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Implementation and evaluation of geography education using QGIS for Japanese high school students

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Abstract

In recent years, demand for geography education using GIS has been growing among junior and senior high school teachers. QGIS has attracted attention because it is freely available and enables advanced spatial visualization and analysis. However, the implementation of QGIS in education for junior and senior high school students remains limited compared with GIS education in universities. In this study, we conducted educational events for junior and senior high school students to examine three aspects: students' ability to operate QGIS, their understanding of spatial data concepts and processing, and their interpretation of geographical features across multiple layers. The QGIS-based exercises were conducted as part of one-day or half-day educational programs introducing various GIS applications. The events were held eight times between 2018 and 2025. During the QGIS-based exercises, we focused on teaching basic GIS operations and spatial thinking by processing data related to the Kyodo River alluvial fan in Yamanashi Prefecture, Central Japan. At the end of the exercises, we asked the students to submit their answers to the assignments and complete a questionnaire.
The results indicate that geography education using QGIS is feasible for junior and senior high school students. While most students understood basic GIS operations and spatial data concepts, many, particularly younger students, struggled to interpret their maps from a spatial thinking perspective. These findings highlight the importance of strengthening existing map-reading education in schools. In addition, it is important to enhance students' basic computer skills and improve the exercise design by incorporating a self-directed learning approach.

1. Introduction

In recent years, demand for geography education using GIS has been growing among junior and senior high school teachers. Since 2022, the compulsory geography curriculum in Japanese senior high schools has emphasized the use of maps and GIS in classrooms (Ministry of Education, Culture, Sports, Science and Technology, 2018). Many educational practices using WebGIS are being conducted in junior and senior high schools in Japan (e.g., Song et al., 2022; Song et al., 2023; Nagata et al., 2024). Although WebGIS is suitable for education because it allows users to view maps without installing software on a PC and can display maps on tablets and mobile devices (Fargher, 2018), many free online platforms are still unfamiliar with general spatial data analysis tasks. WebGIS can be easily operated by users who have mastered basic spatial thinking and map-reading skills, but it has challenges in educating spatial data concepts and their analysis. Desktop GIS may be a suitable learning topic for the first step in GIS education compared with WebGIS. If students do not learn spatial data concepts such as raster data cell size, they may misunderstand the geographical characteristics of the actual region.

QGIS is useful for geography education because, as a FOSS4G (Free and Open Source Software for Geospatial) tool, it is freely available, supports spatial data management and analysis, and can be customized for specific educational purposes (Ciolli et al., 2017; Novo et al., 2022; QGIS project, 2026). At the 2026 Spring High School Poster Session organized by the Association of Japanese Geographers, several high school geography research projects involving the use of QGIS were presented. However, the implementation of QGIS in general education for junior and senior high school students remains limited compared with GIS education in universities.

In this study, we conducted educational events for junior and senior high school students aged approximately 12–18 years to examine three aspects: students' ability to operate QGIS, their understanding of spatial data concepts and processing, and their interpretation of geographical features across multiple layers.

2. Implementation of the exercise and surveys

2.1 Summary of the Educational Programs

The QGIS-based exercises were conducted as part of one-day or half-day educational programs that introduced GIS utilization and related applications such as operating drones, handling 3D-printed models, and participating in VR field trips. The events were held eight times between 2018 and 2025. As shown in Table 1, we held three types of educational programs at The University of Tokyo (Case A and Case C) and The University of Tsukuba (Case B). Although the teaching topics varied slightly across events, each QGIS-based exercise was consistently implemented using the same instructional content.

The participants ranged from first-year junior high school students to third-year senior high school students. Case A was open to anyone, Case B to high school students, and Case C to students participating in a high school program. They joined the workshops after seeing online advertisements or receiving recommendations from their parents or teachers. Most participants were from Tokyo, Saitama, Chiba, Kanagawa, and Ibaraki prefectures in Japan's Kanto region. Overall, 210 junior and senior high school students attended the educational programs, although a few participants joined multiple times.

Case	Years	Participants
Case A	2018, 2019, 2021, 2022, and 2023	162 (7th to 12th grade students)
Case B	2022 (Two times)	40 (10th to 12th grade students)
Case C	2025	8 (10th grade students)

Table 1. Summary and participants of the educational programs.

2.2 Procedure of QGIS-Based Exercise

At the beginning of the events, we delivered a 20–30-minute lecture introducing fundamental GIS concepts. The exercises, which lasted 60–75 minutes, required each student to operate QGIS individually. During the exercises, we focused on teaching basic GIS operations and spatial thinking by processing data related to the Kyodo River alluvial fan in Yamanashi Prefecture, Central Japan (Figure 1). The elevation of the apex of the alluvial fan is approximately 600 m, whereas that of the toe is approximately 350 m. The fan is characterized by a relatively steep slope from the apex to the toe. Among Japanese geography educators, this alluvial fan has been recognized as a typical example of a landform closely related to land use. Using printed topographic maps and aerial photographs, teachers often explain that orchards are concentrated in the middle part of the Kyodo River alluvial fan, whereas buildings are mainly distributed to the north of the middle part, around the toe of the fan, and further downstream along the Kyodo River.

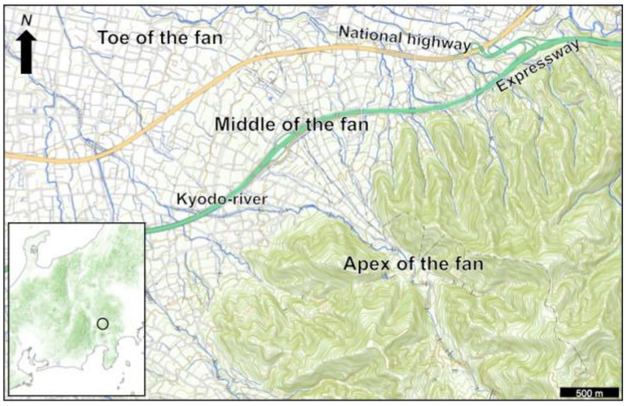

Figure 1. Location of the Kyodo River alluvial fan. This map was created using GSI Maps Vector provided by the Geospatial Information Authority of Japan.

Each exercise had about 8 to 20 participants. Case A was conducted separately for each group. The session included one or two assistants in addition to the lecturer. If students encountered difficulties in learning or experienced technical issues, the lecturer and assistants provided supportive help. Additionally, at the beginning of the workshop, we distributed printed materials that explained the exercise topics.

The exercise was structured into three sections: introduction, a QGIS-based exercise, and the completion of assignments and a questionnaire (Figure 2, Table 2). At the beginning of the session, the educator briefly explained basic PC terminology and the topographic characteristics of the alluvial fan. After the introduction, the students practiced QGIS processing while following the educators' explanations on the screen (Figure 3).

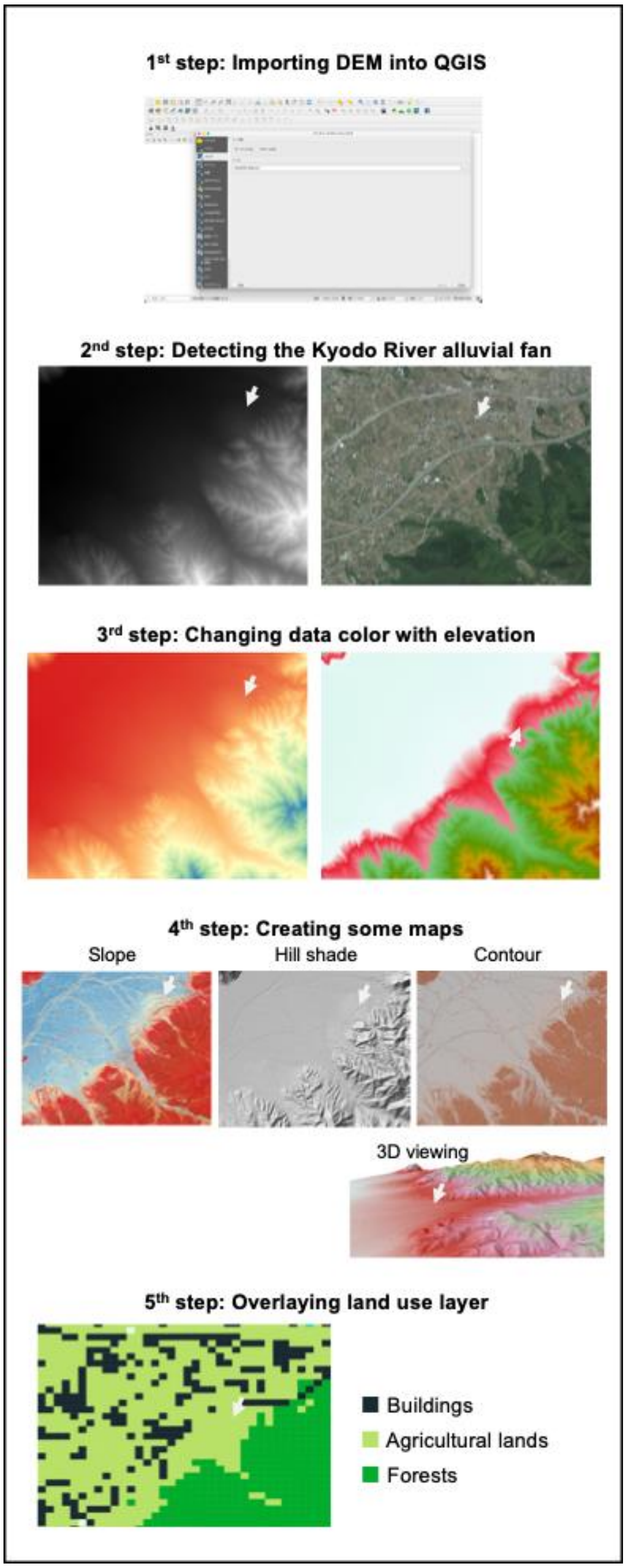

Figure 2. QGIS processing corresponding to the exercise procedure. White arrows indicate the location of the Kyodo River alluvial fan.

The QGIS-based exercise component consisted of five steps. In the first step, the students imported a 5-m resolution DEM (Digital Elevation Model) into QGIS. In the second step, the students attempted to identify the Kyodo River alluvial fan using the default DEM display, in which elevation values were represented from black to white. In the third step, they edited the DEM color settings based on cell values to enhance the visualization of the alluvial fan. In the fourth step, they created a slope map, a hillshade map, a 5-m contour map, and a 3D visualization to interpret the apex, middle, and toe areas of the alluvial fan. In the fifth step, they added land-use data to QGIS to examine the relationship between topography and land-use distribution by overlaying multiple layers. Finally, students attempted to complete two assignments and a questionnaire.

Time	Explanations and practices
10 minutes	Introducing the teaching objectives, an overview of the teaching area's alluvial fan and its land use, and basic computer terminology such as a folder.
40 to 45 minutes	The students learned QGIS operations, the interpretation of an alluvial fan, and its land use through five steps.
5 to 10 minutes	Assignments and a questionnaire

Table 2. Procedure and educational topics of the exercise.

Figure 3. Scenes from the practice.

2.3 Assignments and a Questionnaire

After the educational programs, we asked the students to submit their assignments and a questionnaire to assess their learning achievements and evaluate the educational effectiveness. Before administering the assignments and questionnaires, we explained the purpose of the survey two or three times and informed the students that their responses would be used in the study anonymously. These surveys were conducted only after obtaining the students' consent to participate.

The assignments were designed as two questions to assess students' learning outcomes: (A) whether they understood GIS operational procedures, and (B) whether they could interpret the geographical relationship between the alluvial fan and its land use.

Assignment A was to answer "How should the raster dataset be styled in QGIS to display the rivers more clearly? Please include the following terms in your answer: elevation values, color allocation, hillshade, and overlay." We assumed that the correct answer was "To show rivers more clearly, set the threshold elevation values for color allocation in the raster data, focusing on lower elevation areas. Additionally, apply transparency to the re-colored raster data and overlay it on the hillshade layer."

Assignment B was to answer "Explain the geographic characteristics by analyzing the relationship between orchards and man-made structures such as buildings and roads." We assumed that the correct answer is: "In this region, orchards are widely distributed and tend to be concentrated from the apex to the middle part of the alluvial fan, where slopes range from approximately 2 to 10 degrees. In contrast, buildings are typically observed around the middle to toe of the fan and in the northwestern area, where slopes become gentler, at approximately 1 to 2 degrees. Buildings are also distributed along roads that follow the shape of the fan and maintain elevations similar to those of the middle and toe of the fan."

The questionnaire consisted of two items: (a) simplicity of the exercise and (b) moments of difficulty or stumbling during the exercise. Item a was evaluated using a five-point Likert scale, where 1 indicated "complex," and 5 indicated "simple." Item b consisted of seven options: "difficulty in following the instructor's GIS operations," "understanding computer terminology," "communicating with educators when asking questions," "importing and saving GIS data," "typing on the keyboard," "other," and "none." Students were allowed to select one or more options. Item b was not asked of students in Case B.

3. Results

3.1 Assignments

We collected responses from 167 students for Assignment A and from 150 students for Assignment B (Tables 3 and 4). To examine whether the distribution of correct and incorrect responses differed among grade levels, a chi-square test of independence was conducted for the results of two assignments.

Grade	Respondents	Percentage of correct respondents
7th grade	36	31 (86.1 %)
8th grade	22	21 (95.5 %)
9th grade	27	22 (81.5 %)
10th grade	41	34 (82.9 %)
11th grade	21	18 (85.7 %)
12th grade	20	18 (90.0 %)
Total	167	144 (86.2 %)

Table 3. Result of Assignment A.

To assess students' understanding of GIS processing and DEM features, Assignment A was scored based on whether their responses included the four terms: "elevation values," "color allocation," "hillshade," and "overlay." The results show that approximately 80% to 95% of the students answered correctly, regardless of grade level. The chi-square test revealed no significant differences among grade levels ($\chi^2 = 2.71$, df = 5, p = 0.745). Most incorrect responses included three or fewer terms, and very few responses showed a complete misunderstanding.

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Grade	Respondents	Percentage of correct respondents
7th grade	25	10 (40.0 %)
8th grade	17	6 (35.3 %)
9th grade	27	10 (37.0 %)
10th grade	40	13 (32.5 %)
11th grade	21	16 (76.2 %)
12th grade	20	16 (80.0 %)
Total	150	71 (47.3 %)

Table 4. Result of Assignment B.

On the other hand, the overall correctness rate for Assignment B was 47.3%, which varied by students' grades. Over 75% of 11th- and 12th-grade students submitted correct answers, compared to 30%–40% of 7th- to 10th-grade students. The result indicated a significant association between students' grade level and achievement levels ($\chi^2 = 21.78$, df = 5, $p < 0.001$). The following types of incorrect responses were observed: descriptions that focused solely on agricultural or built areas, and misinterpretations of the GIS maps or the characteristics of an alluvial fan. Another criterion for Assignment B was whether they could identify elevation or slope values from the GIS data; however, only three senior high school students included such values in their responses. Most participants expressed general representations such as "this area is a steep slope," "gentle slope," "high elevation," or "low elevation."

3.2 Questionnaire

In the questionnaire survey, 181 students responded to Item a and 142 to Item b. The perceived simplicity of the exercise was distributed as follows: 35 students (19.3%) selected "complex," 75 (41.4%) "relatively complex," 34 (18.8%) "neither," 26 (14.4%) "relatively simple," and 11 (6.1%) "simple" (Figure 4).

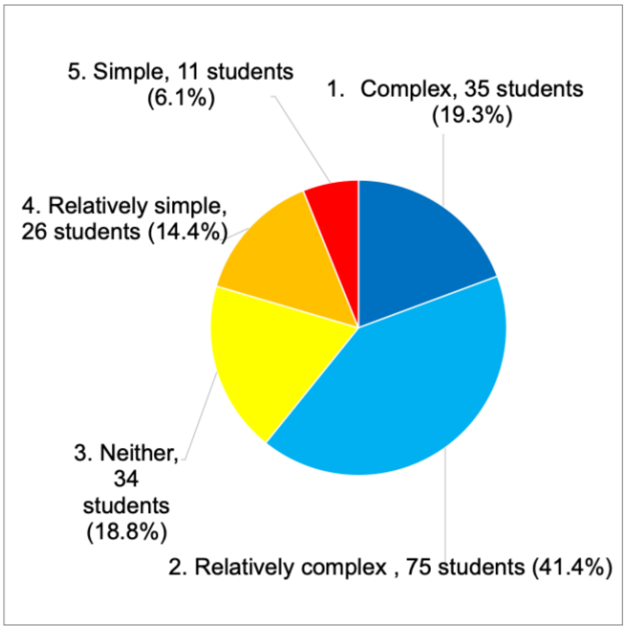

Figure 4. Result of Item a in the questionnaire (N = 181).

For Item b, no single difficulty was reported by more than 50% of respondents (Figure 5). The most frequently selected option was "Difficulty in following the instructor's GIS operations," selected by 46 students (32.4%). Approximately 20% of respondents selected "understanding computer terminology" and "none."

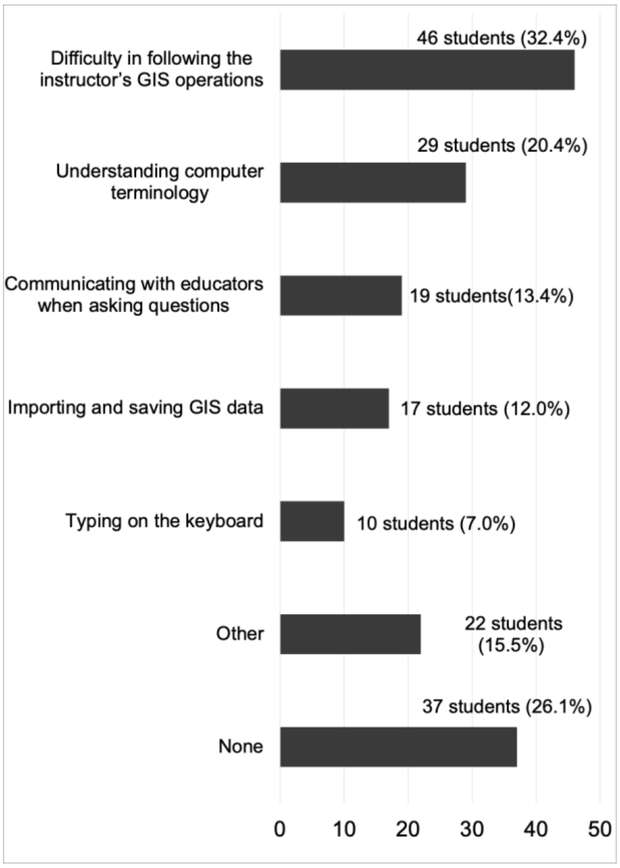

Figure 5. Result of Item b in the questionnaire (N = 142).

4. Discussion and conclusions

The results indicate that geography education using QGIS is feasible for junior and senior high school students. While most students understood basic GIS operations and spatial data concepts, many, particularly younger students, struggled to interpret their maps from a spatial thinking perspective. Pivarníková and Trojan (2023) also demonstrated that QGIS has potential for use in high school geography lessons when the theory behind GIS and maps is carefully explained. They further emphasized the importance of collaborative learning among students.

In our research, topics related to basic computer knowledge and operations, as well as learning while following the instructor's explanations, left some students with negative impressions. These findings highlight three major challenges in GIS education for junior and senior high school students: 1) developing fundamental map-reading skills, 2) acquiring basic computer knowledge and operational skills, and 3) learning while simultaneously following educators' explanations. These challenges have already been identified in previous studies on a wide range of GIS education contexts, particularly those involving university students. For instance, Yamauchi et al. (2025) showed that, even when WebGIS was used, some students had difficulty developing a deeper understanding of geographical features. This suggests the importance of strengthening existing map-reading education in schools. Basic computer knowledge can also become a stumbling block for beginner GIS users (Aladağ, 2014; Walshe, 2017). When simultaneous instruction is used, some students feel frustrated or dissatisfied because of differences in their computer operation skills and learning pace (Ooms et al., 2015; Vojtekova et al., 2021). Bearman et al. (2015) and Yamauchi et al. (2024) suggest that self-directed learning with digital learning materials is suitable for many students; however, it is also important to create a learning environment in which students can seek help from educators when they encounter difficulties.

These previous studies suggest that the effectiveness of GIS software-based education is not determined simply by students' age. Rather, it is strongly influenced by their prior knowledge of maps, basic computer operation skills, and the learning methods employed. The results of this study also indicate that students in the second year of senior high school or above can achieve sufficient learning outcomes. In particular, developing online GIS educational materials that support self-directed learning is important. Such materials should include explanations of basic computer operations and map-reading methods across multiple cases, allowing a wide range of students to practice GIS operations step by step and contributing to more effective learning.

A major advantage of FOSS4G software is that it is freely available to anyone. This is especially important for the wider use of GIS in school education, as it enables students and educators to use GIS without licensing fees. Beyond this, FOSS4G software offers additional advantages, including access to source code, customization through plugins, and flexible licensing (Ciolli et al., 2017). The wider adoption of FOSS4G can support the development and sharing of various types of educational materials on diverse topics, thereby improving the learning environment for GIS education. GIS can also contribute to project-based learning by enabling students to analyze real-world geographical issues (Demirci et al., 2011). Furthermore, by incorporating AI tools, students can engage in more specific geographic learning and research while developing and sharing their own regional analysis tools.

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