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# Geographic Information Systems Methods in Practice: Higher Education Curricula and Practitioner Registration Standards in South Africa

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**Abstract:** Integrating geographical information systems (GIS) in various sectors has significantly increased the global demand for skilled professionals, particularly in South Africa. Despite integrating GIS methods into higher education curricula, challenges like resource limitations, curriculum updates, and competency standardization may limit practical training scope. This study explores the alignment of South African qualifications and practitioner registration standards, including the South African Qualifications Authority (SAQA), National Qualification Framework (NQF) requirement, South African Council for Natural Scientific Professions (SACNASP), and South African Geomatics Council (SAGC), with job market demands. A structured literature review of scientometric research from 2004 to 2023 was used to assess the current GIS educational programs in South Africa, identify training gaps and skills, and propose strategies to enhance their relevance. The results indicated that, despite adhering to policies and standards, the GIS curriculum's capacity to meet market demands is uncertain due to insufficient job market research and disparities between higher education curricula and practitioner registration standards (HEC_PRS). The University of Cape Town (UCT) and the University of South Africa (UNISA) are the top two South African institutions contributing significantly to GIS practice through published articles, with a few coming from affiliated research centres. The results revealed significant changes in higher education from 2004 to 2018, with teacher education becoming the most prominent theme. The 2019–2021 period emphasized interconnectedness between curriculum development, experiential learning, and 21st-century skills, while the 2022–2023 segment used curriculum as the most prevalent theme in this field. The prominence of key terms like "higher education", "curricula", "students", and "teaching" highlights the role of educational institutions in preparing students for professional practice in GIS. These findings provide strategies for evaluating current GIS practices, identifying areas for improvement, and implementing modifications to enhance their effectiveness in practice.

**Keywords:** curriculum development; GIS methods; higher education; teaching and learning; sustainable development

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## 1. Introduction

Misconceptions often arise regarding the complexity of tasks like map-making, which often require prior knowledge of spatial analysis and training. Modern technologies like Geographic Information Systems (GIS), often assumed to be easy to use for map analysis and decisionmaking, further fuel this misconception [1,2]. However, GIS, like any tool, necessitate a fundamental comprehension of their language, encompassing spatial awareness, cognition, spatial analysis, and geographical data. Integrating higher education teachings with GIS professional requirements ensures that student training is tailored to individual student needs, aligning with work requirements and competencies [3,4].

Hence, this study explores the alignment of GIS curricula with South Africa's registration requirements, emphasizing the significance of this alignment for its seriousness. Numerous studies underscore the significance of integrating basic geographical concepts and principles for effective GIS user service, potentially impacting the GIS profession in South Africa [5–8]. A well-developed spatial awareness, essential in GIS education and practice, involves understanding one's environment, organising surroundings, and recognising spatial patterns, making it a skill rather than a necessity. Positioning is comprehending one's position among one's surroundings, including people and objects. A study accentuates the significance of spatial awareness in achieving effective orientation, wayfinding, and navigation, highlighting its enhancement through exposure to diverse environments and territories [9]. Spatial analysis requires reading spatial patterns and making decisions based on proximity, scale, and direction.

Global Positioning Systems (GPSs) and smartphone devices rapidly complete spatial analysis, making them accessible to non-specialists [9,10]. The effectiveness and efficiency of GIS as a tool are largely dependent on the user's proficiency in the tool's language [11,12]. Spatial awareness is a vital skill in GIS, and its significance should not be underestimated in the field. Many studies have proven the successful application of GIS in field research projects, their advancements in understanding complex spatial patterns, and their real-world impact in addressing environmental and societal challenges [2,8,12,13]. Therefore, the current GIS education in South African universities is inadequate, indicating a gap between academic programs and industry demands, particularly in high school curricula. The higher education curricula and practitioner registration standards (HEC_PRS) in South Africa provide frameworks and guidelines governing education, training, and professional qualification in specialized fields like Geographic Information Systems, Geomatics, and related disciplines. These elements are crucial for graduates to possess the necessary knowledge, skills, and credentials to meet industry standards and contribute effectively to their respective sectors, ensuring that they are well-equipped to meet these standards. Therefore, the gaps in higher education curricula and professional body registration standards pose significant implications for the GIS workforce. This study aims to enhance GIS education, professionalise the workforce, and bridge the gap in curriculum development and GIS technology to tackle societal challenges. In addition, the study employs scientometrics to analyse the evolution of research articles on GIS methods in South Africa's higher education curricula and practitioner registration standards (HEC_PRS). Scientometrics is widely used for assessing research advancements, scientific publications, and collaboration networks across various niche areas [14–17]. This study examines South Africa's curricula integration of Geographic Information Systems methods in practice in HEC_PRS. Additionally, the study evaluates GIS education and professionalisation by promoting curriculum alignment and fostering a skilled workforce capable of using spatial intelligence for sustainable development. Understanding the dynamic trend of GIS methods in South Africa's HEC_PRS is crucial given their prominence in the workforce and the global economy.

*Spatial Analysis*

Quantitative studies primarily utilize numbers to count and measure people or objects, as they are the foundation for data analysis. Spatial analysis involves manipulating spatial data to identify, evaluate, and predict relationships. Several authors agree that the common characteristic of spatial data is a study of phenomena that occur in space [18–21].

> "The quantitative study of phenomena that manifest themselves in space." (Anselin 1989, 2)

> "…studies how the physical environment and human activities change with distance from reference locations or objects of interest" (Wang 2014, 27).

> "The process by which we turn raw data into useful information, in pursuit of scientific discovery, or more effective decision making" (Longley et al., 2011).

> "A set of techniques designed to find a pattern, detect anomalies, or test hypothesis based on spatial data" (Goodchild 2008, 200).

Spatial analysis is a term that includes "spatial data manipulation through Geographical Information Systems (GIS), spatial data analysis in a descriptive and explorative way" [22]. A study described spatial analysis as a collection of methods and techniques that integrate concepts to analyse, investigate, and explain geographic context patterns, actions, or behaviours [23]. Spatial analysis has various functions, ranging from investigating population patterns and vegetation species to determining the distance and scale of an area [22,23]. The concept of spatial analysis is divided into various categories for its various uses, as follows:

Social systems: for studying human interaction in social, political, and economic contexts;

Environment: studying natural phenomena, natural resource management, and sustainable development;

Economy: for analysing, mapping, and modelling interrelations among humans and various economic dimensions of economic life.

Geographic Information Systems are one way of conducting spatial analysis. Accordingly, GIS is a powerful tool for comprehensive location study, enabling the identification and analysis of land features, climates, boundaries, populations, and resources [24]. GIScience, a combination of GIS software and hardware, enables users to manipulate layers to answer questions, explain phenomena, or track events over time. GIS software can be categorized into general-purpose geo-computation platforms like ArcGIS, QGIS, and SuperMap and specialized tools like Landserf, TauDEM, and SoLIM [25]. Research indicates that, despite the advancements in spatial analysis software, proper training is still necessary for users to effectively utilize these tools [21,25,26]. A study indicates that successful software usage necessitates users to complete specialized courses or even pursue degrees [25]. The increasing use of GIS in various fields may pose challenges for non-GIS-trained individuals, potentially leading to a mismatch or insufficiency in GIS-quality work. This study aims to assess the alignment of South African qualifications and practitioner registration standards, including the South African Qualifications Authority (SAQA), National Qualification Framework (NQF) requirement, South African Council for Natural Scientific Professions (SACNASP), and South African Geomatics Council (SAGC), with job market demands. Additionally, the study explores the implementation of GIS education in South African universities, focusing on classroom teaching and practical applications for sustainable development, addressing three key questions.

(i) How do we integrate GIS curricula in South African high school curriculum policy and practitioner registration standards based on learning objectives for GIS skills and qualifications?
(ii) How does HEC_PRS overcome the challenges of regional disparities and create opportunities for harmonization to enhance accessibility and applicability in the workforce?
(iii) What are the evolutionary trends of the dominant themes influencing GIS methods in South Africa's HEC_PRS hotspots using scientometric analysis for future research directions?

Hence, the findings of this study are crucial for overcoming barriers and utilizing GIS opportunities to improve field research, drive innovative solutions, promote equitable development, and provide sustainable professional workforce opportunities.

## 2. GIS Education

GIS education is a comprehensive academic and professional training that focuses on the theory, principles, and practical applications of GIS technology [27,28]. GIS education is crucial for creating a skilled workforce capable of using spatial data for decisionmaking, planning, and problemsolving across sectors, identifying gaps, addressing regional disparities, and offering strategies for integration and standardization. The Curriculum and Assessment Policy Statement (CAPS) by the Department of Basic Education guides

South Africa's high school curriculum. For instance, GIS application in grade subjects aims for a standardized, equitable education system, preparing students for higher education, vocational training, and workforce readiness [29]. The CAPS policy outlines the learning objectives, content, and assessment criteria for Grade 10 to Grade 12 students. GIS education covers fundamental concepts, software proficiency, spatial analysis, cartography, map design, data management, applications across disciplines, remote sensing integration, and project-based learning [30,31]. However, GIS is taught as part of the geography subject in the final three years of high school. The curriculum focuses on improving students' understanding of GIS data, preparing them for higher education, and providing basic training in GIS skills and methods from Grades 10 to 12, as shown in Table 1.

**Table 1.** GIS curriculum focused on skills and techniques.

| Grade 10 | Grade 11 | Grade 12 |
|---|---|---|
| Concept of GIS. | Spatially referenced data. | GIS concepts: remote sensing and resolution. |
| Reasons for the development of GIS. | The spatial and spectral resolution. | Spatial and attribute data, and vector and raster data |
| Concept of Remote Sensing. | Different types of data: line, point, area, and attribute. | Data standardisation, data sharing, and data security |
| How remote sensing works. | Raster and vector data. | Data manipulation: data integration, buffering, querying, and statistical analysis. |
| GIS concepts: spatial objects, lines, points, nodes, and scales. | Application of GIS to all relevant topics in the grade. | |
| | Capturing different types of data from existing maps, photographs, fieldwork, or other records on tracing paper. | Application of GIS by government and the private sector. |
| | | Develop a "paper GIS" from existing maps, photographs, and other records on layers of tracing paper. |

The South African Qualifications Authority has outlined the learning objectives for GIS qualification at the National Qualification Framework (NQF) levels 4, 5, and 6. NQF level 4 is an entry-level education for someone entering the field of GIS; NQF level 5 is intended for persons who aim to achieve career advancement by gaining GIS skills, leading to the qualification. At NQF level 6, the individual will have a basic understanding of GIS data structures for data capture, their relationship to GI Science, and their potential benefits across various disciplines, as shown in Table 2.

**Table 2.** National Qualification Framework (NQF) levels based on GIS skills and qualifications.

| Level 4 | Level 5 | Level 6 |
|---|---|---|
| Launch the application and access geo-information. | A prescribed spatial reference framework will set up a data capture environment. | Demonstrate a generic understanding of what GIS is. |
| Perform basic queries and data manipulation. | Use the appropriate feature type when capturing data. | Demonstrate an appreciation of the specialist knowledge needed to build a proper GI Science. |
| Produce primary product output. | Explain the basic theory and principles of spatial data models in data capture. | Demonstrate an understanding of how GIS can be used in different industries. |
| | Explain basic database structures for data capture. | Demonstrate an understanding of the functionality available from a GIS. |
| | Exploit big geo-data | |

Overall, GIS education is available at various levels, including secondary schools, colleges, universities, and through professional development programs. The goal is to equip individuals with the necessary knowledge and skills to utilize GIS technology in various industries and sectors effectively.

*GIS in the Workplace (Job Requirements and Work Scopes)*

Geographic Information Systems positions require technical skills, domain knowledge in geography, environmental science, and urban planning, and soft skills in communication, problemsolving, and project management. Advanced positions may necessitate programming, spatial statistics, database management, and programming proficiency. GIS professionals are advised to stay abreast with emerging technologies such as machine learning and cloud-based GIS platforms. GIS professionals play a crucial role in decision-making processes by providing valuable insights from spatial data analysis and visualization across various industries. GIS-related job requirements and scope vary significantly based on the industry and specific job functions. The relevance of GIS taught in higher education in South Africa to workplace requirements can vary depending on numerous factors [32,33]. These factors may include the curriculum alignment with industry requirements, practical skills development, industry collaboration, technology focus, soft skills, job market trends, and continued professional development [34,35]. To assess if South Africa's GIS education meets workplace needs, it is recommended to consult recent graduates, employers, and industry experts for feedback on strengths and areas for improvement. Some of the GIS-recognised practitioner registration standards and registration set by professional bodies are shown below.

1. The South African Geomatics Council (SAGC) 2024 regulates GIS practice in South Africa, stipulating the requirements and conditions for registration as a GIS candidate, technician, technologist, or professional. The Geomatics Profession Act (Act 19 of 2013) makes allowances for people from professions outside of GIS to register, provided the process follows the following stages:

- Completion of an academic qualification that complies with the particular branch and category (https://www.sagc.org.za/ (accessed on 15 May 2024)).
- Registration as a candidate.
- Completion of prescribed work-integrated learning.
- Successful completion of the SAGC Law exams and assessments.
- Registration in the respective category.

The registration process requires that an academic qualification offers particular Knowledge Areas (KAs), which are as follows:

- Fundamental KAs—Geographical Science: Geographical Science, Mathematics and Statistics, and Physical Science. The students should have geographical knowledge and spatial orientation knowledge.
- * Core KAs: Analytical models, conceptual foundation, cartography and visualization, design aspects, data modelling, and data manipulation. Students should have the ability to use GIS software to collect, process, and model data.
- Non-core KAs—Research methodology: The students should have the ability to conduct research projects.

Registration with the South African Geomatics Council (SAGC) is often a requirement in the GIS workplace; it is an added advantage in some work advertisements. This indicates that the GIS content in higher education has to adhere to the KAs stipulated by the Council, but this is not always the case. This creates a gap between higher education content and job requirements, which begs the following question: Are the GIS curricula relevant to what is required to what is needed in the workplace?

2. The South African Council for Natural Scientific Professions (SACNASP) Act of 2003 mandates the registration and practice of natural scientists in various fields, which are now gazetted in the amended schedule I of the Act (NOTICE 469 of 2021).

Some currently gazetted fields of practice related to GIS are listed as follows—the SACNASP's current Code of Conduct for registered scientists.

- Geospatial science, water resources science, environmental science, ecological science, atmospheric science, and conservation science (https://www.sacnasp.org.za/ (accessed on 16 May 2024)). The goal is to uphold high professional and ethical standards for the natural scientific workforce, promote science engagement in South Africa, and facilitate professional development and transformation.
- * Geological and Earth Science (Includes L4 Competent Natural Science Geo-Professionals). The Natural Scientific Professions Act of 2003 mandates all natural scientists to register under Sections (18) and 20(2)(a).
- Registration offers quality assurance of one's capability to current or prospective employers/clients. The Council stipulates that GIS content in the workplace must adhere to the code of conduct if a person is a practising natural scientist in South Africa. South African natural scientists must register under the Natural Scientific Professions Act to ensure legal compliance and quality assurance for employers and clients. The Act requires all practising natural scientists to adhere to Sections (18) and 20(2)(a). This may not always be the case, leading to a gap between education content and job requirements. This raises questions about whether GIS curricula are relevant to any sub-fields under appropriate fields of practice in Natural Science or are not a requirement in the workplace.

## 3. Data Identification and Methodology

### *3.1. Documentary Review of GIS Methods in Practice*

The study utilized specific search phrases to identify articles on "geographic information systems methods in practice" and "higher education curricula and practitioner registration standards in South Africa". The Scopus, Google Scholar, and Web of Science databases were utilized as search engines to review and search for English-only papers. The documentary analysis utilized a qualitative research method to review changes and transformations in existing research on geographic information systems methods in practice, higher education curricula, and practitioner registration standards in South Africa through peer-reviewed journal publications [33,34]. The content analysis was analyzed using GIS methods to align South African qualifications and practitioner registration standards [35,36], including SAQA, NQF requirements, SACNASP, and SAGC, with job market demands, ensuring effective data analysis in practice.

#### 3.1.1. Scientometric Mapping

Scientometrics is a widely used method that reviews academic research to develop a new approach and provide a scientific understanding of a niche research area [37,38]. This method encourages researchers to advance their specialisations, influencing academic affiliations and the thematic evolution of keywords through findings from review-based studies [39]. The literature has connected scientometric studies with a conceptual–theoretical review based on existing research or studies [27,29]. Scientometric analysis is a methodological approach used to assess the scope and appropriateness of research efforts in a specific area of expertise [16,37–39]. The analysis utilized the search phase "Geographic Information Systems Methods in Practice" OR "Higher Education Curricula" OR "Practitioner Registration Standards in South Africa" to retrieve published research documents and summarise our scientific findings on the research outputs. Zipf's law was used to select frequent author keywords that reflected the broader research subjects, directions, and trends of all publications in the field [40].

#### 3.1.2. Scientometric Data Identification and Processing

This study utilized the Scopus database for systematic data mining on 15 May 2024, as shown in Table 3. The scientometric analysis was conducted using the bibliometrix R-package (RStudio v.3.4.1 software) and biblioshiny, both open-source software designed for web interface use. The documents focused on GIS methods in higher education curricula and practitioner registration standards (HEC_PRS) in South Africa were retrieved from 46 articles published between 2004 and 2023. The databases were selected based on their reliability, coverage, efficiency, and high-impact scientific research [39,40]. This study used search criteria for Scopus based on these keywords: ("Geographic Information Systems Methods in Practice") OR ("higher education curricula") OR ("Practitioner Registration Standards in South Africa") AND PUBYEAR > 2004 AND PUBYEAR < 2023 AND (LIMIT-TO (AFFILCOUNTRY, "South Africa")). The search generated the titles, abstracts, and keywords (author keywords and keywords plus) of articles published between January 2004 and December 2023. Studies utilize precise titles and topics in databases to ensure significant recovery and minimal loss compared to multiple searches [37–40]. In addition, the retrieved publications included articles, proceeding papers, review articles, book chapters, editorial materials, book reviews, and books. The analysis used 46 articles from the Scopus database, specifically focusing on GIS methods in HEC_PRS in South Africa, as detailed in Table 3. The study involved 104 international authors with a global co-authorship index of 21.74% and 18 single-authored documents, contributing to advancements in scientific research publications on G_MFRA during the study period. The study evaluated published articles from 39 sources, with an average citation of 9.457 per document, 2.33 co-authors, and an average age of 5.09 per document. The annual percentage increase rate for citations per analysis article in South Africa was 12.88%, indicating a minor focus on GIS methods in practice to develop high school curricula and sustainability policies, as depicted in Table 3.

**Table 3.** Descriptive information on GIS methods in practice.

| Description | Results |
|---|---|
| Scopus | Database |
| Timespan | 2004–2023 |
| Sources (journals, books, etc.) | 39 |
| Documents | 46 |
| Annual growth rate % | 12.88 |
| Document average age | 5.09 |
| Average citations per doc | 9.457 |
| References | 0 |
| DOCUMENT CONTENTS | |
| Keywords plus (ID) | 13 |
| Author's keywords (DE) | 176 |
| AUTHORS | |
| Authors | 104 |
| Authors of single-authored docs | 18 |
| AUTHORS COLLABORATION | |
| Single-authored docs | 20 |
| Co-authors per doc | 2.33 |
| International co-authorships % | 21.74 |
| DOCUMENT TYPES | |
| Article | 31 |
| Book | 1 |
| Book chapter | 8 |
| Conference paper | 3 |
| Review | 3 |

## 4. Results and Discussion

### *4.1. Assessment of GIS Methods in Practice*

GIS methods are constantly evolving to meet specific spatial analysis and decision-making needs across various sectors and industries [41,42]. GIS practice encompasses data collection, management, spatial analysis, geoprocessing, cartography, visualization, modeling, decision support, web and mobile GIS, and spatial data infrastructure. Consequently, GIS courses and their applications enhance decisionmaking, critical thinking, and inquiry-based and learner-centred learning, improving education quality. GIS professionals utilize these techniques to provide valuable insights, address intricate spatial issues, and facilitate informed decisionmaking in both public and private sectors.

In response to the following question: Is the GIS taught in higher education in South Africa relevant to what is required in the workplace?We explored geography curriculum policies, GIS qualification requirements, and SAGC registration requirements. These are aligned at face value, limiting a skills shortage for GIS-focused jobs.

Can curricula and the South African Qualifications Authority (SAQA) and SAGC registration requirements align with what the job market requires? The relationship between geography curricula policies, GIS qualification requirements, and SAGC registration requirements can influence the skills shortage for GIS-focused jobs in South Africa. Each factor plays a significant role in controlling these requirements, as shown below.

1. Curricula Policies for Geography:

The relevance of geography curricula policies influences the content and structure of GIS education in South African universities [8,43]. An outdated or unsuitable curriculum can result in graduates lacking the crucial skills that employers require. Policies encouraging flexibility and innovation in curriculum design enable universities to adapt GIS programs to the industry's ever-changing demands. This can help to bridge the skills gap by ensuring that graduates have the necessary skills.

2. GIS Qualification Standards:

Precise qualification requirements for GIS-related programs ensure a standardised level of knowledge and skills among graduates, which can assist employers in evaluating job applicants' qualifications [41,42]. The degree or certificate specificity of GIS qualification requirements can significantly influence the level of skills that graduates acquire. Specialised programs can produce highly skilled professionals, while general programs may offer broader but potentially shallower knowledge.

3. SAGC Registration Qualifications:

The SAGC registration sets professional standards for geomatics practice, including GIS. Due to the requirements for registration and the influence of qualifications and experience, GIS education often emphasizes specific skills [8,43]. SAGC's registration ensures that practitioners meet specific standards, indirectly addressing skill shortages by upholding professional competence, as shown in Table 4.

**Table 4.** Impact on the skill shortages in GIS-based SAGC registration.

| Positive Impact | Negative Impacts |
|---|---|
| Clear geography curricula policies, GIS qualification requirements, and SAGC registration can help to address skill shortages by producing graduates with the required skills and credentials. | Overly rigid or outdated policies can hinder innovation and adaptability in GIS education, potentially leading to mismatches between graduate skills and industry needs. |

#### 4.1.1. Has the South African Curriculum Kept Pace with the Technological Advancements and Methods in GIS Practice?

South African geography curricula have adapted to incorporate Geographic Information Systems methods and technologies, keeping up with global geospatial trends [44,45]. South African education has integrated GIS methods and practices into its curricula through the following.

1. Integration into Geography Education: GIS have become a crucial element of geography education in South Africa. Schools- and university-level geography curricula frequently incorporate modules or courses centred on GIS concepts, applications, and techniques.

2. National Curriculum Statements: The South African Department of Basic Education has integrated Geographic Information Systems (GIS) into the National Curriculum Statement (NCS) for geography, especially in the Further Education and Training (FET) phase. This inclusion ensures that students are exposed to geospatial technologies and their practical applications.
3. Inclusion in University-level Programs: South African universities offer degree programs in GIS and related fields like Geographic Information Science and Geomatics. These programs extensively cover GIS methods and prepare students for careers in various industries where GIS is utilized.
4. Advancements in Research and Development: South African academic institutions and research organisations are actively involved in GIS research and development, contributing to its continuous evolution and integration into educational curricula.
5. Collaborative Initiatives: Educational institutions, government bodies, and private sector organisations collaborate to integrate GIS technologies into South African curricula. This collaboration ensures that educational content remains relevant and updated with technological advancements.
6. Market Demand and Employment Landscape: The increasing demand for GIS professionals in South Africa has influenced the integration of GIS into curricula. These curricula are designed to equip students with practical skills that are highly sought after in the job market.
7. Continued Professional Development (CPD): Initiatives are being implemented to offer continuous training and professional development in GIS for teachers and educators. This ensures that educators are adequately equipped to effectively teach GIS and stay abreast of the latest advancements in the field.

South African curricula have made significant efforts to keep up with the latest GIS methods and technological advancements. GIS and related fields curricula are constantly updated and refined to keep up with the latest trends and developments.

#### 4.1.2. Practitioner Registration Standards: Assessment and Challenges

The current state of higher education curricula includes GIS courses offered by universities and technical institutions, which prioritise theory over practical application [45,46], reflecting the increasing emphasis on theoretical learning in the field. For instance, professional registration faces obstacles like costs, geographic access, awareness, and disparities among graduates, highlighting the gap between academic training and professional needs. The educational backgrounds and regional inequities of registered practitioners can significantly influence their professional competency and readiness [47,48]. Regional disparities in GIS education are primarily due to course quality, availability, and economic and social barriers, disproportionately affecting remote or underserved students and rural institutions. Rural and underserved institutions face challenges like resource limitations, faculty expertise differences, financial constraints, and limited practical training, limiting their access to GIS technology and software. Additionally, the curriculum-industry misalignment gap highlights a lack of practical GIS skills in education and outdated technologies in academic programs, necessitating professional registration and certification of SAGC, SAQA, SACNASP and NQF requirements to ensure GIS practitioners adhere to these standards. This study emphasises the importance of geo-information access for employers to enhance skills and competencies, improve accessibility, and increase awareness.

The continuous assessment and improvement of GIS methods are crucial for maintaining the competence of GIS professionals and ensuring that GIS education remains relevant to industry needs. This assessment should evaluate GIS methods, academic performance, and professional certification data through strategies, professional development, industry collaboration, policy, and regulation. Consequently, regular reviews of GIS curricula are crucial for ensuring alignment and relevance, considering feedback from employers and practitioners. This study provides strategies for assessing current GIS practices, identifying areas for improvement, and implementing modifications to enhance their effectiveness in practice. South Africa can tackle GIS skill shortages by utilizing industry feedback, improving curricula, promoting professional development, fostering collaboration, and implementing robust policies. The goal is to equip graduates with essential technical, problem-solving, and soft skills, fostering knowledge exchange and curriculum enhancement through collaborations between academia, industry, and professional organizations. Addressing educational disparities can bridge the GIS skills gap, enhance spatial data analysis capabilities, and promote sustainable regional development.

### *4.2. Scientometric Analysis*

#### 4.2.1. Analysis of Top Author's Affiliations and Thematic Evolution of Keywords

Figure 1 shows the top 20 contributors to the publication outputs of affiliated institutions regarding GIS methods in higher education curricula and practitioner registration standards (HEC_PRS) in South Africa. The University of Cape Town (UCT) was ranked first and was closely followed by the University of South Africa (UNISA), with ($n$ = 6 articles, 13.04%) and ($n$ = 5, 10.87%) published articles. Other South African institutions and affiliated research centres, including the North-West University, Universitat Autonoma de Barcelona, University of Johannesburg, University of Botswana, and Coventry University, ranked among the top 20 contributors. Collaborative pathways among South African scholars were intra-national and very scant, as indicated by the few articles. This connotes that studies on GIS methods in practice in HEC_PRS are rare. However, only a few South-African-affiliated institutions have received attention regarding GIS education in practice. This may also be attributed to the challenges of incorporating GIS modules or subjects centred on GIS methods, concepts, and applications in high school curricula. On the other hand, the publication of articles in the field by affiliated institutions needs to be more prominent to keep up with the global trends in geospatial information science education. This implies that research erudition is mainly witnessed at UCT and UNISA, contributing to the total number of publications in South Africa, while a few came from internationally affiliated institutions. Specifically, the UCT Geomatics Department accentuates a shortage of professionals in surveying, geographic information science, and remote sensing [44]. Globally, affiliated institutions and research centres may have significantly influenced the structure of collaboration and funding for geospatial information science education at the national level. Studies indicate that South Africa has been enhancing its international collaborations through mobility funding initiatives, focusing on reviewing GIS applications in secondary schools and enhancing skills in teaching with or through GIS [36,45,48]. This may significantly influence the development of GIS education in South Africa at various levels, including secondary schools, colleges, universities, and professional development programs. As such, this may signal a notable increase in GIS education, including methods in practice, concepts, and applications, particularly in high school curriculum development.

The relationship between the top author affiliations and the thematic evolution of keywords in South Africa's GIS methods in practice is depicted in Figure 1. The thematic advancement, research clusters, and origin were determined by analysing the occurrence of key phrases in the field. The bar's height indicates the frequency of publications used to understand and visualize the thematic evolution of keywords over time [49,50]. The thematic evolution of the author keywords revealed stable themes clustered into the following three research timeframes: 2004–2018, 2019–2021, and 2022–2023 (Figure 1). The results show that the most stable author themes with a significant appearance were higher education transformed into teacher education in 2004–2018. The second segment of 2019–2021 reveals higher education and curriculum development interconnected to several methodologies used in the research domain. These methodologies may include experiential learning, e-learning, and 21st-century skills, which evolved into higher education curricula and became prominent in 2019–2021. The last segment of 2022–2023 shows that curriculum remains the most commonly used keyword theme in this field in recent decades. The literature suggests that teacher education, design thinking, lifelong learning, entrepreneurship, and sustainability education could be integrated into curriculum development, design, and review. Therefore, GIS education in South African higher education curricula and high school curriculum policy is still lacking. This indicates its minimal use, particularly in education research, in South Africa [8,43,44]. This draws attention to the gaps in research and practice methods, as well as concepts and applications of GIS in higher education and high school curricula. The Sustainable Development Goals emphasize promoting spatial intelligence and pedagogical skills in teacher-training universities for sustainable development. This aligns with the Education for Sustainable Development Goals, SDG 4, to promote lifelong opportunities and inclusive quality education, incorporating various sustainability themes [45,46]. South Africa's research efforts to integrate GIS methods into practice, including practical skills development, industry collaboration, and technology focus, have not been fully incorporated. Others include job market trends, concepts, applications, soft skills, and professional development. Many studies have not fully considered these aspects, resulting in the insufficient integration of GIS methods in HEC_PRS in South Africa [23,50,51]. Therefore, the thematic evolution of the author keywords highlights the scientific progress and research gaps in applying geospatial technologies to South Africa's higher education curricula and practitioner registration standards (Figure 1).

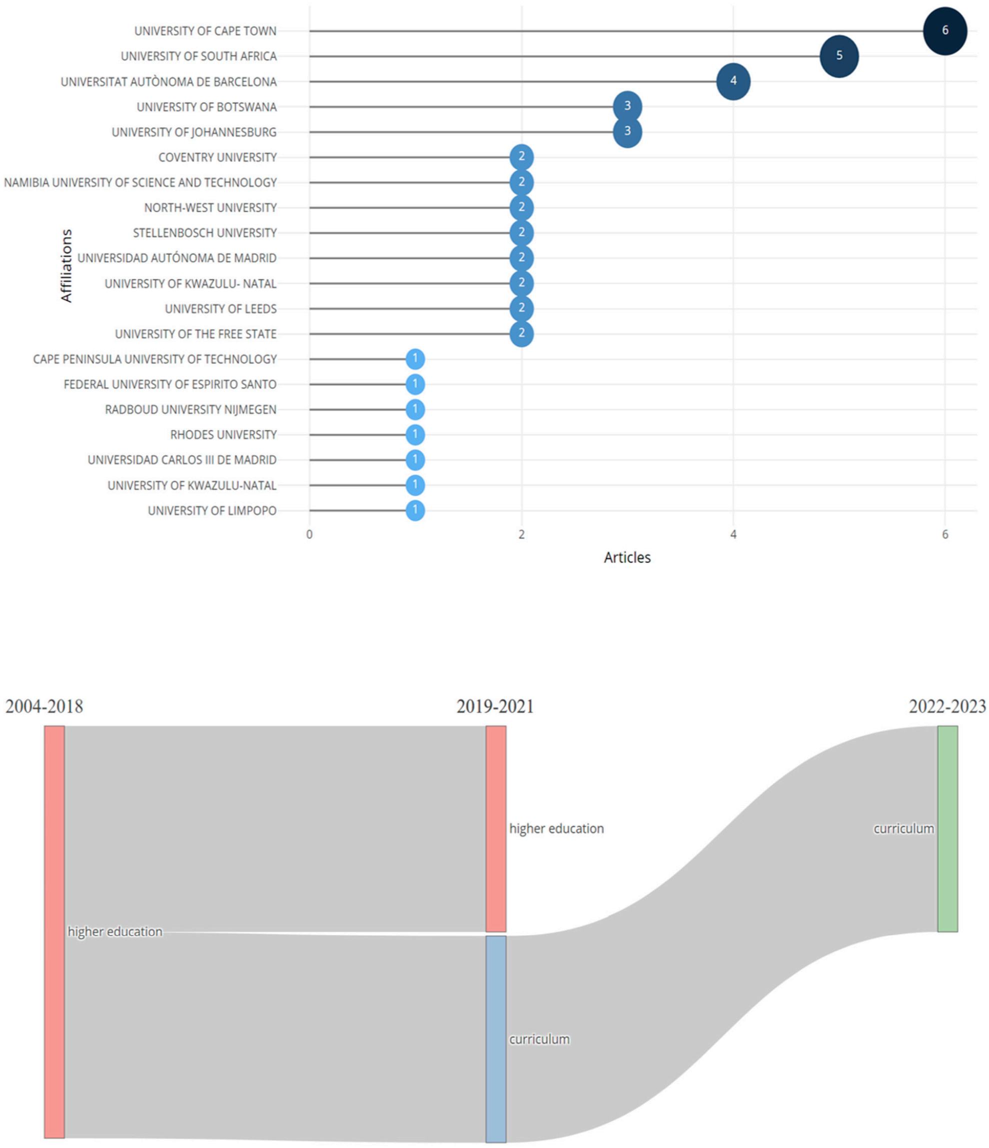


**Figure 1.** Relationship between the affiliations of top authors and the thematic evolution of keywords in South Africa's GIS methods in practice.

4.2.2. Analysis of Word Cloud Visualization

Figure 2 shows the word cloud of frequently occurring keywords in GIS methods in higher education curricula and practitioner registration standards (HEC_PRS) in South Africa. The word cloud visualization shows each keyword's strength and frequency within the literature, as indicated by size. The closer the keywords are to each other, the more likely their interrelation in the literature during the survey period. The word cloud visualizes the key terms in studies on GIS methods in HEC_PRS in South Africa, highlighting specific focus areas for future directions. For example, higher education, curricula, student, engineering education, learning, sustainable development, curriculum, and education. Other dominant terms are high education, e-learning, design, education computing, education curriculum, personal training, professional development, and perception, etc. The study reveals that higher education and curriculum are the main keywords in this niche area, based on the observed trends in GIS methods. Their development can be associated with the influence of curriculum development, design, and review on higher education curricula and policy [23,52,53]. The study of GIS methods in higher education and curriculum is undergoing continuous scientific innovation, which should be further advanced by addressing the identified gaps provided by these keywords. Keywords focusing on GIS methods, practical skills development, industry collaboration, technology focus, job market trends, concepts, applications, soft skills, and professional development did not significantly appear. South Africa's higher education curriculum incorporates word cloud visualization, utilizing GIS methods for sustainable development and modern technologies, emphasizing their interdisciplinary nature. Overall, the prominence of key terms like "higher education", "curricula", "students", and "teaching" underscores the centrality of educational institutions and their role in preparing students for professional practice within the field of GIS.. The identified gaps are crucial for advancing knowledge of GIS methods in HEC_PRS, particularly in South African high school curricula.

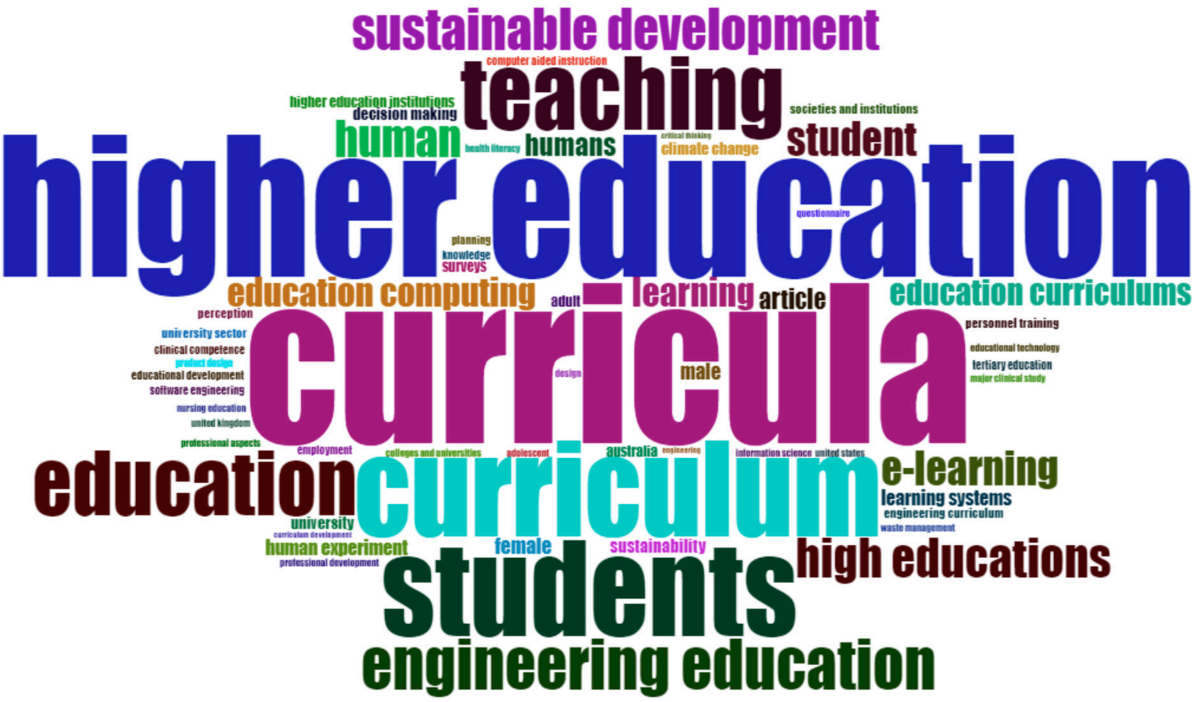


**Figure 2.** Word cloud visualization of GIS methods in HEC_PRS in South Africa.

*4.3. GIS Technology and Advancements*

Geographic Information Systems have revolutionised how we analyse and interpret spatial data, including data acquisition, processing, analysis, and visualization techniques [54,55]. Geographic Information Systems (GIS) have advanced significantly since their introduction in the 1960s, making possible their broad applicability in various fields [56,57]. GIS have played a vital role in various sectors of the economy and society, including transportation, public health, environmental management, urban planning, and disaster response [58,59]. Despite studies on their use in teacher training and retraining on GIS technology in high-income countries, GIS education is a relatively new field of study in southern African countries, particularly South Africa [45,48,60]. A study showed that only South Africa, Botswana, and Malawi teach GIS in their teacher-training universities and high schools, while Lesotho only teaches it in high schools [61]. In Zambia, Namibia, and Zimbabwe, GIS is not taught in teacher-training universities or high schools, but only applies to universities or departments that do not offer teacher training [62]. Moreover, GIS areis not offered at universities in Angola, Mozambique, Eswatini, and Lesotho [45,48]. In South African universities, including academic programs and industry demands, GIS education still needs to be improved, particularly in high school teaching and learning [7,48]. This study explores a comprehensive overview of GIS curricula in South Africa and their advancement in high school curriculum development and policy. The implementation gap delves into implications for policy, practice, research, and the prospects of GIS curricula. In addition to examining the societal effects and difficulties related to GIS implementation, it dives into the technical components, including data collection, processing, analysis, and visualization approaches. Developing GIS professionals through higher education curricula and practitioner registration standards (HEC_PRS) is crucial. There is a gap in the current state of GIS education in South African universities, including academic programs and industry demands [6,45,63,64].

The implementation gap in the HEC_PRS set by professional bodies has implications for the GIS workforce [11,35,65,66]. This study aims to enhance GIS education and professionalisation by addressing these alignments, fostering a skilled workforce capable of utilizing spatial intelligence for sustainable development. Examining the gap in curriculum development and associated GIS technology and methods is crucial in addressing societal challenges. This, therefore, would bridge the gap between higher education curricula and practitioner registration standards into promoting innovation in sustainability curriculum development. Over the years, one significant initiative in higher education institution curricula included subjects like Information and Communication Technology (ICT) [65,66]. Consequently, tackling socio-environmental challenges has extended beyond the conventional scope of ICT, which typically covers technology and services related to information processing, telecommunications, and electronic systems [66]. Satellite technology advancements have developed GIS tools to tackle socio-environmental issues like floods, drought, wildfire risks, air pollution, heat stress, greenhouse effects, and environmental degradation on local, regional, and global scales [67–70]. For instance, emerging technologies like machine learning, artificial intelligence, and predictive analytics have enabled tackling complex climate-related challenges [71–73].

South Africa's higher education curricula and practitioner registration standards have continuously been updated to keep up with technological advancements, a process similar to many other countries [74,75]. The country recognises the significance of incorporating GIS technology and methods into HEC_PRS. This initiative aims to equip students with the necessary skills for the contemporary workforce and the global economy. The implementation gap identified by professional bodies in HEC_PRS still lacks a full integration of GIS methods, particularly within South African curricula, to effectively align with technological advancements [35,51]. Therefore, these challenges identified in the body of the extant literature about implementation may be related to resource constraints and a lack of consultation with technical expertise in the field of study. The rapid pace of technological change has created challenges in incorporating GIS curricula into South African high school curriculum policy and ensuring that the curricula stay fully current [65,76]. Moreover, the limited access to technology in some schools and disparities in resources between urban and rural areas have also contributed to these challenges. This study proposes a holistic solution that incorporates this subject as a whole to equip students with digital literacy skills with ICT and the ability to effectively utilize GIS technology to co-design sustainability solutions to promote sustainable development goals in South Africa. There is a need to prioritise the holistic solution of these interconnected technological advancements by integrating technologies across various subjects to improve teaching and learning experiences. Hence, this study suggests further investigation into the integration of Geographic Information Systems methods in South Africa's curricula. The continuous review and adaptation of curricula are essential to address these challenges and ensure that South African students receive a relevant and quality education that prepares them for the future.

This study underscores the importance of adopting a holistic approach integrating ICT and GIS intelligence to leverage cutting-edge technology. This approach is essential for developing a skilled workforce capable of harnessing spatial intelligence for sustainable development. This all-inclusive approach calls for continuous teacher training and retraining on GIS technology, webinar series, in-person seminars, workshops, and collaborative efforts to co-design sustainability solutions. It emphasizes innovations in curriculum development and plenaries on education and workforce development. This approach can enhance discussions from the summer webinar series hosted by organisations like the National Service Scheme (NSS) and the National Senior Certificate (NSC) Examination, especially for higher education students. This will help them to achieve their goals by facilitating the informed implementation of GIS technology and providing valuable insights into its advancement. As a result, this serves as a valuable resource for stakeholders engaged in GIS education, including policymakers, educators, industry professionals, and students.

#### 4.3.1. Innovative Solutions to Addressing the Skill Shortages in GIS Methods in Practice

The field of Geographic Information Systems (GIS) is rapidly evolving due to technological advancements and the growing demand for spatial data analysis across various sectors [76–78]. South Africa faces a significant GIS skills shortage, necessitating a multifaceted approach involving technological innovation, curriculum reforms, professional development, and collaborative efforts to bridge this gap. Addressing the skill shortages in GIS methods in practice requires coordinated efforts by professional bodies, educational institutions, and government agencies. Partnerships between institutions and policy frameworks between SAGC, SAQA, and SACNASP are crucial for setting high standards for education and professional practice in the GIS workforce. Fostering collaboration between academia, industry, and professional bodies is crucial for addressing skill shortages and ensuring curriculum alignment with industry requirements. South African higher education can cultivate a proficient GIS workforce through innovative methods like e-learning, virtual reality, interdisciplinary programs, industry partnerships, and open-source resources. Strategic partnerships and continued investment in education and training are crucial for bridging the skills gap and maximizing the use of GIS technologies across various sectors. The goal is to ensure that qualification requirements are flexible enough to accommodate the diverse career paths within GIS. Strategic policy requires continuous review and updating to keep up with technological advancements and evolving job market demands. Geography curricula policies, GIS qualification requirements, and SAGC registration are crucial in shaping the skills landscape for GIS-focused jobs in South Africa, addressing skill shortages and ensuring that graduates are well-prepared for successful careers in GIS. The alignment of GIS curricula with South Africa's job market requirements is crucial, requiring collaboration between academia and industry. The regular evaluation and adaptation of curricula are crucial to ensure that graduates are well-prepared for successful careers in GIS, alongside SAQA requirements and SAGC registration standards. This study examined the alignment of South Africa's curricula requirements for GIS, SAQA, and SAGC registration and their influence on the skills and knowledge of graduates entering the job market.

#### 4.3.2. Limitations and Future Prospects in GIS Methods in Practice

Addressing educational disparities can bridge the GIS skills gap, enhance spatial data analysis capabilities, and promote sustainable regional development. This can bridge academic training gaps, promote uniform standards, and support the equitable advancement of GIS education and practice across South Africa, enhancing the overall skill set and promoting uniformity in industry requirements. Research centres and institutions face financial constraints due to the high costs of GIS software licenses, data acquisition, and field equipment, especially in low- and middle-income nations or remote areas. Moreover, many high school teachers and researchers often lack GIS training, hindering their ability to utilize its capabilities to equip students with highly sought-after practical skills in the job market. This hinders their capacity to acquire accurate and up-to-date spatial data. There is a need for collaboration between educational institutions, industry stakeholders, and government agencies to ensure GIS education accessibility and standardization in South Africa. GIS education necessitates specialized knowledge in spatial analysis, data processing, and visualization for efficient use, providing detailed insights into geographical features and effective stakeholder communication. Consequently, this review scope should extend into the policy domain to guide the development of GIS methods in South Africa's higher education curricula and practitioner registration standards, ensuring industry alignment and equitable professional access. The scientometric assessment suggests the need for further research on integrating various databases to identify potential developments, improvements, and future research directions.

## 5. Summary and Recommendations

The insufficient GIS education at South African universities, particularly in high school, is causing a gap between academic programs and industry demands, impacting the GIS workforce This study reveals that the disparity between higher education curricula and professional body registration standards significantly affects the GIS workforce. The assessment and approach described will aid the comprehension of GIS methods in South Africa's higher education curricula and practitioner registration standards (HEC_PRS). The study indicates that, despite adhering to policies and standards, the GIS curriculum's capacity to effectively meet market demands is uncertain due to insufficient job market research. Therefore, this study suggests the need for future research using questionnaire surveys to assess job market demands and ensure that curricula, policies, and standards effectively meet market demands. Furthermore, the study assessed South Africa's GIS practices, identifying research hotspots, top authors affiliation, the thematic evolution of keywords, and word cloud visualization in the intellectual domain. The University of Cape Town and the University of South Africa were the top two South African institutions contributing significantly to GIS research, indicating the need for empirical studies and potential solutions. The findings reveal that higher education and curriculum were the most significant keywords in preparing students for professional practice in GIS, emphasizing the role of educational institutions in this field. This study highlights regional disparities in GIS education, challenges in aligning with practitioner standards, and barriers to broader GIS applicability in South Africa, highlighting the need for further research and development.

The key results are associated with the significant roles of GIS curriculum development, design, and review in enhancing higher education curricula and policy, indicating their potential for curriculum advancement. Governments and institutions should integrate GIS and pedagogical skills in teacher-training universities to bridge the gap between higher education curricula, market demands, and employment opportunities. This study recommends that future research re-evaluate the content of South Africa's GIS-specific qualifications and compare it to global market standards. Moreover, collaboration with GIS industries can aid scholars in comprehending their expectations for potential employees and pinpointing areas for enhancement in future recruitment. The findings reveal research hotspots and the current GIS education curricula in South African universities and high schools, providing insights into market demands and employment opportunities for GIS-focused jobs. This study contributes to advancing GIS methods in practice, achieving the SDGs for educational outcomes, and promoting quality education and lifelong learning opportunities.

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