

Article

Adapting Environmental and Participatory Science Education in Kazakhstan: Two Complementary Case Studies

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Abstract

Kazakhstan faces growing water security and environmental management challenges and needs more practice-oriented environmental science education. This study examines two complementary Kazakhstan-based cases. Case Study 1 analyzes faculty and student surveys from the 2022 Science with a Purpose project, which delivered short courses in water quality, air quality, remediation, sampling methods, and scientific communication. Case Study 2 examines the 2025 pilot adaptation of the Nebraska-based Know Your Well (KYW) participatory-science model. An exploratory comparative two-case-study design drew on survey responses, project documentation, instructional materials, participant feedback, workflow analysis, and two illustrative laboratory water analyses. In Case Study 1, 22 of 25 faculty members responded (88.0%); student response rates were 14 of 18 (77.8%) before and 10 of 18 (55.6%) after the courses. Participants generally rated practice-oriented content positively. In the KYW pilot ($N = 15$), 14 participants (93.3%) reported that the training met expectations, and 14 (93.3%) considered the skills fully or partially applicable. The pilot demonstrated a feasible workflow linking preparation, field activity, sample handling, and laboratory-supported interpretation. Although the findings do not establish national representativeness, intervention effects, long-term learning outcomes, or large-scale monitoring impact, they support complementary capacity-building pathways for Kazakhstan.

Keywords: environmental science education; short-course training; participatory water monitoring; Know Your Well; groundwater literacy; Kazakhstan; Central Asia; practice-oriented learning



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1. Introduction

Kazakhstan's water-security challenges are increasingly connected not only with the physical availability of water, but also with the country's capacity to monitor, interpret, and manage environmental risks through education, research, and applied practice. Groundwater is especially important in this context. Globally, fresh high-quality groundwater supports drinking water supplies, agriculture, ecosystems, and climate resilience and is particularly important in arid and semi-arid regions where surface-water availability is

uneven or seasonally limited [1–3]. At the same time, groundwater often remains less visible than rivers, reservoirs, and other surface-water systems. Because it is hidden, spatially heterogeneous, and technically difficult to observe, groundwater depletion and contamination may develop faster than monitoring systems, institutions, and educational programs can respond [1–3].

These concerns are highly relevant for Kazakhstan. The country's water security is shaped by dependence on transboundary water flows, climatic variability, uneven territorial distribution of resources, aging infrastructure, and fragmented water-management arrangements [4–8]. In recent years, policy and development discussions have increasingly emphasized that water management in Kazakhstan cannot be treated as a narrow technical issue alone. It is also linked to climate adaptation, agricultural modernization, infrastructure renewal, digitalization, ecological resilience, and institutional coordination [4–10]. Groundwater occupies a significant but often underrepresented place within this broader water-security agenda.

Existing studies show that groundwater and drinking-water risks in Kazakhstan are real and regionally differentiated. Research has documented contamination pressures associated with industrial sites, petrochemical activity, nitrate pollution, agricultural land use, and local hydrogeological conditions [11–14]. At the same time, household-level studies show that official indicators of drinking-water access and quality do not always fully reflect local experiences of reliability, safety, and usability [7,15]. These findings suggest that Kazakhstan needs not only stronger formal monitoring systems, but also complementary approaches that can improve local water awareness, field-based skills, and site-specific interpretation.

The wider Central Asian context reinforces this need. Water governance in the region remains affected by fragmented institutions, uneven research capacity, limited science-policy integration, and difficulties in producing and circulating usable water-related information [8,16,17]. In such settings, the challenge is not simply the absence of data, but also the weak connections between public perception, data, education, field practice, and decision-making. Groundwater governance therefore depends partly on informational governance: who collects water-related information, how it is interpreted, and whether students, researchers, institutions, and local users can apply it in meaningful ways [17].

Participatory monitoring and citizen-science approaches offer one possible way to address this gap. International studies show that community-based and citizen-based monitoring can expand local observation, strengthen environmental awareness, and improve engagement when supported by clear protocols, training, and quality-control procedures [18–24]. In groundwater monitoring, such approaches are especially relevant because wells, springs, and shallow aquifers are often locally important but poorly understood outside formal expert systems [19–22]. However, participatory monitoring should not be viewed as a substitute for official monitoring. Its more realistic value lies in complementing formal systems by building practical skills, increasing local awareness, and creating additional channels for water-related learning and observation.

One participatory science model that combines many of these functions, and addresses public perception, is the Nebraska-based Know Your Well program. This model links student participation, field sampling, basic water-quality observation, laboratory comparison, and communication with well owners [25,26]. Its relevance lies in its dual character: it is both a monitoring-oriented and an educational model. Students are not only introduced to groundwater as a theoretical topic; they participate in a structured process of preparation, sampling, interpretation, and communication. This makes the model potentially useful for contexts where groundwater monitoring and groundwater education both require strengthening.

The educational dimension is especially important in addressing public perception. Groundwater remains difficult to teach because it is hidden, spatially complex, and often poorly understood by students and non-specialists [27–34]. Research on groundwater education shows that students may struggle with subsurface processes, conceptual models, spatial reasoning, and the connection between field observations and hydrogeological interpretation [28–32]. At the same time, field-based, experiential, and practice-oriented learning can improve student engagement, conceptual understanding, and the ability to connect theoretical knowledge with real environmental problems [35–39]. In Kazakhstan, this is particularly relevant because environmental science and water-related education need stronger links with field methods, laboratory analysis, and interdisciplinary problem-solving.

This article examines two related but distinct Kazakhstan-based case studies that address these issues from different angles. The first case study focuses on the 2022 Science with a Purpose (SWAP): Improving Environmental Science in Kazakhstani Universities project. This project involved development of environmental science short courses, curriculum evaluation, and applied training in areas such as water quality, air quality, remediation, sampling methods, and scientific communication. In this article, the SWAP project is used to examine whether students and faculty demonstrated receptiveness to practice-oriented environmental science education.

The second case study focuses on a 2025 pilot adapting elements of the Know Your Well (KYW) participatory science model in Kazakhstan. This case study examines how a participatory water education and localized observation framework was adapted through pre-field preparation, field activity, sample collection, participant feedback, and laboratory-supported interpretation. Unlike the first case study, the KYW pilot was not a curriculum-evaluation project. It was a field-based educational and complementary monitoring pilot designed to test whether the KYW logic could be operationalized in the Kazakhstani context.

The two case studies are connected analytically rather than causally, longitudinally, or through a shared participant population. Case Study 1 does not provide direct evidence of readiness for, or effectiveness of, the KYW model. Instead, it examines one dimension of environmental science capacity building: the extent to which participants in the SWAP project recognized the relevance of applied environmental topics, field methods, sampling, and curriculum integration. Case Study 2 examines a different dimension: whether the core functions of a participatory water-education model could be translated into a structured field-to-laboratory workflow in a Kazakhstani pilot setting.

The analytical complementarity of the cases therefore lies in their coverage of two distinct capacity-building dimensions: educational enabling conditions and operational implementation. The first concerns the perceived relevance of practice-oriented environmental science education within a defined project cohort. The second concerns the procedural feasibility and participant reception of an adapted participatory water-learning workflow. The findings are synthesized only at the interpretive stage and are not used to imply a causal relationship between the 2022 and 2025 initiatives.

Accordingly, the article addresses three research questions:

- (1) What patterns in the SWAP faculty and student survey responses indicate the perceived relevance and the limitations of the available evidence regarding receptiveness to practice-oriented environmental science education within the participating project cohort?
- (2) To what extent did the Kazakhstan-adapted KYW pilot preserve the core educational functions of the original model by linking pre-field preparation, structured field activity, sample handling, laboratory-supported interpretation, and participant reflection?

- (3) What complementary contributions and limitations emerge when the two cases are interpreted within a two-dimensional capacity-building framework comprising educational enabling conditions and operational implementation?

By addressing these questions, the article contributes pilot-level evidence on how short-course training and participatory water monitoring can support environmental science education and localized water awareness in data-scarce and institutionally fragmented settings. The study does not claim to provide nationally representative groundwater-quality data or large-scale evidence of monitoring effectiveness. Its contribution is more specific: it shows how two applied initiatives can be interpreted as complementary pathways for strengthening environmental science capacity in Kazakhstan.

2. Literature Review

2.1. *Water Security, Monitoring Gaps, and Environmental Science Capacity in Kazakhstan*

Groundwater is a strategic but often under-monitored component of water security. Famiglietti characterizes the global groundwater crisis as a hidden but critical dimension of climate and water insecurity, while Gleeson et al. show that the volume of modern groundwater available for active human use is much more limited than total groundwater storage suggests [1,2]. More recently, Jasechko et al. demonstrate that rapid groundwater-level declines are widespread across many aquifer systems globally [3]. Together, these studies show that groundwater management depends on distributed monitoring, timely interpretation, and stronger public and institutional understanding of subsurface water systems.

Kazakhstan reflects many of these challenges. Zhupankhan et al. and Karatayev et al. show that the country's water security is shaped by transboundary dependence, uneven territorial distribution of water resources, infrastructural limitations, and fragmented management arrangements [5,6]. Tussupova et al. further demonstrate that access to drinking water and sanitation remains uneven, especially in rural areas [7]. Groundwater is also affected by regionally specific risks. Radelyuk et al., Tleuova et al., and Sailaukhanuly et al. document contamination pressures related to industrial sites, petrochemical activity, nitrate pollution, agricultural land use, and local hydrogeological conditions [11–14]. Recent evidence from Adenova et al. further confirms that groundwater and soil quality in West Kazakhstan are vulnerable to salinity, oil- and gas-related contamination risks, and climate-related pressures [40].

In Central Asia more broadly, water governance remains constrained by weak institutional coordination, uneven research capacity, limited science–policy integration, and difficulties in producing and sharing usable water information. Abdullaev et al. connect these governance challenges directly with research, higher education, and science–policy interaction, while Schmidt et al. emphasize the importance of informational governance in groundwater management [16,17]. These findings point to a need for stronger links between environmental education, monitoring practice, and local interpretation. For Kazakhstan, this means that water security should not be approached only through infrastructure or regulation. It also requires investment in applied environmental science capacity, including field skills, laboratory interpretation, and practice-oriented training.

2.2. *Practice-Oriented Environmental Science Education and Short-Course Training*

Environmental science education is most effective when it connects theory with applied methods, field observation, laboratory work, and interdisciplinary problem-solving. Cherry argues that groundwater remains a “missing” component of environmental education despite its importance for water security [27]. Studies by White, Jimenez-Martinez, Dickerson et al., and Unterbruner et al. show that students often struggle with subsurface processes, spatial reasoning, and the connection between field observations and conceptual

models [28–31]. Field-based and experiential learning can help address these difficulties by improving engagement, practical confidence, and the ability to connect classroom knowledge with real environmental conditions [35–39].

Short-course training is one way to introduce such practice-oriented learning into higher education systems. This need is also supported by recent evidence from Kazakhstan’s water-sector education, where Skakova et al. identified a persistent policy-to-competence gap, strong student demand for practice-oriented learning, and reported constraints related to limited laboratory access and insufficient real-world professional experience [41]. Unlike full degree-program reform, short courses can be implemented more flexibly and can target specific capacity gaps, such as water-quality analysis, air-quality monitoring, remediation methods, sampling techniques, and scientific communication. The relevance of modular training is also reflected in international water-capacity initiatives, where online and short-course formats are used to support water-quality monitoring, quality assurance, river and lake monitoring, and groundwater assessment [42].

This is relevant for Kazakhstan because environmental science education is very young and still developing as an interdisciplinary and applied field. A short-course model can help universities connect existing disciplinary strengths in chemistry, geography, hydrogeology, ecology, and engineering with more problem-based environmental training. It is also relevant for air-quality education in Kazakhstan, where monitoring networks have expanded, but data coverage, calibration, quality assurance, and institutional capacity remain important challenges for effective air-quality management [43]. For the present study, this literature supports the interpretation of the SWAP project as a capacity-building case study rather than as a direct evaluation of the KYW model.

2.3. Participatory Monitoring, Citizen Science, and the Know Your Well (KYW) Model

Participatory monitoring and citizen science have become increasingly important in environmental governance. Conrad and Hilchey show that community-based environmental monitoring can expand local observation and strengthen public engagement, while Nath and Kirschke specifically emphasize the potential of citizen science for groundwater monitoring when projects are supported by clear protocols, training, and validation [18,19]. Other studies also show that citizen-generated water data can be useful, but only when quality assurance and institutional support are carefully addressed [20–24]. Evidence from the Flint water crisis further demonstrates that citizen-led water sampling can reveal serious drinking-water problems when sampling is organized through clear instructions, appropriate containers, and laboratory validation [44]. The more recent analytical-chemistry literature also shows that citizen science is becoming more feasible through portable tools and simplified procedures, although reliability still depends on training, validation, and careful interpretation [45].

However, participatory monitoring should not be treated as a substitute for official monitoring systems. Its value is more specific. It can complement formal monitoring by building practical skills, increasing local awareness, and creating additional channels for observation and learning. This distinction is important for pilot studies because small-scale participatory projects cannot demonstrate national monitoring impact, but they can show whether a model is educationally feasible and procedurally credible.

The Nebraska-based KYW model is one example of participatory science. Earlier project descriptions presented KYW as a groundwater-quality initiative designed to inform both students and well owners through sampling, testing, and communication [46]. Olson et al. [25] later evaluated KYW as a youth-led citizen-science model for improving domestic well-water monitoring, while the University of Nebraska–Lincoln project materials show that the program combines student participation, field sampling, water-quality testing,

laboratory comparison, and communication with well owners [26]. Its main strength is that it links monitoring and education in a single workflow.

From an educational perspective, participation alone is not an adequate outcome. The relevant learning process also includes procedural competence, interpretation of results, and communication of findings. The evaluation of the Nebraska KYW model [25], together with international field-based and community-university water-education studies [37,38], indicates that structured participation can connect local sampling with scientific understanding. At the same time, these outcomes depend on instructional design and should not be inferred from participation counts or satisfaction responses alone.

Recent international evidence further supports this distinction. A systematic review of empirical community and citizen science research found positive outcomes related to science-content knowledge, scientific inquiry skills, environmental attitudes, self-efficacy, stewardship, and community connectedness, although the strength of these outcomes depended on project design and evaluation quality [47]. An assessment of 57 citizen-science projects in South Africa showed that educational goals were often secondary to scientific data collection and that learning outcomes were more frequently evaluated through informal feedback than through systematic assessment [48]. Similarly, a curriculum-based environmental citizen-science project in Canada found that structured participation supported the development of science competencies, while outcomes such as science identity and understanding of the nature of science required more explicit instructional design [49]. Together, these studies reinforce the need to distinguish participant satisfaction and perceived applicability from directly measured learning outcomes.

For Kazakhstan, the KYW model is useful not because it can be directly copied from Nebraska, but because its logic can be adapted. The Kazakhstani context requires attention to local institutional settings, available laboratory capacity, student training needs, language accessibility, and field logistics. Therefore, the adaptation of KYW should be understood as a context-sensitive pilot rather than a simple transfer of an existing program.

2.4. Research Gap and Analytical Position of This Study

The reviewed literature establishes four key points. First, groundwater is globally important but often under-monitored and poorly understood outside expert systems [1–3]. Second, Kazakhstan and Central Asia face water-security challenges linked to transboundary dependence, fragmented governance, uneven monitoring capacity, and local water-quality risks [4–8,11–17,40]. Third, environmental science education requires stronger links with applied methods, field practice, and laboratory interpretation [27–39]. Fourth, participatory monitoring and citizen science can complement formal systems when they are supported by clear protocols, training, validation, and laboratory-supported interpretation [18–26,44–46].

What remains less developed is evidence from Kazakhstan showing how these approaches can be implemented in practice. In particular, there is limited analysis of how short-course environmental science training and participatory water monitoring can function as complementary pathways for capacity building. This article addresses that gap through two related but distinct case studies. The first examines the 2022 SWAP environmental science short-course and curriculum evaluation project. The second examines a small pilot adaptation of the KYW participatory science model. Together, the two case studies are used to assess how practice-oriented environmental science education and participatory water monitoring can support groundwater literacy, localized water awareness, and applied environmental capacity in Kazakhstan.

3. Materials and Methods

3.1. Study Design

This study used an exploratory, comparative two-case-study design. The cases were not components of a single intervention and were not linked through a common participant population, longitudinal follow-up, or a shared outcome measure. They were selected because they addressed two analytically distinct dimensions of practice-oriented environmental science capacity building in Kazakhstan.

The first dimension, termed educational enabling conditions, concerns how participants within the 2022 SWAP project perceived the relevance of applied environmental science topics, curriculum integration, sampling methods, and practice-oriented training. The second dimension, termed operational implementation, concerns whether the core logic of the KYW model could be translated into a structured pre-field, field, and laboratory/classroom educational workflow during the 2025 pilot.

The cases were analyzed independently using their respective evidence sources and were compared only during the cross-case synthesis. Case Study 1 was not used to infer the feasibility or effectiveness of Case Study 2. Likewise, Case Study 2 was not treated as an outcome of the SWAP project. The cross-case analysis instead examined whether the findings provided complementary insights into the educational and operational dimensions of environmental science capacity building. The alignment between the research questions, evidence sources, analytical procedures, and corresponding results sections is summarized in Table 1.

Table 1. Alignment of research questions, evidence, analytical procedures, and results sections.

Research Question	Primary Evidence	Analytical Procedure	Corresponding Results
RQ1	Faculty survey; student pre-course and post-course surveys; SWAP project documentation	Descriptive analysis of response distributions, absolute counts, response rates, and documented limitations	Section 4.1
RQ2	KYW instructional materials; field forms; sample-handling procedures; participant feedback; two illustrative laboratory protocols	Procedural workflow analysis and descriptive analysis of participant feedback	Sections 4.2–4.4
RQ3	Independently analyzed findings from both cases	Cross-case comparison using the two-dimensional framework of educational enabling conditions and operational implementation	Sections 4.5 and 5

3.2. Case Study 1: 2022 Environmental Science Short-Course and Curriculum Evaluation Project

The first case study was implemented through cooperation between the University of Nebraska–Lincoln and three Kazakhstani partner universities. The project aimed to strengthen environmental science capacity by modernizing graduate-level environmental science curricula, enhancing teaching capacity, and introducing short courses in water quality, air quality, remediation methods, sampling techniques, and scientific communication. The SWAP included M.Kh. Dulaty Taraz State University, Innovative Eurasian University, and Al-Farabi Kazakh National University. Its educational activities included short-course training in water quality and treatment, air quality monitoring and treatment, and research methodology/scientific writing. The short courses were designed as applied learning activities combining lectures, field or laboratory demonstrations, sampling methods, analytical techniques, and student research communication.

The data used from this case study included faculty survey responses, student pre-course and post-course survey responses, short-course materials, project reports, and summary figures from the final project documentation. The SWAP survey data were used to assess project-level indications of educational receptiveness to practice-oriented environmental science learning. They were not used as direct evidence of readiness for KYW as a named model.

3.3. Case Study 2: 2025 Know Your Well Adaptation Pilot

The second case study focused on the Kazakhstan adaptation of the Nebraska-based KYW model. The original KYW model combines student participation, water sampling, field measurements, laboratory comparison, and communication of results [25,26]. In Kazakhstan, this logic was adapted for higher education and workshop-based training rather than directly replicated as a community domestic-well program.

The 2025 pilot was reconstructed from instructional workbooks, field forms, sample-labeling instructions, workshop materials, participant feedback charts, and two laboratory water-analysis protocols. The adapted model was organized into three main stages: pre-field preparation, field activity, and classroom/laboratory interpretation. This structure was used to assess whether the KYW logic could be translated into a feasible educational and complementary monitoring workflow in Kazakhstan. The analytical distinctions between the two case studies are summarized in Table 2.

Table 2. Analytical distinction between the two case studies.

Component	Case Study 1	Case Study 2
Year	2022 (SWAP)	2025 (KYW)
Main focus	Environmental science education and curriculum capacity	Participatory water education and localized observation
Main project frame	Science with a Purpose short courses	Know Your Well adaptation
Main evidence	Faculty and student surveys, short-course materials, project report	Instructional workbooks, field forms, sample-handling procedures, participant survey feedback, workshop documentation, and two illustrative laboratory water-analysis protocols
Main outcome assessed	Project-level indications of the perceived relevance of applied environmental science training	Procedural feasibility and participant reception of an adapted field-to-laboratory water-education workflow
Interpretation	Educational enabling-conditions case; not evidence of national or institutional readiness for KYW	Operational implementation case; not an evaluation of long-term learning or monitoring effectiveness

The instructional workbooks, field forms, sample-handling materials, workshop documentation, and laboratory protocols were treated as project documentation for reconstructing the pilot workflow. Participant feedback was analyzed separately and descriptively as a small pilot dataset.

3.4. Participants and Survey Data

For Case Study 1, the faculty survey included 25 invited faculty members, of whom 22 completed the questionnaire, giving a response rate of 88.0%. Faculty participants were involved in curriculum evaluation and environmental science course review. The student survey included 18 invited participants. Fourteen students completed the pre-

course questionnaire, corresponding to a response rate of 77.8%, and ten completed the post-course questionnaire, corresponding to 55.6% of the original invited student group.

Because the number of participants was modest and the post-course student survey did not include all pre-course respondents, the student data are interpreted as indicative rather than representative. The student component is therefore treated as a repeated educational survey with partial continuity, not as a fully balanced panel.

For Case Study 2, the participant-feedback dataset comprised 15 completed responses. The available pilot documentation does not provide a complete census-style roster of all individuals involved in the broader field and training activities. Accordingly, the feedback results are interpreted as evidence from a small pilot educational cohort rather than from a statistically sampled population. The Case Study 1 survey samples and response rates are summarized in Table 3.

Table 3. Survey sample and response rates for Case Study 1.

Survey Component	Invited	Completed	Response Rate
Faculty survey	25	22	88.0%
Student pre-course survey	18	14	77.8%
Student post-course survey	18	10	55.6%

3.5. Data Collection Timeline

The two case studies belong to different project periods. For Case Study 1, the faculty survey was distributed on 17 May 2022, the student pre-course survey on 23 May 2022, and the student post-course survey on 19 July 2022. Follow-up reminders were sent through the Qualtrics online survey platform (Qualtrics, Provo, UT, USA; web-based platform, version not applicable). The faculty survey closed on 2 August 2022, the student pre-course survey on 6 July 2022, and the post-course survey on 20 September 2022.

For Case Study 2, the available KYW workshop materials document the implementation activities conducted in Koksū on 3 July 2025. Two laboratory water-analysis protocols used in the article are dated 12 November 2025.

This chronological distinction is important. The SWAP survey data were used to examine project-level indications of educational receptiveness to applied environmental science learning. The 2025 data were used to examine the operational feasibility of an adapted KYW-style field-to-laboratory educational workflow. The two cases were interpreted together only at the synthesis stage.

3.6. Survey Instrument Development, Administration, and Analysis

The SWAP survey instruments were developed as project-specific evaluation tools by the project researchers in cooperation with the Bureau of Sociological Research (BOSR) at the University of Nebraska–Lincoln and members of the international project team. BOSR supported questionnaire development, programmed and administered the web surveys using the Qualtrics platform described above, distributed invitations and follow-up reminders, and processed the resulting data using IBM SPSS Statistics (IBM Corp., Armonk, NY, USA; the software version was not recorded in the archived project documentation). The questionnaires were aligned with the objectives of the curriculum-evaluation and short-course activities rather than designed as standardized psychometric scales. The faculty questionnaire addressed the perceived compatibility of existing courses with environmental science, the relevance of current curricula, the potential for syllabus modification, and willingness to participate in further curriculum discussion. The student pre-course questionnaire assessed perceptions of environmental science, the relevance of the proposed short-course subjects, and the importance of applied methods and equipment. The student

post-course questionnaire assessed perceived changes in understanding and the usefulness of the completed training activities.

The instruments were developed specifically for the SWAP project. The available project documentation does not indicate that a previously standardized questionnaire was used or that a separate large-sample psychometric validation or pilot-testing study was undertaken. Accordingly, the instruments are not described in this article as validated measurement scales. Internal-consistency statistics such as Cronbach's alpha were not calculated because the questionnaire items were not designed to form a composite scale measuring a single underlying construct. Instead, the items addressed substantively different dimensions, including curriculum relevance, perceived usefulness, the importance of practical methods, and willingness to participate in curriculum development. The responses were therefore analyzed at the individual-item level.

The student pre-course and post-course responses could not be reliably matched at the individual level. Consequently, the student surveys were treated as repeated project surveys with partial participant continuity rather than as paired longitudinal observations. Survey responses were summarized using absolute frequencies and percentages calculated from the number of valid responses to each item.

No inferential comparison between the student pre-course and post-course surveys was performed. Paired procedures, including a paired-samples test or Wilcoxon signed-rank test, would not have been methodologically justified because individual responses could not be matched across the two survey waves. The small sample sizes, attrition in the post-course survey, item-level missing responses, and project-specific participant selection also limited the value of unpaired statistical comparisons and effect-size estimates. Confidence intervals were considered but were not used to imply population-level precision because the respondents constituted small project cohorts rather than probability samples. To improve transparency, the revised Section 4 reports absolute counts, percentages, and item-specific sample sizes wherever these data are available.

The analysis was therefore descriptive and exploratory. The results were used to identify project-level patterns in participant perceptions and were not used to estimate population parameters, demonstrate intervention effects, or generalize to Kazakhstan higher education as a whole.

3.7. Ethical Considerations

The SWAP surveys and the KYW participant-feedback activities were originally conducted as educational program-evaluation and training-feedback procedures. The present study uses only aggregated, non-identifiable project data. No names, contact details, sensitive personal information, individual-level records, or other information that could reasonably identify participants are included in the manuscript.

The study was reviewed and approved by the Ethics Committee for Research Evaluation of Kazakh-British Technical University (Protocol No. 14, approved on 15 July 2026). The Committee confirmed that the study involved voluntary questionnaires and did not include medical, clinical, or experimental interventions.

3.8. Analysis of the KYW Adaptation Workflow

The 2025 KYW pilot materials were analyzed to reconstruct the operational logic of the adapted model. The analysis focused on three stages.

First, the pre-field stage included background preparation, introduction to groundwater and water-quality indicators, well or site information, sample-labeling instructions, and review of field procedures.

Second, the field stage included site observation, geolocation, visual assessment of environmental risk factors, in situ measurements, sample collection, labeling, and preservation.

Third, the classroom/laboratory stage included interpretation of field observations, review of laboratory results, discussion of water-quality indicators, and participant feedback.

This workflow analysis was used to determine whether the adapted model preserved the core KYW logic of linking preparation, field activity, laboratory interpretation, and educational reflection, as illustrated in Figure 1.

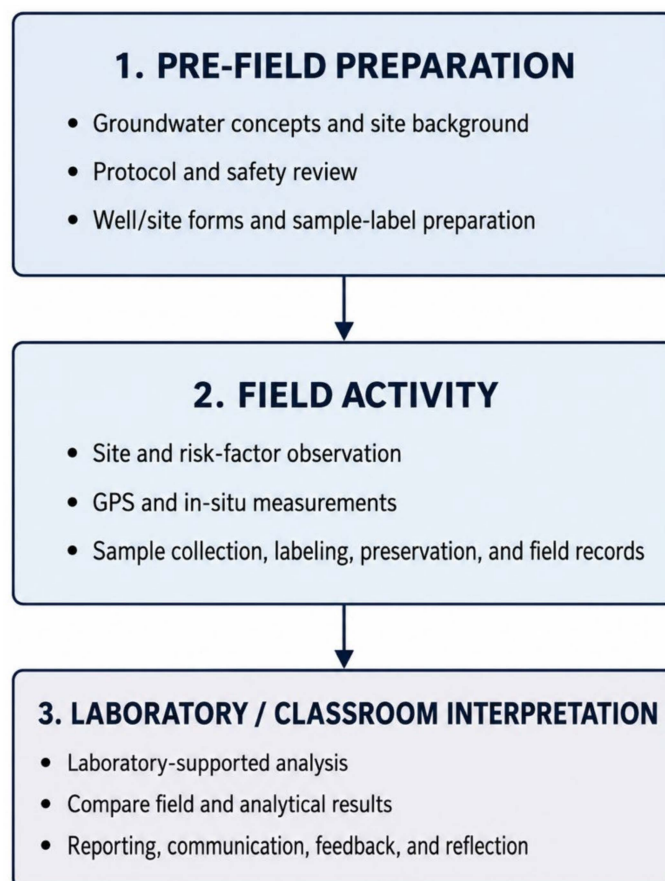


Figure 1. Kazakhstan-adapted KYW field-to-laboratory educational workflow reconstructed from the 2025 instructional workbook, field forms, sample-handling procedures, and workshop materials.

3.9. Laboratory Water Analysis

The hydrochemical component of Case Study 2 was based on two laboratory protocols dated 12 November 2025. The analyzed samples included one surface-water sample from the Kazachka River and one shallow-well sample. The measured parameters included pH, mineralization, dry residue, total hardness, carbonate hardness, silica, sodium, potassium, calcium, magnesium, bicarbonate, chloride, sulfate, nitrate, and fluoride. The archived laboratory protocols did not specify the manufacturers or model numbers of the analytical instruments or the suppliers of the reagents used for these measurements.

These two samples were not treated as a groundwater-quality dataset for Kazakhstan. They were used only as illustrative evidence showing how a field-based educational model can be connected to laboratory-supported interpretation. The comparison focused on basic differences between the two samples, especially pH, mineralization, hardness, bicarbonate, calcium, magnesium, nitrate, and fluoride. No inferential statistical analysis was conducted because the number of samples was too small for broader hydrochemical conclusions.

3.10. Methodological Limitations

Several limitations should be noted. First, the study combines two separate case studies rather than one unified intervention dataset. The 2022 survey evidence and the 2025 KYW pilot materials were produced in different project contexts and were therefore interpreted separately before being compared at the synthesis stage.

Second, the survey samples were modest, and the student post-course survey included fewer respondents than the pre-course survey. The survey findings are therefore indicative of perceived relevance of practice-oriented environmental science education among the participating SWAP respondents within the project context, not representative of all Kazakhstani universities.

The survey instruments were developed for project-evaluation purposes and were not standardized psychometric scales. No separate construct-validation study, large-sample pilot test, or internal-consistency assessment was conducted. The findings should therefore be interpreted as responses to specific project questions rather than as validated measurements of a unified construct such as educational readiness, competence, or learning gain.

The survey findings may also be affected by self-selection, non-response, and attrition bias. Participants who completed the surveys, particularly the post-course questionnaire, may have been more engaged with or more positively oriented towards the training than those who did not respond. Because the pre-course and post-course records could not be matched reliably at the individual level, changes in the distribution of responses cannot be attributed to within-person learning or attitude change. Positive response patterns may therefore overstate the perceptions of the full invited participant group.

Third, the 2025 KYW pilot materials document feasibility, procedural structure, and participant reception more strongly than long-term monitoring outcomes. The pilot can support claims about educational and operational feasibility but not claims about national groundwater-monitoring impact.

Fourth, the laboratory evidence is limited to two water samples. These results can illustrate field-to-laboratory interpretation, but they cannot support conclusions about regional groundwater quality patterns.

Accordingly, the study should be read as a pilot-level analysis of two complementary capacity-building pathways: environmental science short-course training and participatory water monitoring education.

4. Results

4.1. Case Study 1: Educational Receptiveness to Applied Environmental Science Training

The first case study examined the SWAP environmental science short-course and curriculum evaluation project. The results are presented as evidence of project-level indications of educational receptiveness to applied environmental science training, rather than as direct evidence of readiness for the Know Your Well model. This distinction is important because the SWAP project had its own objectives, participants, and outcomes. It focused on curriculum evaluation, interdisciplinary environmental science training, and short courses in water quality, air quality, remediation methods, sampling techniques, and scientific communication.

The faculty survey achieved an overall response rate of 88.0%, with 22 of the 25 invited faculty members completing the questionnaire. The survey results suggest that many faculty members viewed their existing courses as potentially compatible with environmental science education. Before reading a formal definition of environmental science, 58.8% of respondents indicated that some of their courses could be included in an environmental science curriculum, while 35.3% indicated that none of their courses could be included. After the definition was provided, the proportion of respondents who considered at least

some of their courses compatible with environmental science increased, and the share rejecting such compatibility disappeared.

A similar pattern was observed in the perceived relevance of existing courses. Before reading the definition, 43.8% of respondents considered their courses very relevant to environmental science. After reading the definition, this figure increased to 58.8%. This result suggests that some faculty members may not initially frame their teaching as environmental science but may recognize stronger relevance once the interdisciplinary scope of the field is clarified.

Faculty responses also indicated openness to curriculum modification. In both the pre-definition and post-definition responses, 58.8% of respondents stated that the curriculum of some of their courses could be modified to incorporate more environmental science aspects. Among the 17 faculty members who provided a valid response to this item, 14 (82.4%) expressed willingness to further discuss their course syllabi, whereas 3 (17.6%) did not, as shown in Figure 2. These responses indicate openness among the participating faculty to further curriculum discussion and applied environmental science integration.

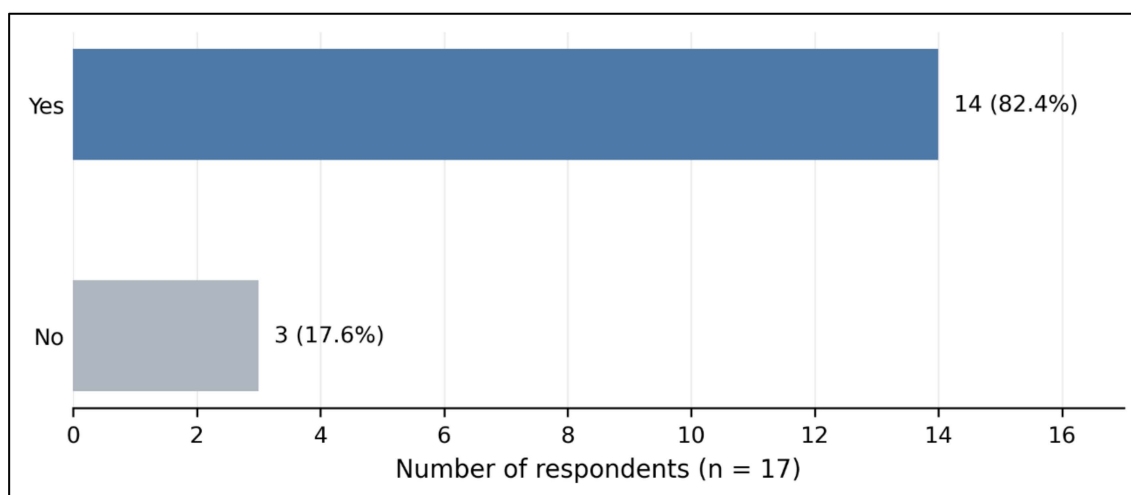


Figure 2. Faculty willingness to further discuss course syllabi in the future ($n = 17$).

The student survey results also indicated strong interest in applied environmental science learning. Fourteen of the eighteen invited students completed the pre-course survey, while ten completed the post-course survey. Although the sample was modest and the post-course group was smaller than the pre-course group, the responses provide useful pilot-level evidence on student perceptions of the short-course format.

Students generally rated the applied short-course subjects positively. For Water Quality and Treatment, 11 of 14 respondents (78.6%) selected “very relevant,” while 3 of 14 (21.4%) selected “relevant.” For Air Quality, 11 of 14 respondents (78.6%) selected “very relevant,” 2 of 14 (14.3%) selected “relevant,” and 1 of 14 (7.1%) selected “a little relevant.” Scientific Writing received more varied responses: 6 of 14 respondents (42.9%) selected “very relevant,” 7 of 14 (50.0%) selected “relevant,” and 1 of 14 (7.1%) selected “a little relevant.” These distributions, shown in Figure 3, indicate positive perceptions of the applied water- and air-related topics within the participating student group.

The post-course survey further indicated that the short courses influenced how students understood environmental science. Nine of the ten post-course respondents provided a valid answer to the item concerning changes in their understanding of environmental science. Of these nine respondents, five (55.6%) stated that their definition of environmental science had changed “a lot,” while two (22.2%) reported no change. Because the surveys were not matched at the individual level and the item had only nine valid responses, this

result should not be interpreted as a direct measure of learning gain. It indicates only that several post-course respondents perceived a substantial change in their understanding.

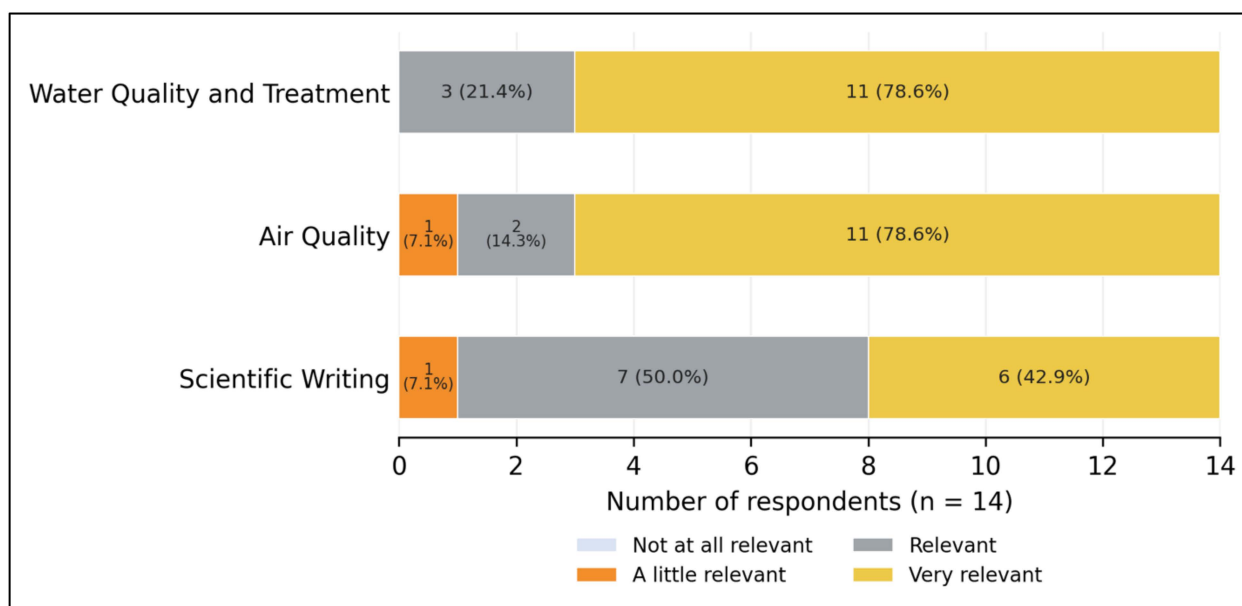


Figure 3. Student-rated relevance of short-course subjects in an environmental science graduate program ($n = 14$).

Another important result concerns sampling methods and equipment. Seven students provided a valid response to the pre-course item concerning sampling methods and equipment. All seven respondents (100%) rated sampling methods and equipment as “very important” for solving environmental science problems. As shown in Figure 4, no responses were recorded in the other categories. Given the small item-specific sample, this finding should be interpreted as a unanimous response among seven participating students rather than as evidence of a broader student population trend.

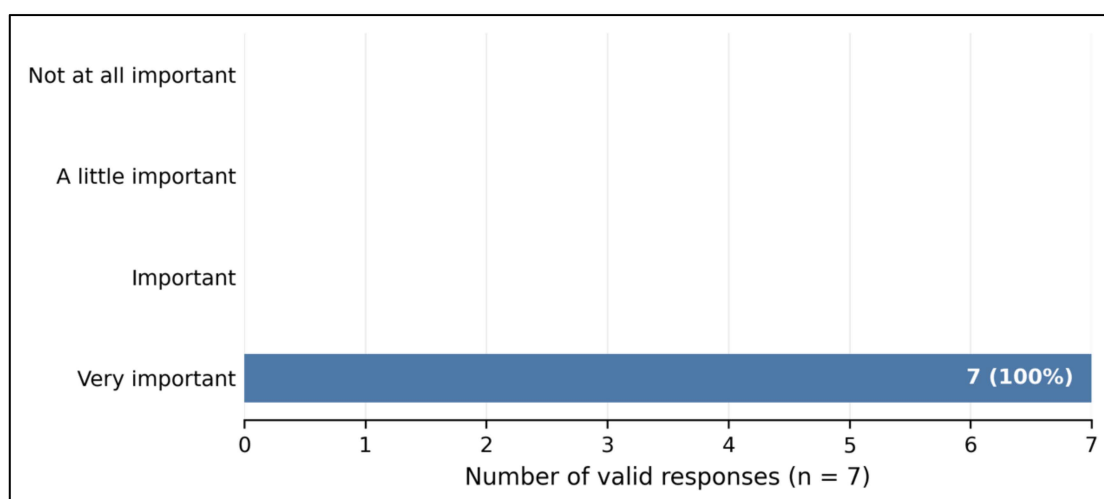


Figure 4. Importance of sampling methods and equipment for solving environmental science problems (pre-course student survey; $n = 7$).

Overall, Case Study 1 provided preliminary, project-specific evidence of positive participant perceptions of applied environmental science training. Faculty responses showed openness to curriculum discussion and possible environmental science integration, while student responses showed strong interest in applied subjects, especially water quality,

air quality, and sampling-related skills. These results do not demonstrate readiness for KYW as a specific model. Instead, they indicate that practice-oriented environmental science education was perceived as relevant by participating faculty and students within the SWAP project context.

4.2. Case Study 2: Operationalization of the Kazakhstan-Adapted KYW Participatory Science Model

The second case study examined the pilot adaptation of the Know Your Well model. Unlike the SWAP short-course and curriculum evaluation project, this case study focused specifically on participatory water education, localized observation, sample collection, and laboratory-supported interpretation. The available workbook, field forms, and workshop materials show that the adapted KYW model was organized as a structured educational workflow rather than as a single sampling activity.

The Kazakhstan-adapted model followed three main stages: pre-field preparation, field activity, and classroom/laboratory interpretation. This structure preserved the central logic of the original KYW model while adapting it to a higher-education and workshop-based setting in Kazakhstan. The aim was not simply to introduce students to water sampling but to guide them through a full sequence of site understanding, protocol preparation, field observation, sample collection, basic water-quality assessment, and interpretation. The three-stage structure of the adapted workflow is illustrated in Figure 1.

The pre-field stage focused on conceptual and procedural preparation. Students were introduced to the KYW program, its adaptation to Kazakhstan, and the main tasks expected from participants. The theoretical component covered the water cycle, the role of groundwater in Kazakhstan, basic well structure, regional water sources, and key water-quality indicators such as hardness, pH, iron content, and mineralization. The practical component introduced students to sample labeling, protocol completion, and the step-by-step sampling algorithm before actual fieldwork.

A central element of the pre-field stage was the collection of background information about the selected well or sampling site. Students were required to record information on the well user, installation year, odor or taste complaints, history of drying, recent maintenance, land-use changes around the well, number of users, nearby manure or pesticide application, GPS coordinates, total depth, water level, aquifer type, aquifer class, drilling method, and casing material. These variables helped connect water-quality sampling with site context, infrastructure, land use, and human dependence on the water source.

The field stage focused on supervised observation, measurement, and sample collection. Students described the site setting, recorded GPS coordinates, observed the condition of the wellhead, identified nearby surface water, cropland, septic systems, pasture or barnyard areas, and noted topographic conditions around the well. They also collected water samples, labeled containers, and conducted simple on-site tests or rapid field analyses. The field materials included pH measurement using litmus paper or a portable pH meter, hardness testing, and iron-content testing using a kit or drop method. Required field equipment included field journals, protocols, test tubes, bottles, markers, pH meters or indicator strips, test kits, and a portable cooler or thermal bag for sample storage. The archived instructional materials identified these items only as generic equipment categories and did not specify commercial manufacturers, brands, or model numbers.

The classroom/laboratory stage focused on interpretation, presentation, and feedback. Students were expected to demonstrate understanding of the full KYW algorithm and present well passports, field protocols, water-analysis protocols, field photos, and basic interpretations of water-quality results. They also discussed communication with well owners and reflected on practical difficulties encountered during the work. This final stage

was important because it moved the activity beyond sample collection and into analytical reflection, communication, and evaluation.

Overall, the 2025 materials show that the KYW adaptation was operationalized as a complete field-to-laboratory learning cycle. The pilot did not present water sampling only as a technical procedure. Instead, it combined site research, field observation, sample handling, basic analysis, interpretation, presentation, and feedback. This supports the interpretation of the Kazakhstan-adapted KYW model as a practice-oriented educational and complementary monitoring framework.

4.3. Participant Feedback from the 2025 KYW Pilot

Participant feedback from the 2025 KYW pilot provides preliminary evidence on how the adapted model was received by trainees. Because the available cohort was small ($N = 15$), the results should be interpreted as indicators of pilot reception rather than as generalizable evidence of training effectiveness.

The feedback results were positive. When asked whether the training content met their expectations, 14 of 15 participants (93.3%) answered positively, while 1 of 15 (6.7%) indicated that it met expectations only partially. No negative responses were recorded. This indicates that the pilot content was generally aligned with participant expectations within the participating cohort.

A second feedback item measured whether participants believed they could apply the acquired skills. As shown in Table 4, 9 of 15 participants (60.0%) reported that they would be able to apply the new skills fully, 5 of 15 (33.3%) stated that they could apply them partially, and 1 of 15 (6.7%) indicated difficulty applying them at the present stage. This result is important because it moves beyond general satisfaction and addresses the perceived practical transferability of the training.

Table 4. Summary of participant feedback on the 2025 KYW pilot training.

Indicator	Category	<i>n</i>	%
Training content met expectations	Yes	14	93.3
	Partially	1	6.7
	No	0	0.0
Applicability of new skills	Fully applicable	9	60.0
	Partially applicable	5	33.3
	Difficult to apply for now	1	6.7

As shown in Figure 5, the project documentation also reported aggregate evaluation scores for five dimensions of the training: overall satisfaction (94%), quality of organization (92%), format effectiveness (88%), applicability of knowledge (85%), and correspondence with expectations (90%). The available project documentation did not retain the individual-level response matrix or a complete description of the original score-normalization procedure. Therefore, the values are presented as project-reported aggregate evaluation scores rather than as simple proportions of positive responses.

These aggregate scores are consistent with the generally positive response distributions presented in Table 4. However, they should not be interpreted as participant proportions or used for inferential analysis because the original item-level scoring procedure could not be reconstructed fully from the archived project documentation.

Taken together, the 2025 feedback results indicate that the adapted KYW model was positively received at pilot level. The findings do not demonstrate long-term learning outcomes or large-scale implementation effectiveness. However, they suggest that the model was understandable, practically relevant, and perceived as applicable by most participants. This supports the interpretation of the 2025 KYW pilot as a feasible field-based

educational workflow for localized water awareness and applied water-quality learning in Kazakhstan.

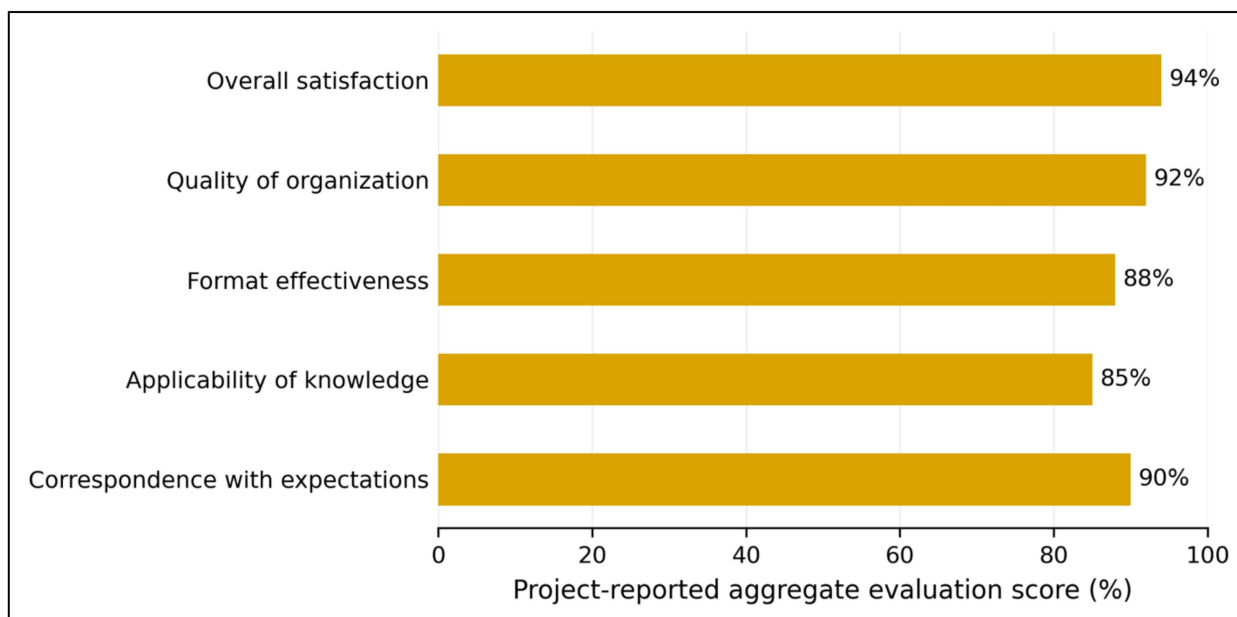


Figure 5. Aggregate participant-evaluation scores reported for the 2025 KYW pilot training. The values summarize five feedback dimensions derived from the project questionnaire ($N = 15$).

4.4. Educational Illustration of the Field-to-Laboratory Analytical Workflow

The laboratory component of the 2025 KYW pilot was used to demonstrate how field-based water education can be connected with laboratory-supported interpretation. Two water samples were analyzed: one surface-water sample from the Kazachka River and one shallow-well sample. The results are presented in Table 5. These data are not used to infer regional groundwater-quality patterns. Their purpose is to illustrate how students can move from field sampling and observation to basic hydrochemical comparison.

Table 5. Educational illustration of laboratory reporting using two water samples.

Parameter	Sample 1: Kazachka River	Sample 2: Shallow Well
pH	7.41	7.20
Mineralization (mg/L)	429	614
Dry residue (mg/L)	306	406
Total hardness	4.15	6.15
Carbonate hardness	2.90	5.30
SiO ₂ (mg/L)	7.6	12.9
Na (mg/L)	35.3	35.5
K (mg/L)	2.8	4.0
Ca (mg/L)	49.0	74.1
Mg (mg/L)	20.7	29.8
HCO ₃ (mg/L)	177.0	323.4
Cl (mg/L)	10.6	10.6
SO ₄ (mg/L)	118.1	120.7
NO ₃ (mg/L)	6.9	1.0
F (mg/L)	1.22	1.53

As shown in Table 5, both samples had near-neutral pH values: 7.41 for the Kazachka River sample and 7.20 for the shallow-well sample. The shallow-well sample had higher measured values for mineralization, dry residue, total hardness, carbonate hardness, silica,

calcium, magnesium, bicarbonate, potassium, and fluoride. The Kazachka River sample had a higher nitrate concentration, at 6.9 mg/L compared with 1.0 mg/L in the shallow-well sample. Sodium and chloride concentrations were nearly identical, while sulfate concentrations were also similar.

These observations are limited to a descriptive comparison of the two laboratory protocols. Because the exercise included only one sample from each source type, without replication or repeated sampling, the results cannot support conclusions about hydrogeochemical processes, contaminant sources, water–rock interaction, temporal variability, or regional water-quality patterns.

The value of the comparison is educational rather than hydrogeochemical. It demonstrates how participants can move from field sampling and sample labeling to laboratory reporting and cautious comparison of measured parameters. The exercise also provides an opportunity to distinguish between direct analytical observations and environmental interpretations that would require a larger, replicated dataset. Accordingly, Table 5 should be read solely as an illustration of the field-to-laboratory learning sequence within the adapted KYW workflow.

4.5. Cross-Case Synthesis of Results

Taken together, the two case studies show different but complementary pathways for strengthening environmental science capacity and localized water awareness in Kazakhstan.

Case Study 1 showed that the responding faculty and students generally reported positive perceptions of practice-oriented environmental science training. Faculty responses indicated openness to curriculum discussion and possible environmental science integration. Student responses showed strong interest in applied short-course subjects, especially Water Quality and Treatment and Air Quality, and confirmed the perceived importance of sampling methods and equipment. These findings suggest that practice-oriented environmental science training had institutional and student-level relevance in the 2022 project context.

Case Study 2, based on a KYW participatory science pilot, showed that a participatory water education model could be operationalized as a structured field-to-laboratory workflow. The adapted model included pre-field preparation, field observation, sample collection, basic express testing, laboratory-supported interpretation, presentation, and participant feedback. The pilot feedback was positive: most participants reported that the training met their expectations, and most considered the acquired skills fully or partially applicable.

The two case studies should not be interpreted as one continuous intervention. The 2022 project did not directly test the KYW model, and the 2025 pilot did not evaluate a full environmental science curriculum. Instead, the cases address different parts of the same broader capacity-building problem. The first case demonstrates project-level indications of educational receptiveness to applied environmental science training. The second case demonstrates the feasibility of adapting a participatory water-monitoring model into a practical educational workflow.

The results therefore support a cautious but meaningful conclusion. Short-course training and participatory water monitoring can function as complementary approaches for building environmental science capacity in Kazakhstan. The evidence does not show national representativeness, long-term learning outcomes, or large-scale groundwater-monitoring impact. However, it does provide pilot-level evidence that applied environmental science education and KYW-style field learning can help connect classroom instruction, field methods, laboratory interpretation, and localized water awareness.

5. Discussion

The results show that the two case studies addressed different but connected aspects of environmental science capacity building in Kazakhstan. The SWAP case provided project-level indications that participating respondents perceived practice-oriented environmental science training as relevant, whereas the KYW pilot demonstrated the feasibility of adapting a participatory water-education model into a structured field-to-laboratory workflow. These findings should not be interpreted as evidence from one continuous intervention. Rather, they show how two separate initiatives can contribute to the same broader goal: strengthening practice-oriented environmental science education and localized water awareness.

5.1. Case Study 1: Environmental Science Training as Capacity Building

The first case study supports the argument that applied environmental science training can play a meaningful role in Kazakhstan's water and environmental education context. Faculty responses showed openness to curriculum discussion and possible integration of environmental science content, while student responses showed strong interest in applied short-course subjects, especially water quality, air quality, sampling methods, and equipment. These findings are consistent with the broader literature showing that water and groundwater education require stronger links between theoretical instruction, field practice, laboratory analysis, and interdisciplinary problem-solving [27–39].

The importance of this result lies not only in positive survey responses but in what they reveal about educational conditions. The SWAP project did not test KYW directly, and it should not be presented as evidence of KYW effectiveness. Its contribution is different: it shows that the responding students and faculty generally valued applied, practice-oriented environmental science training within the SWAP project context. This is important because participatory water monitoring models require more than technical protocols. They also require educational environments in which field methods, sampling, and laboratory interpretation are valued as part of learning.

This interpretation is also supported by recent evidence on Kazakhstan's water-sector education. Skakova et al. [41] identify a policy-to-competence gap in Kazakhstan's water sector, including strong student demand for practice-oriented learning and reported limitations in laboratory access and real-world professional experience. In this sense, the SWAP short-course can be understood as one practical response to a wider educational challenge: the need to move from mainly theoretical environmental instruction toward more applied and competence-oriented formats.

5.2. Case Study 2: KYW Adaptation as a Field-to-Laboratory Learning Model

The second case study shows that the KYW model can be adapted to Kazakhstan as a pilot educational workflow. The materials demonstrate that the model was not limited to collecting water samples. It included pre-field preparation, site background research, field observation, sample labeling, express testing, laboratory interpretation, presentation, and participant feedback. This full sequence is important because participatory monitoring is only credible when participants understand both the procedure and the meaning of the data they help produce [18–22].

The participant feedback suggests that the adapted model was understandable and practically relevant for the pilot cohort. Most participants reported that the training met their expectations, and most considered the acquired skills fully or partially applicable. These results do not prove long-term learning outcomes, but they do support pilot-level feasibility. For an early-stage adaptation, this is an appropriate and realistic outcome. The main value of the pilot is therefore not that it generated a large water-quality dataset but that

it tested whether a structured water-monitoring education model could be implemented in a Kazakhstani training setting.

The two laboratory protocols provided a limited demonstration of how field sampling can be linked to laboratory reporting. Because only one river sample and one shallow-well sample were available, the comparison was not used to infer hydrogeochemical processes, contaminant sources, or source-specific water-quality patterns. Its value was educational: participants could practice reading analytical results, comparing measured parameters, and distinguishing descriptive observations from environmental interpretations that would require replicated sampling. This is consistent with the educational logic of KYW, in which students participate in preparation, sampling, testing, interpretation, and communication [25,26].

Compared with the Nebraska KYW program, which is organized around youth-led sampling of domestic wells and communication with well owners [25,26], the Kazakhstan pilot transferred the same preparation–sampling–interpretation logic into a higher-education and workshop setting. This resembles community-university and field-based water-education initiatives reported elsewhere [35,37,38], but the evidentiary emphasis differs: those studies examine partnership or course experiences, whereas the present case documents procedural feasibility and participant reception in a small pilot. The data-quality cautions identified in groundwater and water-quality citizen-science studies [19–22] are therefore directly relevant. Studies of community engagement and locally supported monitoring [23,24] further show that institutional roles and sustained collaboration are important for translating observations into water-management practice. Supervised protocols and laboratory-supported interpretation provide an initial quality-control layer, but repeated sampling, external validation, and explicit quality-assurance and quality-control procedures would be required before the model could contribute reliable monitoring data beyond its educational role.

5.3. Linking Education, Monitoring, and Local Water Awareness

The combined findings suggest that short-course training and participatory water monitoring can serve as complementary capacity-building pathways. The first pathway identifies project-level indications that participating faculty and students valued applied environmental science content and methods. The second pathway translates this applied orientation into a specific water-education workflow. Together, they help connect classroom learning, field practice, laboratory interpretation, and localized environmental awareness.

This connection is particularly relevant for Kazakhstan and Central Asia. The literature shows that water governance in the region is affected by transboundary dependence, fragmented institutions, uneven monitoring capacity, and weak science–policy integration [4–8,11–17]. Groundwater is especially difficult to manage because it is less visible than surface water and often poorly understood outside expert systems [1–3,17]. In this context, participatory educational models cannot replace official monitoring, but they can help build the human and institutional capacity needed to support better water awareness and interpretation.

The study therefore supports a modest but useful proposition. In data-scarce and institutionally fragmented settings, participatory water education can function as a bridge between formal scientific knowledge and local understanding. This bridge is not created through awareness alone. It requires structured protocols, field practice, laboratory support, and educational reflection. The Kazakhstan-adapted KYW pilot illustrates one way this bridge can begin to be built.

5.4. Practical Implications and a Phased Scaling Pathway

Practical implementation requires differentiated institutional roles. Universities can embed KYW-style modules in hydrogeology, environmental science, chemistry, and teacher-

training courses; train instructors; and use bilingual standardized forms as assessed field or laboratory assignments. Partner laboratories and environmental agencies can define sampling, preservation, chain-of-custody, quality-assurance, and result-communication procedures, while local authorities and well users can support site access and contextual information. These arrangements should preserve a clear boundary: student-generated observations may support education and preliminary screening, but regulatory decisions should remain based on validated official data.

A phased scaling pathway is more appropriate than immediate expansion. Phase 1 would standardize the Kazakhstan-adapted workbook, instructor training, and minimum equipment requirements. Phase 2 would test the model across multiple institutions and hydrogeological settings using repeated sampling and laboratory validation. Phase 3 would introduce georeferenced mobile reporting with mandatory metadata, validation flags, controlled user access, and institutional data stewardship. Phase 4 would evaluate learning outcomes, data quality, costs, and institutional uptake before broader integration into university curricula or agency outreach. In this form, digital tools could help narrow the regional informational-governance gap [17] without overstating the evidentiary status of pilot observations.

5.5. Methodological Caution and Future Development

The findings should be interpreted cautiously. The SWAP survey samples were modest, and the student post-course survey included fewer respondents than the pre-course survey. The KYW pilot in Kazakhstan involved a small participant cohort and limited laboratory evidence. The hydrochemical results were based on only two samples and cannot support broader conclusions about groundwater quality. For these reasons, the study should be read as a pilot-level analysis of feasibility and educational relevance, not as an evaluation of national monitoring impact.

Future research should build on this pilot in four directions. First, the KYW adaptation should be tested across a larger number of institutions and sites, including wells in different hydrogeological and land-use settings. Second, repeated sampling, field duplicates, laboratory validation, and documented quality-assurance and quality-control procedures should be used to strengthen the field-to-laboratory comparison. Third, georeferenced mobile reporting should be evaluated with mandatory metadata, validation rules, and clear institutional responsibility for data review and access. Fourth, longer-term educational outcomes should be assessed using matched participant records where ethically and methodologically appropriate, including whether KYW-style activities improve practical competence, professional orientation, and engagement with water stewardship.

Overall, the two case studies show that Kazakhstan has both a need and an opportunity to strengthen applied environmental science education. The 2022 SWAP surveys provided project-level indications of positive participant perceptions of practice-oriented training, while the 2025 KYW pilot showed that participatory water education could be organized as a structured field-to-laboratory workflow. The contribution of this study is therefore not a claim of large-scale effectiveness, but a clearer demonstration of how educational capacity building and localized water-monitoring practice can be linked in Kazakhstan.

6. Conclusions

This study examined two related but distinct Kazakhstan-based case studies that address the same broader challenge: strengthening practice-oriented environmental science capacity and localized water awareness. The first case study analyzed a 2022 Science with a Purpose (SWAP) environmental science short-course and curriculum evaluation project.

The second examined a small adaptation of the Nebraska-based Know Your Well (KYW) model for participatory water education and localized observation.

The findings show that the SWAP surveys provided preliminary, project-specific evidence of positive participant perceptions of applied environmental science training. Faculty responses indicated openness to curriculum discussion and possible integration of environmental science content, while student responses showed strong interest in applied subjects such as water quality, air quality, sampling methods, and equipment. These results suggest that short-course formats can serve as useful instruments for testing and strengthening practice-oriented environmental science education in Kazakhstan.

The 2025 KYW pilot showed that a participatory water-monitoring model can be adapted into a structured field-to-laboratory educational workflow. The adapted model included pre-field preparation, field observation, sample collection, basic water-quality testing, laboratory-supported interpretation, presentation, and feedback. Participant responses were generally positive, and most trainees reported that the acquired skills were fully or partially applicable. The two laboratory water analyses further illustrated how field-based learning can be connected to basic hydrochemical interpretation, although they do not provide a basis for regional groundwater-quality conclusions.

The main contribution of this article is therefore not evidence of large-scale monitoring effectiveness or national representativeness. Rather, it provides pilot-level evidence that short-course environmental science training and KYW-style participatory water education can function as complementary capacity-building pathways. The first pathway identifies educational enabling conditions at the project level and can inform curriculum modernization; the second demonstrates how localized water observation can be organized as a practical learning cycle.

This study has clear limitations, as the SWAP survey samples were modest, the student post-course response group was smaller than the pre-course group, the KYW pilot cohort was limited, and the hydrochemical evidence consisted of only two illustrative samples. For these reasons, the findings should be interpreted as evidence of feasibility and educational relevance, not as proof of long-term learning outcomes or groundwater-monitoring impact at scale.

The institutional and policy recommendations presented above are therefore prospective scaling options rather than outcomes demonstrated by the current pilot data.

Future work should expand the number of participating institutions, field sites, and water samples; include repeated sampling across different hydrogeological and land-use settings; introduce digital and georeferenced reporting tools; and assess longer-term educational outcomes. Further research should also examine how universities, laboratories, local authorities, and water-sector institutions can cooperate to sustain participatory water education beyond isolated pilot activities.

Overall, the two case studies show that Kazakhstan has both a need and an opportunity to strengthen applied environmental science education through practice-based formats. Short-course training and participatory water monitoring should not be seen as substitutes for formal curricula or official monitoring systems. However, when properly structured, they can help connect classroom learning, field methods, laboratory interpretation, and localized water awareness. In this sense, they offer a practical direction for further testing and phased scaling of environmental science capacity-building initiatives in Kazakhstan and, potentially, in other data-scarce settings in Central Asia.

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(Ranida Arystanova); Data curation, A.S., R.A. (Raushan Amanzholova), D.D.S., R.A. (Ranida Arystanova), M.K., O.K. and M.Y.; Writing—original draft, A.S., R.A. (Raushan Amanzholova), A.U. and M.Y.; Writing—review and editing, A.S., R.A. (Raushan Amanzholova), A.U., O.K., D.D.S. and M.Y.; Visualization, R.A. (Raushan Amanzholova), D.D.S. and M.Y.; Supervision, A.S. and R.A. (Raushan Amanzholova); Project administration, A.S., R.A. (Raushan Amanzholova) and M.Y.; Funding acquisition, A.S. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Participation in the original questionnaires and training-feedback activities was voluntary. The study involved educational program-evaluation activities only and did not include medical, clinical, or experimental interventions. Only aggregated, non-identifiable data are reported in this article.

Data Availability Statement: The aggregated data supporting the findings of this study are contained within the article. Additional project documentation and anonymized survey summaries may be made available by the corresponding author upon reasonable request, subject to institutional and ethical restrictions.

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Abbreviations

The following abbreviations are used in this manuscript:

KYW	Know Your Well
GPS	Global Positioning System
SWAP	Science with a Purpose

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