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Green Geochemical Education in Libya: Current Status, Applications, Challenges, and Future Perspectives

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Abstract

The integration of geochemistry education with green technology, sustainable resource management techniques, and environmental sustainability concepts is known as green geochemical education. Due to issues with groundwater quality, petroleum operations, environmental pollution, climate change, and sustainable resource use, Libya has a greater need for environmentally conscious education. Current studies conducted in Libya indicate that there is an association between sustainability and geoscience education and development, albeit to a small extent. Education in sustainability through geochemistry present possibilities for incorporating green principles within geochemical education, laboratories, and research. Inclusion of green learning practices within the realm of geochemistry can foster awareness among learners, instill sustainable practices in the lab, and help develop future geochemists who will be able to face environmental issues. The principles, uses, prospects, difficulties, and potential future paths of green geochemical education in Libya are all examined in this paper.

Keywords: Green Geochemical Education; Green Geochemistry; Sustainable Development; Libya.

1. Introduction

Green geochemical education involves the inclusion of sustainability ideas, environmental awareness, and environmentally friendly approaches within the field of geochemistry in both teaching and research. This approach seeks to enable students and researchers to use their understanding of geochemistry in an environmentally sustainable manner. Green curriculum (e.g., Shaltami, 2022; Paswan and Mehta, 2025), field education (e.g., van Loon, 2008; Koretsky et al., 2012; Ravachol, 2018; Needle et al., 2022; Fang et al., 2025), sustainable practices (e.g., Fedeski and Gwilliam, 2007; Wagner, 2011; Gasbarro et al., 2017; Scheihing et al., 2022; Panda and Haque, 2026), green laboratories (e.g., Wiseman et al., 2005; Tobiszewski and Namieśnik, 2012; Armenta et al., 2019; Kaya et al., 2022; Moniz and Sarraguça, 2026), digital tools (e.g., Skeppström and Olofsson, 2005; Acosta et al., 2011; Momo et al., 2016; Dornan et al., 2020; Hao et al., 2025), and community and industry partnership (e.g., Eklund, 2015; Ferraro et al., 2020; Jonbekova et al., 2025) are the components of green geochemical education (Fig. 1). Moreover, the key educational activities in green geochemical education include field sampling and surveys, laboratory analysis, data analysis and modeling, geographic information system (GIS) and mapping, community awareness, and reporting and solutions (Fig. 2).

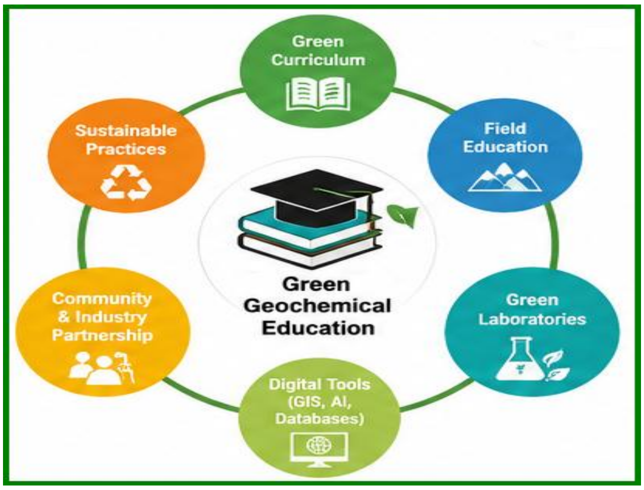

Fig. 1: Components of green geochemical education.

2. Objective

Sustainable education has increasingly gained significance within the scientific fields. Within the country of Libya, sustainable education is gradually being integrated into the field of higher education and environmental sciences (Ben Hkoma et al., 2026). The following goals are the focus of this study:

(1) Examine the current state of knowledge regarding geochemistry education and environmental awareness in Libya.

(2) Evaluate the importance of green geochemistry ideas in minimizing environmental impact linked with geochemistry and geological operations.

(3) Explore the possibility of introducing sustainable practices to geochemistry education and research.

(4) Evaluate the contribution of green geochemical education towards achieving sustainable resource use in Libya.

(5) Develop strategies for improving geochemistry curricula with regard to environmental sustainability at Libyan universities.

(6) Raise awareness among learners regarding environmentally sound geochemistry practices.

The authors created a flowchart for green geochemical education in Libya (Fig. 3) based on the information that will be presented later in this work.

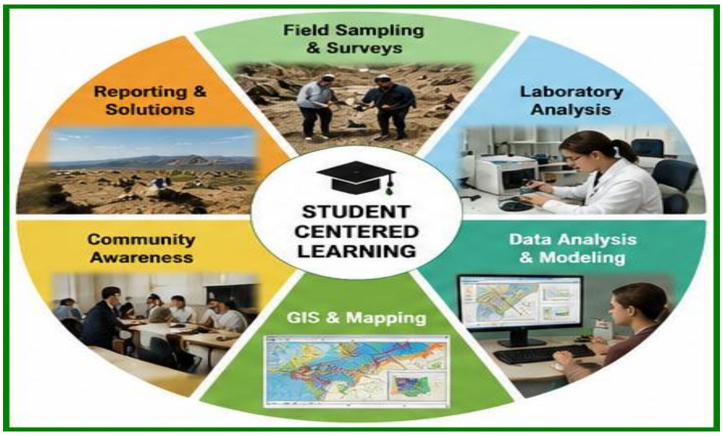

Fig. 2: Key educational activities in green geochemical education.

3. Research Problem

Problem statement in the research is due to the following issues:

(1) Insufficient research on green geochemical education in Libya.

(2) Inadequate evaluation of Libyan institutions' green laboratory methods.

(3) Inadequate studies on geochemical education aided by AI.

(4) Frameworks that connect national sustainability objectives with geochemical education are necessary.

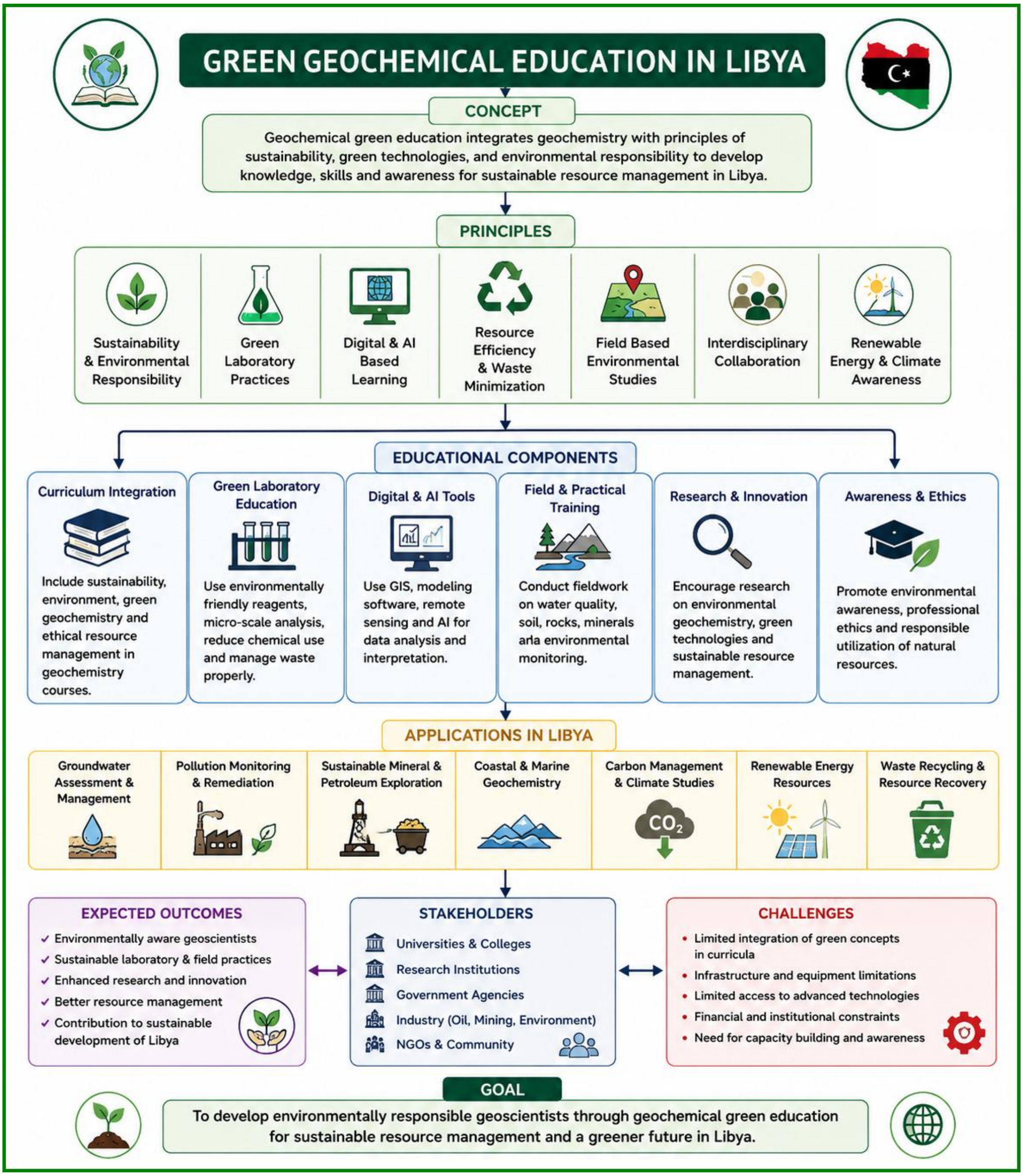

Fig. 3: Flowchart for green geochemical education in Libya.

4. Geochemistry and Sustainability in Libya

Natural resources found within Libya include hydrocarbons, groundwater, mineral deposits, marine ecosystems, and renewable energy resources. Current research in Libya that relates to geochemistry and sustainability has highlighted the following aspects of mineral deposits (Shaltami et al., 2025a), hydrogeochemistry (Shaltami et al., 2025b), soil geochemistry

(Shaltami et al., 2026), karst geochemistry (Shaltami et al., 2025c), and blue carbon geochemistry (Shaltami et al., 2025d).

5. Green Geochemical Education in Libya

5.1. Applications

5.1.1. Green Laboratory Education

Education on green laboratories should focus on minimizing the use of harmful chemicals and reducing waste in the laboratory by using microscale experiments, analytical reagents, energy-efficient equipment, and chemical recycling practices (Fig. 4).

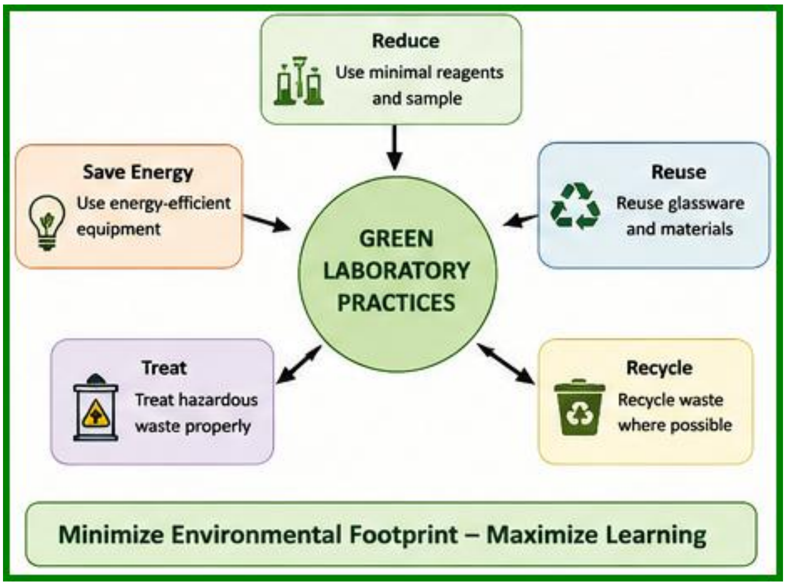

Fig. 4: Green laboratory practices in geochemistry.

5.1.2. Digital and AI-Based Geochemical Learning

Modern educational technologies could revolutionize the teaching of geochemistry by means of geochemical modeling applications, GIS technology, AI in geochemical analysis, and computer-generated laboratories (Fig. 5).

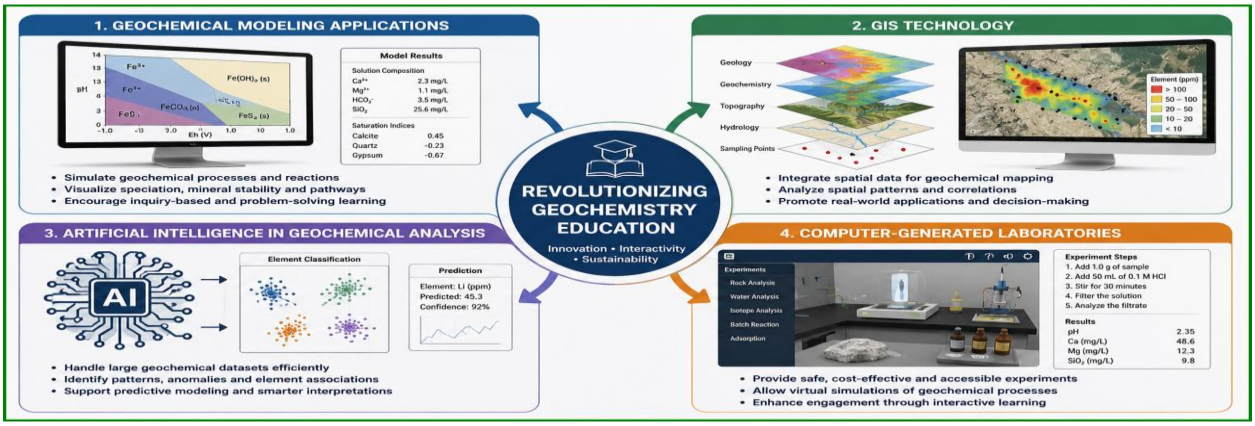

Fig. 5: Modern educational technologies that have revolutionized the teaching of geochemistry.

5.1.3. Environmental Monitoring Education

Water, soil, and air quality monitoring, as well as environmental impact assessment, can be taught to students (Fig. 6).

5.1.4. Sustainable Resource Management

Sustainable mineral exploration, water resources conservation, carbon management, and renewable energy can be integrated into educational programs (Fig. 7).

5.1.5. Challenges

The main factors hindering green geochemistry education in Libya include: (1) Sustainability topics are not widely included in curricula; (2) Restrictions on laboratory infrastructure; (3) Limited availability of cutting-edge analytical tools; (4) Insufficient multidisciplinary cooperation; and (5) Budgetary constraints (Fig. 8).

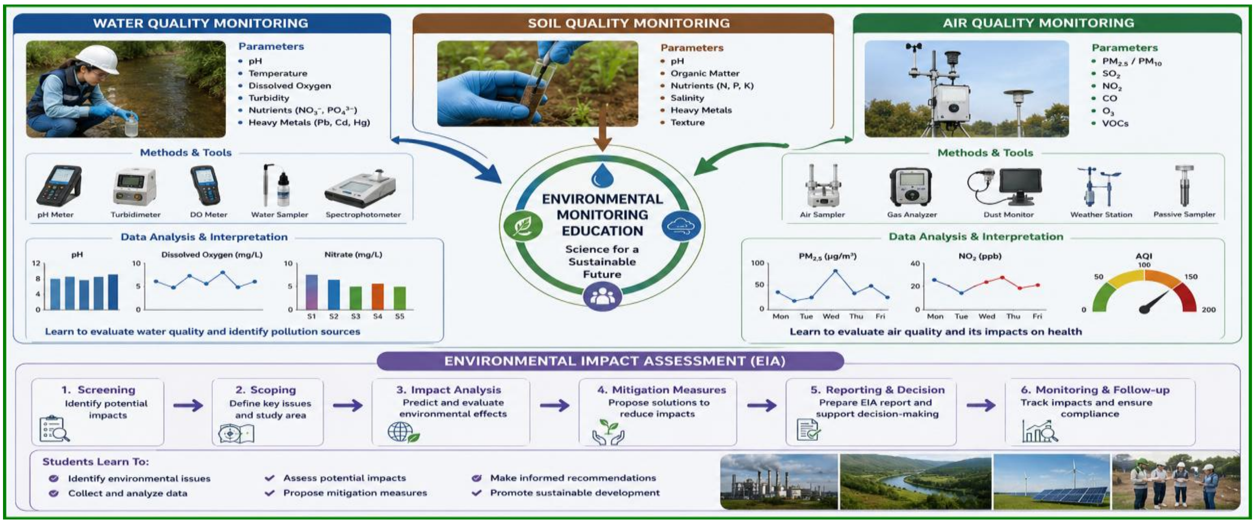

Fig. 6: Fundamentals of environmental monitoring education.

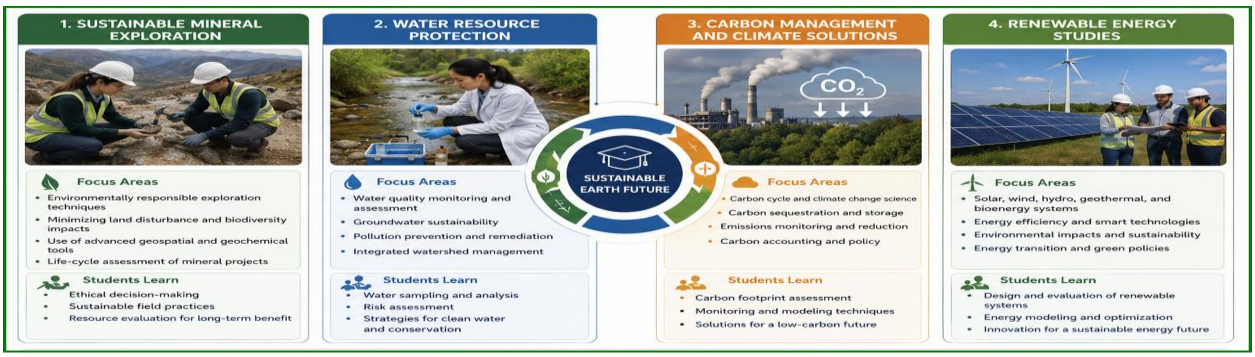

Fig. 7: Sustainable resource management approaches.

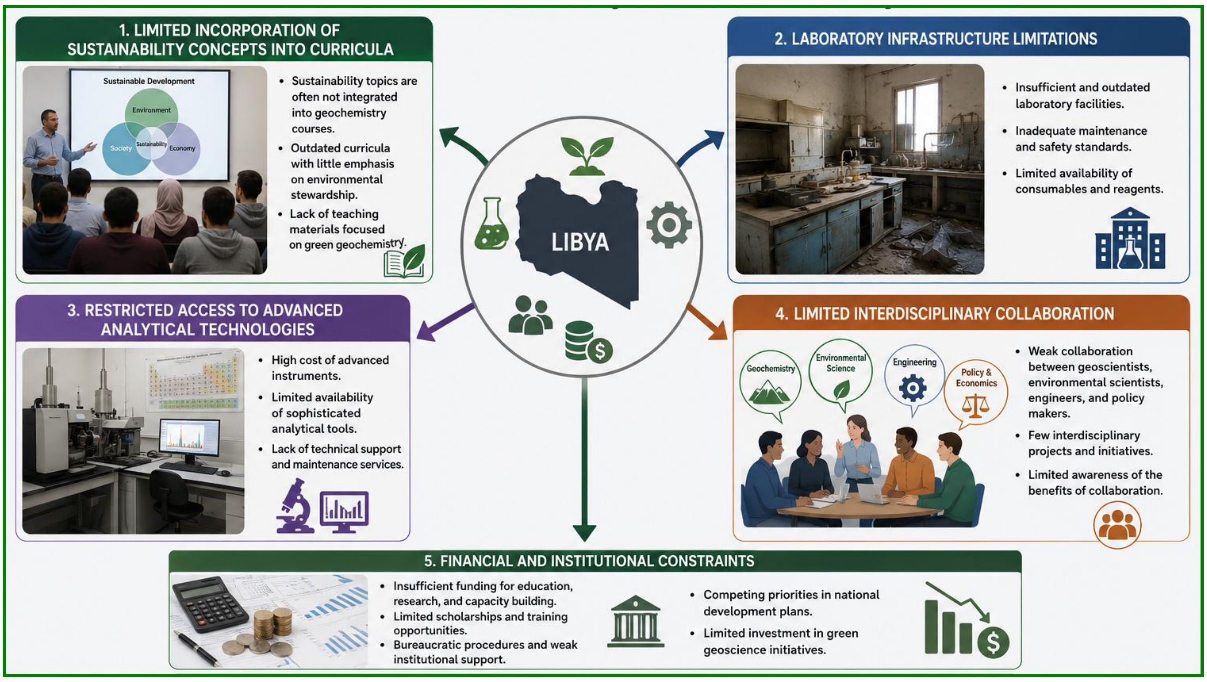

Fig. 8: The main factors hindering green geochemistry education in Libya.

5.1.6. Future Trends

Future trends related to green geochemical education in Libya may comprise: (1) Introduction of specialized green geochemistry courses; (2) Inclusion of sustainability concepts in geoscience curricula; (3) Collaboration between educational institutions; (4) Emphasis on online learning and use of AI; and (5) Interdisciplinary approach to environmental studies (Fig. 9).

6. Conclusions

One significant technique to include environmental sustainability concepts into geological teaching in Libya is through green geochemistry education. Students' comprehension of sustainable resource management, environmental preservation, and responsible use of natural resources can be enhanced by incorporating green principles into geochemical courses. The use of educational technologies of the modern era, such as GIS, AI, modeling tools, and virtual laboratories, may be an opportunity for improving the quality of training by making it more interactive. In addition, adding new courses like sustainable mineral exploration, water resource protection, carbon handling, and renewable energy can improve their practical knowledge and expertise. The advancement of green geochemical education in Libya is nevertheless hampered by a number of issues, such as the scant incorporation of sustainability concepts into curricula, poor laboratory facilities, limited access to cutting-edge analytical tools, poor interdisciplinary cooperation, and institutional and financial constraints. Future success will rely upon the reformation of curricula, provision of state-of-the-art laboratory facilities and technological tools, fostering partnerships between universities and research institutions, as well as undertaking interdisciplinary studies related to the environment. Implementation of the above methods could set up a firm platform for green geochemical education in Libya.

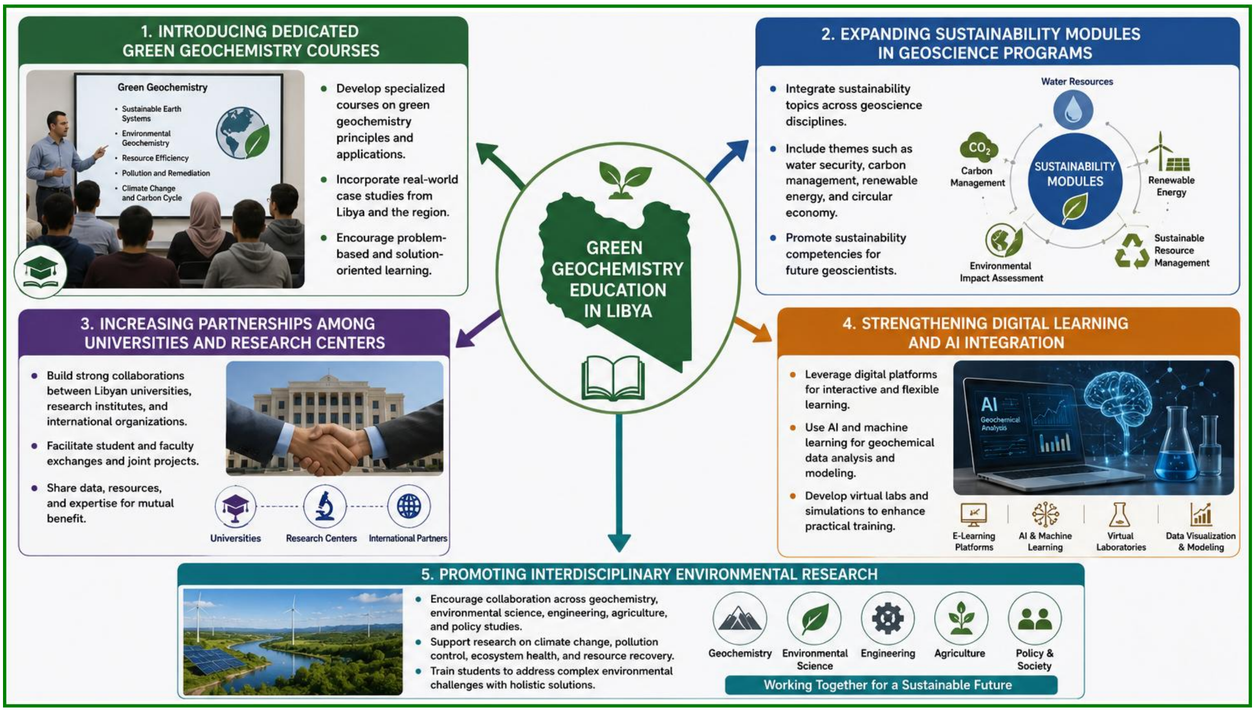

Fig. 9: Future trends related to green geochemical education in Libya.

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