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Identification of Chemical Science Literacy Skills of Madrasah Aliyah Students in the Environmental Science Competency Aspect

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Abstract

Scientific literacy, particularly environmental science competency, is essential for enabling students to understand and respond to contemporary environmental challenges. However, research on chemical science literacy in Islamic senior high schools (*madrasah*), especially in suburban regions, remains scarce — particularly studies linking the Fundamental Laws of Chemistry to the PISA 2025 environmental science competency framework. This study aimed to identify the level of chemical science literacy of 578 students from State Islamic Senior High Schools in Bogor Regency using a quantitative descriptive survey. Data were collected through a 40-item science literacy test based on the PISA 2025 framework, assessing three indicators: explaining human interactions with Earth systems, evidence-based environmental decision making, and respecting diverse perspectives in socio-ecological crises. Results showed students achieved a high overall level of chemical science literacy. The highest achievement was explaining human interactions with Earth systems, while evidence-based decision-making was the lowest. These findings imply that chemistry teachers should integrate inquiry-based and socio-scientific strategies into instruction, and that curriculum developers should embed PISA-oriented environmental tasks to strengthen students' scientific decision-making competency.

1. INTRODUCTION

The 21st century is marked by rapid advances in information technology, increasing globalization, and constantly changing social dynamics (Mardhiyah et al., 2021). These conditions present challenges that require students to develop critical, creative, and adaptive thinking skills to solve the various problems they face (Yunita & Mandasari, 2025). Science education, in this context, serves not only to convey basic knowledge but also to equip students with 21st-century skills relevant to current demands (Mashudi, 2021). One such skill is scientific literacy, a key competency that

enables students to interpret scientific phenomena and make evidence-based decisions amid global developments (Yusmar & Fadilah, 2023).

To meet the needs of the 21st century, scientific literacy is a crucial skill. Scientific literacy encompasses the ability to use scientific knowledge to identify problems, draw conclusions based on evidence, understand natural phenomena, and consider the impact of human activities on the environment (OECD, 2023b). Zainuri et al. (2022) emphasized that scientific literacy is a crucial competency needed by individuals to improve their quality of life and keep pace with developments in science and technology. Beyond simply understanding concepts, scientifically literate individuals can design and evaluate scientific investigations, interpret data, and use scientific evidence in decision-making (Ding, 2022). Therefore, scientific literacy is closely linked to the ability to understand environmental issues and evaluate the risks or impacts of human activities on environmental systems.

To comprehensively assess scientific literacy levels, the Programme for International Student Assessment (PISA) conducted by the OECD has become an international reference (Zuhri et al., 2023). In the PISA scientific literacy framework, the OECD (2023a) divides scientific literacy into three main dimensions: context, knowledge, and competence. Furthermore, PISA 2025 strengthens four interrelated pillars: scientific knowledge, context, scientific competence, environmental competence and scientific identity. The environmental competency pillar is highly relevant in the context of chemistry education, as it requires students to use their scientific understanding to interpret environmental issues, assess the impact of human activities, and consider evidence-based solutions (OECD, 2025). This demonstrates that scientific literacy is not only conceptual but also applicable and closely related to the ability to interpret environmental problems.

However, global scientific literacy achievements show that Indonesia remains below the OECD average. The OECD's PISA 2022 data (2023b) noted that Indonesia's scores in reading, mathematics, and science decreased compared to PISA 2018. This situation prompted the government to develop a national literacy measurement system (Afryansyah et al., 2025). In the madrasah (Islamic school) sector, the Ministry of Religious Affairs has also implemented a literacy-based diagnostic assessment. Based on data from the 2024 National Assessment in the 2025 Education Report for Bogor Regency, the literacy level of Madrasah Aliyah students is in the moderate category, with minimum competency scores ranging from 40.00 to 70.00%. This situation indicates the need for a more in-depth mapping of scientific literacy skills, particularly in dimensions related to environmental issues.

On the other hand, chemistry learning, as part of science education, plays a significant role in developing students' scientific literacy. According to Mellyzar et al. (2022), chemistry learning can improve students' ability to interpret phenomena, solve problems, and understand concepts scientifically. The relevance of chemistry learning to environmental competencies is strong because chemical concepts directly relate to issues such as air pollution, water pollution, changes in the chemical composition of the environment, combustion reactions, and the dynamics of chemical compounds in nature. However, various studies have shown that students often struggle to understand abstract chemical concepts, resulting in an underdeveloped ability to relate them to environmental contexts (Johari, 2021). In the context of State Islamic Senior High Schools (MAN), these challenges can be exacerbated by variations in learning quality, students' prior knowledge, and limited learning facilities (Uno, 2016). As a result, environmental science competencies within chemical science literacy have not been optimally identified in students.

Previous research on scientific literacy among high school students has shown low to moderate achievement. Husain & Ramdani (2024) found that the scientific literacy of Makassar State High School students was in the moderate category, with a low achievement percentage of 86%. Aryani & Susilowati (2022) also reported that the chemical literacy of science students at SMA Batik 1 Surakarta only reached 59%. Meanwhile, Randan et al. (2022) reported that the achievement dimensions of content knowledge, procedural knowledge, and epistemic knowledge were 65.6%, 58.5%, and 56%, respectively, among North Toraja High School students. Pikoli et al. (2023) found that the scientific literacy of eleventh-grade students in two high schools was low, at 33.53% and 30.44%, respectively. However, these studies generally focused on a general overview of scientific literacy. They did not specifically examine environmental science competencies in the context of chemical science literacy, particularly in madrasah-based educational institutions.

Based on this gap, this study has a novel focus on specifically identifying students' chemical science literacy abilities in the aspect of environmental science competency at MAN throughout Bogor

Regency. This study not only describes the achievement of scientific literacy in general but also examines how students use chemical concepts to understand environmental phenomena, analyse the impacts of human activities, and evaluate scientific solutions to environmental issues. This study is expected to make new empirical contributions to mapping chemical science literacy through environmental competency, while also providing a basis for developing chemistry learning strategies that are more contextual and responsive to current environmental problems.

2. METHOD

The research design used in this study is quantitative descriptive research, which is widely used to systematically identify, describe, and map educational phenomena by using numerical data and statistical analysis (Tanjung & Shinta, 2024). This design was chosen because it aligns with the research objective: to identify students' chemical science literacy skills in the environmental science competency, which encompasses their ability to understand, analyse, and use chemical concepts to explain environmental issues and evaluate the impact of human activities on environmental systems. The quantitative approach is used to present measurable information regarding the achievement of environmental science competencies based on indicators in the PISA 2025 draft scientific literacy framework (OECD, 2025). Quantitative data were obtained from a multiple-choice test specifically designed to measure chemical literacy in the environmental science competency domain. This research design does not aim to test hypotheses, but only to describe the level of student mastery of these skills factually (Sulistyawati et al., 2022).

The target of this study was students of State Islamic Senior High Schools in Bogor Regency during the odd semester of the 2025/2026 academic year. The total number of students involved in this study was 578, which was determined using the Slovin formula (Tanjung & Shinta, 2024). All participants had previously studied basic chemistry concepts relevant to environmental issues, including chemical reactions, changes in matter, substance composition, pollution, energy, and interactions of substances within ecosystems. This target group was selected based on the curriculum characteristics of MAN, which emphasizes the integration of science and character education, making it relevant to examine how students understand environmental science competencies as part of chemical science literacy. The data in this study consisted of empirical evidence obtained from a chemical science literacy test specifically designed to measure environmental science competencies based on the PISA 2025 framework. All quantitative data were used to answer the research question regarding the level of mastery of chemical science literacy in environmental science competencies.

The research instrument was a chemical science literacy test consisting of 40 multiple-choice questions. All test items were developed based on the draft PISA 2025 scientific literacy framework (OECD, 2025), with a dominant focus on Environmental Competencies and Scientific Competencies, and on the principles of valid and reliable instrument development as proposed by Arikunto (2016). The test items were adapted to the context of environmental issues, including air pollution, water quality, plastic waste, climate change, energy management, and chemical reactions that drive environmental change. Each question was designed to require students to connect chemical concepts (e.g., combustion reactions, properties of substances, basic stoichiometry, physical-chemical changes, or the structure of matter) with environmental phenomena. The test was administered to all respondents as the sole data-collection method because this study focused on mapping abilities rather than measuring attitudes or behaviour. This instrument underwent content validation by chemistry education experts before data collection.

The data analysis technique used quantitative descriptive analysis, which aims to provide a comprehensive overview of the level of mastery of environmental science competencies in chemical science literacy. The analysis was conducted by interpreting the results based on the formulated scientific literacy ability criteria. The ability categories used are based on Arikunto (2016). A percentage of 81–100 is categorised as very high, while a percentage of 61–80 is categorised as high. Furthermore, a percentage of 41–60 is considered sufficient, and 21–40 is considered low. A percentage of 0–20 is categorised as very low. These categories are used to group students' abilities in environmental science competencies to provide a comprehensive picture. All analysis results are then systematically described to provide a comprehensive understanding of students' chemical science literacy levels in environmental science competency aspects.

3. RESULTS AND DISCUSSION

The measurement of scientific literacy in this study focused on the environmental science competency, an important part of chemical science literacy. Data were analyzed to display student achievement on each environmental competency indicator based on the PISA 2025 framework. The average score for each indicator was then classified into scientific literacy categories to indicate the level of student mastery. The summary results are displayed in Figure 1, which provides an overview of students' achievement in environmental competency.

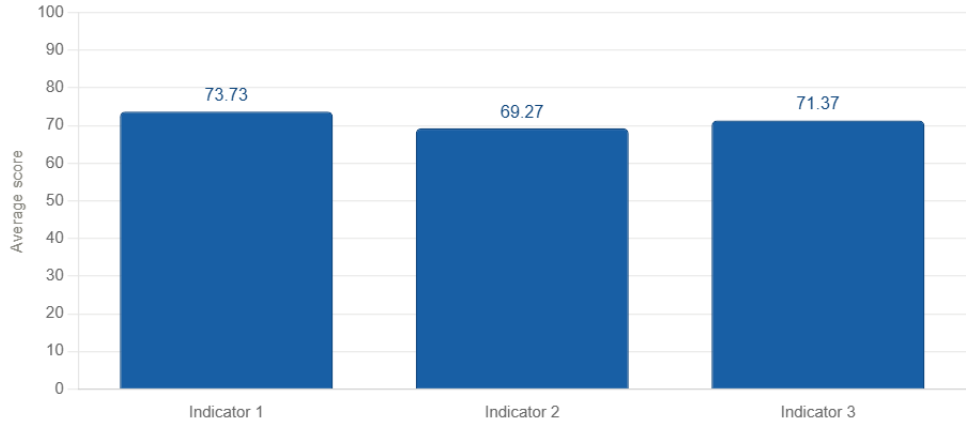

Figure 1. Science Literacy Results Graph for Environmental Science Competency Aspects

Based on the three indicators displayed in Figure 1, which shows the results of scientific literacy in the environmental science competency aspect for MAN students across Bogor Regency, the environmental science competency of students is in the high category. The first indicator scored 73.73, the second 69.27, and the third 71.37. This achievement indicates that students can connect chemical concepts to environmental issues such as pollution and climate change. Overall, these findings indicate that chemistry learning can strengthen scientific literacy in an environmental context. The results of this study also show that students have learned basic chemical concepts relevant to real-life environmental issues. Environmental science competency is a subset of science competency that focuses on understanding the interactions between humans and the environment, both global and local environmental issues, as well as the application of scientific knowledge to maintain sustainability and solve environmental problems (OECD, 2025).

The positive impact of the Ethno-ESD Engineering-Based Learning model on students' sustainability attitudes and self-reported sustainable behaviours aligns with constructivist learning theory, which emphasises learning through active engagement and real-world problem-solving (Ariyatun et al., 2025). These findings align with the Sustainable Development Goals (SDGs), specifically SDG 4 (Quality Education), which emphasises the importance of relevant science education; SDG 13 (Addressing Climate Change); and SDG 15 (Terrestrial Ecosystems). These research findings align with those of Pujiyanti et al. (2025), who stated that integrating environmental issues into chemistry learning can improve students' motivation and scientific literacy. Sarapung et al. (2025) also emphasised that science learning based on environmental contexts encourages active student involvement in understanding real-world problems—furthermore, Br. Simangunsong & Darmana (2025) found that the relationship between scientific concepts and environmental phenomena plays an important role in improving students' critical thinking skills. Research by Pratidhina et al. (2025) shows that using environmental contexts in chemistry learning can strengthen motivation for learning and the understanding of scientific concepts. This is supported by the findings of Harpina et al. (2025), who stated that environmental-based learning is effective in developing students' scientific literacy. In addition, Kumar (2024) found that integrating environmental issues into science learning helps students make decisions based on scientific evidence. Arafat et al. (2025) added that students' understanding of environmental issues also develops scientific literacy skills in the competency domain, as they are accustomed to studying scientific knowledge alongside real-world problems. Thus, environmental science competencies not only support the improvement of scientific literacy but also contribute to achieving SDG targets in the field of education and environmental aspirations.

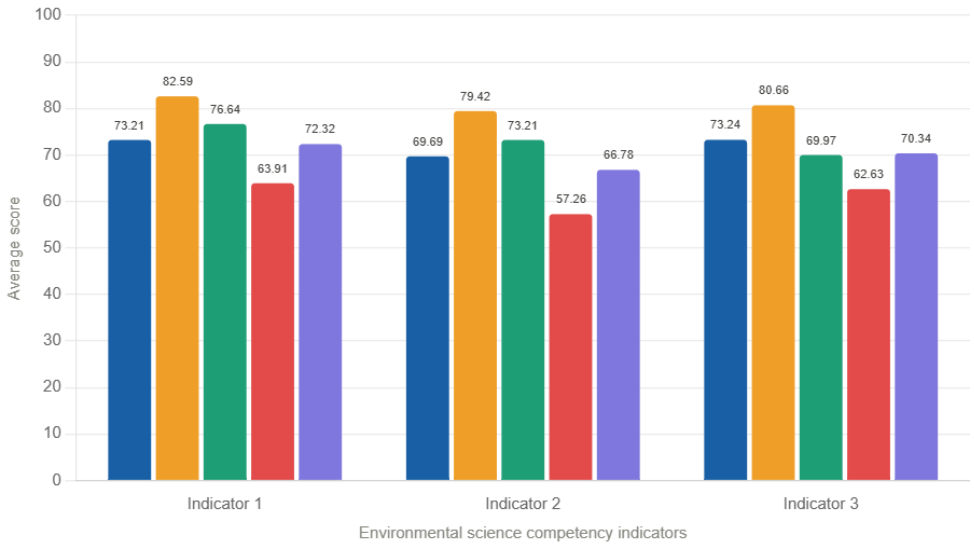

Table 3. Indicator Values of Environmental Science Competency Aspects Among MANs in Bogor Regency

As shown in Figure 2, the achievement of students' environmental science competencies in each indicator and school shows variation, with a tendency to be in the high category. Furthermore, upon further review of the indicators for each aspect and each school, the first indicator, explaining the impact of human interaction on the Earth's systems, achieved an average score of 73.73, making it the highest-achieving indicator in the environmental competency aspect. MAN B Bogor had the highest score of 82.59, while MAN D Bogor had the lowest score of 63.61. This variation in achievement remains in the high category, demonstrating consistent conceptual mastery. This finding confirms that students can understand the relationship between human activities and changes in Earth's systems. The ability to explain the impact of human-Earth system interactions requires an understanding of basic chemistry, such as pollution, atmospheric chemical reactions, and carbon emissions. The OECD Framework (2025) emphasises that this competency encompasses an understanding of physical and biological systems affected by human activity. Students who master this concept can connect chemical reactions to environmental phenomena. Such understanding is crucial for developing responsible Anthropocene agents for environmental sustainability.

Modern scientific literacy requires students to analyse the impacts of human activities using scientific evidence (Allen et al., 2025). This ability includes critical thinking skills in assessing the causes and effects of environmental change. Permatasari & Fitriza (2025) emphasised that scientific literacy must integrate conceptual understanding and scientific decision-making. This indicates that the first indicator plays a crucial role in enhancing environmental competency. Based on research results, the first indicator is in the high category. This achievement needs to be sustained by strengthening contextual learning focused on environmental issues. The integration of chemical concepts with real-world environmental phenomena has been shown to increase students' understanding and awareness. This strengthening is expected to shape students who are capable of acting as agents of environmental change.

Furthermore, the second indicator is making informed decisions to act based on the evaluation of various sources of evidence and the application of creative and systematic thinking to renew and maintain the environment. The second indicator achieved an average score of 69.27, making it the lowest-scoring indicator in environmental competency. MAN B Bogor achieved the highest score of 79.42, while MAN D Bogor had the lowest score of 57.26. These scores range from the high to the adequate category. This achievement indicates that evidence-based decision-making skills still need strengthening. HOTS in the context of chemistry include skills such as assessing experimental data, predicting the outcomes of chemical reactions, and selecting evidence-based solutions. This ability reflects higher-order thinking skills, defined as the capacity to use the mind broadly to acquire new knowledge and apply new or prior information to solve problems in dynamic situations (Sarah et al., 2021). The OECD (2025) emphasises that scientific decision-making is at the core of environmental

competence. Therefore, the relatively low achievement in this indicator may be due to suboptimal inquiry-based learning.

Creative thinking helps students develop innovative solutions to environmental issues (Hasanah et al., 2023). Systematic thinking supports a structured process of evaluating evidence in decision-making (Wulandari, 2017). Both of these skills are crucial to learning chemistry because many environmental phenomena result from complex chemical reactions. The OECD (2025) emphasises that a combination of creativity and systematic thinking is essential in the Anthropocene era. The second indicator is categorised as high, although its score is the lowest compared to the others. Reinforcement needs to focus on problem-solving-based learning to improve students' HOTS. The integration of chemistry-based environmental projects can enhance evaluative and creative skills. This reinforcement is expected to help students become responsible scientific decision-makers.

The final indicator is "Demonstrating respect for diverse perspectives and hope in finding solutions to socio-ecological crises." This third indicator achieved an average score of 71.37, categorised as high. MAN B Bogor achieved the highest score of 80.66, while MAN D Bogor had the lowest score of 62.63. The difference in achievement between schools remained in the high category. These results indicate that students have a good understanding of diverse perspectives on environmental issues. The OECD (2025) states that environmental competence encompasses not only scientific knowledge but also the ability to appreciate social perspectives. Classroom discussions on environmental issues help students understand differing views arising from social and economic backgrounds. This skill is crucial because environmental issues often contain moral, cultural, and political aspects. Strong scientific literacy enables students to integrate scientific evidence with social values.

Scientific argumentation helps students assess and defend opinions based on evidence (Fadlika et al., 2022). This skill is crucial for building shared decisions on socio-ecological issues. Collaborative learning enhances the ability to appreciate differing perspectives in environmental discussions. Mudawamah's (2020) research shows that scientific literacy can strengthen the ability to evaluate environmental issues holistically. Achievement of the third indicator demonstrates students' ability to appreciate diverse perspectives on environmental issues. This skill is crucial in addressing multidimensional socio-ecological crises. Strengthening this skill can be achieved through discussions based on environmental chemistry issues relevant to the local context. This strengthening will help students become critical and collaborative individuals in addressing environmental challenges.

Overall, MAN students throughout Bogor Regency demonstrated high achievement across all three environmental competency indicators. The first indicator was the most prominent, while the second indicator still requires strengthening of HOTS skills. Variations in the learning strategies used across schools influence differences in achievement. Environmental-based chemistry learning has been shown to improve scientific literacy and learning relevance.

4. CONCLUSION

This study concludes that the chemical science literacy of MAN students throughout Bogor Regency in the environmental science competency aspect is in the high category. Students can connect basic chemical concepts with environmental issues such as pollution, climate change, and ecosystem degradation, with the highest achievement in the indicator of the ability to explain the impact of human interactions on the Earth system. However, the indicator of evidence-based decision-making shows the lowest achievement, although it remains in the high category, indicating a need to strengthen higher-order thinking skills, especially in evidence analysis, data evaluation, and the determination of scientific solutions.

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