Japan

[5]Graduate school of Agriculture, Kyoto University, Kyoto, Kyoto, Japan

[6]Center for Arts and Sciences, Fukui Prefectural University, Fukui, Japan

[7]Department of Disaster Prevention, Meteorology and Hydrology, Forestry and Forest Products Research Institute, Ibaraki, Japan

[8]Faculty of Agriculture, Niigata University, Niigata, Niigata, Japan

[9]Graduate School of Bioresources, Mie University, Mie, Japan

Correspondence

Soyoka Makino, Research Institute for Humanity and Nature, 457-4 Motoyama, Kamigamo, Kita-ku, Kyoto, Kyoto, Japan.
Email: makino.soyoka.n44@kyoto-u.jp

Funding information

Research Institute for Humanity and Nature, Grant/Award Number: RIHN14200156; Japan Society for the Promotion of Science, Grant/Award Numbers: 15H04515, 19H03012,

Abstract

Mountain streamwater chemistry is an effective indicator of forest condition. In 2022, we conducted a nationwide investigation of mountain streamwater chemistry in Japan, leveraging citizen-participatory sampling. This approach involved 629 individuals with regular exposure to mountain and natural environments. Although our primary aim was to sample at locations from a 2003 study, we also welcomed samples from new sites. In total, 1414 streamwater samples were collected one time from each forested watershed at the baseflow condition. Our study focused on stream nitrate (NO_3^-) concentration as a key indicator of anthropogenic nitrogen (N) loading impacts on forests. We compared NO_3^- concentrations in 2022 with those from 2003 at identical sampling points. After excluding 179 points with evident human-created features upstream, the mean NO_3^- concentration in 2022 was 0.328 mg N L^{-1} ($n = 1236$). Comparing data from 1088 points sampled in both years, the mean value in 2022 (0.324 mg N L^{-1}) was significantly lower than that in 2003 (0.359 mg N L^{-1}, $p < 0.05$). Notably, 88.5% of sampling points showed differences within ±0.25 mg N L^{-1}. The spatial distribution pattern of mountain stream NO_3^- concentrations in 2022 did not consistently align with large cities, industrial areas, or N deposition sources. This unique approach marked the first nationwide participatory survey for collecting mountain streamwater in Japan. Our success in ensuring sample quality through accessible explanations, manuals, and videos demonstrates the potential of citizen science. However, the quantitative evaluation of scientific accuracy remains a forthcoming challenge.

22H02385, 23K05316; Strategic International Collaborative Research Program, Grant/Award Number: JPMJSC19C3

KEYWORDS

citizen science, citizen-participatory survey, forest ecosystem, mountain streamwater chemistry, nitrate

1 | INTRODUCTION

Forest ecosystems require monitoring as they experience adverse conditions such as soil acidification, declining biodiversity, and forest decline sometimes due to various factors, including air pollution, human activities, and natural disturbances. Mountain streamwater chemistry serves as an effective indicator of forest health, reflecting regional and local environmental characteristics, such as volcanic influences, climate, air pollution, and disturbances. For instance, the acid buffering capacity, crucial for protecting forests from acid rain, is influenced by precipitation (Chadwick et al., 2003), volcanogenic deposits (Takahashi et al., 2001), volcanic parent soils (Baba et al., 1995; Fujii et al., 2020), and soil texture (Wei et al., 2022), and can be assessed through water alkalinity and cation concentrations. Nitrogen (N) and phosphorus (P), both essential for plant growth and ecosystem sustainability, may leach out due to disturbances such as deforestation (Gundersen et al., 2006; Piirainen et al., 2004) and overgrazing by predators of understory vegetation (Mekuria et al., 2007; Sakai et al., 2022), despite limited N and P availability in terrestrial ecosystems (Elser et al., 2007).

Conversely, air pollution from N compounds can lead to N-saturation in forest ecosystems and soil-to-stream N leaching, primarily in the form of nitrate (NO_3^-) (Aber et al., 1989; Itoh et al., 2004; Nishina et al., 2017). High rate of N leaching is detrimental to both forests and aquatic ecosystems. N-saturation can trigger soil acidification, reduced plant species diversity, and even forest decline (Aber et al., 1989, 1998; Schmitz et al., 2019), and elevated NO_3^- levels can disrupt aquatic ecosystems (Fukushima, 2012). Additionally, climate changes, including global warming, may have altered forest conditions and stream chemistries in recent years (Groffman et al., 2018). These factors highlight the importance of monitoring forest conditions through wide-scale mountain streamwater chemistry assessments encompassing various forest environments.

Given that headwater chemistries exhibit significant variability due to geology, soil types, and land use, and tend to homogenize downstream through hydrological mixing (Asano et al., 2009), it is crucial to investigate water chemistry in mountain streams, rather than midstream or downstream, to accurately gauge how forest conditions respond to specific environments. Although extensive surveys of midstream and downstream chemistry are available in the United States, using data compiled by national or state governments (e.g., Estévez et al., 2019; Jun et al., 2016; Larned et al., 2004; Nash et al., 2009; Prause, 2014), extensive surveys of mountain streamwater chemistry remain limited owing to the considerable time and labor required for their completion (Scanlon et al., 2021). In Japan, such surveys are rare, with only a few nationwide surveys conducted in the past (Hirose et al., 1988; Konohira et al., 2006; Toda et al., 2000). Among these, the 2003 survey conducted by Konohira et al. (2006) is the most recent, boasting the highest number of sampling points, totaling 1278 across Japan.

The survey of Konohira et al. (2006) was conducted by only 11 trained individuals and involved the collection of streamwater samples from each forested watershed during baseflow conditions from July 1 to October 11, 2003, employing a manual and methods as consistent as possible throughout Japan. Samples were collected in 1 or 2 L polycarbonate bottles (No. 2015, Nalgene, Nalge Nunc International, USA) in situ following thorough cleaning (Konohira et al., 2006). They were promptly shipped under refrigerated conditions to Nagoya University, filtered through glass fiber filter paper (Whatman GF/F, Whatman PLC), stored in 50 mL polyethylene bottles (I-BOY, AS ONE Corporation), and maintained at −40°C until analysis (Konohira et al., 2006). Upon thawing at room temperature, the samples underwent additional filtration through a 0.22 μm membrane filter, followed by element concentration measurement using an ion chromatograph (DX500, Dionex Inc.) (Konohira et al., 2006). Notably, among all elements, NO_3^- concentrations exhibited the widest range, with relatively high levels observed in urban prefectures such as Tokyo (the Capital city of Japan), Kanagawa, Osaka, and Fukuoka, as well as in suburban prefectures such as Gunma and Saitama (Konohira et al., 2006). Their accomplishment, considering the scale, was remarkable and would be unattainable under normal circumstances. For this reason, in our research, we adopted a citizen-participatory survey approach for nationwide streamwater sample collection.

Citizen science, or citizen-participatory surveying, represents an effective and promising approach as it enables comprehensive surveys across wide geographical areas, the acquisition of large datasets, and the expansion of scientific research. According to the Oxford English Dictionary, citizen science is defined as scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions. This concept gained momentum in the 1990s (Pretty, 2003), particularly in North America and Europe (Lawrence, 2006). In Japan, it has recently flourished, particularly in the field of ecology (e.g., Kadoya et al., 2009; Kobori et al., 2016; Miyazaki, 2016; Sahashi et al., 2020). Although several projects have explored streamwater quality using citizen-participatory survey methods (e.g., Izaak Walton League of America, 2023; K-TESST, 2003), they have not consistently focused on forested watersheds, and the overall number of such projects remains limited to date.

Citizen science presents certain issues that warrant careful consideration before implementation. One major concern revolves around ensuring the quality of samples collected by nonexperts. To address this challenge, several methods can be employed: (1) conducting comprehensive training sessions and providing detailed instructions on sampling techniques in advance; (2) encouraging multiple participants to sample the same objects to identify discrepancies in their results; and (3) conducting meticulous data scrutiny, and in cases of anomalous data, having experts revisit the same sampling points and/or conditions to verify the findings. Many projects employ a combination of these methods to maintain data integrity (Wiggins et al., 2011). Efforts to ensure data quality have led to reports indicating that data obtained by citizen volunteers are on par with those obtained by experts (Kosmala et al., 2016; Lewandowski & Specht, 2015). Another substantial concern revolves around issues of exploitation. To prevent situations where researchers benefit unilaterally without providing any return to participants or exploiting their motivation, potential measures include providing feedback to participants and explicitly acknowledging their contributions in project deliverables and publications (European Citizen Science Association, 2015).

In 2022, approximately two decades after the survey of Konohira et al. (2006), we investigated mountain streamwater chemistry throughout Japan. We revisited the same sampling points investigated by Konohira et al. (2006), collaborating with individuals across Japan who possessed regular experience with mountain and nature environments, under a project named "Mountain Health Checkup" in which the current spatial distribution of mountain streamwater chemistry was assessed. Although monitoring forest conditions entails the examination of various elements in mountain streamwater chemistry, this study initially focused on NO_3^- because it is essential for ecosystems, but its elevated rate of leaching from forests into streams is detrimental to both forest and aquatic ecosystems.

In brief, this study details the citizen-participatory survey of mountain streamwater chemistry conducted throughout Japan in 2022, primarily aimed monitoring forest conditions. It includes an investigation of the spatial distribution of stream NO_3^- concentrations and a comparison with data from 2003.

2 | MATERIALS AND METHODS

2.1 | Overview of the "Mountain Health Checkup" project

In 2020, the Field Science Education and Research Center at Kyoto University (Field Research Center, Kyoto University) and Montbell Co., Ltd., a prominent Japanese outdoor company, entered into a comprehensive cooperation agreement with the shared goal of contributing to the development of a sustainable society. In 2022, under this collaboration, we initiated the "Mountain Health Checkup" project with the objective of resurveying the same sites examined by Konohira et al. (2006) to assess the current state of mountain streamwater chemistry. Montbell operates a membership organization that extends certain benefits to its members, allowing us to engage with individuals across Japan who are familiar with mountains and natural environments. This collaboration with motivated citizens facilitated a multipoint survey.

Both Montbell club members and nonmembers were invited to participate in the project through various channels, including our websites. Participants were asked to provide personal information, including their addresses and email addresses, either on the Montbell website (Montbell website, 2022) or on the "Mountain Health Checkup" website (Mountain Health Checkup project, 2022a). They were then instructed to reserve a sampling point on the "Mountain Health Checkup" website. Subsequently, water sampling kits containing syringes, filters, and bottles were dispatched from the Field Research Center at Kyoto University to the participants. The sample bottles were returned to the Field Research Center for chemical analysis (refer to Section 2.2 for further details).

To safeguard against the exploitation of participants' motivations, we conducted two debriefing sessions. The first took place as an interim debriefing in August during the water sampling period, whereas the second occurred at the end of March as a final debriefing. Additionally, we explicitly acknowledge the participants' contributions to this project in the present study, and we will continue to do so in future studies.

2.2 | Preparing the sampling kits, website for recording sampling data, and manual

First, we tested the water sampling procedure with Montbell employees, who are not researchers, and collected

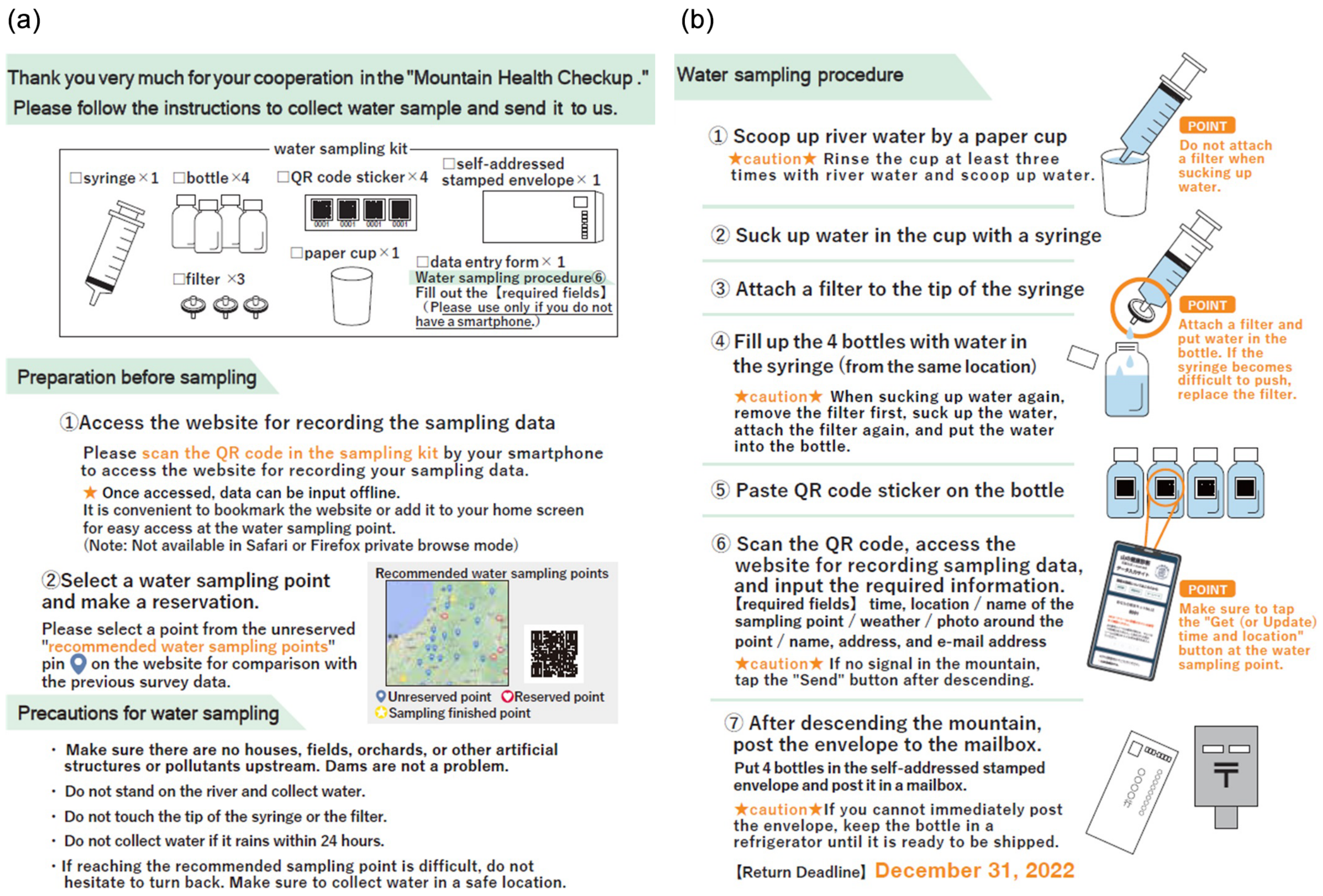

FIGURE 1 (a) Actual distributed contents of the water sampling kit and manual of sampling method with illustrations to all participants (page 1). (b) Actual distributed contents of the water sampling kit and manual of sampling method with illustrations to all participants (page 2).

valuable feedback. In April 2021, we engaged two to four Montbell employees at each site to perform water collection at three points. The variation in stream NO_3^- concentrations was <5%, confirming the accuracy of water sampling by nonresearchers. Guided by employee feedback, we refined the sampling method explanations and water sampling kit contents (Figures 1a,b and S1a,b). We created an explanatory video (Mountain Health Checkup project, 2022b) illustrating the sampling method on our website (Mountain Health Checkup project, 2022a) and provided a manual (Figures 1a,b and S1a,b) to all participants. The manual, designed for nonscientists, avoided technical jargon and incorporated numerous diagrams and images for clarity. Additionally, we ensured prompt and meticulous responses to participant inquiries throughout the project.

The water sampling kit included a syringe (SS-10Sz, TERUMO Corp.), three 0.45 μm disc filters (GLCTD-MCE2545, Shimadzu GLC, Ltd.), four 30 mL bottles (40 mL when filled; B-type medication bottle, KM Chemical Co.), a paper cup (individual packaged assembly-type paper cups, Mine Co., Ltd.), a QR code sticker, a data entry form, and a self-addressed stamped envelope for participants (Figures 1a,b and S1a,b). Considering the cost-effectiveness of mail returns, we selected small bottles that could fit into envelopes and provided four bottles per sample to ensure an adequate sample volume.

Prior to dispatching the sampling kit (Figures 1a,b and S1a,b) to participants, we conducted pretests on the B-type medication bottles and individual packaged assembly-type paper cups, as they are not typically used for experiments. Three bottles and three paper cups were randomly chosen, filled with Milli-Q water, and subjected to testing for element dissolution. The tests, conducted over 1 week for bottles and 15 min for paper cups, involved the use of an ion chromatography (Aquion, Thermo Fisher Scientific Inc.) and a total organic carbon analyzer (TOC-L, Shimadzu Corporation) simultaneously. In all cases, element concentrations in both bottles and cups were below the detection limit specified in JISK0102 (Japanese Standards Association, 2019).

We prepared QR code stickers with unique IDs for reporting sampling information, including sampling date and time, GPS coordinates, sampling point name, weather conditions on the day and the previous day, photographs

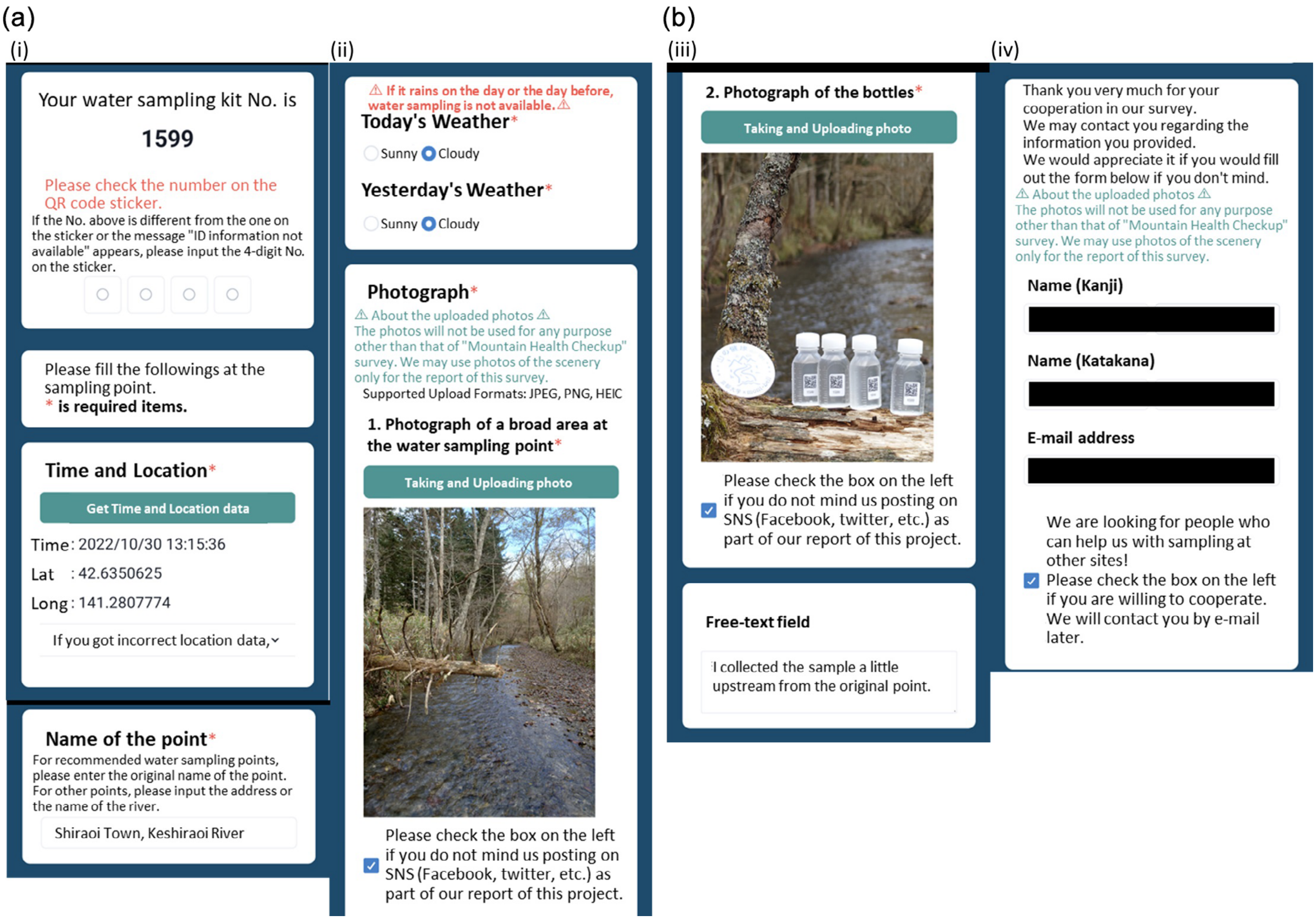

FIGURE 2 (a) Screenshot of one sampling data recorded via our dedicated website for online recording. (i) ID, sampling date and time, location (GPS coordinate) and name of the sampling point, (ii) weather on the day and the day before, and photograph of the scenery around the sampling point. (b) Screenshot of one sampling data recorded via our dedicated website for online recording. (iii) Photograph of the bottles (iv) participant's name and email address.

of the sampling point surroundings and bottles, and participant names and email addresses (Figures 2a,b, and S2a,b). Participants could scan the QR code with their smartphones to access our dedicated website for online recording of sampling data (Figures 2a,b and S2a,b), which is now closed. The website allowed data input even without mobile phone signal, with the option to manually correct location data if necessary. Data registration occurred when mobile phone signal was available. Participants without smartphones or those experiencing difficulties with data entry via smartphones could use the data entry form included in the water sampling kit.

2.3 | Study sites

The study was conducted across Japan except for the Southwest Islands (chain of islands extending from southwestern Kyushu to northern Taiwan), spanning a large environmental gradient. Northern Japan and the Japan Sea side are characterized by heavy snowfall, whereas the southern Pacific Ocean side experiences substantial summer rainfall. In contrast, the Seto Inland Sea region is comparatively dry.

2.4 | Citizen-participatory sampling of mountain streamwater

In 2022, we extended invitations to citizen participants from mid-May to the end of November, asking them to collect mountain streamwater from any of the 1278 sampling points identified by Konohira et al. (2006). The survey period was designated as June to November 2022 to coincide with the growing season and ensure a unified nationwide survey period. As previously mentioned, we provided participants with the water sampling kit (Figures 1a,b and S1a,b).

In the field, participants were instructed to use the sampling kit for water collection and to record essential sampling information, including location, either via the dedicated sampling data recording website (Figures 2a,b and S2a,b) or on the provided data entry form. In cases where the preserved sampling point was inaccessible due to road conditions or natural disasters occurring over the past two decades since the previous survey, participants were tasked with finding the nearest safe point along the same river or a nearby one. They confirmed the absence of evident human-made features, including paddy fields, vegetable fields, orchards, or buildings, upstream before collecting water samples. In instances where none of the points sampled by Konohira et al. (2006) were available, participants searched for new points following the same criteria.

Regarding water sampling, participants were instructed to collect mountain streamwater samples during baseflow conditions, excluding rainy or snowy days, as stream chemistry is markedly influenced by rainfall or snowmelt events (Rusjan et al., 2008; Stoddard, 1994). Mountain streamwaters are typically investigated during baseflow conditions to gain insights into spatial variations in stream chemistries (e.g., Konohira et al., 2006; Nishina et al., 2017; Shinozuka et al., 2017).

Participants followed the procedure of scooping mountain streamwater into a paper cup, drawing it into the syringe, filtering it through the 0.45 μm disc filter to minimize potential microbial activity, and then filling the four bottles with the filtered water sample. Whenever feasible, participants directly drew water from the stream using the syringe. The sample bottles were promptly mailed in the self-addressed stamped envelope provided in the kit to the Field Research Center at Kyoto University, where the samples were stored in a refrigerator at 4°C until analysis. Although mountain streamwater was sampled only once at each site, it was anticipated that the spatial differences in stream NO_3^- concentrations would be more pronounced than seasonal variations (Forestry and Forest Products Research Institute, 2014; Komai, 2010; Sakai et al., 2019).

2.5 | Chemical analysis of water samples and statistical analysis

Participants were instructed to fill all four bottles with the same filtered water samples at the sampling site, effectively treating the samples in the four bottles as identical during analysis. To determine the NO_3^- concentration of the water samples, we used ion chromatography (Aquion, Thermo Fisher Scientific Inc.). Notably, the detection limit specified in JISK0102 for ion chromatography is 0.1–50.0 mg L^{-1} (Japanese Standards Association, 2019). To determine the difference in mountain stream NO_3^- concentration among regions (Figure S3), Steel–Dwass multiple comparison test was conducted in the R version 4.3.2 (R Development Core Team, 2023). In addition, the difference in mountain stream NO_3^- concentration in 2003 and 2022 was calculated using Konohira et al.'s (2006) data and our data at the same sampling points and was compared among regions by Steel–Dwass multiple comparison test.

2.6 | Examination whether 2003 and 2022 are typical years for temperature and precipitation across Japan

Across Japan's regions, we assessed annual mean temperature anomalies from 1991 to 2022 as the deviations of mean annual temperature in each year from the average mean annual temperature from 1991 to 2020, using meteorological data from the Japan Meteorological Agency (2023a). We also examined the ratios of annual precipitation in each year from 1991 to 2022 to the average annual precipitation from 1991 to 2020, using the meteorological data (Japan Meteorological Agency, 2023b).

3 | RESULTS

3.1 | Participant and sample count

In total, 629 individuals participated, resulting in the collection of 1428 samples. However, 14 samples were acquired outside the designated "Mountain Health Checkup" project period (June–November 2022) and were subsequently excluded from the study. Therefore, the total number of adopted samples was 1414 (Table 1). The distribution of sample collection by month was as follows: 310 in June, 208 in July, 171 in August, 117 in September, 293 in October, and 315 in November. Out of these samples, 1241 were obtained from the sample points of Konohira et al. (2006), with the unexpected duplication of 56 samples. Additionally, 120 samples were directly collected by our research team, 10 of which overlapped with sampling points selected by citizen participants. In total, 173 samples were sourced from new points, distinct from those of Konohira et al. (2006).

Upon receiving the sampling data, we examined the location data for all sampling points on a geographic map (Geospatial Information Authority of Japan, 2023). This review identified 179 points within watersheds displaying clear signs of human-made features, such as paddy fields, vegetable fields, orchards, or buildings, which were

TABLE 1 The number of water sampling points where mountain streamwaters were collected throughout Japan from June to November 2022.

	Not-overlapping points	Overlapping points	Sum
Konohira et al.'s (2006) points	1185	56[a]	1241
New points	173	0	173
Sum	1358	56	1414

[a]At each of the 56 points specified by Konohira et al. (2006), two samples were collected unexpectedly.

TABLE 2 The number of water sampling points without obvious human-created features upstream where mountain streamwaters were collected throughout Japan from June to November 2022.

	Not-overlapping points	Overlapping points	Sum
Konohira et al.'s (2006) points	1043	45[a]	1088
New points	147	0	147
Sum	1042	45	1235

Note: We found 179 points whose watersheds have obvious human-created features such as paddy fields, vegetable fields, orchards, or buildings after receiving the sampling data, which we removed from all 1414 points.

[a]At each of the 56 points specified by Konohira et al. (2006), two samples were collected unexpectedly.

subsequently excluded from the analysis (Table 2). This process resulted in a total sample count of 1235, of which 1088 samples originated from the points of Konohira et al. (2006), including 45 instances of unexpected duplication.

3.2 | Mountain stream NO_3^- concentrations of overlapping samples

Among the 56 overlapping samples collected unexpectedly, the differences in stream NO_3^- concentrations were consistently <0.25 mg N L^{-1}, indicating minimal variation. Similarly for the 10 overlapping samples collected by our research team and citizen participants, the stream NO_3^- concentrations exhibited differences of <0.25 mg N L^{-1}.

3.3 | Spatial distribution of mountain stream NO_3^- concentrations across Japan in 2022

In 2022, during baseflow conditions, mountain stream NO_3^- concentrations exhibited a broad range from values below the detection limit (0.01 mg N L^{-1}) to 6.96 mg N L^{-1}, with a mean of 0.328 mg N L^{-1} ($n = 1235$, including 147 new points beyond the 1088 locations of Konohira et al., 2006; Tables 2 and 3). The frequency distribution of stream NO_3^- concentrations exhibited a gradual decline with increasing concentrations (Figure 3). Notably, elevated mountain stream NO_3^- concentrations were observed not only in suburban areas of urban centers such as Tokyo, Osaka, and Fukuoka, but also in northern Shikoku, particularly in Kagawa Prefecture (Figures 4 and S3). As a result, average mountain stream NO_3^- concentration was the highest in the Kanto region, second highest in the Northern Kyushu region, and third highest in the Kinki region (Figures 5 and S3).

TABLE 3 Mean NO_3^- concentrations in mountain streamwaters collected at the sampling points without obvious human-created features upstream collected in 2003 and 2022.

	2003	2022
Konohira et al.'s (2006) points	0.359 (0.0115)	0.324 (0.0106)
New points		0.358 (0.0316)
Sum		0.328 (0.0101)

3.4 | Differences in the mountain stream NO_3^- concentrations across Japan in 2003 and 2022

There was not big difference in the spatial distribution pattern of mountain stream NO_3^- concentrations at baseflow conditions between 2003 (Figure 6; Konohira et al., 2006) and 2022 (Figure 4). Comparing the 1088 values from sampling points assessed in both years, the mean concentration in 2022 (0.324 mg N L^{-1}), was significantly lower than that in 2003 (0.359 mg N L^{-1}; Tables 2 and 3). However, the differences between the 2 years were typically <0.25 mg N L^{-1} at the majority (88.5%) of points (Figures 7 and 8). In the Kanto region, mountain stream NO_3^- concentrations tended to be lower in 2022 than in 2003 (Figure 7), and the difference between 2 years was significantly lower than other regions (Figure 9).

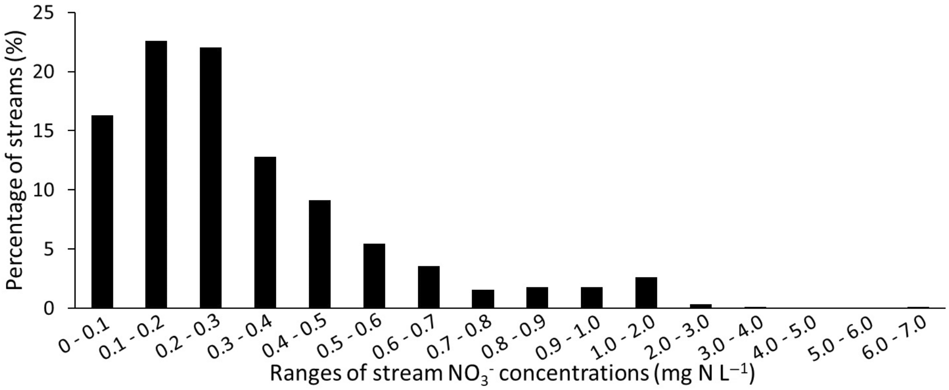

FIGURE 3 Percentage of mountain streams with each NO_3^- concentrations at the baseflow condition throughout Japan in 2022.

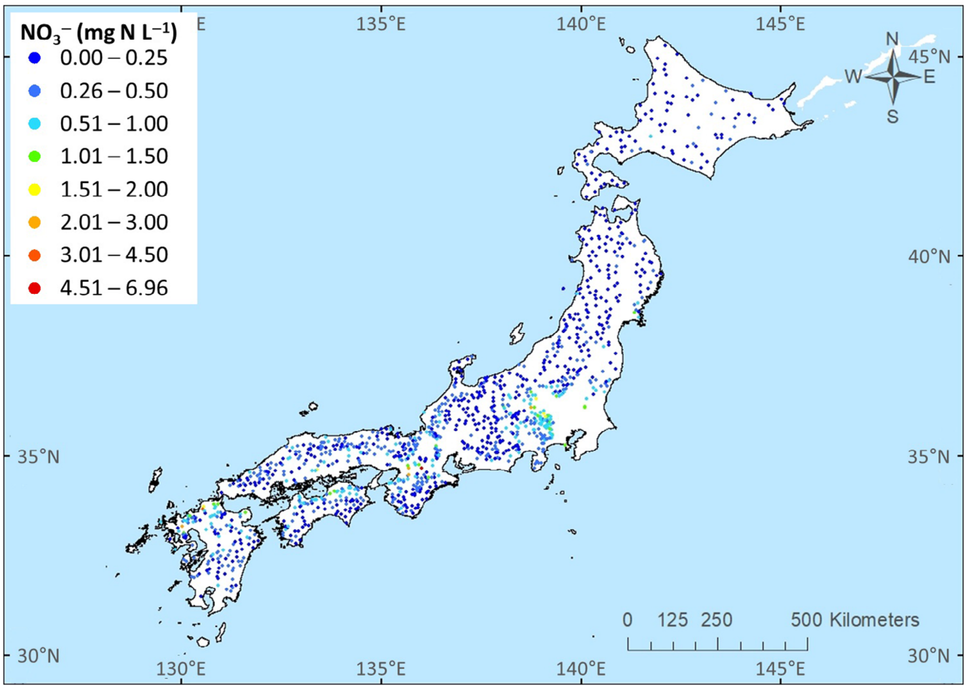

FIGURE 4 Spatial distribution of mountain stream NO_3^- concentration at the baseflow condition throughout Japan in 2022.

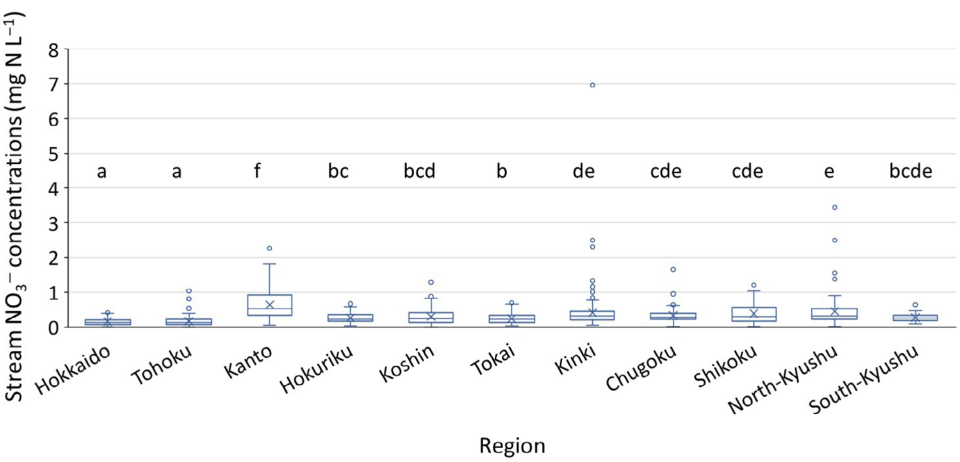

FIGURE 5 Box plots of mountain stream NO_3^- concentration at the baseflow condition by region throughout Japan in 2022. (Cross [×] represents average values, circle symbol [°] represents outlier, Different lowercase letters above plots indicate significant differences among the regions [$p < 0.05$], which were found by Steel–Dwass multiple comparison test).

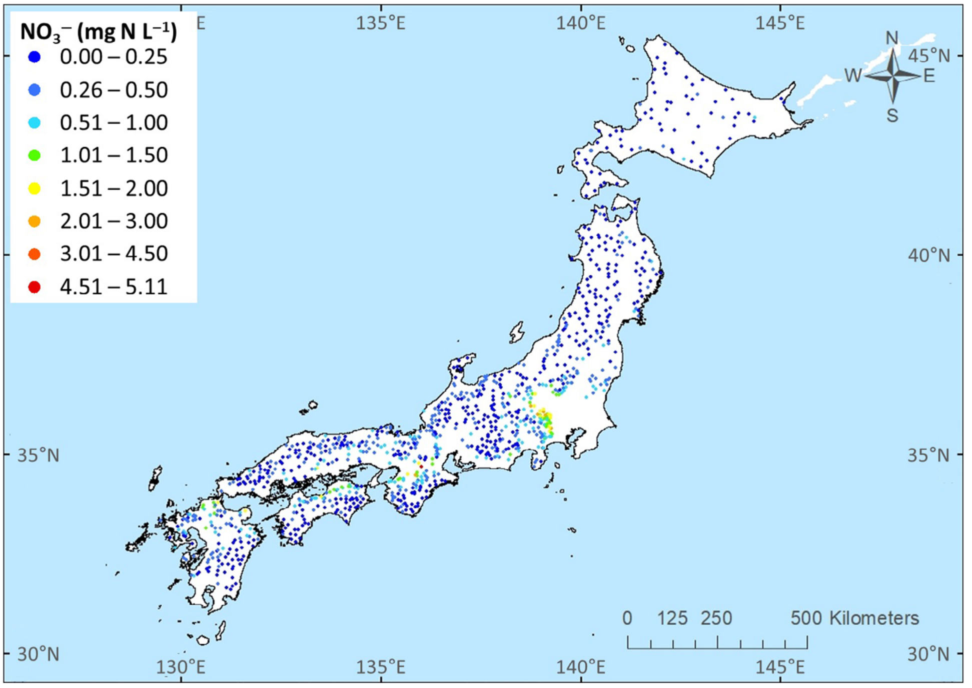

FIGURE 6 Spatial distribution of stream NO_3^- concentration at the baseflow condition throughout Japan in 2003. *Source*: The 2003 data were collected by Konohira et al. (2006).

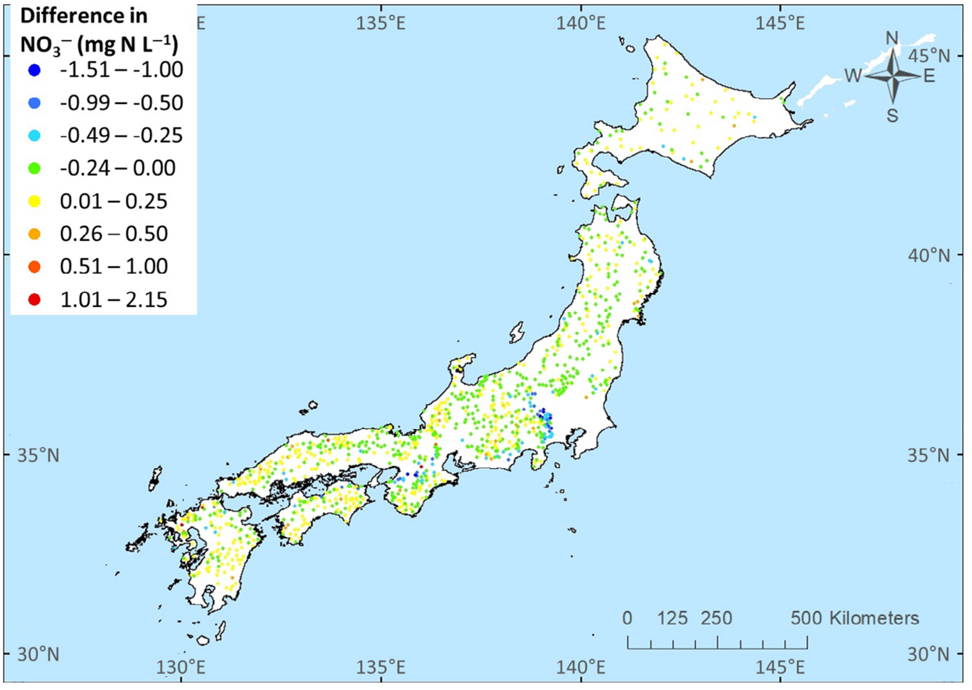

FIGURE 7 Differences in mountain stream NO_3^- concentrations at the baseflow condition throughout Japan in 2003 and 2022, 2022 minus 2003. *Source*: The 2003 data were collected by Konohira et al. (2006).

3.5 | Temperature and precipitation across Japan in 2003 and 2022

In annual mean temperature anomalies, gradual increasing trends were observed for all regions from 1991 to 2022 (Figure S4, Table S1). To assess outliers of annual mean temperature anomalies, we performed linear regression analysis between annual mean temperature anomalies and years for all regions on the data from 1991 to 2020 in the R version 4.3.2 (R Development Core Team, 2023). Outliers were calculated using the differences between the annual mean temperature anomaly and the one calculated from the linear regression equation for each region. The outliers were determined to be higher than 1.15, 1.35, 1.11, 1.11, 1.13, 0.954, 0.878, 0.712, 0.769, and 0.777°C and lower than −0.960, 1.37, −1.13, −1.15, −1.18, −0.956, −0.888, −0.736, −0.779, and −0.860°C in Hokkaido, Tohoku, Kanto-Koshin,

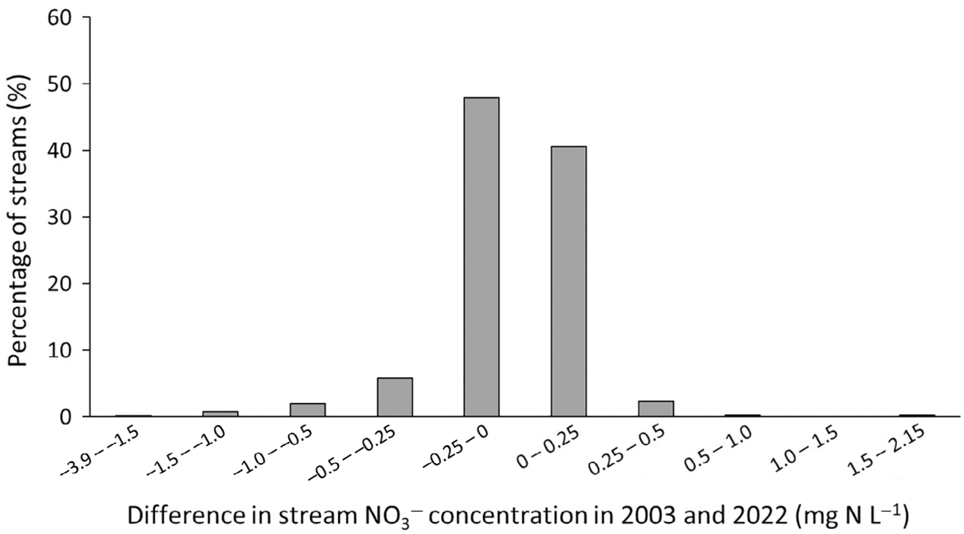

FIGURE 8 Percentage of mountain streams with each difference in the NO_3^- concentrations at the baseflow condition throughout Japan in 2003 and 2022, 2022 minus 2003. *Source*: The 2003 data were collected by Konohira et al. (2006).

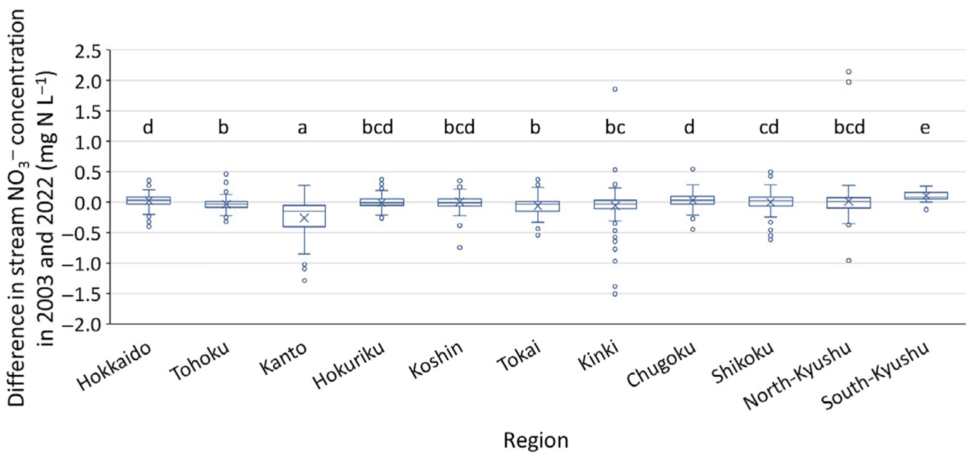

FIGURE 9 Box plots of difference in mountain stream NO_3^- concentration at the baseflow condition in 2003 and 2022 by region throughout Japan. (Cross [×] represents average values, circle symbol [°] represents outlier, different lowercase letters above plots indicate significant differences among the regions [$p < 0.05$], which were found by Steel–Dwass multiple comparison test).

Hokuriku, Tokai, Kinki, Chugoku, Shikoku, Northern Kyushu, and Southern Kyushu, respectively (Figure S5a–c). The differences between annual mean temperature anomalies and regression line in both 2003 and 2022 were not higher or lower than the outliers and not notably high or low for all regions of Japan (Figure S4).

In the ratios of annual precipitation in each year to the 30 years' average annual precipitation, significant trends were not observed for all regions (Figure S6). Outliers for the ratios of annual precipitation to the 30 years' average were determined higher than 130%, 126%, 126%, 141%, 145%, 144%, 146%, 148%, 146%, and 142% and lower than 74.0%, 76.0%, 76.3%, 61.6%, 57.3%, 60.3%, 51.1%, 53.8%, 51.4%, and 61.4% in Hokkaido, Tohoku, Kanto-Koshin, Hokuriku, Tokai, Kinki, Chugoku, Shikoku, Northern Kyushu, and Southern Kyushu, respectively (Figure S6). The ratios of annual precipitation to the 30 years' average in both 2003 and 2022 were not higher or lower than the outliers and not notably high or low for all regions of Japan (Figure S6).

4 | DISCUSSION

4.1 | Challenges faced in this project

The number of collected water samples was the second highest in the first month and gradually declined until September. However, in October, we took proactive steps to boost participation by personally inviting our acquaintances to join the water sampling efforts and engaging our research team in sampling activities. Toward the end of October, we sent an email to all previous participants as an earnest "last request," appealing for their renewed participation. These efforts yielded an increase in water sampling activities in October, with the highest number recorded in November. In October and November, 9.5% of the samples were collected by our team, accounting for 8.5% of all samples collected during June–November.

Several challenges were encountered during this project. One issue involved broken bottle caps. Although no bottles were damaged during shipping, a few bottle caps broke off during storage in our laboratory. Fortunately, the samples did not leak, and we promptly replaced the broken caps. Another challenge was the omission of QR code stickers on a few bottles. For these samples, we relied on names on the envelopes to match them with the information received via the dedicated website for recording sampling data (Figures 2a,b and S2a,b).

Thorough validation of sampling data, particularly location data, was necessary. For instance, although the automatic input function registered location data in the 10-decimal system, some data were erroneously entered in the 60-decimal system when using manual input. Consequently, we had to review and standardize the decimal system for all data. This process involved cross-referencing data with a geographic map (Geospatial Information Authority of Japan, 2023), comparing them with the original reserved point's location data, and consulting additional information noted in the data. This experience underscored the importance of specifying the decimal system in the manual input system. In some cases, the automatic input function registered location data in residential areas with no adjacent forests, and the collectors were contacted to correct them.

4.2 | Accuracy of citizen-collected mountain streamwater samples

As a nationwide survey, the “Mountain Health Checkup” project presented a formidable challenge that we tackled using the citizen-participatory survey method. This approach is highly valuable, enabling large-scale surveys that would be challenging for researchers to accomplish alone and expanding the scope of scientific research. Nevertheless, ensuring the quality of samples collected by nonexperts poses a major concern. To address this, we prepared easy-to-understand explanations, a manual, and a video based on preliminary sampling (refer to Section 2.2 for details).

Our results showed that the spatial distribution of mountain stream NO_3^- concentrations in 2022 closely mirrored the 2003 results. Furthermore, as discussed in Section 3.2, there were minimal discrepancies in stream NO_3^- concentrations for the majority of 56 overlapping samples collected unexpectedly by citizen participants and even in 10 overlapping samples collected unexpectedly by our researchers and citizen participants. These findings suggest that, to some extent, the quality of the samples was assured.

Even in cases where unusual data points arose, they could be managed through multipoint analysis, as 1414 points were included in the study, ensuring sufficient accuracy for studying concentration spatial distribution. When employing a citizen-participatory survey method, the advantage of collecting a substantial number of samples across a broad area outweighs the possibility of occasional noise. Nevertheless, such noise may contain signals indicating important phenomena, necessitating individual scrutiny in subsequent studies.

4.3 | Spatial distribution of mountain stream NO_3^- concentrations across Japan in 2022

In 2022, some forests exhibited mountain stream NO_3^- concentrations exceeding 1.0 mg N L^{-1} (Figures 3 and 4), potentially indicating N-saturation (Gundersen et al., 2006). These elevated concentrations were observed not only in suburban areas such as the Kanto region and the area near Osaka or Fukuoka, but also in northern Shikoku, particularly Kagawa Prefecture, which lacks major cities or industrial zones (Figures 4 and S3), resulting in comparable concentrations in Shikoku as Kinki and Northern Kyushu, which include urban areas (Figures 5 and S3). Conversely, mountain stream NO_3^- concentrations tended to be lower along the Japan Sea side (Figures 4 and S3), where seasonal northwest winds transport air pollutants from continental Asia, especially in winter, contributing to higher N loading (Morino et al., 2011).

In the Japan Sea side region, these winds carry not only pollutants but also heavy snow that traps deposited N, releasing it during snowmelt periods (Brooks & Williams, 1999; Mitchell, 2011; Stoddard, 1994), potentially reducing mountain stream NO_3^- concentrations during baseflow conditions in areas with heavy snowfall. Conversely, the Seto Inland Sea area, including northern Shikoku, experiences comparatively drier conditions in Japan. In regions with heavy precipitation, N in rain and snow is swiftly flushed out (e.g., Chiwa et al., 2010; Ohte et al., 2001; Shichi et al., 2005), leading to lower mountain stream NO_3^- concentrations in the growing season. However, in drier regions, limited precipitation may allow N to integrate into forest ecosystem, resulting in higher mountain stream NO_3^- concentrations during baseflow conditions. Clearly, multiple environmental factors influence mountain stream NO_3^- concentrations, necessitating their consideration in future studies.

4.4 | Differences in the spatial distribution of mountain stream NO_3^- concentrations across Japan in 2003 and 2022

First, we determined whether 2003 and 2022 represented typical years for temperature and precipitation using meteorological data from the Japan Meteorological Agency (2023a, 2023b), as these climatic factors influence stream NO_3^- concentrations (Murdoch et al., 1998; Ohte et al., 2001; Rusjan et al., 2008). Our analysis revealed that the differences in mean temperature and precipitation ratios between 2003 and 2022 were not notably high or low for all regions of Japan (Figures S4, S5a–c, and S6), suggesting that both years experienced typical temperature and precipitation patterns.

N deposition time trends were as follows: according to Tokuchi et al. (2023), over the period 2000–2018, N wet deposition showed an increasing trend in Northern Japan, a turn from an increasing trend to a decreasing trend in 2004 in Eastern Japan and in 2012 in the Japan Sea side, a decreasing trend in Western Japan and Southwest Islands, and repeated increasing and decreasing trends in Central Japan. In Japan as a whole, N wet deposition has decreased since approximately 2012 (Tokuchi et al., 2023). Total N deposition decreased from 2000 to 2015 in Japan as a whole (Hayashi et al., 2021).

The spatial distribution pattern of mountain stream NO_3^- concentrations at baseflow conditions remained nearly unchanged between 2003 and 2022 (Figures 4 and 6) and the differences in the concentration between the 2 years were typically <0.25 mg N L^{-1} at most points (Figures 7 and 8), despite recent changes in N deposition (Hayashi et al., 2021; Tokuchi et al., 2023) and temperature (Figure S4; Japan Meteorological Agency, 2023a, 2023b). In other monitoring research conducted by Forestry and Forest Products Research Institute (2014) at 19 points in Japan, there was no significant time trend in mountain stream NO_3^- concentration at 12 points, while there was significant but slight time trend in mountain stream NO_3^- concentration (−0.02 to 0.006 mg N L^{-1} yr^{-1}) at 5 points from 2000 to 2008. Other studies also showed no significant time trend from 2000 to 2015 in the Shikoku region (Sakai et al., 2019), 2000 to 2014 in the Tohoku region (Shinomiya et al., 2018), 2001 to 2014 in the Kyushu region (Tsurita & Ohnuki, 2017) and a slight declining trend (−0.02 to −0.004 mg N L^{-1} yr^{-1}) in the Kyushu region (Chiwa, 2021). In Northern Japan, Hokkaido and Tohoku region, it is considered that the increasing N deposition have not exceeded the ecosystem demands. In the Japan Sea side area and Western Japan, these time trends could be attributed to the continuous accumulation of N in forests even after reductions in atmospheric N deposition (Crossman et al., 2016), and the lengthy recovery from substantial NO_3^- leaching (Gilliam et al., 2019).

In suburban regions, such as the Kanto region, mountain stream NO_3^- concentrations tended to be lower in 2022 than in 2003, with larger differences noted compared with other regions (Figures 7 and 9), possibly due to a decline in N wet deposition in Eastern Japan since approximately 2012 (Tokuchi et al., 2023). In another study in the Kanto region, declining trend in mountain stream NO_3^- concentration (−0.07 mg N L^{-1} yr^{-1}) and rain NO_3^- concentration were observed (Kobayashi et al., 2018). Similarly, in the Tokai region including Chukyo industrial area (Sase et al., 2019), mountain stream NO_3^- concentrations tended to be slightly lower in 2022 than in 2003 (Figures 7 and 9), possibly due to a decline in N deposition (Sase et al., 2019). In the Tohoku region as well, mountain stream NO_3^- concentrations tended to be slightly lower in 2022 than in 2003 (Figures 7 and 9), despite an increasing in N wet deposition in Northern Japan (Tokuchi et al., 2023). One possible reason is increasing N uptake by vegetation (Mitchell et al., 1996; Stoddard, 1994) enhanced by increasing temperature (Figure S4; Japan Meteorological Agency, 2023a; Greaver et al., 2016).

In the southern Shikoku and southern Kyushu regions, a slight increasing trend was observed (Figures 7 and 9). Southern Kyushu, in particular, is a hub for livestock farming (Kyusyu Regional Agricultural Administration Office, 2021). Considering the rising domestic consumption and export of meat products in Japan (Ministry of Agriculture, Forestry and Fisheries, 2023), increased ammonia evaporation from livestock may contribute to the slight increase in stream NO_3^- concentrations in southern Kyushu.

As N emissions from China began decreasing in 2012 (Liu et al., 2020; Sun et al., 2018; Wang et al., 2023), there is potential for future recovery from substantial NO_3^- leaching in Japan (Chiwa, 2021), especially in the Japan Sea side region (Sase et al., 2021). Recent global warming may also introduce complex changes to N cycling in forests (Groffman et al., 2018). Vigilance is required to monitor these ongoing developments.

5 | CONCLUSIONS

In 2022, we conducted the first nationwide survey using a citizen-participatory approach to extensively monitor forest conditions and elucidate the spatial distribution of mountain stream chemistries across Japan, comparing them to results from 2003. This endeavor revealed a greater number of motivated citizens than initially expected, highlighting the immense potential of citizen science. However, we exercised caution to ensure the ethical treatment of participants and reciprocate their contributions as much as possible. Numerous challenges arose during sampling, data recording, and sample management. Resourcefulness and diligence enabled us to overcome these obstacles. The easy-to-understand explanations, manual, and instructional video, designed to ensure the quality of samples collected by nonexperts proved effective, resulting in negligible discrepancies observed in the stream NO_3^- concentrations of most overlapping samples collected unexpectedly. Furthermore, the spatial distribution of mountain stream NO_3^- concentrations in 2022 closely aligned with the findings from 2003. However, this distribution did not consistently align with the presence of major cities, industrial areas, or total N deposition, remaining largely consistent with the 2003 patterns (Figures 4 and 6), despite recent changes in N deposition and climate. Identifying the environmental factors governing forest conditions and NO_3^- concentrations in mountain streams will be a focus of future research. Our "Mountain Health Checkup" project underscored the effectiveness and promise of citizen-participatory surveys, enabling nationwide research and advancing the reach of science.

ACKNOWLEDGMENTS

This study was completed thanks to the following persons and companies' cooperations. General citizen participants cooperated in collecting mountain streamwater. Montbell Co., Ltd. collaborated with us on a project called "Mountain Health Checkup." HORIBA Advanced Techno, Co., Ltd. and HORIBA Techno Service, Co., Ltd. helped us in analyzing the samples. Dr. Karibu Fukuzawa and Dr. Yoshiyuki Inagaki also provided great help in water sampling and guidance in the discussion of the data. We really would like to thank to them. This research was supported by a Grants-in-Aid for Scientific Research; 15H04515, 19H03012, 22H02385, 23K05316, JST SICORP Japan; JPMJSC19C3, and Research Institute for Humanity and Nature (RIHN: a constituent member of NIHU) Project No. RIHN14200156.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Soyoka Makino https://orcid.org/0000-0002-5148-1436
Naoko Tokuchi https://orcid.org/0000-0001-5508-5951

REFERENCES

Aber, J., McDowell, W., Nadelhoffer, K., Magill, A., Berntson, G., Kamakea, M., McNulty, S., Currie, W., Rustad, L., & Fernandez, I. (1998). Nitrogen saturation in temperate forest ecosystems: Hypotheses revisited. *Bioscience*, *48*(11), 921–934.

Aber, J. D., Nadelhoffer, K. J., Steudler, P., & Melillo, J. M. (1989). Nitrogen saturation in northern forest ecosystems. *Bioscience*, *39*(6), 378–386.

Asano, Y., Uchida, T., Mimasu, Y., & Ohte, N. (2009). Spatial patterns of stream solute concentrations in a steep mountainous catchment with a homogeneous landscape. *Water Resources Research*, *45*(10), 1–9.

Baba, M., Okazaki, M., & Hashitani, T. (1995). Effect of acidic deposition on forested Andisols in the Tama Hill region of Japan. *Environmental Pollution*, *89*(1), 97–106.

Brooks, P. D., & Williams, M. W. (1999). Snowpack controls on nitrogen cycling and export in seasonally snow-covered catchments. *Hydrological Processes*, *13*(14–15), 2177–2190.

Chadwick, O. A., Gavenda, R. T., Kelly, E. F., Ziegler, K., Olson, C. G., Elliott, W. C., & Hendricks, D. M. (2003). The impact of climate on the biogeochemical functioning of volcanic soils. *Chemical Geology*, *202*(3–4), 195–223.

Chiwa, M. (2021). Long-term changes in atmospheric nitrogen deposition and stream water nitrate leaching from forested watersheds in western Japan. *Environmental Pollution*, *287*, 117634.

Chiwa, M., Maruno, R., Ide, J. I., Miyano, T., Higashi, N., & Otsuki, K. (2010). Role of stormflow in reducing N retention in a suburban forested watershed, western Japan. *Journal of Geophysical Research: Biogeosciences*, *115*(G2), 1–11.

Crossman, J., Eimers, M. C., Casson, N. J., Burns, D. A., Campbell, J. L., Likens, G. E., Mitchell, M. J., Nelson, S. J., Shanley, J. B., Watmough, S. A., & Webster, K. L. (2016). Regional meteorological drivers and long term trends of winter-spring nitrate dynamics across watersheds in northeastern North America. *Biogeochemistry*, *130*(3), 247–265.

Elser, J. J., Bracken, M. E., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., Ngai, J. T., Seabloom, E. W., Shurin, J. B., & Smith, J. E. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecology Letters*, *10*(12), 1135–1142.

Estévez, E., Rodriguez-Castillo, T., González-Ferreras, A. M., Cañedo-Argüelles, M., & Barquin, J. (2019). Drivers of spatio-temporal patterns of salinity in Spanish rivers: A nationwide assessment. *Philosophical Transactions of the Royal Society B*, *374*(1764), 20180022.

European Citizen Science Association. (2015). Ten principles of citizen science. https://ecsa.citizen-science.net/wp-content/uploads/2020/02/ecsa_ten_principles_of_citizen_science.pdf

Forestry and Forest Products Research Institute (FFPRI). (2014). *Forest atmospheric depositions and stream water chemistry data base* (in Japanese). http://www.ffpri.affrc.go.jp/labs/fasc

Fujii, K., Kanetani, S., & Tetsuka, K. (2020). Effects of volcanic parent materials on the acid buffering capacity of forest soils on Yakushima Island, Japan. *Soil Science and Plant Nutrition*, *66*(5), 680–692.

Fukushima, K. (2012). Nitrogen cycling. In The Japanese Society of Forest Environment (Ed.), *Balance in forests—Interaction between plants and soil* (pp. 227–235). Tokai University Press. (in Japanese).

Geospatial Information Authority of Japan. (2023). Geographic map. https://maps.gsi.go.jp/#5/36.104611/140.084556/&base=std&ls=std&disp=1&vs=c1g1j0h0k0l0u0t0z0r0s0m0f1

Gilliam, F. S., Burns, D. A., Driscoll, C. T., Frey, S. D., Lovett, G. M., & Watmough, S. A. (2019). Decreased atmospheric nitrogen deposition in eastern North America: Predicted responses of forest ecosystems. *Environmental Pollution*, *244*, 560–574.

Greaver, T. L., Clark, C. M., Compton, J. E., Vallano, D., Talhelm, A. F., Weaver, C. P., Band, L. E., Baron, J. S., Davidson, E. A., Tague, C. L., Quinn, E. F., Lynch, J. A., Herrick, J. D., Liu, L., Goodale, C. L., Novak, K. J., & Haeuber, R. A. (2016). Key ecological responses to nitrogen are altered by climate change. *Nature Climate Change*, *6*(9), 836–843.

Groffman, P. M., Driscoll, C. T., Durán, J., Campbell, J. L., Christenson, L. M., Fahey, T. J., Fisk, M. C., Fuss, C., Likens, G. E., Lovett, G., Rustad, L., & Templer, P. H. (2018). Nitrogen oligotrophication in northern hardwood forests. *Biogeochemistry*, *141*(3), 523–539.

Gundersen, P., Schmidt, I. K., & Raulund-Rasmussen, K. (2006). Leaching of nitrate from temperate forests effects of air pollution and forest management. *Environmental Reviews*, *14*(1), 1–57.

Hayashi, K., Shibata, H., Oita, A., Nishina, K., Ito, A., Katagiri, K., Shindo, J., & Winiwarter, W. (2021). Nitrogen budgets in Japan from 2000 to 2015: Decreasing trend of nitrogen loss to the environment and the challenge to further reduce nitrogen waste. *Environmental Pollution*, *286*, 117559.

Hirose, A., Iwatsubo, G., & Tsutsumi, T. (1988). Study on run-off water chemistry in Japanese forest (1). *Bulletin of the Kyoto University Forests*, *60*, 162–173. (in Japanese).

Itoh, Y., Miura, S., Kato, M., & Yoshinaga, S. (2004). Regional distribution of nitrate concentrations in the streamwater of forested watersheds in the Kanto and Chubu districts. *Journal of the Japanese Forestry Society*, *86*(3), 275–278. (in Japanese with English abstract).

Izaak Walton League of America. (2023). Nitrate watch. https://www.iwla.org/water/stream-monitoring/nitrate-watch

Japan Meteorological Agency. (2023a). Differences between the mean annual air temperature and the averaged one from 1991 to 2020. https://www.data.jma.go.jp/cpd/cgi-bin/view/allhist.php?reg_no=36&year=2022&month=0&kind=0&elem=0

Japan Meteorological Agency. (2023b). Ratios of the annual precipitation to the averaged one from 1991 to 2020. https://www.data.jma.go.jp/cpd/cgi-bin/view/allhist.php?reg_no=36&year=2022&month=0&kind=0&elem=1

Japanese Standards Association. (2019). *JISK0102 test methods for industrial water and industrial effluent* (in Japanese). Japanese Standards Association. https://www.jisc.go.jp/app/jis/general/GnrJISNumberNameSearchList?show

Jun, Y. C., Kim, N. Y., Kim, S. H., Park, Y. S., Kong, D. S., & Hwang, S. J. (2016). Spatial distribution of benthic macroinvertebrate assemblages in relation to environmental variables in Korean nationwide streams. *Water*, *8*(1), 27.

Kadoya, T., Ishii, H. S., Kikuchi, R., Suda, S. I., & Washitani, I. (2009). Using monitoring data gathered by volunteers to predict the potential distribution of the invasive alien bumblebee *Bombus terrestris*. *Biological Conservation*, *142*(5), 1011–1017.

Kobayashi, M., Yoshinaga, S., Ito, Y., Shinomiya, Y., Aizawa, S., Okamoto, T., & Tsurita, T. (2018). Precipitation and streamwater chemistry in the Katsura Fudo-yatsu experimental watershed in the Kanto region, 2001–2014. *Bulletin of Forestry and Forest Products Research Institute*, *17*(4), 333–373. (in Japanese with English abstract). https://www.jstage.jst.go.jp/article/ffpri/17/4/17_333/_pdf/-char/ja

Kobori, H., Dickinson, J. L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., Kitamura, W., Takagawa, S., Koyama, K., Ogawara, T., & Miller-Rushing, A. J. (2016). Citizen science: A new approach to advance ecology, education, and conservation. *Ecological Research*, *31*, 1–19.

Komai, Y. (2010). Evaluation of the effect of acid deposition to the stream water chemistry in Yakushima Island based on the long-term periodical and fixed point observation. *River Foundation Japan*, 1–25. (in Japanese). http://public-report.kasen.or.jp/211211025.pdf

Konohira, E., Shindo, J., Yoshioka, T., & Toda, T. (2006). Stream water chemistry in Japan. *Japanese Association of Hydrological Sciences*, *36*(3), 145–149. (in Japanese with English abstract). https://www.jstage.jst.go.jp/article/jahs/36/3/36_145/_article/-char/ja/

Kosmala, M., Wiggins, A., Swanson, A., & Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment*, *14*(10), 551–560.

K-TESST. (2003). Knoxville–Tennessee environmental soil and stream testing. https://sites.google.com/vols.utk.edu/k-tesst/home

Kyusyu Regional Agricultural Administration Office. (2021). *Let's take a look! Agriculture in Kyushu—2021* (in Japanese). Kyusyu Regional Agricultural Administration Office. https://www.maff.go.jp/kyusyu/toukei/hensyu/attach/pdf/toukeipaneru-53.pdf

Larned, S. T., Scarsbrook, M. R., Snelder, T. H., Norton, N. J., & Biggs, B. J. (2004). Water quality in low-elevation streams and rivers of New Zealand: Recent state and trends in contrasting land-cover classes. *New Zealand Journal of Marine and Freshwater Research*, *38*(2), 347–366.

Lawrence, A. (2006). 'No personal motive?' Volunteers, biodiversity, and the false dichotomies of participation. *Ethics Place and Environment*, *9*(3), 279–298.

Lewandowski, E., & Specht, H. (2015). Influence of volunteer and project characteristics on data quality of biological surveys. *Conservation Biology*, *29*(3), 713–723.

Liu, X. J., Xu, W., Du, E. Z., Tang, A. H., Zhang, Y., Zhang, Y. Y., Wen, Z., Hao, T. X., Pan, Y. P., Zhang, L., Gu, B. J., Zhao, Y., Shen, J. L., Zhou, F., Gao, Z. L., Feng, Z. Z., Chang, Y. H., Goulding, K., Collett, J. L., … Zhang, F. S. (2020). Environmental impacts of nitrogen emissions in China and the role of policies in emission reduction. *Philosophical Transactions of the Royal Society A*, *378*(2183), 20190324.

Mekuria, W., Veldkamp, E., Haile, M., Nyssen, J., Muys, B., & Gebrehiwot, K. (2007). Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. *Journal of Arid Environments*, *69*(2), 270–284.

Ministry of Agriculture, Forestry and Fisheries. (2023). *Table of food supply and demand*. Ministry of Agriculture, Forestry and Fisheries. (in Japanese). https://www.maff.go.jp/j/zyukyu/fbs/

Mitchell, M. J. (2011). Nitrate dynamics of forested watersheds: Spatial and temporal patterns in North America, Europe and Japan. *Journal of Forest Research*, *16*(5), 333–340.

Mitchell, M. J., Driscoll, C. T., Kahl, J. S., Likens, G. E., Murdoch, P. S., & Pardo, L. H. (1996). Climatic control of nitrate loss from forested watersheds in the northeast United States. *Environmental Science & Technology*, *30*(8), 2609–2612.

Miyazaki, Y. (2016). The relationship between citizen science and biodiversity information databases. *Japanese Journal of Ecology*, *66*, 237–246. (in Japanese).

Montbell website. (2022). *Join the "Mountain Health Checkup" project checking the mountain stream water quality to keep nature* *in better condition!* (in Japanese). https://www.montbell.jp/generalpage/disp.php?id=629

Morino, Y., Ohara, T., Kurokawa, J., Kuribayashi, M., Uno, I., & Hara, H. (2011). Temporal variations of nitrogen wet deposition across Japan from 1989 to 2008. *Journal of Geophysical Research: Atmospheres*, *116*(D06307), 1–17.

Mountain Health Checkup project. (2022a). *Website of Mountain Health Checkup project* (in Japanese). https://fserc.kyoto-u.ac.jp/wp/yamaken/

Mountain Health Checkup project. (2022b). *Video explaining the sampling method* (in Japanese). https://www.youtube.com/watch?v=-YHK6efW35k

Murdoch, P. S., Burns, D. A., & Lawrence, G. B. (1998). Relation of climate change to the acidification of surface waters by nitrogen deposition. *Environmental Science & Technology*, *32*(11), 1642–1647.

Nash, M. S., Heggem, D. T., Ebert, D., Wade, T. G., & Hall, R. K. (2009). Multi-scale landscape factors influencing stream water quality in the state of Oregon. *Environmental Monitoring and Assessment*, *156*, 343–360.

Nishina, K., Watanabe, M., Koshikawa, M. K., Takamatsu, T., Morino, Y., Nagashima, T., Soma, K., & Hayashi, S. (2017). Varying sensitivity of mountainous streamwater base-flow NO_3^- concentrations to N deposition in the northern suburbs of Tokyo. *Scientific Reports*, *7*(1), 7701.

Ohte, N., Tokuchi, N., Shibata, H., Tsujimura, M., Tanaka, T., & Mitchell, M. J. (2001). Hydrobiogeochemistry of forest ecosystems in Japan: Major themes and research issues. *Hydrological Processes*, *15*(10), 1771–1789.

Piirainen, S., Finér, L., Mannerkoski, H., & Starr, M. (2004). Effects of forest clear-cutting on the sulphur, phosphorus and base cations fluxes through podzolic soil horizons. *Biogeochemistry*, *69*, 405–424.

Prause, M. V. (2014). *River and stream water quality monitoring report for water year 2013*. Washington State Department of Ecology. https://apps.ecology.wa.gov/publications/UIPages/SummaryPages/1403047.html

Pretty, J. (2003). Social capital and the collective management of resources. *Science*, *302*(5652), 1912–1914.

R Development Core Team. (2023). *R version 4.3.2.: A language and environment for statistical computing*. R Foundation for Statical Computing. http://www.R-project.org

Rusjan, S., Brilly, M., & Mikoš, M. (2008). Flushing of nitrate from a forested watershed: An insight into hydrological nitrate mobilization mechanisms through seasonal high-frequency stream nitrate dynamics. *Journal of Hydrology*, *354*(1–4), 187–202.

Sahashi, G., Maruyama, M., Aruga, N., Morita, K., Okamoto, M., Mukai, T., Mizumoto, H., Ueda, K., Fujii, K., Watanabe, K., Ohkuma, K., & Araki, H. (2020). Is there sampling bias in biological photos with location information collected in a citizen participatory research?—Based on a comparison of citizen and expert data of anadromous salmon and related photographs. *Japanese Journal of Conservation Ecology*, *25*, 307–315. (in Japanese with English abstract).

Sakai, H., Yamada, T., Torii, A., Shinomiya, Y., Inagaki, Y., Yoshinaga, S., Noguchi, K., & Morishita, T. (2019). Monitoring of rainwater and streamwater chemistry from 2000 to 2015 in forested catchments in the upper reaches of the Shimanto River, Shikoku Island, Japan. *Bulletin of Forestry and Forest Products Research Institute*, *18*(1), 129–187. (in Japanese with English abstract). https://www.jstage.jst.go.jp/article/ffpri/18/1/18_129/_article/-char/ja/

Sakai, M., Fukushima, K., & Nakagawa, H. (2022). Indirect effects of deer overgrazing on stream ecosystems. In *Sika deer: Life history plasticity and management* (pp. 463–482). Springer Nature Singapore.

Sase, H., Saito, T., Takahashi, M., Morohashi, M., Yamashita, N., Inomata, Y., Ohizumi, T., & Nakata, M. (2021). Transboundary air pollution reduction rapidly reflected in stream water chemistry in forested catchment on the sea of Japan coast in central Japan. *Atmospheric Environment*, *248*, 118223.

Sase, H., Takahashi, M., Matsuda, K., Sato, K., Tanikawa, T., Yamashita, N., Ohizumi, T., Ishida, T., Kamisako, M., Kobayashi, R., Uchiyama, S., Saito, T., Morohashi, M., Fukuhara, H., Kaneko, S., Inoue, T., Yamada, T., Takenaka, C., Tayasu, I., … Ohta, S. (2019). Response of river water chemistry to changing atmospheric environment and sulfur dynamics in a forested catchment in central Japan. *Biogeochemistry*, *142*, 357–374.

Scanlon, T. M., Riscassi, A. L., & Galloway, J. N. (2021). Observed changes in chronic and episodic acidification in Virginia mountain streams in response to the Clean Air Act and amendments. *Atmospheric Environment*, *252*, 118279.

Schmitz, A., Sanders, T. G., Bolte, A., Bussotti, F., Dirnböck, T., Johnson, J., Peñuelas, J., Pollastrini, M., Prescher, A. K., Sardans, J., Verstraeten, A., & de Vries, W. (2019). Responses of forest ecosystems in Europe to decreasing nitrogen deposition. *Environmental Pollution*, *244*, 980–994.

Shichi, K., Hashimoto, T., Miura, S., Aizawa, S., & Ikeda, S. (2005). Streamwater quality through years and snowmelt period in a forested inland basin in Tohoku, northern Japan. *Journal of the Japanese Forest Society (Japan)*, *87*(4), 340–350.

Shinomiya, Y., Yamada, T., Hirai, K., Ono, K., Noguchi, S., Kubota, T., & Abe, T. (2018). Monitoring the chemistry of rainwater and streamwater from a small forested watershed: Results in the Kamabuchi experimental watershed, Yamagata prefecture, Tohoku district, Japan between 2000 and 2014. *Bulletin of Forestry and Forest Products Research Institute*, *17*(3), 273–303. (in Japanese with English abstract). https://agriknowledge.affrc.go.jp/RN/2030925365.pdf

Shinozuka, K. I., Chiwa, M., Tayasu, I., Yoshimizu, C., Otsuki, K., & Kume, A. (2017). Differences in stream water nitrate concentrations between a nitrogen-saturated upland forest and a downstream mixed land use river basin. *Hydrology*, *4*(3), 43.

Stoddard, J. L. (1994). Long-term changes in watershed retention of nitrogen: Its causes and aquatic consequences. *Advances in Chemistry*, *237*, 223–284.

Sun, W., Shao, M., Granier, C., Liu, Y., Ye, C. S., & Zheng, J. Y. (2018). Long-term trends of anthropogenic SO_2, NO_x, CO, and NMVOCs emissions in China. *Earth's Future*, *6*(8), 1112–1133.

Takahashi, M., Sakata, T., & Ishizuka, K. (2001). Chemical characteristics and acid buffering capacity of surface soils in Japanese forests. *Water, Air, and Soil Pollution*, *130*, 727–732.

Toda, H., Sasa, K., Sato, F., Shibata, H., Nomura, M., Ichikawa, K., Fujito, E., Takanishi, T., Seiwa, K., Tsukahara, H., Iida, T., Taniguchi, N., Nakata, M., Kuwabara, S., Uchida, T., Haruta, Y., Inoue, M., Yagi, H., Tsukagoshi, T., … Enoki, T. (2000). Stream water chemistry of university forests over. *Journal of the Japanese Forestry Society*, *82*(3), 308–312. (in Japanese with English abstract).

Tokuchi, N., Iwasaki, A., Yamaguchi, T., Hisatsune, K., Nakagawa, H., Yago, H., Makino, S., & Murano, K. (2023). Analysis of long-term variations of nitrogen deposition in Japan (1977–2018). *Journal of the Japanese Forestry Society*, *105*, 199–208. (in Japanese with English abstract).

Tsurita, T., & Ohnuki, Y. (2017). Rainwater and streamwater chemistry between 2001 and 2014 in the Kahoku experimental watershed no.3, Kyushu. *Bulletin of Forestry and Forest Products Research Institute*, *16*(1), 29–60. https://www.jstage.jst.go.jp/article/ffpri/16/1/16_29/_pdf/-char/ja

Wang, P., Liu, D., Mukherjee, A., Agrawal, M., Zhang, H., Agathokleous, E., Qiao, X., Xu, X., Chen, Y., Wu, T., Zhu, M., Saikawa, E., Agrawal, S. B., & Feng, Z. (2023). Air pollution governance in China and India: Comparison and implications. *Environmental Science & Policy*, *142*, 112–120.

Wei, H., Yang, J., Liu, Z., & Zhang, J. (2022). Data integration analysis indicates that soil texture and pH greatly influence the acid buffering capacity of global surface soils. *Sustainability*, *14*(5), 3017.

Wiggins, A., Newman, G., Stevenson, R. D., & Crowston, K. (2011). Mechanisms for data quality and validation in citizen science. In *IEEE seventh international conference on e-Science Workshops* (pp. 14–19). IEEE.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Makino, S., Tokuchi, N., Akaishi, D., Koyama, L. A., Komai, Y., Itaya, Y., Maung, N. L., Ishimaru, K., Oda, T., Shibata, R., & Numamoto, S. (2024). Citizen-participatory nationwide survey of mountain streamwater chemistry in Japan in 2022: Comparison of nitrate concentrations with the 2003 survey. *Ecological Research*, 1–16. https://doi.org/10.1111/1440-1703.12465