A new approach to volcanic geoheritage assessment in the Auckland Volcanic Field, New Zealand

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Abstract

The concept of conserving geoheritage was announced in 1991 because of concern about the disappearing geological and geomorphological integrity from the Earth's surface. The degradation imposes a high risk on resilience and future scientific work. Geology-related research has primarily been linked to natural hazard mitigation studies and mineral resource exploration and management. In this study, we build a conceptual framework for geoheritage conservation to incorporate geoeducation into land use planning in Auckland. The study's main goal is to assist geoheritage conservation initiatives in the Auckland Volcanic Field (AVF) by providing a synthesis of concepts and their integration into a GIS environment for successful policy implementation. In the lack of clearly defined values, the valuer must rely on their own perception of value that is shaped by cultural, economic and scientific background. The peer-reviewed scientific literature contains a collection of concepts that need to be organised into a framework. The difficulty of quantifying the benefits of protecting scientific value led to the inclusion of cultural, touristic, aesthetic, recreational and biotic values. Scientific value in the light of economic benefits can be easily overviewed as we revealed it through a meta-analysis of influencing factors on the conceptual background of geoheritage implementations. A conceptual framework must reinforce Geoeducation as the essence of geoheritage. Geopreservation Inventory is the result of a collaboration of New Zealand Earth Scientists under the leadership of Bruce Hayward. The recognised geoheritage sites still wait for recognition and inclusion in urban planning under a clarified geoheritage preservation plan. From a broad aspect, the outstanding features are all small-volume volcanoes, but the inventory clearly reflects their diverse nature. It is seen from the map that none of the features that were assigned the highest importance is typical tourist destinations. The landforms are classified by the Topographic Position Index of the area based on the one-meter digital elevation model produced from high-resolution light detection and ranging (LiDAR) point cloud data. The classified landforms, geology map and Geopreservation Inventory are aggregated into a Geoeducational Capacity Map. The high geoeducation capacity areas are compared with the areas receiving high visitation in order to understand the role of scientific value in land use planning. The high indigenous value of geoheritage sites is assessed from a cultural aspect. The communities need to be involved with promoting geoeducation from geoscientific and indigenous aspects to increase the depth of geoheritage and bring the concept closer to the society to create resilience and a sense of respect for the relicts of geology.

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Terminology

Geoheritage in our study means sites of geological and geomorphological interest. The extent of the site ranges from the size of an outcrop to the size of a well-defined landform. Geoheritage value is interpreted as an aggregated set of different objectives of geoscientific, geoeducational, recreational, and geoconservation aspects.

Geoconservation means any manifestation of pursuing the conservation of geological and/or geomorphological geoform or feature.

Geodiversity applies the entire range of rock formations, minerals, fossils, soils, water, landforms/geoforms and natural processes that created them. It is considered the abiotic equivalent of biodiversity.

Geoeducation sites mean specific geoheritage sites of high scientific value and high efficacy in assisting the public in the process of visualisation of revealed geologic processes.

Geosite means any geological, geomorphological outcrop or landform/geoform with the potential to become a geoheritage site.

Geomorphosite means a specific type of geoheritage of outstanding geomorphological interest.

Geopark means a designated non-confined area containing one or more geoheritage sites along with cultural displays strictly managed by local communities. Sites of geoheritage interests are organised into a facilitated network of interpretive stations.

Geosystem Services means the geological, geomorphological and geoeducational elements of ecosystem services.

Ecosystem Services are the benefits to humans provided by the healthy relationship of the five systems of Earth: geosphere, biosphere, cryosphere, hydrosphere and atmosphere.

Sustainability is a wide concept established to minimalise and potentially reverse harmful effects of industrial development on human rights, communities` wellbeing and the natural environment. The consumption of the present generation should not by any means be at the expense of future generations. In the case of our study, sustainability mainly implies the restructuring of the tourism industry into a locally based, community-oriented geotourism that aims to provide knowledge for visitors along with the recreational experience.

Open Space means areas within urban development that are available for public for recreational purposes and are under the management of the local or regional authority.

Economics in our study is considered to be orthodox that follows rational choice theory. Decisions are made to maximise utility and are based on statistical and mathematical models to evaluate economic developments.

Chapter 1. *Introduction*

This chapter introduces the background to research geoheritage especially, to studies that proposed the concept and methodology for geoheritage evaluation. An extensive comparison is made among a range of existing geoheritage evaluation methods. This chapter also explores the geoheritage-associated research on geodiversity and geotourism and the alternative GIS-based value assessment methods used in other branches of nature conservation and land use planning.

Chapter Contents

Chapter 1. The geoheritage conservation initiatives from around the world

1.1. Background

This research focuses on defining the degree of reliability of the available geoheritage assessment methods. This study places special focus on leveraging geospatial analysis in order to enhance spatial accuracy and comparability of the geoheritage assessments. Building an evidence-based assessment tool is imperative to generate successful decision-making outcomes in geoconservation. Conservation Acts` (e.g. Resource Management Act, Reserves Act) primary concern is the protection of the biosphere with a critically low focus on the lithosphere, despite its vital role in an ecosystem (Avtzis et al., 2018; Evers et al., 2018; Mair et al., 2018). The essence of geoheritage is the 4,6 billion years of Earth's history enclosed in the lithosphere, the rigid, outermost rocky shell of the Earth's rocks and minerals. Tectonic processes shape the Earth's surface through interactions among the mantle, lithosphere and the hydro-atmosphere. The shapes are mountain ranges, deep valleys, volcanoes, huge plains, and flat areas showing us the story of their genesis. These different shapes also provide fundamental habitats that determine the existence of the biosphere and the urbanised modern society. The lithosphere is vital to humans as this is also the part of Earth that supports us, provides for us and gives us a wealth of materials to use. Its providing capacity is becoming severely depleted by the ever-growing human population. It is one of the main responsibilities of the contemporary population to protect, preserve and, if needed, restore our abiotic environment through sustainable planning (Eder & de Mulder, 2009).

Extreme population growth on Earth, alongside rapid industrialisation, has placed a high demand on natural resources that has resulted in the deterioration of the environment (AbdelMaksoud et al., 2018; Chan & Godsey, 2016; Santos et al., 2017). In 1991, geoheritage (Anonymous, 1991), a new branch of nature conservation, emerged in geosciences aiming to satisfy the need for developing successful geoconservation programs. Its main goal is to prevent unnecessary loss of geological and geomorphological sites. Even though numerous studies have been devoted to formulating sound geoheritage concepts, the principles of the discipline are still heavily debated. The lack of agreement regarding the definition of the core concept of geoheritage limits the proper development of geoconservation ideas and practices. The first use of the term by Bradbury (1993) describes geoheritage as "those aspects of the Earth which are important to our understanding of Earth's history. The nature of geoheritage sites, which are akin to cultural heritage sites or documents, means that they are non-renewable resources". However, the main aim behind all geoheritage endeavours is to define areas, or geosites/geomorphosites, that need to be preserved for future generations for purposes such as geotourism and geoeducation (Bradbury, 1993; Brilha, 2016; Brocx & Semeniuk, 2007; Bruschi & Cendrero, 2005; Bruschi et al., 2011; Coratza & Giusti, 2005; Dixon, 1996; Erikstad, 2008; Henriques et al., 2011; Németh et al., 2017; Németh & Moufti, 2017; Pereira & Pereira, 2010; Pereira et al., 2007; Wimbledon, 2011a). There are multiple strikingly different approaches to defining the exact scope and scale of geoheritage and arranging all the related terms into a conceptual framework (Reynard & Brilha, 2018a, 2018b). The elements of these concepts – geoconservation, geotourism, geodiversity, geoheritage sites, geoparks, geosites, geomorphological sites, and geomorphosites – carry conflicting attributes in different assessment frameworks opportunity thus given for scientific debates upon geoheritage site designation (Brilha, 2018; Rybar, 2010).

The main aim of geoheritage is to preserve geology of outstanding value in varying scales and for various purposes. The various objectives (tourism, education, community engagement etc.) make it challenging to define the exact scope of geoheritage conservation. In this research, the geologic sites or geosites are interchangeable terms meaning the unit of landforms representing the region's morphogenetic processes and which are subjects of geoheritage conservation (Ilies & Josan, 2009; Moufti & Nemeth, 2016). Before discussing the magnitude of scope and scale of these features, it is worth mentioning that the general motivation behind securing geoheritage at all levels of public administration as a new conservation discipline is to encourage people to look at the world through the prism of geology and reflect on the story of the given geoheritage site. Raising awareness creates a sense of belonging that draws habitual care and attention toward the geologic feature (Oakes & Price, 2008). In addition, these sites provide insights into the evolution of Earth, into the history of science and reveal the influence geology has on the progression of our recent lifestyle.

1.2. Geoheritage as an emerging discipline

The The United Kingdom is considered the birthplace of modern geology discipline (Brocx & Semeniuk, 2007). The increasing knowledge about the processes and elements that form our environment shed light on the immense diversity of the landforms and generated studies for defining the abiotic equivalent of biodiversity. Geodiversity is the natural range of geological rocks, minerals, fossils and geomorphological forms (Gray, 2004). The term geo-heritage emerged to express the need for the protection of the elements of geodiversity, and the efforts toward achieving it are called geoconservation (Brocx & Semeniuk, 2007). Such actions are, for example, the Geodiversity Action Plans (GAPs), the establishment of geoparks or inscription of a geosite as a World Heritage Property developed by the United Nations Educational, Scientific and Cultural Organization (UNESCO). GAPs are widely used in the UK to inform and record an action for geodiversity and geoconservation that is often carried out by local, county-based groups resulting in record-keeping of Regionally Important Geological and Geomorphological Sites (RIGS) (Burek & Prosser, 2008; Whiteley & Browne, 2013). The GAP concept works equally at all scales through the UKGAP website that was launched in 2011. Site adoption by local groups ensures site and access improvements, site-specific information panels, public programmes, lectures and workshops (Whiteley & Browne, 2013). The same concept spread across the globe, and other countries adopted the same structure to monitor geoconservation activities, however, under the control of various organisations. Mainly the geological survey of the given country steps in to develop and maintain an inventory of the outstanding geoheritage features and geoconservation activities (Geological Survey Ireland, 2018; Servicio Geologico Colombiano, 2018; The Geological Society of America, 2011).

Typically, an area set aside by a national government for the preservation of the natural environment is called a national park. The discipline of geoheritage roots in the idea of enabling national parks to educate the public through geosites of different sizes that will explain the dynamics of Earth. Improvement in the effectiveness of geoheritage interpretation has led to the establishment of geoparks that are to be used as a means of information delivery. Geoparks utilise geotourism as a complete contextual communication system (Ren et al., 2013). A geopark is a geographically defined area containing geoheritage sites selected on the basis of scientific, cultural, archaeological, ecological or historical importance (Nowlan et al., 2004). The ultimate goal of the geoparks program is to provide a better understanding of geological heritage and wise use of the Earth while fostering local economic development (Ren et al., 2013). Since geology has no administrative borders, these geoparks showcase their international significance by joining together as the Global Geopark Network. The first Global Geoparks were established in 2004 in Europe and China (Abberley & Malvern Hills Geopark, 2018) (UK: http://www.geopark.org.uk/; Astroblème Châtaigneraie Limousine, France: http://www.europeangeoparks.org/?page_id=1152; Danxiashan Geopark, China: http://www.globalgeopark.org/aboutGGN/list/China/6405.htm; Vulkaneifel European Geopark, Germany:https://www.geopark-vulkaneifel.de/en/networks/european-geoparks/595-veg.html). Later in 2015, the request of the Global Geopark Network to be united and managed under the umbrella of UNESCO was accepted with the creation of the International Geoscience and Geopark Programme. At present (2020), there are 161 UNESCO Global Geoparks in 44 countries.

UNESCO Global Geoparks empower local communities through exclusive partnerships that enable them to reconnect with their landscape. Their area's significant geological processes, features, and periods of time are promoted through geoeducational and cultural activities. Although the first geoparks were formed within formally protected national parks, they soon began to appear anywhere around the world, including urban agglomerations. The reason, on the one hand, is that the number of geoparks outgrows the confines of formally protected regions. On the other hand, the geopark movement currently acts as a trigger mechanism to highlight the need for geoconservation; hence commonly, new geoparks form the basis of the establishment of new protected regions. Geoparks are not designed to restrict any existing land use/land management practices within their boundaries but to facilitate taking reasonable measures to recognise and protect geoheritage features (Cabo de Gata Nature Reserve: https://www.cabogataspain.com/, Iberian Pyrite Belt Geosites:http://www.igme.es/patrimonio/GEOSITES/Chapter_04_SGFG.pdf, Naturpark Erzgebirge: http://www.naturpark-erzgebirge-vogtland.de/).

Geoheritage evaluation is fundamentally not carried out to establish geopark; in fact, the most adapted geoheritage evaluation methods were developed to aid national inventories or national/regional conservation management and planning. Inventories form the basis of geopark establishment.

The World Tourism Organization (http://www2.unwto.org) - a specialised organisation of the United Nations for tourism issues - has endorsed ecotourism and sustainable tourism since the 1990s. In 2012, a resolution on the "Promotion of ecotourism for poverty eradication and environment protection" was adopted by the Second Committee of the United Nations

General Assembly, and two years later, the General Assembly adopted the resolution "promotion of sustainable tourism, including ecotourism, for poverty eradication and environment protection" (Reynard & Brilha, 2018a; United Nations, 2014). The notion, beyond promoting sustainability, is to encourage respect toward the environment and local societies and lead to increased recognition of the importance of geological features. Consequently, in 2014 the International Union for Conservation of Nature (IUCN) established a Geoheritage Specialist Group within the World Commission on Protected Areas (WCPA) (Reynard & Brilha, 2018a; Woo, 2017). This group follows four main objectives: (1) to establish Best Practice Guidelines for geoheritage management in protected areas; (2) to revise the IUCN study on volcanic sites of outstanding values (Wood, 2009) (3) to revise criterion viii (to be outstanding examples representing major stages of Earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features /https://whc.unesco.org/en/criteria/ accessed: 07.06.18) (4) to initiate a `Key Geoheritage Site` concept (Reynard & Brilha, 2018a). The idea that sustainable regional development could emerge from the protection and enhancement of the geological heritage has given rise to numerous publications since the millennium.

1.3. Geoheritage evaluation methods

Due to the extensive work on the subject, there has been a global recognition of geoheritage importance, but without regard to a general protocol, that addresses the matter of scope and scale of geoheritage. Approaches vary, reflecting different objectives by different stakeholder groups (Figure 1).

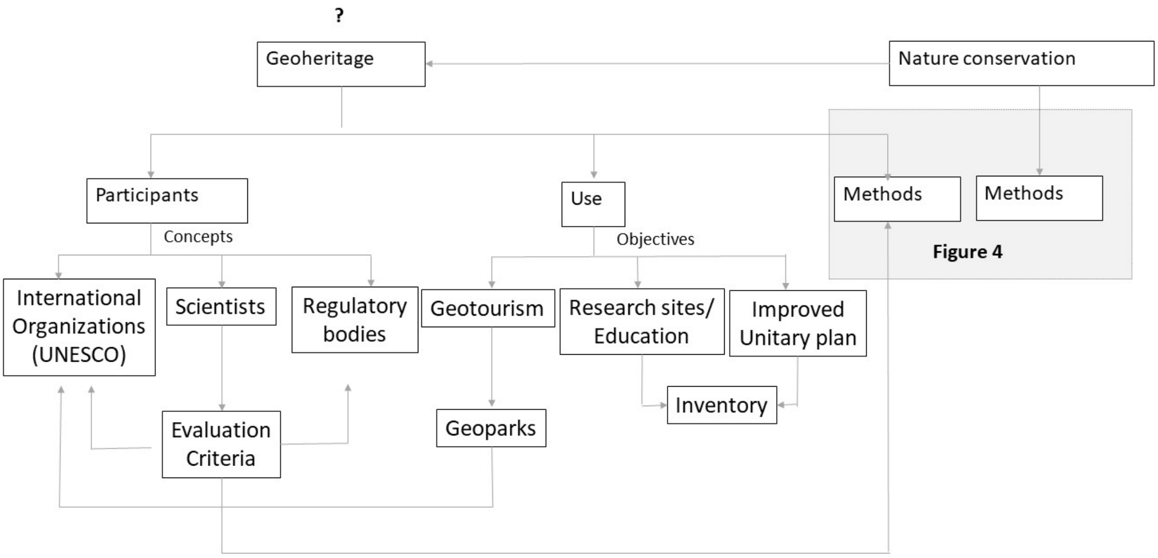

Figure 1 What is geoheritage? Integration of the elements of the geoheritage literature. Implementation of geoheritage conservation initiatives depends on the concepts of the leading practitioners. This figure explains that the geoheritage conservation method is different to nature conservation methods. The evaluation criteria defined (see Figure 4) by scientists are influenced by geotourism and the field of scientists preparing the evaluation. The objective of geoheritage inventory is to record geoeducational sites to make them visible in unitary plans that feed into geotourism and not the way around.

1.3.1. Conceptual background for selecting evaluation criteria

The first and foremost step toward successful geoconservation is the identification of the potential geoheritage sites. Having knowledge of all aspects of an area is essential in establishing evaluation criteria. Very often, the criteria used to select geoheritage sites are not explained. Geoheritage assessments generally lack one of the following successive steps: There has to be (1) an explicit conceptual framework that is mutually approved by stakeholders, (2) followed by a process of elimination (determining constraints) and (3) the explanation of objectively measurable criteria.

Conceptual conflicts form a barrier to successful decision-making to protect geoheritage. The lack of agreement on the core basis of geoheritage values reduces the criteria validity and, consequently, the reliability of the used assessment method (Crofts et al., 2021). Spatial scale and the magnitude of significance (international, national, regional etc.) of geoheritage protection are some of the main topics heavily debated in the scientific literature. Studies offer solutions such as Brocx and Semeniuk (2007), however, no consensus has been reached. It is still not determined whether geoheritage value is of local, regional, national or international significance and whether the spatial extent is potentially as large as a landscape or as small as an individual crystal. The only convention that incorporates geological heritage, UNESCO, explicitly and exclusively recognizes features of international significance and of the large spatial extent of an area. According to the guidelines written by the United Nations Educational, Scientific and Cultural Organization (UNESCO), a heritage site has a single or combined attribute of 'outstanding universal value' (Migoń & Pijet-Migoń, 2018; UNESCO, 2015). The global perception of the value of our geological heritage is therefore associated with it, leading to unnecessary loss of geoheritage resources that might not accommodate international but regional importance. In the following section, this study depicts a detailed analysis of the available geoheritage assessment methods and ideologies in order to identify major conflicts and agreements in the scientific literature.

1.3.1.1. International organisations: UNESCO/IUCN/Global Geopark Network

The UNESCO world heritage site (WHS) status is considered a symbol of quality and a seal of approval (Adie, 2017b; Ryan & Silvanto, 2011b). Branding provides a framework for managing the image of a place. The UNESCO WHS label is a cost-effective marketing tool for boosting tourism anywhere in the world, but it is particularly important for developing countries in generating economic growth (Ryan & Silvanto, 2011b). Explanation by UNESCO that the heritage site has a single or combined attribute of 'outstanding universal value' means that the cultural and/or natural significance is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole (Migoń, 2018). The advisory body to the World Heritage Committee on Natural Heritage is the International Union for Conservation of Nature (IUCN www.iucn.org).

The roles of the advisory body are to advise on the implementation of the World Heritage Convention, to assist in the development and implementation of the UNESCO WHS strategy, to evaluate the properties nominated as WHS and to monitor the state of conservation. IUCN`s mission is to bring together national governments and scientists in a worldwide partnership and to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable (UNESCO, 2017). UNESCO published a guideline in 2002 for an international program to refer to territories with unique geological landforms typical of certain geological evolutionary history (Xinhua News Agency, 2004). UNESCO WHS are typically focused on cultural value or on the link of cultural development to its natural environment and less on the geological story of an area. Whereas it is recognised that geology is important for a sustainable future, much still remains to be done to equalise geology, nature and culture in heritage protection.

The geoparks initiative was originally founded in 2000 with the creation of the European Geoparks Network (EGN) (Ramsay, 2017). In 2004, the European Geoparks Network and 8 Chinese geoparks joined at UNESCO headquarters in Paris to form the Global Geopark Network (GGN), which later, in 2015, achieved the creation of the label, UNESCO Global Geoparks for the better recognition of the importance of managing outstanding geological sites and landscapes at international level (Erfurt-Cooper, 2010; Jones, 2008; Ren et al., 2013; UNESCO, 2016a). UNESCO Global Geoparks use their geological heritage, in connection with all other aspects of the area`s natural and cultural heritage, to enhance awareness and understanding of key issues facing society. It addresses how to use Earth`s resources sustainably in a way that gives local people a sense of pride and consequently strengthens their identification with the area (UNESCO, 2016a).

1.3.1.2. European geoheritage concept: ProGEO

According to Wimbledon (1999), geoconservation is an activity of importance to all geologists: It is a vital support to the prosecution of geological research, education and training. Geomorphological sites and terrains of outstanding global significance merit recognition on par with other internationally significant sites, such as those protected for wildlife or their wilderness or cultural value.

The GEOSITES project was set up by the International Union of Geological Sciences (IUGS**)** on behalf of the international geological community, focusing on identifying globally significant sites and compiling an international inventory. IUGS initiated the " GEOSITES " project, which is now also supported by UNESCO, to address the problem of having no international listing of key earth science sites, no inventory, and no database. The other objective was to register geologists' ambitions toward having a representative selection of internationally significant sites included in world and regional listings. Finally, the aim beyond inventorying geoheritage was that simply involving more geologists in such activities would incidentally help to raise awareness nationally of the need to protect geoheritage (Wimbledon, 2011a).

The new Global Geosites project, under the guidance of the IUGS Global Geosites Working Group (GGWG), aims to produce an evolving, comprehensive inventory of the most valuable sites for geology. It is a global inventory and an allied comparative assessment for the designation of geoheritage sites all around the globe to minimise subjectivity embedded in geoheritage assessments (Wimbledon, 2011a).

The concept is based on a lesser number of sites that might have sufficed to demonstrate global patterns. The inventory presents a limited but representative set of sites to produce a balanced coverage between countries and regions. This group of sites represents many of the truly significant processes and events, time periods, features and topics of geology and geomorphology. It is important to have a global inventory because if sites are viewed in isolation, the result is a fairly random product, leaving too much to chance (Wimbledon, 1999). Geosites of this inventory are the sites best representing processes and features through geological time or large-scale geologic events that have been recorded during the 4.6 billion years. In this inventory, only scientific value is taken into account to avoid pitfalls and subjective approaches. The evaluation method is comparative and thematic. The objective is to compare sites` interests and their merits in a defined framework – topic, event, time, and regional geotectonic element. Sites are not to be selected in isolation but in a chosen context (Erikstad, 2013; ProGEO, 2011; Wimbledon, 1999).

The purpose and uses of the sites are to compile the geosite inventory for geoconservation. However, the project brings workers together in many countries, offering possibilities for cross-border cooperation and opportunities to promote the methodical compilation and documentation of listings. ProGEO (international association for the conservation of geological heritage) is acting as an agent for IUGS. The framework is based on four objectives that target (1) to extend the network of involved specialists in each country, (2) to identify the vital elements of the geology of the country, (3) select geosites and (4) use the standard recording format (ProGEO, 2011; Wimbledon, 1999, 2011a). In June 2021, the General Assembly decided to expand its geographical scope, and now ProGEO is an international association (www.progeo.ngo).

1.3.1.3. Geoconservation framework: José Brilha

The most recent framework for the scope and scale of geoheritage (Figure 2) was published by Brilha (2016), introducing a new approach that links geodiversity and geoheritage together. The concept is based on the theory that the need for conservation is recognised first by geoscientists when accessing representative geodiversity elements (minerals, rocks, fossils, soils, landforms, etc.) to obtain research data. Therefore, according to this concept, the main purpose of geoconservation is to protect such sites from allowing their scientific use by present and future geoscientists.

Brilha (2016) proposes a systematic approach suggesting that geoconservation is about identifying, protecting, and managing the valuable elements of geodiversity. Brilha (2016) also provides a new definition for geoheritage, saying that geoheritage sites are either in situ occurrences of geodiversity elements with high scientific value or ex situ occurrences displaced from their natural location, maintaining high scientific value. Both in situ (e.g., Columnar jointing in the basalt of the Giant`s Causeway in Northern Ireland) and ex situ (e.g., Devonian Trilobites of Morocco displayed in the Natural History Museum, London) geoheritage sites may also have educational, aesthetic, and cultural value. However, a site with only educational and/or touristic value is called a geodiversity site. A geodiversity site that is part of geodiversity but does not carry the imperative scientific value cannot qualify as a geoheritage site.

This concept proposes restriction on the use of the term `geosite` to only the occurrences with scientific value, hence the introduction of the term ‘geodiversity site’. As mentioned above, geodiversity sites would be those that do not have particular scientific value but are still important resources for education, tourism, or the cultural identity of local communities. (Brilha, 2016, 2018; Brilha et al., 2018).

The concept also offers a solution for the scale of significance problem: Considering that geoheritage is measured by scientific value, the relevance of geoheritage can only be international or national because there is no `local science`. Finally, the concept also proposes a guideline for geoconservation strategy, stating that it is made up of five successive steps that should always be followed; inventory, quantitative assessment, conservation, interpretation and promotion, and monitoring of the sites (Brilha, 2016, 2018; Brilha et al., 2018).

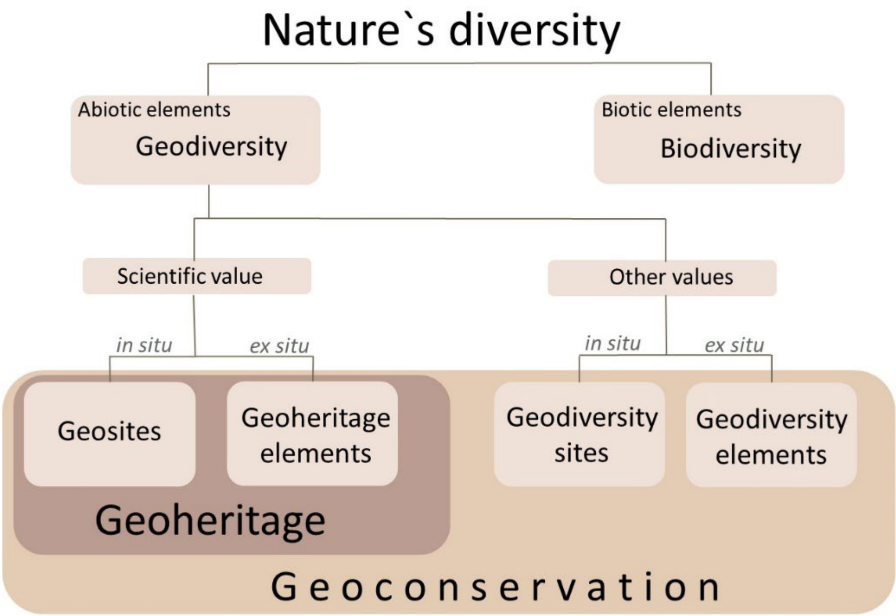

Figure 2 Conceptual framework for geoconservation strategies established by (Brilha, 2016)

1.3.1.4. Geodiversity: Murray Gray

A study by Barthlott et al. (1996) describes biodiversity as mainly the consequence of an area's geodiversity (the diversity of abiotic factors), and geodiversity as a quality is in its own right of the same order as biodiversity. Fassoulas et al. (2012) interpret the above-mentioned definition as that geodiversity represents the diverse products of all of Earth's history of geological as well as atmospheric processes and their interactions with the biosphere and, more recently, with the human race.

Outstanding and unique geodiversity features within an area constitute a geological heritage that merits conservation (Gray, 2008a). Geodiversity is defined by Gray (2004) as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, physical processes), and soil features, including their assembles, relationships, properties, interpretations and systems. The term's first appearance was in Tasmania at the beginning of the1990s (Sharples, 1993) when the Tasmanian geoscientist drew parallels between biodiversity and geodiversity, indicating that nature consists of two equal components, living and non-living (Gray, 2005). The term has gained international acceptance and became an integral part of the Australian Heritage Charter (Australian Heritage Commission, 1996) and widely used in Scandinavia (Johansson, 2000), in the United Kingdom (Dunlop et al., 2018; Gray, 2004) in China (Wang et al., 2015) and in Brazil (Manosso & de Nóbrega, 2016). The United Kingdom has introduced a method called the Geodiversity Action Plans (GAP) to record geoconservation activities carried out by local, county-based groups. The purpose of the plan is to establish clear targets for geodiversity audits, in addition to monitoring, funding and policy influencing (Dunlop et al., 2018).

The geodiversity concept has been used to select geoconservation sites in many countries. Its use is also increasing in guiding the nomination and assessment processes for geological World Heritage Sites (Gray, 2008b). Gray (2018) describes geodiversity as the backbone of geoheritage, as geoheritage sites are those parts of the `identified geodiversity of the Earth that are deemed to be worthy of conservation because of their importance/value.' According to this concept, the currently favoured way of assessing the value of the natural environment is to analyse the ecosystem services. Ecosystem services are the goods and functions of an ecosystem that benefit society (Gray, 2011). Most published works on ecosystem services refer mainly to biotic services; therefore, the concept clarifies that the ecosystem includes the abiotic components of habitat. Geodiversity is the abiotic equivalent of biodiversity, and in view of this, geosystem services are to be recognised as the goods and functions associated with geodiversity (Gray, 2008c). Since the early 2000s, there has been increasing recognition of the wider values of geodiversity involving historical and cultural heritage values.

Biodiversity conservation, sustainable land management, economic development, climate change adaptation and societal well-being (Gordon et al., 2012; Hjort et al., 2015) form the building elements of ecosystem services (Millennium Ecosystem Assessment, 2005b). Geodiversity is considered a non-renewable capital asset, the key component of ecosystem services (Gordon & Barron, 2013; Gray et al., 2013). Geosystem services deliver many essential supporting services, including habitat, soil formation for the biosphere, water cycling, entire ocean basins, or mountain ranges that provide explicit indicators for the distribution of biodiversity (Anderson & Ferree, 2010; Hjort & Luoto, 2012; Schnitzler et al., 2011).

1.3.1.5. Geotourism

Geoheritage studies adopting the term geomorphosites repeatedly refer to the extensive work done by Mario Panizza and Vincent Grandgirard on establishing a conceptual framework for geomorphosite assessment (Bâca & Schuster, 2011; Bollati et al., 2018; Bollati et al., 2017; Brilha, 2016; Carton et al., 2005; Erhartič, 2010; Fassoulas et al., 2012; Kubalíková, 2013; Mocior & Kruse, 2016; Moroni et al., 2015; Palacio Prieto, 2013; Pereira & Pereira, 2010; Rapprich et al., 2017; Reynard, 2005, 2009; Štrba et al., 2015; Wang et al., 2015). Geomorphosites are geomorphological landforms that have acquired a scientific, cultural/historical, aesthetic and/or social/economic value due to human perception or exploitation (Panizza, 2001). The concept starts with the theory that the scenic value particularly depends on the spectacular and intrinsic aspect of a geomorphological site because it is based on natural rarity, didactic exemplarity, palaeogeographical testimony, and ecological value of a geomorphological site (Panizza, 2001; Panizza & Piacente, 1991; Panizza & Piacente, 1993). In contrast, the cultural value depends on an art event or a cultural custom in relation to a geomorphological site. Lastly, economic value is based on a geomorphological site's usable and workable characteristics (e.g. in a tourist and recreational context) (Panizza, 2001; Pralong, 2005; Pralong & Reynard, 2005). Panizza (2001) proposes his concept and terminology to be accepted universally due to the increasing interest in geosites, mainly those of outstanding geomorphological value, which creates the need to introduce the term geomorphology.

Several procedures for geomorphosite assessment exist in the literature (Cendrero & Fischer, 1997; Coratza & Giusti, 2005; Grandgirard, 1997; Grandgirard, 1999; Panizza, 2001; Panizza & Piacente, 1991; Pereira & Pereira, 2010; Pereira et al., 2007; Pralong, 2005; Pralong & Reynard, 2005; Reynard, 2008b; Reynard et al., 2007a; Rivas et al., 1997; Serrano & Gonzalez-Trueba, 2005; Zouros, 2007). This concept brings in geospatial and morphometric techniques to delineate and quantify the value of landscape components that have been judged as representative of the scenic quality of the landscape. However, other procedures have been condemned by Panizza for their subjectivity. Further discussing the problem, he describes the limitations that appear to be considered in all cases. The subjectivity inherent in judgements is conditioned by both the sensitivity and the experience of the observer. Either because several important components are omitted, and a vision of the landscape as a whole is lost, or because by breaking up the resource itself, it is distorted and permanently stripped of its wholeness and essence (Panizza, 1996; Panizza, 2001).

According to M. Panizza (2001), a geomorphosite is a landform to which a value can be attributed. The attributes that may confer value to a geomorphosite are scenic, socioeconomic, cultural, and scientific. A geomorphological resource is a geomorphosite that can be used by society. The terminology suggests that this geoheritage concept includes other than scientific values as well as the approval of society.

Peer geomorphologist Vincent Grandgirard (1997) developed a similar geoheritage assessment framework, adding that geomorphosites can occur as single, isolated landforms (e.g., a waterfall, an erratic boulder, etc.) or in groups of landforms forming a large geomorphological landscape. Vincent Grandgirard (1997) uses the term `geotope` equivalent to geomorphological sites that are `landforms', having particular importance for the comprehension of the Earth's history and its present or future evolution. Therefore, the evaluation of geomorphological objects is based essentially on the scientific value of the studied sites from the geomorphological point of view (integrity, representativeness, rarity, palaeogeographical value). Their ecological, scenic, cultural, socioeconomic, etc. values are not considered in the evaluation process. This approach, leading to selection of geomorphological sites of great scientific value, is suitable in the context of protection or inventory (Grandgirard, 1997; Grandgirard, 1999). However, the concept created a conflict with Panizza`s (1991) point of view regarding the value system. The lack of a universal view slows down the ongoing recognition of geoconservation. Even after two decades, the question remains on how to define the value of geoheritage features.

1.3.1.6. Geological Society of Australia and The Geological Society of America

The UNESCO Global Geopark Network (UGGN) connects 38 different countries from Europe, Asia, South America and Canada. Australia and the United States form gaps on the UGGN map. In Australia the objectives are to promote the understanding and conservation of geological heritage through a national inventory of identification, documentation, and evaluation of the significance of geological features.

The criteria set that is applied for the assessment of geological features worthy of protection is formulated by divisional subcommittees of the Geological Society of Australia (Geological Society of Australia, 2012). The term geoheritage is used to refer to globally, nationally, regionally, and locally significant features of geology, such as igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogical, palaeontological, geomorphic, pedologic, and hydrologic attributes at all spatial scales. They are intrinsically or culturally important sites, offering information or insights into the formation or evolution of the Earth or into the history of science. The term geodiversity is used to refer to the `diversity of geological features` that may occur in each region (Brocx & Semeniuk, 2007; Geological Society of

Australia, 2012). The aim is to provide the framework and resources that facilitate a centralised database and a systematic inventory-based assessment of geoheritage in all states and territories. The geoheritage and geodiversity could be utilised for (Geological Society of Australia, 2012):

1. Earth science research
2. Environmental forecasting
3. Education and training, and as a
4. Cultural and tourism resources (with some places attracting hundreds of thousands of visitors each year)
5. Management of sites of geoheritage significance, and
6. Integrated multidisciplinary environmental planning and management.

The Australian Government`s heritage body, the Australian Heritage Commission, was established in 1975 to compile the Register of the National Estate, including places of natural, historical, and Aboriginal heritage. The Geological Society of Australia members became the expert nominators of the register (Creaser, 2008; Joyce, 2010a). The first attempt to have a UNESCO-accredited geopark happened in the Etheridge Shire, Australia, in 2017; however, Australia withdrew their application due to raising concerns for future agricultural development. After a grazier backlash, the advisory committee paused the geopark development to investigate further sustainable development in both tourism and agriculture in the area (Barker, 2017). The case also reflects the need for a complex value set that considers the viewpoints of all stakeholders for successful geoconservation.

The future of North American geoparks has yet to be determined. Geoparks network differs from other park concepts in North America; land managers and the public are not open to the integration of a new program. Geoparks network is considered a European model where the European Union provides money for their establishment in the form of regional development grants (Bailey et al., 2010). In North America, provision for protected areas is scarce. The other challenge is that communities perceive geoparks as city, county, state, and national parks, leading to eminent domain issues and land use restrictions (Bailey et al., 2010). National Parks of the United States are world famous because of their numerous monumental and active-dynamic representatives of given geological and geomorphological processes. "The entire history of the United States has been shaped by the geological resources and features of the land. The influence of geology is pervasive throughout American history." – written by Dr Harry A. Butowsky, National Park Service Historian, 1990.

The Geological Society of America (GSA) supports the conservation of geoheritage sites to meet present and future educational, scientific, aesthetic, cultural, and economic needs. Geoheritage is a term applied to sites or areas of geologic features with significant value, and these geoheritage sites serve and should serve the public interest. Such sites are critical to advancing knowledge about geological, hydrological, atmospheric, and geomorphological processes. These sites have a high potential for scientific studies, outdoor classrooms, enhancement of public understanding of science, recreational use, and economic support to local communities. Geoheritage sites can be small but scientifically significant sites, such as a road cut or extensive areas with international recognition, such as the Grand Canyon or Yellowstone National Park. Conservation strategies appropriate to the type of site and nature of ownership are important to protect geoheritage sites and maintain them for the long-term public interest. GSA encourages U.S. participation in the UNESCO Global Geoparks Network with geoheritage sites carrying particularly significant, unique, and outstanding geologic characteristics and cultural history. As of April 2021, none of the 169 Global Geoparks designated in 44 countries is in the United States in spite of the benefits UNESCO Global Geopark designation provides, such as geotourism, research, connection to the landscape, and sustainability of local economies (National Park Service, 2015; The Geological Society of America, 2011). According to the National Park Service, America`s geologic heritage holds abundant values – aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific – for all Americans and encourages the involvement of the public and communities of all kinds in its conservation for future generations. The same publication establishes that the geologic heritage resources come in all sizes, from the regional scale to the microscopic, and every place they occur is part of a physiographic province with its own geologic characteristics that are a part of communities` local geologic heritage (National Park Service, 2015).

1.3.2. Criteria Assessment

To encourage geoconservation actions worldwide, many studies have been devoted to formulating criteria set for inventories. Studies use the same building blocks, although each study creates a different structure depending on the purpose and philosophy of the researcher. Assessment review papers investigate the materially different outcomes of the different assessment methods and attempt to create a framework that can be used as a universal approach

(Brilha, 2016; Kubalíková, 2013; Štrba et al., 2015). Analysing the existing methods is the first and defining step to acquiring a broad understanding and solid foundation for an adequate, sustainable and objective volcanic geoheritage inventory in the Auckland Volcanic Field.

According to the geoheritage concept review by Brilha (2016), the inventory of geological and geodiversity sites is the first and crucial step in any geoconservation strategy, regardless of the size of the area under analysis. After reviewing the existing numerical evaluations of the value and degradation risk of geosites, his paper proposes new criteria and guidelines for systematic site inventories applied to different scales and values from countries to parks. His concept is based on the theory that the least subjective data is the scientific data. Therefore they should be primarily used for geoheritage site selection and underlines that the geoscientific community should do it. Geosites with no scientific value but other additional value should not be considered geoheritage. He points out that these geosites that do not meet scientific criteria are still subjects of geoconservation but cannot be included in the scope and scale of geoheritage. Since geoheritage will be only justified by the scientific value, it means that the relevance of geoheritage can only be international or national because there is no `local science`. Sites still important resources for education, tourism and the cultural identity of communities are described as geodiversity sites or geodiversity elements that can have local to international relevance.

The review of Štrba et al. (2015) approaches geosite assessments with an objective of reaching beyond the scientific scope of geoheritage and featuring geotourism and public interest. The premise behind this is that geotourism brings new research issues to be solved, such as geosite identification and assessment for geopark establishment. Their overview of the literature constructed a collection of assessment methods (Bâca & Schuster, 2011; Bruschi et al., 2011; Fassoulas et al., 2012) (Pereira et al., 2007; Reynard et al., 2007a; Rybar, 2010; Štrba et al., 2015) are each applied on the same selection of geosites. This analysis returns such varying geosite rankings that directly raise the need for further research in the field. The methods (Bruschi et al. (2011), Reynard et al. (2007) Bâca and Schuster (2011) and Rybar (2010) that prioritise scientific values over cultural and additional values produced fairly similar outcomes for ranking the geosites. The method suggested by Pereira et al. (2007) promoted a holistic approach by integrating management values and produced a significantly different outcome from the methods above. The method of Fassoulas et al. (2012) has three final scores for each geosite, the three indexes that present touristic, educational, and protection values offering flexibility in having multiple objectives in the assessment. Comparing the final scores of the different assessment methods proved that further research is necessary for geotourism planning and geoheritage management.

Kubalíková (2013) presents a review paper with a slightly different concept in mind. She seeks the assessment method that best suits geotourism purposes. To achieve this, she analyses the most significant assessment tools used in geoconservation through a critical review (Bruschi & Cendrero, 2005; Coratza & Giusti, 2005; Pereira et al., 2007; Pralong, 2005; Reynard et al., 2007a; Serrano & Gonzalez-Trueba, 2005; Zouros, 2007). Her conclusion is that geodiversity is the most important resource for geotourism activities and that such use of geodiversity is generally made through the exploitation of geoheritage.

All the methods Kubalíková (2013) reviews follow the idea that the significance of geoheritage is defined by geomorphology rather than geology. Therefore only geomorphosites are subjects of geoheritage evaluation.

Erhartič (2010) gives a very useful comparison of four major assessment models (respectively: Reynard et al., 2007; Pereira et al., 2007; Pralong, 2005 and Serrano and Gonzales-Trueba 2005), concluding that the contemporary models are not effective for geosite comparison in general because of pervading subjectivity. For this reason, the aims of future procedures are to reduce the subjective factor strongly affecting the results by applying progressive numerical assessment. Furthermore, the improvement in assessment reliability would enable a better comparison among geosites or even among heritage features that are situated within areas under different management (Erhartič, 2010).

Inventory and assessment methodologies that are reviewed by these papers list similar assessment criteria, although the weights assigned to them differ according to the objectives that lead to the need for geosite evaluation. The different aims are:

- protection only to provide a resource for future research and education
- protection and promotion for enhancing tourism activities
- less emphasis on protection and more on promotion to trigger economic growth in less developed regions
- to find a cultural link to the natural environment through geoheritage site identification

Regardless of the aim, criteria of scientific value are at the centre of each assessment method. That said, the level of importance of the scientific value changes depending on whether the aim is identification or utilisation.

1.3.2.1. Viola Bruschi and Antonio Cendrero

Their work provides a solid base for subsequent evaluations (Brilha, 2016; Coratza et al., 2011; Fassoulas et al., 2012; Feuillet & Sourp, 2011; Zgłobicki & Baran-Zgłobicka, 2013). The aim was to develop a reduced subjectivity method that better reflects social values and interests, promoting careful use and conservation of geosites. This approach is based on the definition of three groups of criteria related to: a) intrinsic quality of sites (scientific merit); b) potential threats and protection needs; c) potential for use.

The preface is that the one problem that permeates all stages of the process is subjectivity. To make conservational plans work, the evaluation should reflect social values that are expressed by specific stakeholder groups (earth scientists, decision-makers, elected officials, conservationists) or the public.

There are no details about the evaluation criteria selection process, which suggests a certain level of subjectivity. However, the methodology includes a questionnaire sent to 24 local experts to collect site `applicants` and establish criteria weights. The second questionnaire is then sent to another group of experts to quantify the value of geosites based on the criteria developed in the paper.

The criteria are as follows:

(i) Intrinsic quality - abundance/rarity; degree of scientific knowledge; usefulness as a process model/ example; diversity of elements of interest; age; type locality; integrity; association with historical, archaeological, artistic heritage; association with other natural heritage.

(ii) Potential for use (social usefulness) – activities that can be carried out; observation conditions; accessibility; extent; proximity to service centres; socio-economic condition of the area.

(iii) Potential threats and protection need - inhabitants in the surroundings; present or potential threats; possibility to collect objects; relationship to the existing planning; interest for mineral exploitation; land ownership.

Bruschi (2011) further develops this method using a statistical approach to optimize geoheritage assessment procedures and minimize subjectivity. Complete elimination should not be pursued as subjectivity is unavoidable and even desirable to reflect the interest of all stakeholder groups. By 2011 several assessment procedures had been proposed and applied. According to Bruschi`s review of the assessments, all of them encountered the same problems, such as subjectivity at a deteriorating level and, consequently, the difficulty for one operator to replicate results obtained by another. After attaining a ranked list of coastal geomorphosites made by 20 experts, the means of a direct method and the means of a parametric method are applied to obtain the ranking of the geomorphosites. This analysis enables a reduction in the number of criteria, elimination of redundancies and replicability.

The criteria are as follows:

(i) Intrinsic quality – good example of process; abundance/rarity; diversity of elements; other processes associated; degree of knowledge.

(ii) Potential for use- landscape interest; observation conditions; cultural interest; accessibility; environmental services; economic significance; educational interest.

(iii) Potential threats and protection need – naturalness; fragility; related with human issues; recreational interest; natural protected area; size; degree of preservation.

1.3.2.2. Paulo Pereira

Pereira et al. (2007) propose a complex assessment procedure that unfolds the potential of geoheritage sites for geotourism (Barale & d'Atri, 2016; Maran-Stevanovic, 2015; Shayan et al., 2015; Zangmo Tefogoum et al., 2014). The aim of this study is to develop a holistic methodology that is equally effective in defining either the scientific value or the tourist potential. This methodology also follows the concept of Panizza (2001) to the effect that geomorphosites are landforms that have acquired a special value through human perception or exploitation that makes them worthy of conservation.

The method is composed of four successive steps: (1) identification, (2) qualitative assessment, (3) selection and characterisation of geomorphosites, followed by (4) numerical assessment and ranking. It is built up by two stages to emphasise the need for subjectivity that is balanced out by objectivity. The first and novel stage is the qualitative assessment of the geosites. The second stage - which addresses the reduction of subjectivity -is the numerical assessment that applies equal weights for scientific -, cultural -, use -, and protection aspects. This approach is meant to be equally effective for defining the degree of both scientific value and geotourism potential. Finally, the values are quantified using selected criteria through numerical assessment. The numerical assessment uses a maximum of 10 points for each criterion. The sum of all criteria determines the total value of a geomorphosite.

The criteria are as follows:

(i) Scientific value – rareness in relation to the area; integrity/intactness; representativeness of geomorphological processes and pedagogical interest; number of interesting geomorphological features; other geological features with the heritage value; scientific knowledge of geomorphological issues; rareness at national level; additional values.

(ii) Cultural value – aesthetic value; ecological value

(iii) Use value – accessibility; visibility; present use of the geomorphological interest; present use of other natural and cultural interest; legal protection and use limitations; equipment and support service.

(iv) Protection value – Integrity/intactness; vulnerability of use as geomorphosite.

1.3.2.3. Emmanuel Reynard

The significance of this methodology is two-fold. Reynard`s inventory uses the advantages of Geographic Information Systems (GIS) to define geomorphological attributes in conjunction with a simplified assessment method with smaller criteria set that allows for better understanding and straightforward application (Martin, 2010; Pelfini & Bollati, 2014; Regolini-Bissig, 2018; Rovere et al., 2011; Ruban, 2016a). The aim is to develop a method that combines the assessment of central scientific values with additional, context-specific values to find geosites that could integrate natural and cultural aspects of landscapes (Panizza & Piacente, 1991). Two main objectives determine the structure of the method: (1) simplicity in order to be used by students and research departments and (2) comprehensiveness. The method adapted Panizza`s (2001) concept and terminology and the scientific criteria of Grandgirard (1999). This study also points out that the terminology is inconsistent in the literature, and their use depends on the objective of the research.

The motivation for developing this assessment method is to achieve integrated geoheritage and cultural landscape management. It reinforces the need for a restrictive definition of geosites of particular importance and a broader definition of geotourism. This method proposes the use of two value sets, scientific value and additional values. It is an intriguing innovation that the educational value is concluded from the final scores of the assessment and not included as a criterion to be defined by the valuer.

The valuers are given a card divided into six parts, each with a few sub-criteria, making use of both quantitative and qualitative measures. These cards represent the steps to make, such as general data collection, descriptive data collection, scientific value assessment, additional value assessment, and synthesis (global value, educational value, threats, and management measures). The method suggests that the assessor is an expert in earth sciences, and therefore, the aim of additional values is not to give an exhaustive analysis of the site in terms of economy, ecology, arts, or history but to highlight possible links that may exist between geomorphology and other aspects of nature or culture. The synthesis is essentially a quantitative and qualitative summary of the previous parts.

The criteria are as follows:

(i) Scientific value – integrity, representativeness; paleogeographical value; rareness; ecological value; ecological impact; protected species

(ii) Additional value – (a) Aesthetic values: number of viewpoints; contrasts, vertical development. (b) Cultural value: religious importance; historical importance; artistic importance. (c) Economic value: economic products.

1.3.2.4. Paola Coratza and Christian Giusti

This assessment methodology is focused on the scientific parameters of a geosite. Added values are still incorporated but with low weights assigned to them. The aim is to assess the scientific quality of geomorphosites. This is a quantitative assessment method with a series of qualitative assessment guidelines that together give rise to numerous geoheritage studies (Bollati et al., 2015; Bruschi et al., 2011; Reynard et al., 2016a; Reynard et al., 2007a; Rovere et al., 2011). It aims to create a useful tool for Environmental Impact Assessment by enabling the selection of those aspects of the landscape that deserve to be identified, known, and safeguarded.

The method uses the conceptual framework given by Panizza (2001) that postulates that a geomorphosite of particular and significant attributes is a component of the cultural heritage of a given territory. Following this concept, Coratza and Giusti (2005) formulate a definition for geomorphosites, saying that they make up the landscape, habitat, elements of geodiversity, knowledge of the dynamics of the Earth`s past, the memory of biological evolution and Man`s life from its very beginning. They also add that geomorphosites are essential resources for economic and scientific development. The method utilises GIS techniques for the selection and visualisation of geomorphological assets.

The criteria are as follows:

(i) Value for scientific research: Based on the number and importance of scientific publications.
(ii) Educational value: Characterized by the representativeness of a particular form or process and quotation in educational textbooks, itineraries, other educational material.
(iii) Area: Calculated as the area of the geomorphosite divided by the total area occupied by all the geomorphosites of the same type in the are considered.
(iv) Rareness: Assessed according to the quantity of similar elements present in the territory investigated.
(v) Degree of conservation: How natural and anthropogenic factors affecting the degree of degradation.
(vi) Exposure: Considered as the visibility of a geomorphosite, the presence of human development or human structures and how difficult to reach the geomorphosite.
(vii) Added value (level of awareness): There are further geological elements or includes additional ecological, tourism-economic or historical-cultural values.

1.3.2.5. Enrique Serrano and Juan José González-Trueba

This method places emphasis on management values (Ballesteros et al., 2015; Pellitero et al., 2011; Ramón et al., 2015). Their aim is to develop a methodology that is suitable for the assessment of regionally important geomorphosites within protected areas. The ambition of this methodology is the achievement of maximum objectivity in the analysis of geomorphic elements from a scientific point of view. It is a great challenge as it recognises the need for the inclusion of added values subject to a greater social, historical and personal subjectivity. It recalls the argument made by Cendrero and Fischer (1997) that “the assessment of geomorphosites cannot be made by means of statistical parameters or mathematical formula since we are faced with intangible values”.

The paper follows Panizza`s (2001) concept. It emphasises that the three similarly interrelated factors – environment, history and philosophy and culture – must be taken into account in the study and assessment of geomorphosites. Their paper states that geomorphosites represent cultural, economic, tourist, educational and environmental resources equally. Moreover, these areas have their own characteristics when it comes to defining geomorphosites because the interest is concentrated locally on their detailed territorial and cultural relationships.

The method uses a three-layered evaluation based on geomorphological mapping, a descriptive card, and further analytical cards for each selected site. There are three analytical cards for scientific value assessment, cultural and added value assessment and use or management value assessment. The three analytical cards give three well-distinguished values for each geomorphosite. The last step of the method is to fit the geosites into groups with certain characteristics.

The criteria are as follows:

(i) Scientific value –genesis; morphology; dynamics; chronology; lithology; geologic structures; sedimentary structures.

(ii) Added values – landscape and aesthetic; cultural elements; educational value; representativeness.

(iii) Use/management value – accessibility; fragility; vulnerability; intensity of use; risk of degradation; integrity; impacts; conditions for observation; limits of acceptable change.

1.3.2.6. Nickolas Zouros

The advantage of this method is its transparency, which makes it easy to follow and apply for further studies (Fassoulas et al., 2012; Hicham et al.; Mouriki & Fassoulas, 2009; Rovere et al., 2011; Tomić et al., 2018). It was developed to evaluate geomorphosites in national protected areas in Greece. It is a useful management tool to quantify the values of their geomorphosites in relation to the whole geographical setting of the region in order to establish geoparks.

The main problem this method addresses is that geomorphosites have failed to gain attention autonomously as areas of value for conservation and management. They are not mentioned in the management plan of the national parks nor in their educational publications and promotional materials. The concept is that a reliable geomorphosite assessment methodology can help to emphasize their value and importance as locations worthy of conservation, research, and sustainable management.

The method is a semi-quantitative approach. Each indicator is given a value between 0-10 or 0-5, with the highest possible score representing the highest value. The score of each criterion is thus the sum of its indicators. Its total number of credits can therefore express the quality of a geomorphosite, with 100 being the highest score attainable. The method is tested separately at national park and geopark levels on geomorphological landscapes with significant underlying geology such as fossil sites (Petrified Forest of Lesvos), volcanic landforms (Santorini volcanic caldera), tectonic landforms (Lavrion ancient mines included in the Sounion National Park), karstic landforms (Diros Caves in Peloponnesus), erosional landforms (Meteora, the Olympus Mountain), and coastal/fluvial landforms (Samaria Gorge in Crete).

The criteria are as follows:

(i) Scientific and educational value – integrity; representativeness; rarity; exemplarity.

(ii) Geodiversity value – number of phenomena within area.

(iii) Ecological and aesthetic value – presence of the natural heritage sites or nature reserves.

(iv) Cultural value – presence of the cultural heritage sites.

(v) Potential threats and protection need – legal protection; vulnerability.

(vi) Potential for use – recognisability; geographical distribution; accessibility; economical potential.

1.3.2.7. Jean-Pierre Pralong

The aim of developing this method is to propose criteria that quantify and qualify scenic, scientific, cultural, and economic values. The assessment scores establish the potential for spatial and temporal use and the maximum degree of exploitation.

Pralong (2005) adopts assessment criteria from previous methods creating an instrument that suits all types of conservation endeavours (Beranová et al., 2017; Bujdosó et al., 2015; Hieu et al., 2017; Maghsoudi et al., 2018; Rypl et al., 2018). The criteria collection is constituted of tourist values by Grandgirard (1997), scenic/aesthetic values by Coratza and Giusti (2005), scientific values by Rivas et al. (1997) and social/economic values by Panizza (1996).

This method assesses tourist and exploitation values of geomorphological sites separately. The comparison between tourist potential and exploitation degree is carried out to discuss the sustainable use of the studied geomorphological sites. Scientific and cultural values are the weighted main values. Scenic, economic, and exploitation values have no weighting because, as described in the guidelines, there is no objective reason to think that a specific value is less important than the other one when we must determine the theoretical tourist potential of a site.

The criteria for tourist value assessment are as follows:

(i) Scenic value – number of viewpoints; average distance to the viewpoints; surface; elevation; colour contrasts.

(ii) Scientific value – paleogeographic interest; representativeness; area; rarity; integrity; ecological interest.

(iii) Cultural value – cultural and historical customs; iconographic presentation; historical and archaeological relevance; religious and metaphysical relevance; art and cultural events.

(iv) Economic value – accessibility; natural risks; annual number of visitors; official level of protection; attraction.

The criteria for exploitation value assessment are as follows:

(i) Degree – used surface; number of infrastructures; seasonal occupancy; daily occupancy.

(ii) Modality – use of the scenic value (advertising optimization); use of the scientific value (didactive optimization); use of the cultural value (didactic optimization); use of the economic value (visitor number).

1.3.2.8. Pavol Rybár

This approach to the geoheritage concept and assessment is widely adopted by researchers who intend to promote geotourism (Čech & Krokusová, 2017; Doktor et al., 2017; Różycka &

Migoń, 2018; Štrba, 2018; Suzuki & Takagi, 2018) Rybár (2010) aims to develop an assessment that can help to perceive the geosite as an object of tourism with dominated geological character. The main objective is to explain why one place is popular and visited by tourists and why some places attract no tourists at all.

The theory proposed by Rybar (2010) is that it is not possible to determine the attractiveness of the locality by non-reliable assessments that express an opinion that should be generally respected. Point ranking is subjective and based on the ranking person's knowledge, experience, and taste. The method is based on the classification of natural and anthropogenic aspects that best address tourist satisfaction. The highest point value is 80/80. Number 80 is a sum of ten eights in natural-scientific and anthropogenic criteria. The value 80/0 means that an object has the highest possible value from a natural viewpoint but zero value expressing the anthropogenic part of the assessment. Vice versa, the value 0/80 indicates that an object has no natural value but has maximal technical and historical anthropogenic value.

The criteria are as follows:

(i) Criterion - natural object – primary geological properties; uniqueness object accessibility; existing scientific and professional publications; conditions of observation (research); information availability on the object; visual value of the object; value of provided services; object in the tourist area.

(ii) Criterion – anthropogenic object – age; historical value; aesthetic value; authenticity; value of municipalities and cultural routes reconstruction; excellence; emotional value; utility value; value of provided services; safety criteria.

1.3.2.9. Charalampos Fassoulas

This method is semi-quantitative and multi-variant based on scientific background and visitor preferences (Fassoulas et al., 2013; Poiraud et al., 2016; Różycka & Migoń, 2018). This research aims (Fassoulas, 2013) to achieve sustainable geotourism, education and conservation of the geological heritage.

The method follows the concept that geoheritage sites are the outstanding features of geodiversity (Gray, 2008a). The method adopts the terms geosites and geotopes from Sturm (1994) and geomorphosites from (Reynard et al., 2007). Fassoulas (2013) states that the wealth of an area`s geodiversity can be expressed by the number and variety of its geotopes. This method is based on the theory that an objective evaluation requires a task force that brings experts in different fields together. Such collaboration reveals relations and links between the abiotic and natural heritage and thus defines the real value of each geotope.

The assessment criteria are set out to suit all types of geotopes in all aspects (Grandgirard, 1995; Pralong, 2005; Reynard et al., 2007a; Rivas et al., 1997; Zouros, 2007). The method is developed by using 63 geotopes of Psiloritis Geopark, Crete (Mouriki & Fassoulas, 2009). It formulates three indexes for touristic, educational and protection values that make this assessment method suitable for all types of geosites.

The criteria are as follows:

(i) Scientific – geological history; representativeness; geodiversity; rarity; integrity.

(ii) Ecological – ecological impact; protection status.

(iii) Cultural – ethics; history; religious; art and culture.

(iv) Aesthetic – viewpoints; landscape difference.

(v) Economic – visitors; attraction; official protection.

(vi) Potential of use – intensity of use; impacts; fragility; accessibility; acceptable changes; ecological risk factor.

1.3.2.10. Ioan Bâca and Eduard Schuster

This is a popular geotourism evaluation method that researchers have adopted in the Balto-Slavic speaking countries (Baláž et al., 2014; Popa et al., 2017; Štrba, 2018; Štrba et al., 2015; Zwoliński et al., 2017) The aim is to complete an inventory list and evaluate geosites within a cultural and historical environment in Bistrita-Nasaud County, Romania for touristic utilisation (Bâca et al., 2011).

The basis of this study is that high scientific, aesthetic, and cultural value does not assure the best utilisation and preservation without high ecological and economic value. Furthermore, it highlights the strong relation between human communities and the characteristics of the terrain. This is the first method that includes the strategic function of a geosite. Strategic functions are represented by prominent peaks and elongated crests that offer good visibility over the nearby communication corridors. The method intends to evaluate the geosites for their touristic utilisation. Bâca and Schuster (2011) use criteria set created by Reynard (2007) with the addition of historical value.

The criteria are as follows:

(i) Scientific value – integrity; representativity; uniqueness; paleo-geographical value; educational value.

(ii) Ecological value – ecological influence; protected sites.

(iii) Aesthetic values – visibility; contrasts, vertical development, and space structuring; chromatic diversity.

(iv) Cultural value – religious and symbolic importance; historic importance; literary and artistic importance; geo-historic importance.

(v) Economic value – accessibility; present utilization and geomorphological interest; present utilization and cultural-historical interest; legal protection and utilisation restrictions; installations and services.

1.3.2.11. Miroslav D Vujičić

The method by Vujičić et al. (2011) provides a solution for the comparability of geosites (Jovana et al., 2015; Németh et al., 2017; Petrović et al., 2013; Różycka & Migoń, 2018; Susan & Wakelin-King, 2014). It proposes a new Geosite Assessment Model (GAM) based on a similar criterion set explained earlier (Pereira et al., 2007; Pralong, 2005; Pralong & Reynard, 2005; Reynard, 2008a; Zouros, 2007).

According to Vujičić et al. (2011), the conservation of geoheritage should happen through promotion and access to geosites through geotourism (Hose, 2005; Vujičić et al., 2011). For this reason, scientific, educational, aesthetical, protection, functional and touristic values need to be considered when assessing geosites.

GAM is made up of two groups of values, main and additional values. The main values are the scientific/educational, scenic and protection values, forming the key elements of the assessment. Additional values are functional and touristic values. The sums of main and additional values are presented in a nine-field matrix where the X axis is the main value, and the Y axis is the additional value. The intersection of X and Y values presents the geosite. The matrix is divided into nine fields, representing the highest to lowest geoheritage value fields.

The criteria are as follows:

(i) Scientific/educational value – rarity; representativeness; knowledge of geoscientific issues; level of interpretation.

(ii) Scenic/aesthetic values – viewpoints; surface; surrounding landscape and nature; environmental fitting of sites.

(iii) Protection – current condition; protection level; vulnerability; suitable number of visitors.

(iv) Functional – accessibility; additional natural values; additional anthropogenic values; vicinity of emissive centres; vicinity of important road network; additional functional values.

(v) Touristic – promotion; organized visits; vicinity of visitor centres; interpretative panels; number of visitors; tourism infrastructure; tour guide/ hostelry/restaurant; service.

1.4. Site selection methods in conservation management

1.4.1 GIS in geoheritage

It is difficult to verify geoheritage assessment without assigning the spatial dimension. GIS is often recognised `as a decision support system involving the integration of spatially referenced data in a problem-solving environment` (Cowen, 1988; Malczewski, 2006). The application of GIS, if successful, will upgrade the image of geography by demonstrating both the advantages of a multi-disciplinary, holistic approach and the irrelevance of clear delimitations between geography and other connected disciplines (Malczewski, 2006; Muller, 1985). GIS has been used to address the problem of allocating resources.

Most of the criteria used in geoconservation planning are expressible through spatial data. GIS techniques are designed for handling spatial aspects of a given topic, in our case, geoconservation. GIS enables researchers to model situations of incomplete data (Rubino & Hess, 2003). It is, therefore, surprising that geospatial techniques are not used in geoheritage assessment. Geomorphosite inventory studies, however, often build a GIS database with geological, topographic, geomorphological and land cover maps and elevation models either for identification or visualisation of relevant sites (Bradbury, 2014; Carton et al., 2005; Cendrero & Fischer, 1997; Coratza et al., 2011; Giusti & González-Díez, 2000; Szepesi et al., 2017).

1.4.1.1. Geodiversity

The word geodiversity appears in multiple scientific disciplines. For example, in environmental sciences, geodiversity calculation is used as a key element of ecological evaluation (Alahuhta et al., 2018; Anderson et al., 2015; Bétard, 2013).

Geodiversity is also an important term in geoheritage and geoconservation. According to Gray (2018), geodiversity is, in fact, the backbone of geoheritage. In light of the significance of calculating geodiversity, the theory applied in geoconservation is rather loose. The term itself is often used as a synonym for geology, geoheritage or geoconservation (Gray, 2018). This promiscuity is shown in the diversity of the approaches to its calculation. Spatial analysis is the basic tool used for geodiversity calculation, yet no studies use spatial analysis for geoheritage assessment. Identifying a specific non-dividable spatial entity (equivalent to individuals of a single species in biodiversity calculation) is a challenge. The concept of geodiversity is at the early stage of development and not explicitly understood and defined in spite of the fact that many have acknowledged the importance of geodiversity evaluation (Gray, 2004; Hjort et al., 2015; Kozlowski, 2004; Zouros, 2007; Zwoliński & Stachowiak, 2012). Geodiversity maps are being created for a variety of purposes. For geotourism purposes, a geodiversity map is applied in order to point out the scale of the area`s tourist attractiveness (Zwoliński & Stachowiak, 2012). Other studies use geodiversity maps to investigate the spatial or genetic relationships with the richness of particular natural environmental components (Mazurek et al., 2015; Najwer et al., 2016). The most common purpose of geodiversity assessment is to improve geoconservation and efficient management and planning of the natural protected areas (Melelli, 2014; Pellitero et al., 2011; Rafał, 2015).

Geodiversity calculations require techniques (Figure 3) that are designed for spatial evaluation. Authors addressing methodological issues of geodiversity calculations develop models in a GIS environment since they provide maps with informational, analytical and visual dimensions (Zwoliński et al., 2018). The most popular methods for calculating geodiversity are geodiversity indices obtained through spatial aggregation and three-dimensional visualisation, landscape metrics, map algebra and statistical modelling (Araujo & Pereira, 2017; Benito-Calvo et al., 2009; Bétard, 2013; Ferrero et al., 2012; Forte et al., 2018; Kot, 2015; Kot &

Leśniak, 2017; Manosso & de Nóbrega, 2016; Melelli et al., 2017; Necheş, 2016; Ruban, 2010; Stavi et al., 2018; Stepišnik & Trenchovska, 2018; Zwoliński et al., 2018).

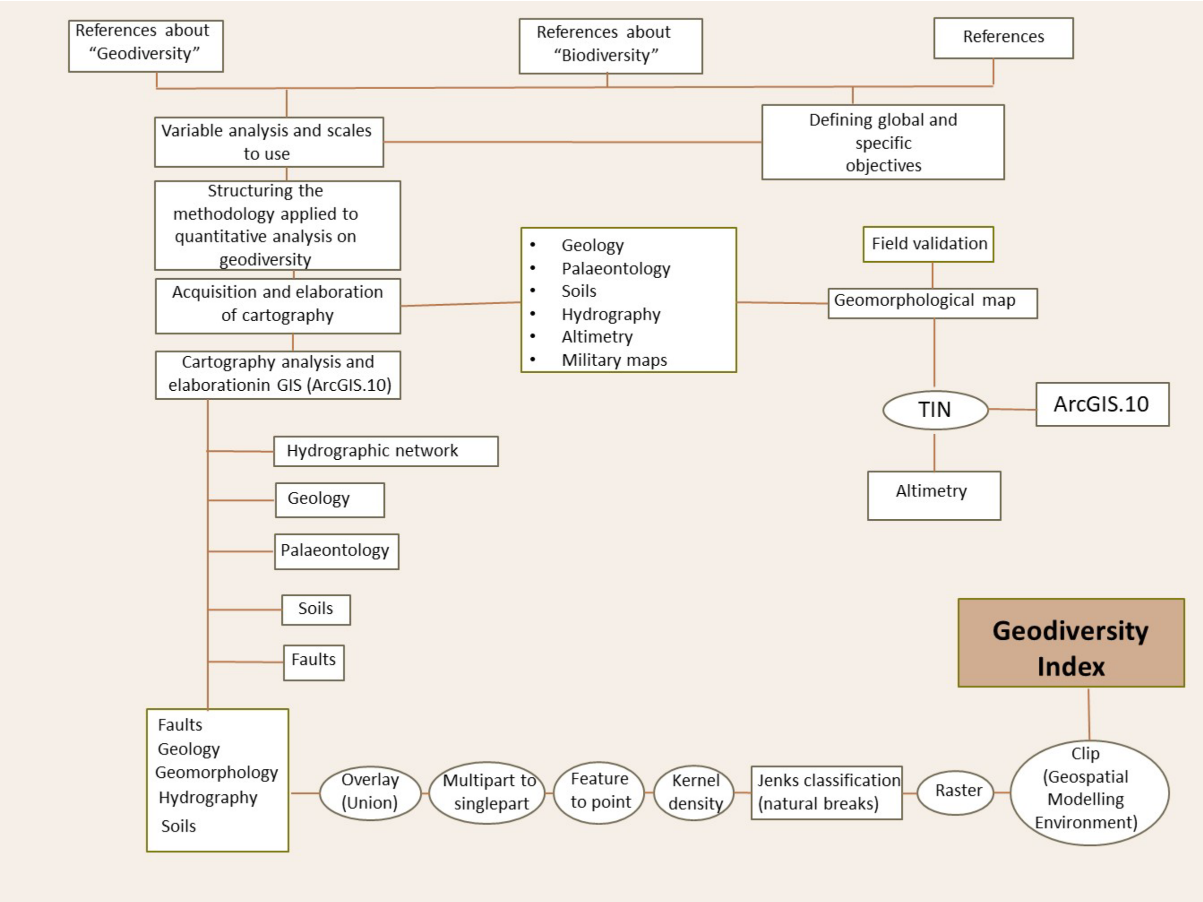

Figure 3 Applied quantitative assessment of geodiversity. The figure is an example of the input layers and the processing steps to quantify geodiversity. In this example, geology, palaeontology, soil, hydrography, altimetry, and topography maps were used. The process involved the creation of a geomorphology map. The overlay tool was used to aggregate the map layers into a geodiversity index map. Modified from Forte et al. (2018)

1.4.1.2. Modern techniques in geoheritage education

Modern techniques have made their way into promoting geoheritage. Information collected with unmanned aerial vehicles and multimedia technologies promotes better visualization of geoheritage by providing 3D terrain models as a base of virtual reality. These technologies allow the public to interact with field geology, which makes geoheritage features more appealing and understandable. Santos et al. (2018) use 360° panoramic images obtained by unmanned aerial vehicles to create an online, infinite-dimensional space where anyone can navigate and interact with geoheritage. Rapprich et al. (2017) selected four volcanic geoheritage sites to display new technologies for communicating geology to non-professionals. They use 3D animations for the generation of virtual models of augmented reality that are applied in the popularization of volcanic geoheritage among school children. Their conclusion is that communication that is amplified using modern visualization and application technologies is attractive for the next generation. Studies also discuss the possibility of creating virtual databases using virtual globes such as Google Earth or other geomatics applications (Martínez-Graña et al., 2021; Martínez-Graña et al., 2014; Martínez-Graña et al., 2013; Triantafyllou et al., 2017). Virtual globes can showcase different types of spatial data, allowing scientists to import and share their findings. For example, Digital Elevation Models, structural geology features in 2D and 3D, scattered data interpolations, cross-sections and oriented raster or georeferenced field pictures or maps (Triantafyllou et al., 2017). These new methodologies can also enhance the value and position of the geological heritage through virtual itineraries, virtual databases or virtual tours, serving land-use planning, interactive teaching and learning concepts. Virtual technologies create a familiar and effective learning environment with the implementation of augmented reality in real-time, virtual 3D flight simulators, descriptive information via QR codes, virtual field notebooks with questionnaires and videos (Migoń & Pijet-Migoń, 2017; Rapprich et al., 2017). These geomatic applications, in fact, are free (however can cost to produce) and can be accessed easily from computer labs, smartphones, and tablets operating under various systems such as Android, iOS or Windows (Martínez-Graña et al., 2014; Martínez-Graña et al., 2013).

1.5. Site selection methods in conservation planning

The integration of GIS and multicriteria decision analysis has attained a significant role in numerous multidimensional assessment methods. For example, spatial decision problems typically involve a large set of workable alternatives and multiple, conflicting and incommensurate evaluation criteria, giving rise to the GIS-based or multicriteria decision analysis (MCDA) (Malczewski, 2006). While GIS integrates spatially referenced data, multicriteria decision analysis (MCDA) provides a rich collection of techniques and procedures for structuring decision-making and designing, evaluating, and prioritising alternative decisions (Malczewski, 2006). A GIS-based multicriteria decision-making approach is applied in varying fields like nature conservation planning, exploration of resources (e.g., geothermal, watershed), suitability analysis (industrial site, landfill site, ecotourism site), susceptibility analysis (soil erosion, landslide, flood) or can even help with refugee aid or other facility allocation plans (Anwarzai & Nagasaka, 2017; Argyriou et al., 2016; Çetinkaya et al., 2016; Dell'Ovo et al., 2018; Feo & Gisi, 2014; Jeong et al., 2016; Kazemi & Akinci, 2018; Neaupane & Piantanakulchai, 2006; Peng & Peng, 2018a, 2018b; Phua & Minowa, 2005; Singh et al., 2017; Tang et al., 2018).

The most relevant field to geoheritage conservation that uses spatial analysis is sustainable tourism planning. Tourism has become an important source of revenue for many countries. However, today the world is facing a pandemic that has impacted travel and tourism activities and caused a global travel collapse since mid-March 2020. It is unknown when, if ever, tourism will fully recover. In our study, we continue to describe the tourism industry from before the outbreak of COVID-19 in the hope that society can soon continue travelling without restrictions.

The tourism industry has drawn negative effects on the environment resulting in extensive academic studies on advancing sustainability (Carrillo & Jorge, 2017; He et al., 2017; He et al., 2018; Kapera, 2018; Kröger & Schäfer, 2016; Rao et al., 2018). Sustainable tourism is considered "tourism which is in a form which can maintain its viability in an area for an indefinite period of time" (Butler, 1993). Sustainable tourism planning always includes factors with spatial characteristics; therefore, methodologies were built on the integration of GIS and MCDA techniques. To reduce the negative effects on the environment caused by mass tourism, the importance of suitability assessments and planning is higher than ever before. To retain the landscape and integrity of the frequented tourist destinations for future generations, it is vital to build reliable models that can predict suitability for sustainable tourism development. A popular approach to suitability assessment is based on the combined application of GIS and MCDA techniques, often involving Fuzzy set membership to standardise factors (Banai, 1993; Bockstaller et al., 2017; Boers & Cottrell, 2007; Boggia et al., 2018; Geneletti, 2004; Gigović et al., 2018; Jeong et al., 2016; Jiang & Eastman, 2000; Malczewski, 1999, 2006; Ristić et al., 2018; Rutherford et al., 2015).

MCDA is the most fundamental decision-support operation that supports spatial characteristics. The main MCDA aggregation operators employed in GIS are Boolean, Weighted Linear Combination (WLC), Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP). Boolean overlay assesses each criterion by thresholds of suitability, producing Boolean maps whereby logical operators such as intersection or union can be further applied. WLC standardises criteria to a common numeric range and then combines them by weighted averaging, resulting in a continuous mapping of suitability that can accommodate qualitative criteria

(Bunruamkaew & Murayam, 2011; Gigović et al., 2018; Gigović et al., 2016; Jiang & Eastman, 2000).

Criteria-based assessment is an essential tool for evaluation as it provides organised information for conceptualisation, implementation and sustainable management (Prabhu et al., 1996). The number of evaluation criteria is usually dependent on the decision problem. The set of evaluation criteria needs to be comprehensive, measurable, complete (cover all aspects of a decision problem), operational (they can be used meaningfully in the analysis), decomposable (they can be broken into parts to simplify the process), non-redundant (they avoid problems of double counting) and minimal (number of attributes should be kept as small as possible) (Malczewski, 1999b). According to the literature, these attributes can be attained through several techniques, such as examination of the relevant literature, analytical study and opinions (Malczewski, 1999b). There has been extensive work on how to structure hierarchies for practical problems (Saaty, 1987).

1.6. Summary

The level of detail included in the model that explicitly or implicitly underlies the decision-making influences the difficulty of implementing a decision analysis. Geoheritage evaluation methods are abundant in the literature, and still, there is no detailed explanation about how to define the minimum set of criteria that most represent the characteristics of a given area. Incorporating well-established decision-making procedures into geoheritage assessment would eliminate subjectivity and organize the dataset into a spatial database. The result of the methodology review is summarized in Figure 4, which explains the interrelations between the existing geoheritage conservation techniques and the most relevant existing nature conservation techniques. The identified interrelations between the techniques used in different conservation disciplines will be used to develop the new geoheritage evaluation method. This research aims to find the least complex combination of these steps for an optimum ranking of geoheritage sites.

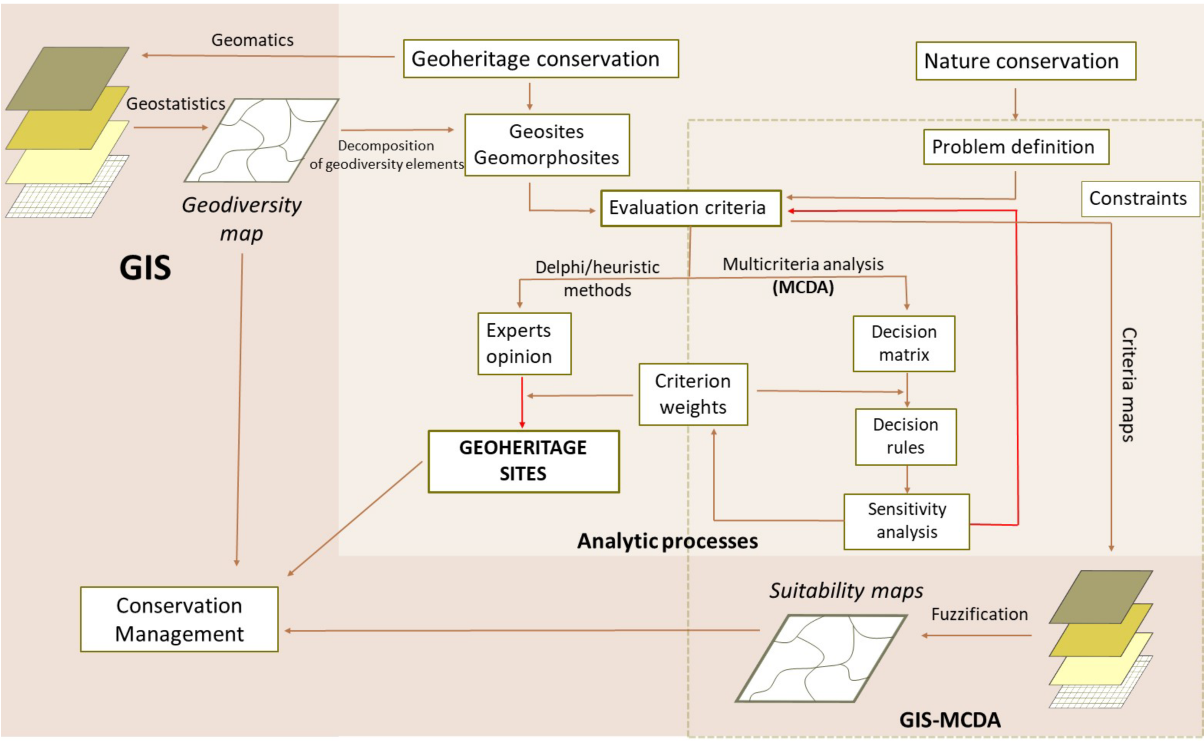

Figure 4 Interrelations between site selection methods for conservation management. This figure is referred to in Figure 1. Its purpose is to present an advanced methodology for site evaluation in nature conservation. Such methods need to be applied to geoheritage site evaluation to make assessments comparable, repeatable, and transparent. Site suitability mapping by aggregating individual map layers is the most common method used to address nature conservation problems.

Chapter 2. *Study area*

This chapter presents an overview of the geologic, societal, and legal context of Auckland city. This chapter creates an understanding of the role of geoheritage features in indigenous society and New Zealand governance and the challenges decision-makers of the complex urban environment of Auckland need to consider.

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Chapter 2. Geoheritage conservation in Auckland, New Zealand

2.1. Geology and geographic setting

The study area is the Auckland Volcanic Field (AVF), a significant monogenetic basaltic volcanic field. It is the most naturally preserved, most concentrated, and most diverse of New Zealand`s monogenetic volcanic fields (Walker, 2014). It is also one of the best examples in the world of a coastal intracontinental monogenetic field where the volcanic landforms have been influenced by post-glacial sea-level rise forming volcanic islands (Rangitoto Island, Puketutu Island, Browns Island) and flooded maar craters (Panmure Basin, Orakei Basin) and coastal cliffs (Tamaki drive sandstone cliffs) (Hayward at al., 2011a; Walker, 2014) (Figure 5).

AVF is situated on the North Island of New Zealand on a continental crust about 400 km to the west of the Hikurangi Margin subduction zone (Hopkins et al., 2016; Seebeck et al., 2014). There are post-Pleistocene intra-plate volcanic fields south of AVF called South Auckland Volcanic Field (act ive 1.6 – 0.5 Ma) (Briggs et al., 1994). The Auckland Volcanic Field has erupted periodically over the last 250 000 years, with the youngest volcano, Rangitoto, being only about 600 years old (Lindsay et al., 2011; Lindsay & Needham, 2010; Lowe et al., 2017; Needham et al., 2011; Nichol, 1992). The AVF is considered to be still active (Hayward et al., 2011b), and magmatic and phreatomagmatic eruptions produced ~53 small volcanic centres (Agustín-Flores et al., 2014; Agustín-Flores et al., 2015; Kereszturi et al., 2014; Németh et al., 2012). The youngest volcano within the AVF (and New Zealand as well) is Rangitoto. It is made of lava flows constructed in two brief eruption episodes about 50 years apart between 550 and 650 years ago (Linnell et al., 2016). This eruption was very likely witnessed by early Polynesian arrivals (Brothers & Golson, 1959; Newnham et al., 2018). Scoria cones, lava flows, maars, tuff cones and tuff rings build up the volcanic landscape overlying early Miocene marine sediments (Hayward et al., 2011b; Leonard et al., 2017). The AVF is one of the most representative examples of a Quaternary monogenetic volcanic field on Earth with respect to eruption style variability, sequence, geoform preservation and volcano types (Németh, 2010).

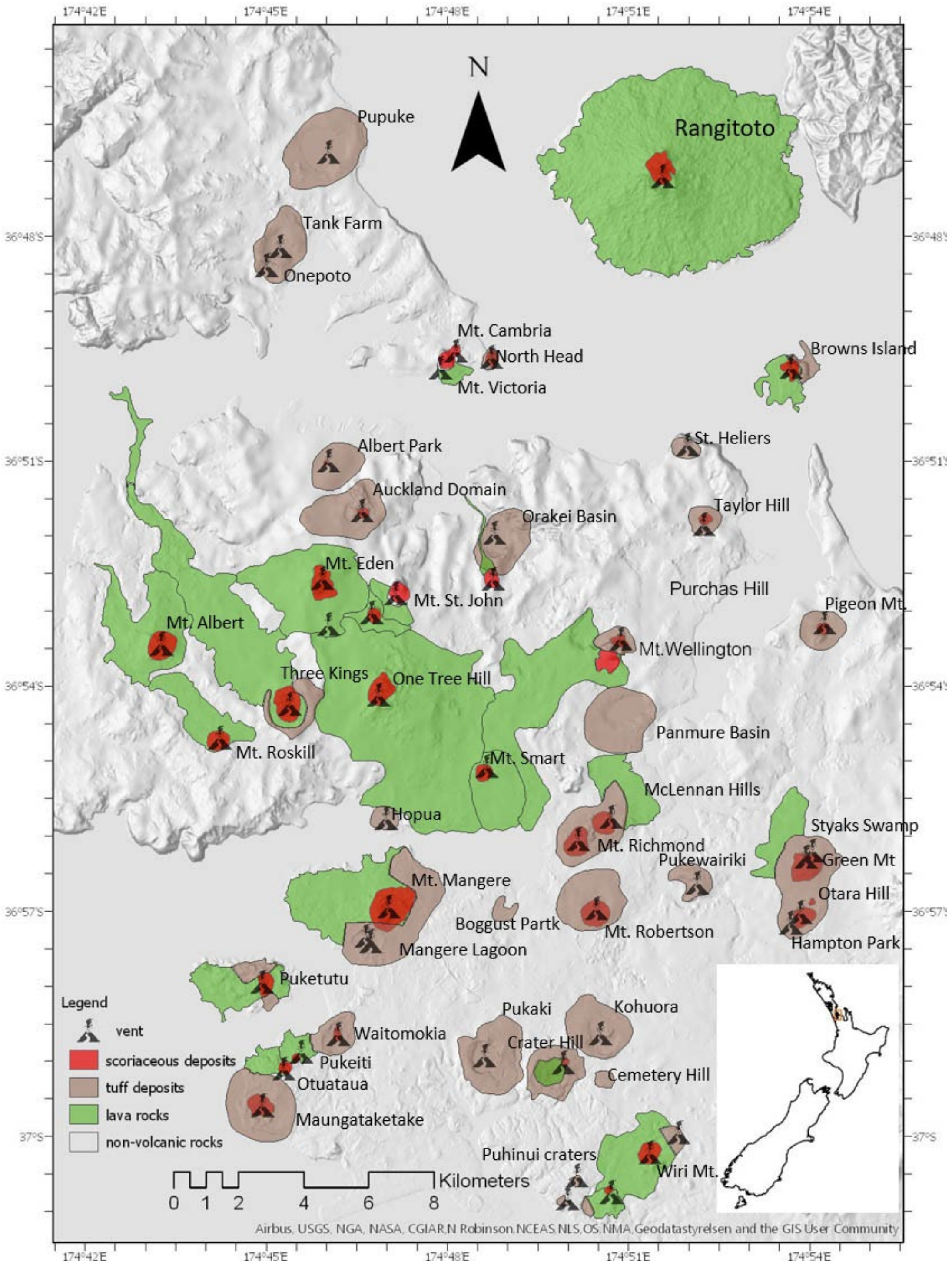

Figure 5: Geology of the Auckland Volcanic Field after Hayward et al. (2011b)

Spatial-temporal patterns and the volume of magma suggest that the AVF is at an early stage in its evolution, and further eruptions could occur (Allen & Smith, 1994). The young age and ambiguous spatial patterns in distribution make it problematic to determine the likelihood and associated risks of future eruptions (Cassidy & Locke, 2010).

The shape and size of the volcanoes depend on the styles and duration of eruption formed and the volume of magma expelled. Three basic eruption styles (phreatomagmatic, Hawaiian, and Strombolian) took place during monogenetic volcano growth producing three different types of mappable volcanic rock assemblages (commonly referred to as tuff, scoria, and basalt lava) (Golson, 1957) and three different kinds of volcanic landform (maar with a tuff ring, scoria cone, lava flow). Inside lava flows, lava caves formed as the molten lava flowed away from the vent, rapidly cooling and crusting on the outside while the hot lava kept moving on the inside (Halliday, 2002; Halliday, 2004; Larson, 1991; Sauro et al., 2019). Wiri lava cave (Hayward & Crossley, 2014; Kermode, 1987) near the centre of Manukau City is the best lava cave protected within a Scientific Reserve but kept locked down from the public (a permit can be attained from the Department of Conservation). Another unique type of feature of the Auckland Volcanic Field is the burned and buried fossil forests. Takapuna Reef fossil forest has one of the best examples in the world of a forest burned and preserved by lava flows. The forest was growing here about 250 000 years ago (Hayward, 2021; Hayward & Hayward, 1995). The Ihumatao fossil forest near the Auckland Airport contains fossils of large kauri tree stumps that are up to 2 metres in diameter (Hayward, 2019; Hayward et al., 2011b). It is unclear what killed the forest as there were already dying trees at the time of the volcanic eruption.

The place names and traditions associated with the Auckland Volcanic Field are the results of centuries of Māori occupation. They have cultivated the coastal land and the volcanic cones themselves by terracing the slopes. As a result, it is a rich archaeological area of international importance. At least 9 of the cones had been terraced and used as small, defendable settlements by the 16th century. The main archaeological sites on the terraces are the depressions left by former food (mainly kumara, taro, and yam) storage pits.

The soils around the cones were more fertile due to their accumulation of ash, tuff and lava flow. The remnants of this gardening landscape are the lava flow stone fields that were used to form garden mounds and boundary walls or windbreaks (Hayward et al., 2011a).

2.2. Role of geoheritage in reducing urban disaster risk

Sustainable development, by Andersson (2006), sustainable development is a broad term including equity and economic and environmental concerns. The rapid and worldwide urbanisation of the human population raises concerns about the sustainability of cities. As the Brundtland report (United Nations World Commission on Environment and Development 1987) states, sustainable development "…seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future" (United Nations World Commission on Environment and Development 1987). The issue is subjective as it debates the way things should be and how we should live. However, there are some elements, such as functioning and healthy ecosystems, that should be included in any sustainability discourses. It is imperative to discuss the importance of ecosystems within cities and how cities can be analysed as landscapes.

Urban has a significant number of meanings and can be related to various conditions, such as population density, type of land cover, or cultural practices. Most authors use their own definition or none. In social sciences, urban is currently associated with population density, while environmental sciences tend to use definitions in terms of dominant land cover (Marzluff & Ewing, 2008).

Geosites, or sites of geological and geomorphological interest, are not restricted to rural, open, or outdoor areas. Valuable geoheritage examples can be found as well in urban spaces. An urban geosite can be defined simply as a site of geological or geomorphological interest within a city and may be natural, derived from geological processes or man-made structures where representative types of rocks were used for their construction. They may also represent a place of interest associated with representative geological and geomorphological processes related to the development of the urban area itself.

Natural hazards frequently occur in Auckland, such as flooding, coastal erosion (including the effects of sea-level rise), freshwater erosion and land instability; and less frequently can occur wildfire, volcanic activity, tsunami, earthquakes, and meteorological hazards (cyclones, tornadoes, and drought).

The Auckland Council manages natural hazards by identifying hazard zones on planning maps, asking for site investigations, and engineering work to assess and reduce risk in areas of identified land instability or areas prone to flooding by stormwater or sea, controlling activities in areas likely to experience these hazards, limiting or prohibiting structures in areas of known risk, requiring more intensive engineering design where necessary.

The Auckland Council assesses risk from natural hazards by managing urban land use using zonation. Coastal hazards are beach erosion, coastal hazard, and flood risks through education, warning systems and emergency preparedness. The low probability but high potential impact hazards are volcanic activity, tsunamis, and earthquakes (www.aucklandcouncil.govt.nz). With the improvement of educational panels on active geological processes, Auckland Council can create a resilient community and significantly lower the tragic outcomes of a potential natural disaster event.

2.3. Geopreservation Inventory and UNESCO World Heritage application

"We have always been aware of the need to preserve our memories – our cultural heritage. Now the time has come to ensure we protect our natural heritage. The past of the Earth is no less important than that of human beings" (Bruce Hayward, http://www.geomarine.org.nz/NZGI/ accessed on 30.5.2021)

The evaluation values for New Zealand`s landforms and geological features (Table 1) are aesthetic, recreational, tourism, education, and research values. The Geological Society of NZ initiated the compilation of the New Zealand Geopreservation Inventory in 1983. They recognized that the lack of protection could lead to the complete loss of the best representative examples of earth science. Initially, the inventory was the responsibility of the Joint New Zealand Earth Science Societies` Working Group on Geopreservation. The working group was comprised of members of the Geological Society of NZ, Geological Society of Australia, NZ Geomorphology Group, NZ Geographical Society, NZ Soil Science Society, NZ Speleological Association and NZ Assoc of Landscape Architects. Today, the inventory is maintained by the NZ Soil Sciences Society. It contains 2576 sites New Zealand-wide. The assessment of importance is divided into three groups `A` being international scientific, aesthetic, or educational value, `B` being national scientific, aesthetic or educational value and `C` being regional scientific, aesthetic or educational value. Attributes assigned to each entry are as follows: site name, regional council district, statement of significance, brief description, the geological age of feature, brief locality description, map reference (NZMS 260), accessibility, type of exposure, foreseeable hazards to the feature, human modifications to the feature, reserve status, earth science informants, date information supplied and literature references about the feature (http://www.geomarine.org.nz/NZGI/ accessed on 30.5.2021).

Table 1. Statistics about the Geopreservation Inventory in October 2021. `A`, `B`, `C` represent the level of importance assigned to the geopreservation site situated in the region. Divided into `A` being international scientific, aesthetic, or educational value `B` being national scientific, aesthetic or educational value and `C` being regional scientific, aesthetic or educational value.

Region	A	B	C	Total
Auckland	8	84	276	368
Bay of Plenty	34	66	104	204
Canterbury	24	124	197	345
Chatham Islands	1	17	14	32
East Coast	0	18	33	51
Hawkes Bay	6	34	89	129
Kermadec Islands	0	11	2	13
Manawatu	2	9	29	40
Marlborough	3	25	53	81
Nelson	18	68	109	195
Northland	8	90	142	240
Otago	22	102	154	278
Southland	12	82	83	177
Subantarctic Islands	1	4	10	15
Taranaki	8	27	35	70
Waikato	26	146	256	428
Wanganui	9	40	27	76
Wellington	4	32	94	130
West Coast	23	68	159	250
Total	209	1047	1866	3122

UNESCO is the only convention that includes geoconservation in some form. In UNESCO`s principles, geoconservation is one criterion among many other criteria with prime importance of cultural and biological values.

Walker (2014) prepared a world heritage case to submit to UNESCO. The application is comprised of 21 volcanic sites of the Auckland Volcanic Field. The features are nominated as Mixed Cultural and Natural Property and a Cultural Landscape under category 2 – an organically evolving landscape and Polynesian geocultural region. All sites have qualities of authenticity and integrity. The nomination is making a case for the outstanding volcanic features of the Auckland Volcanic Field as a culturally significant, regional, tribally based nature of Māori society. The Auckland Volcanic Field is still on the tentative list.

2.4. Legislation and Biculturalism

Protection of New Zealand`s natural environment from adverse activities and exploiting resource use is provided by regulations, standards, legislation, and international conventions. New Zealand strives to take proactive, active, and reactive parts of the global framework for combating environmental challenges (https://www.environmentguide.org.nz/overview/statutory-bodies/environmental-protection-authority/). New Zealand`s main environmental legislation is provided by the Resource Management Act, and Reserves Act (Resource Management Act, 1991). Matters of national importance that must be recognized across all activities in New Zealand:

- natural character of the coastal environment:
- outstanding natural features and landscapes:
- significant indigenous habitats and vegetation:
- public access to waterbodies:
- Māori culture, traditions, ancestral lands, water, sites, waahi tapu, and taonga:
- historical heritage:
- recognised customary activities.

The RMA is a framework for the sustainable management of land, air, and water activities. Sustainable management is managing the use, development, and protection of natural and physical resources for future generations. The RMA controls management through three diverse functions: control of access to and use of natural resources; control of the discharge of contaminants; management of the adverse effects of all activities in the environment.

The RMA focuses on the environmental impact of activities, not the activities themselves. That is why Regional and Local Councils have a crucial role in creating opportunities for geoheritage protection. Regional Councils must prepare regional policy statements and plans that describe and facilitate the management of natural and physical resources (BCITO, 2018).

The Auckland Regional Council Policy Statement details the physical and visual integrity and values of the volcanic cones and other regionally significant volcanic features and the important views of the volcanic cones from urban Auckland and their value as outstanding natural features. Accordingly, they should not be adversely affected by subdivision, use and development that directly impacts their structure, or by inappropriate development in surrounding areas, or should not be compromised by inappropriately located or inappropriately sized development (Auckland Regional Council, 1999).

Auckland Conservation Management Strategy (2014) first developed a framework to meet international obligations. New Zealand is a signatory to many international agreements that are relevant to conservation. The Department implements these agreements in accordance with its functions and has responsibilities for several species under these agreements. Examples of important international agreements of most relevance within Auckland include the (Auckland Conservation Management Strategy, 2014):

- Convention on Biological Diversity
- Convention Concerning the Protection of the World's Cultural and Natural Heritage (World Heritage Convention)
- Convention on International Trade in Endangered Species of Wildlife Flora and Fauna (CITES)
- International Convention for the Regulation of Whaling
- Convention on Migratory Species
- Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention)
- Convention for the Protection of Cultural Property in the Event of Armed Conflict
- Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property

The distinctive features, values and issues of Auckland largely affect the planning of conservation management. Auckland is the largest urban area with the largest population density in New Zealand, with a population of around 1.6 million (2018 Census). Auckland is home to a quarter of New Zealand's Māori population, two-thirds of New Zealand's Asian and Pacific ethnic populations and half of its Middle Eastern, Latin American, and African ethnic group populations. By 2031, Auckland is expected to grow to nearly 2 million people and will be home to 38% of New Zealand's population because of immigration and a steady northward drift within the country. Key themes for managing and contributing to conservation in Auckland include (Auckland Conservation Management Strategy, 2014):

- Working with the multicultural population, which offers challenges as well as opportunities to increase support for conservation.
- Achieving positive conservation outcomes within Auckland's fragmented and depleted natural heritage, which is significantly reliant on working with local communities.

- Recognising the cultural values of tangata whenua regarding the conservation of the natural environment in the Auckland region.
- Raising awareness of and managing island refuges in the Gulf that contain significant natural, historical and cultural heritage.
- Providing easily accessible visitor destinations that showcase the conservation values of Auckland and working with landowners.

A number of shared governance and management models have emerged in New Zealand over the past 20 years (Harmsworth et al., 2015; Ruru, 2009). The legal status of co-governance is based on the Treaty of Waitangi. Under these models, governance structures, legal status, agreements, and the collaborative process varies from region to region. Iwi groups and communities are increasingly engaging in collaborative processes for management plans of natural resources. Māori today play a critical role in the management of freshwater, marine reserves, coastal areas and archaeological sites (Harmsworth et al., 2016). Best practice codes of all industries related to the environment include a legal procedure to allow the discovery and protection of wahi tapu sites (sacred cultural places).

The term biculturalism in NZ refers to Māori and non-Māori. The Treaty of Waitangi put in place a partnership between the Māori and the British Crown. Since the 1970s, the New Zealand Government has moved to a practice that is described as bicultural (Hayward, 2012).

- The place of the Treaty of Waitangi in NZ`s laws.
- Te Reo Māori – the place of Māori language as one of the official languages of New Zealand.
- Preservation and celebration of Tikanga Māori (the right practice) as having equal status and correctness as non-Māori practices.
- Land ownership – considering historical events and present populations and residency.
- Equal opportunities for Māori to succeed economically, educationally and in the justice system.

Before the Treaty of Waitangi was signed in 1840, Māori and British settlers lived separated, forming a bubble within their own culture. After the treaty was signed, the settler population exploded and quickly outnumbered the Māori (Hayward, 2012).

2.5. Māori Custom and Values in New Zealand Law

The foundation of Māori Custom Law is "tikanga Māori" the body of rules and values developed by Māori to govern themselves. The closest equivalent to the law (for which there is no Māori word) is "tikanga"(Law Commission, 2001).

"*Tikanga embodies a set of beliefs and practices associated with procedures to be followed in conducting the affairs of a group of individuals. These procedures are established by precedents through time, are held to be ritually correct, are validated by usually more than one generation and are always subject to what a group or an individual can do.*

Tikanga are tools of thought and understanding. They are packages of ideas which help to organise behaviour and provide some predictability in how certain activities are carried out. They provide templates and frameworks to guide our actions and help steer us through some huge gatherings of people and some tense moments in our ceremonial life. They help us to differentiate between right and wrong and in this sense have built in ethical rules that must be observed. Sometimes tikanga help us survive.

Tikanga differs in scale. Some are large, involve many participants and are very public. Other tikanga are small and are less public. Some of them might be carried out by individuals in isolation from the public, and at other times participation is limited to immediate family. There are thus great differences in the social, cultural and economic requirements of particular tikanga."- expanded description provided by Hirini Moko Mead (2000)

The capacity of tikanga Māori to adapt to new circumstances is explained by Justice Durie (Law Commission, 2001) and conveys a great message for today decision makers about adaptability to create sustainable development.

"*…adherence to principles, not rules, enabled change while maintaining cultural integrity, without the need for a superordinate authority to enact amendments. Custom does not, therefore, appear to have been lacking for vitality and flexibility. Inconvenient precedent could simply be treated as irrelevant, or unrelated to current needs, but precedent nonetheless was regularly drawn upon to determine appropriate action. Accordingly, while custom has usually been posited as finite law that has always existed, customary policy was dynamic and receptive to change, but change was affected with adherence to those fundamental principles and beliefs that Māori considered appropriate to govern the relationships between persons, people and the environment."* - Hirini Moko Mead (2000).

A very important lesson that should reform the way decisions are made is that more than one distinct cultural group can be accommodated within a society. Recognising distinct cultural values and communities and bringing all cultural values in harmony is the key to collective national identity (Law Commission, 2001).

The demand for better representation of cultural considerations in environmental management is mandatory (Satterfield et al., 2013), and geoheritage conservation is no exception.

2.6. Reflecting on Māori cultural rights in environmental protection

The western way of living is an emerging philosophical question that is often criticized: "*The `instruments` of western research require that practitioners be acculturated into the 'Way of the West'? Since the inception of modern science, it has been both argued and shown that science includes a set of norms and a certain worldview that has been characteristic of Western culture since the Enlightenment. Among the fundamental concepts of Western science are the Cartesian split between mind and body. The methodological goals of western science include reductionism, objectivity, scepticism, empiricism, replication, quantification, mathematical abstraction and calculus, precision, standardization, and the accumulation of de-individualized knowledge. Its norms comprise, among others, secularization, idealism, evolutionism, individualism and the commoditization of nature*" (Wråkberg & Granqvist, 2014).

The incorporation of Māori indigenous cosmologies within the Western society and legal system advances positive outcomes in protecting the natural environment (Magallanes & Catherine, 2015). Te Ao Māori (Māori world view) and Mātauranga Māori (Māori knowledge systems) refer to a wide range of cultural concepts founded in indigenous traditional knowledge and philosophy. It provides a distinct set of indigenous cultural, physical, spiritual and metaphysical values (Harmsworth et al., 2016). Mātauranga Māori is being used to inform best practices of industries such as plantation forestry, freshwater management and marine aquaculture. (Harmsworth et al., 2016).

An ecosystem services framework for Māori must recognise that cultural values range from material (e.g., provisioning, regulating, supporting) to non-material (e.g., spiritual, sacred). The Māori ecosystem services framework aligns with iwi's multidimensional goals and aspirations. The acknowledgement and recognition of taonga (treasure) and customary resources are paramount for Māori within an ecosystem management framework. To be effective, the framework needs to show what is required to better protect and manage natural resources and deliver ecosystem services to achieve integrated environmental goals (Harmsworth & Awatere, 2013).

Māori beliefs and values are based on their relationship with the natural environment and their influence on management. Environmental concepts are tāonga (treasures), mauri (life force), wairua (spiritual health and wellbeing), kaitiaki (guardians), and ahi kā (unbroken connections) that are part of the framework of kaitiakitanga (guardianship) that encompasses the philosophical and practical components that establish indigenous environmental ethics. In the Māori tradition, the Universe is a dynamic process, a continuous transformation. Volcanic craters, crater lakes, water springs and other specific landscapes are tapu. For example, Ngāti Rangi refers to the Crater Lake on Ruapehu as Te Wai a Moe, the Sleeping Water, a tapu place related to the most unpredictable phreatic events. Tapu can be considered a hazard mitigation strategy (Pardo et al., 2015)

Chapter 3. *The New Approach*

In this chapter we describe the major gaps and challenges in geoheritage practices. This chapter introduces the multi-objective nature of geoheritage conservation. It also presents an introduction to the new approach to evaluating geoheritage and incorporating the evaluation results into urban planning.

Chapter Contents

Chapter 3. The goals of a comprehensive conservancy

3.1. Problem statement

"*Without data you are just another person with an opinion*" – W. Edvard Deming

"*Without an opinion, you are just another person with data*"

– Milo Jones and Philippe Silberzahn

The values for a geoheritage feature cannot simply be defined by measurable data, and neither can they be simply based on feelings. Their role is two-fold, to educate science and to reinstate community wellbeing. Opinion and instinct influence our ability to interpret data and translate it in a way that benefits society as a whole. Geoheritage bridges the communication gap between scientists and the public. The current literature is missing a sound conceptual framework for geoheritage. The lack of a conceptual background decreases the strength of geoheritage assessments. Evidence-based assessments are necessary for the quality implementation of geoheritage features situated in complex urban environments. Conservation endeavours battle with the needs of the growing population of Auckland (population count increased by 18.1 per cent from 2013 to 2018 according to 2018 Census figures by Stats NZ [stats.govt.nz]) that necessitates the transmission of geoheritage evaluation into GIS models. Non-comparability of geoheritage evaluations weakens the overall geoheritage evaluation process.

3.2. Aim and objectives

The aim of the study is to provide a conceptual framework using the global state of knowledge on geoheritage and to incorporate a comparable, repeatable, and transparent GIS-based geoheritage evaluation into land use planning. The overarching goal is the achievement of more exclusive geoconservation policies that protect the internationally significant geological, geomorphological, and cultural setting of the Auckland Volcanic Field under the rapidly developing urban environment of metropolitan Auckland.

The thesis aims to assist urban planners, decision-makers and conservation practitioners in improving geoheritage conservation and geoeducation outcomes consistent with the indigenous community, sustainable development, and international-national regulatory expectations.

A particular urban geoheritage, the Auckland Volcanic Field, is analysed to illustrate the underlying principles. The case study was chosen to represent an environment where western values are challenged, where nature is considered ancestors from whom humans are descended and where sustainability is not a political force but the preferred way of living. The deterioration of our natural environment and the complete destruction of geomorphology by artificially resurfacing the environment make society less resilient to natural hazards.

Geoheritage conservation addresses this issue by protecting the integrity of high-educational value geosites. Due to the dismissal of strict and exclusive terminology, geoheritage today is perceived more as a niche tourism sector. Geotourism is one of the fundamental goals of geoheritage conservation. It brings benefits to locals economically and culturally by committing to respecting local sensitivities and building on local heritage. However, the evaluation of geoheritage should not be driven by tourist demands.

This study aims to advance knowledge exchange between scientists and policymakers to work toward better public engagement by defining a sound conceptual framework. When there are more robust connections between policymakers and groups in the community, they are more likely to work together to solve problems. Moreover, this study aims to establish a global community that empowers areas with the capacity to communicate and manage geohazards by building a spatial assessment method. This study aims to facilitate geoheritage to enter urban areas and to communicate that geoconservation is an integral part of nature conservation. To achieve the goal of building conceptual clarity and a spatial evaluation instrument, the main objectives of the study are:

- Objective 1 To achieve conceptual clarity by creating the conceptual framework necessary for identifying the geoheritage elements of geodiversity in the Auckland Volcanic Field (AVF). Conceptual unclarity seeps through all aspects of geoheritage research. It is a widespread and fundamental problem that plays a mostly marginal role in geoheritage studies. The first objective addresses the building of the conceptual framework that is needed to move geoheritage forward as a science.

- Objective 2 The objective is to investigate the underlying motives to achieve objectivity and reliability using advanced multivariate statistics. Furthermore, this study seeks correlation among different types of world development indicators with bibliometric data on geoheritage to find critical factors and report geoheritage implementations' directions and their determinants at the global and local levels.

- Objective 3 The objective is to maximise the scientific knowledge exchange in the Auckland Volcanic Field, New Zealand. The aim is to investigate the feasibility of quantifying geoeducation capacity through aggregating automated landform classification and geoheritage values translated to spatial data. A geoeducation capacity map opens opportunities for GIS-based MCDA.

- Objective 4. The objective is to apply the techniques and findings and build a model that considers the spatial character of the main geoheritage assessment criteria used in the literature and create spatial decision support by adopting the approach of coupling geospatial approaches between GIS, MCDA and multi-objective land use planning.

3.3. Methodology

3.3.1. Systematic mapping

Systematic mapping is a form of evidence synthesis. It is the method that summarises a sequence of actions, including searching, screening, coding, describing, and visualising. It follows a protocol that clearly highlights the topic addressed and the methods used in a repeatable and transparent manner (Grant & Booth, 2009). After identifying the relevant material from the literature, the data pertinent to the research is extracted, categorised and analysed (Ahmad et al., 2018; Petersen et al., 2008; Sebastián Rivera et al., 2019). For a discipline that evolves through the scientific discourse of peer-reviewed literature, it is crucial for the output to be mapped out and synthesised around the significant lines of thinking. We focus on global literature that has met the criteria of being indexed in English and provide a clear link to geological conservation dilemmas, actions, evaluation, and other challenges. Keyword extraction happens through manual screening and coding. These keywords are chosen according to their relevance to geoscience, geoconservation, geodiversity geotourism, and sustainability. The main building blocks of the conceptual discourse are then defined and described through the topic clouds.

3.3.2. Correspondence analysis

Exploratory data analysis techniques define systematic relations between variables. The correspondence analysis (CA) method is an unconstrained ordination method that orders individuals characterised by categorical values on multiple variables (Blasius & Greenacre, 2006). CA works on categorical datasets that have been scaled into categories as a powerful tool for finding patterns in large datasets (Deschamps, 2017). This multivariate method is used for almost any data matrix with nonnegative entries that principally involves tables of frequencies of counts and analyses data without explanatory variables (Blasius & Greenacre, 2006). CA is a potent technique to group our indicators in the reduced dimensional spaces to present key insights on relationships. Ordination orders the individuals so that ones with similar profiles are near each other and dissimilar objects are farther from each other. It simplifies complex data and provides an exhaustive analysis of the data (Costa et al., 2013). While CA shows the relationship between variables, multiple correspondence analysis (MCA) analyses relationships within a set of variables, the interrelationships between the statements or categories of variables. MCA is the central analytical tool to embed qualitative data. MCA is applied to detect and represent underlying structures in our dataset to investigate influencing factors for geoheritage designation. Therefore, this analysis can explore whether there is an association between "high geoheritage-related citations" and a "high number of international arrivals". CA can only tell us whether all the categories of the same variable have a statistically significant correlation with any other variable. This method tackles the more general problem of associations among a set of more than two categorical variables (Greenacre, 2006). This unconstrained geometric approach is directly linked to data visualisation.

3.3.3. Social Data Mining

Big Data has the capacity to provide readily available data from which it is possible to gain insights into the preferences, attitudes, needs and sentiments of the society (De Mauro et al., 2016). Being an emerging discipline, the existing definitions for Big Data provide very different perspectives. De Mauro et al. (2016) reviewed the existing definitions to propose a consensual definition that is `Big Data is the Information asset characterised by such a high volume, velocity and variety to require specific technology and analytical methods for its transformation into value`. Instant knowledge exchange created Big Data, an extensive data set that provides a promising new source for measuring, analysing and revealing patterns and trends

(Buhalis & Amaranggana, 2015). The tourism-related Big Data prompts the interconnection of tourism destinations with multiple stakeholders (Public Sector and Government, Tourism Enterprises, Tour Operators, Local Communities, and Host population) through dynamic platforms, knowledge-intensive communication flows and enhanced decision support systems (Buhalis, 2000; Buhalis & Amaranggana, 2015; Vecchio et al., 2017).

The extraction of geotagged photos from social media is a method increasingly used for measuring tourism activity (García-Palomares et al., 2015; Girardin et al., 2008; Kádár & Gede, 2013a; Lieskovský et al., 2017). One of the main motives for exploiting this source of information is to replace traditional surveys that are expensive, need ethical approval and provide limited spatial and temporal coverage (Wood et al., 2013). Scientists traditionally studied recreation by conducting surveys that also can be unintentionally prefabricated depending on the sampling size. The Meta-data of photographs in Flickr, Instragram, Panoramio, and Google gives the visitation rates worldwide and derives other information such as travellers` origin. As it can be a biased subset, it is necessary to validate it. The validation tool is the magnitude of the data of actual arrivals in Auckland. A statistically significant correlation between the volume of monthly arrivals and the importance of monthly pictures taken suggests that FlickR represents visitation frequency in Auckland.

Social media are now considered one of the primary sources of Big Data generation in tourism and efficient decision-making procedures, resulting in a concept called Social Big Data (Vecchio et al., 2017). Comparative studies of this crowd-sourced information versus empirical data attained through classic surveying methods concluded that Social Big Data indeed serve as a reliable proxy for intelligent configuration of destination (Kádár & Gede, 2013; Vecchio et al., 2017; S. A. Wood et al., 2013). Due to the novelty of the subject, however, there is still research on how this massive amount of data can be used for value-creation processes that call for more in-depth analysis (Vecchio et al., 2017).

3.3.4. Spatial Analysis

In this study, we investigate the avenues Social Big Data create value for geoheritage evaluation. To achieve this goal, a case study analysed the volume and location of pictures taken in Auckland Volcanic Field and uploaded them to FlickR. The aim is to develop a value-creation process and to derive implications for more efficient geoheritage assessment.

GIS techniques deliver an ability for users to construct repeatable models. The repeatability of an evaluation method is one of the main criteria for achieving the reliability necessary for quality implementation (Malczewski, 2006). Spatial techniques also make geologic, and geomorphologic features out of sight appear in evaluations providing robust scientific information (Jankowski et al., 1997).

The topographic Position Index creates an accurate map for `rarity`, the main criterion layer. The technique is developed to classify landforms for further analyses and to utilise mainly in ecological decision-making tasks such as biodiversity modelling (Amatulli et al., 2018; Wood et al., 2011), or assessment of soil-moisture (Dyer, 2009; Parker, 1982; Riley et al., 2017), or habitat suitability (Galparsoro et al., 2009; Hook & Burke, 2000) to mention a few.

The topographic Position Index technique is used to classify the landforms. This means clearly defined boundaries and the opportunity to break down a landform into more minor landform features. This increases the likelihood of implementation by giving options for the identification of sites with the highest potential. Once the locations of the highest value are pinpointed in GIS, the map can be inserted into land use planning. This step is a prerequisite for promoting geological heritage in urban settings.

GIS multicriteria decision analysis is widely used in site selection exercises, for example, wind farm site selection (Szurek et al., 2014; Van Haaren & Fthenakis, 2011); agro-industrial complex site selection (Sahnoun et al., 2012); industrial site selection (Eldrandaly et al., 2003); parking site selection (Jelokhani-Niaraki & Malczewski, 2015); investment site selection (Siejka, 2017); landfill site selection (Bahrani et al., 2016). It is also used as best practice in the detection of land use suitability, for example, in urban extension (Chen, 2014; Mosadeghi et al., 2015; Svoray et al., 2005); citrus management (Zabihi et al., 2019); agricultural land use (Janssen & Rietveld, 1990); land management (Joerin & Musy, 2000; Nguyen et al., 2015); biomass residues (Colantoni et al., 2016); or rainfed farming (Kazemi & Akinci, 2018). GIS multicriteria decision analysis is a very useful technique in hazard mapping such as multi-hazard mapping of landslides, floods and earthquakes (Skilodimou et al., 2019); forest hazards (Gigović et al., 2018); hazards in site selection (Ahmadisharaf et al., 2016); forest fire risk (Huyen & Tuan, 2008). It is also used in socio-economic fields to analyse deprivation (Bell et al., 2007); urban water demands (Panagopoulos et al., 2012); climate change (Mokrech et al., 2012); forest landscape restoration preferences (Uribe et al., 2014); or to map zones, for example for groundwater recharge (Chenini et al., 2010); landslide hazard zonation (Bera et al., 2019; Rahamana et al., 2014); protected area zoning (Zhang et al., 2013); or multi-objective land allocation (Gilbert et al., 1985; Hajehforooshnia et al., 2011; Ligmann-Zielinska et al., 2008; Matthews et al., 2000; Zhang et al., 2016). These applications require precise modelling that underlines decision-making. Conservation of geological and geomorphological features gain objectivity by using GIS modelling. Multicriteria analysis is versatile, allowing for multiple objectives to be considered and having all the alternatives on record. The primary constraint of non-GIS-based geoheritage evaluation is the level of subjectivity and the inability to provide multi-objective solutions.

Chapter 4 *Mapping and Integrating Concepts*

In this chapter, a large body of literature has been systematically reviewed for data extraction. From the extracted data a systematic mapping of the scientific literature was undertaken to define key concepts supported by scientific evidence. This chapter presents an understanding of the evolution of the research field between 2000 and 2019 that highly improves conceptual clarity. The information gained allowed us to characterize and list all the major viewpoints present in the scientific literature.

Supplementary data for the Chapter are in Appendix C.

Chapter Contents

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Chapter 4. Geoheritage conservation: systematic mapping study for conceptual synthesis

4.1. Introduction

Rapid industrialisation in both developing and developed countries has placed extreme pressure on geodiversity, on which geoheritage conservation depends (i.e. Belgium, Dusar and Dreesen (2012); China, Wang (2007); Germany, Megerle (2012) United Kingdom, Prosser (2018) Italy). Geoheritage conservation is more than a moral responsibility. Evolving technology and preserved geoheritage sites allow scientists to refine our knowledge of geological processes and engage and educate the community through recreation. The principle of geology (Lyell, 1833) "that the present is the key to the past and leads to the understanding of Earth's future" (Rudwick, 1998; Scott, 1998) was acknowledged at the time against the background of the industrial revolution. Even so, the conservational value of geo(morpho)logy is a relatively new concept yet to be fully recognised.

Conservation practice in New Zealand faces the challenge of bicultural management. To create an indigenous-specific geoheritage framework, a clear understanding of what this means in practice is mandatory. New Zealand is recognised as a country of bicultural governance (Te Papa, 2004) based on The Treaty of Waitangi, signed between the indigenous Māori inhabitants of New Zealand and the Crown (Orange, 1987). Subsequently, conservation and land management policies are required to consider the principles of the treaty when undertaking actions. (Conservation Act, 1987; Resource Management Act, 1991). Bicultural decisions require meaningful consultation, power-sharing agreements, and clearly laid out co-management strategies with relevant stakeholders (Rother, 2016; Tipa & Welch, 2006). Places and resources identified by Māori as having spiritual, ancestral, cultural, customary or historical significance are highly important in any conservation strategy (Nga mana whenua o Tamaki Makauaru and The Crown, 2012). Nature conservation can and should be based on indigenous values, as presented in The New Zealand Biodiversity Strategy (2000). For example, monitoring practices of testing waterways for their cultural health from a Māori worldview interweaves environmental and socio-cultural aspects (Harmsworth et al., 2016) (Harmsworth et al., 2016). In Māori culture, nature and people create a relationship that flows both ways, reflected in the term *tangata whenua*, which may be translated as "people of the land" (Stafford, 2008). Local indigenous knowledge relating to *taonga* (this Māori term is often used to refer to objects but can also include places, cultural landscapes, stories, and intellectual property) (Craig et al., 2012) has a crucial role in conservation practices. The Resource Management Act, the main piece of legislation for the management of our environment, requires local government and iwi authorities to participate equally in the policy-making processes (Resource Management Act, 1991; Saunders, 2017). However, the application of this requirement is not clearly defined by further legislation, often remains unacknowledged in planning and legal processes, and may be widely open to interpretation by regional governance bodies and planning agencies (McCrossin, 2013).

Systematic mapping is a useful tool to address and synthesise knowledge and conceptual diversity of a given domain by categorising and visualising existing literature and indicating directions for further review work (Grant & Booth, 2009). The process initially uses a wide-reaching search string to extract the largest volume of studies related to the specific topic or research question (Ahmad et al., 2018; Petersen et al., 2008; Sebastián Rivera et al., 2019). This type of knowledge synthesis allows a narrowing towards subsequent policy and practice and may give rise to further relevant questions without the need for a formal quality assessment (Lockwood et al., 2019). Systematic mapping was created to compile a type of report that improves conceptual clarity and, in turn, improves the quality of policy outcomes. The procedure, in turn, leads to systematic reviews that are able to define the level of reliability of the identified implications (Haddaway et al., 2016). Healthcare has a long history of developing synthesis tools for monitoring the quality of research instruments through systematic reviews and meta-analyses. The value of systematic reviews may be weakened by poor conceptualisation; however, basing it on prior systematic mapping will rectify this potential shortcoming (Reeves et al., 2010).

The concept of heritage is deeply entwined and rooted in human perceptions, memories, and sensations that allow individuals to feel connected to their past. Systematic mapping with supervised keyword acquisition makes use of semantics to understand concepts, theories, conventions, and research within the scientific literature relating to any given field (de Souza Neto et al., 2018; Petersen et al., 2008). Within the discourse of geoheritage, concepts evoked from deeply embedded semantics and related terminology may differ according to socio-economic background, cultural history, and regional history. The supervised acquisition allows for a higher resolution analysis through algorithmic controls and allows filtering of domain-specific semantics. Geoheritage has evolved into one of the major components of studies on geoconservation. As such, a report on simplified contexts where geoheritage appears is important.

Conceptual ambiguity can be observed in the variety of formulas and terms employed to express geoheritage actions soon after the first mention of the term geoheritage at the First International Symposium on the Conservation of our Geological Heritage in 1991. Among the earliest publications, outstanding geomorphology was addressed by the term geomorphosites, acknowledging the importance of relevant culture and aesthetics alongside geological research (Grandgirard, 1997; Panizza & Piacente, 1993). At the same time, geoheritage conservation was given a narrow definition but was still seen as vital to the progression of geological research, education and training through the protection of geosites and outstanding geological features (Wimbledon, 1999). Concerns were raised about prompt actions to take in order to avoid the multilateral development of a range of conflicting geoheritage concepts (Wimbledon, 1996).

The entwined relationship between promotion and visitation has added to the conceptual diversity. Publicity driven by geotourism can increase foot traffic to geoheritage sites, thereby providing economic benefits to locals. Interpretive and service facilities offered by the geotourism industry have the potential to facilitate appreciation, learning and research by and for current and future generations (Hose, 2012a); provide opportunities for conversation and increase the scope of geoheritage conservation; and reinforce values of local communities and visitors (Bujdosó et al., 2015; Doorne, 2000; Dowling, 2011; Hose, 1996; Newsome & Dowling, 2006; Ruban, 2015; Štrba, 2018). Incorporating geoconservation into the broader field of nature conservation will achieve equal opportunities for geosites alongside sites preserved and promoted based on other values, i.e., cultural, ecological, or aesthetic. Geoconservation includes geoheritage conservation as well as the protection of geodiversity as a contributing factor to biodiversity conservation. Geodiversity, on the one hand, defines abiotic factors such as geological, geomorphological and soil environments, which in turn shape biotic factors such as species distribution patterns, climate and social landscapes (Anderson & Ferree, 2010; Gray et al., 2013; Pickering, 1994).

If providing resources for earth science research and increasing awareness is to be the basis of long-term geoheritage conservation plans, simply increasing visitation alone cannot guarantee that all relevant initiatives worldwide will develop satisfactorily in the long run. While literature reviews are abundant, they all address a specific branch within geoheritage (Brown et al., 2018; Cayla, 2014; Comănescu et al., 2012; García-Ortiz et al., 2014; Kubalíková, 2013; Miljkovic et al., 2018; Mucivuna et al., 2019; Ólafsdóttir & Tverijonaite, 2018; Štrba et al., 2015; White & Wakelin-King, 2014). A key problem affecting the field is that it rests on multilateral conceptualisations of geoheritage-related activities. Robust conceptual boundaries advance the understanding of the most effective strategies to facilitate noncontroversial outcomes and lead to the development of powerful decision-making tools for key stakeholders.

Moreover, the recent history of geoheritage emphasises its fundamental role in sustainability. For example, geoheritage has become an increasingly important UNESCO "product" for local communities in the form of administrative areas that are called geoparks. In many jurisdictions, Geoparks are not subject to the same level of strict "non-use" protection that National Parks may be subject to. Meanwhile, academics are highlighting the scope and scale of geoheritage conservation and whether it is, in fact resulting in slow recognition and loss of important geological relics (Brilha, 2016; Gordon et al., 2018a; Gordon et al., 2012; Grandgirard, 1997; Gray, 2004; Hayward, 2009; Hose, 1995; Németh et al., 2017; Panizza, 2001; Prosser et al., 2006; Reynard, 2008a; Sharples, 1998; Wimbledon, 1999).

Geoheritage does not necessarily require strong measures from governments, and it is more reliant on bottom-up initiatives and local experts' knowledge (Brilha & Reynard, 2018; Prosser et al., 2018). However, it has become crucial in our modern world to strengthen this bottom-up approach with an evidence-based framework drawing on globally accepted values under the scope of geoheritage. Authorised bodies face hard decisions between the economic and life-supporting needs of society and environmental conservation based on intrinsic values. Geoheritage values can be seen as more robust and part of human history, in contrast to biodiversity values based on delicately balanced biotic systems. Therefore, we argue that geoheritage values can coexist with industrialisation and rapid urban development within some common parameters. Industrial and economic developments can be seen as part of our geoheritage in the context of quarrying, mineral extraction, metallurgy, and tool-making evolution through human history. However, these parameters need to be set clearly and aligned with globally accepted criteria. Mindful industrial operation within geologically diverse and interesting landscapes can save small geoheritage objects such as outcrops, well-preserved fossils or even crystal paragenesis at a microscopic scale. This approach proves that geoheritage is more a concept based on traditional touristic values such as aesthetics, and geotourism falls far outside the boundaries of more traditional or mainstream tourism ventures.

To address the conceptual diversity, the goal of this study is to use systematic mapping to identify the current state of knowledge in the pursuit of geoheritage conservation; in particular, this study aims to define the main fields where geoheritage is applied or explained as an emerging concept.

We extend our study to the entire range of geoheritage conservation-related literature to map out the existing perceptions regarding the scope and scale of geoheritage conservation. The paper shows keywords extracted from conceptual framework studies. These keywords vary significantly in the literature depending on the research field.

4.2 Methods

To achieve our goals of mapping the field of geoheritage conservation, identifying shifts in perspectives, and describing research streams, we followed an approach combining systematic mapping with interpretive analysis. Our systematic map procedure followed four steps: data collection and pre-processing; classification by supervised acquisition of geoheritage-specific topics and keywords; mapping the result and conceptual interpretation.

4.2.1. Data collection

To extract data for mapping the literature, we first defined our primary research questions: (q1) What are the identified conceptual patterns in geoheritage conservation? To answer that, we defined two more sub-questions: (q2) What are the main research fields (topics) concerned with geoheritage conservation? (q3) What are the keywords that best describe the geoheritage discourse?

To build the search query, we first used a single word, the central element of our research question. The word ‘geoheritage’ as a single search word was not efficient enough to retrieve the entire range of relevant literature because the literature is characterised by heterogeneity in terminology. To define the most effective search string, we utilised the SciVal web-based analytic platform that enables users to analyse their search results instantly and generates powerful data visualisations (https://www.elsevier.com/solutions/scival). We were interested in the most frequent word occurring in the articles retrieved (n= 638) by the single search word: geoheritage. Therefore, we queried the top word by the relevance of these articles, resulting in the word `geodiversity` (Figure 5) with a maximum value of 1 over the period of 2016-2018, defined by the built-in analytic engine working with automated algorithms (https://service.elsevier.com/app/answers/detail/a_id/27763/supporthub/scival/).

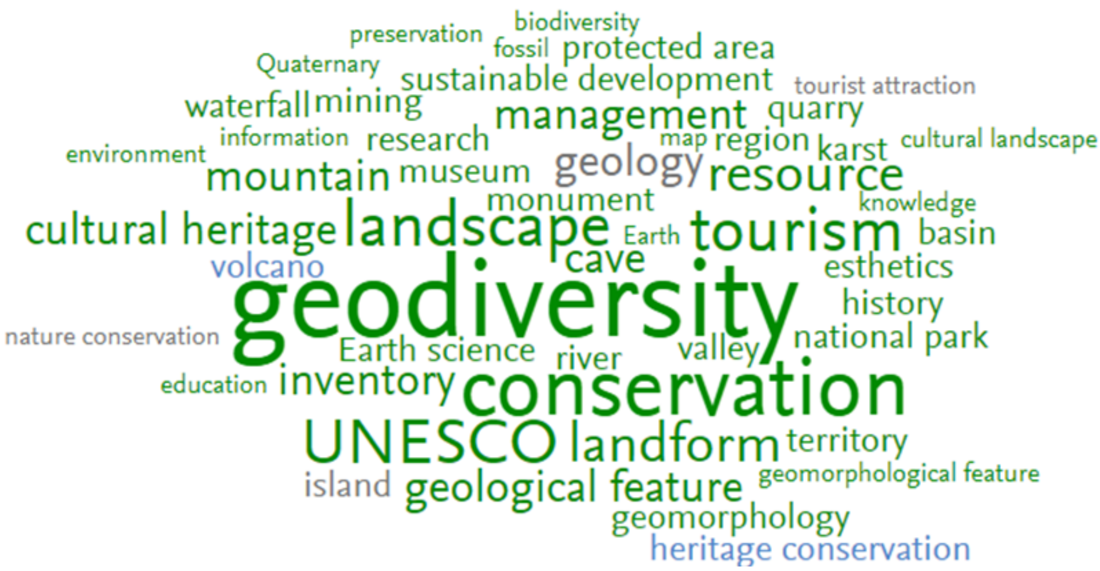

Figure 6 Word-cloud extracted from SciVal for search word `geoheritage`

Therefore, the search string for our systematic mapping study was defined as `geoheritage OR geodiversity` over the period of 2000-2019 due to the very low number of publications in the field from the last century. However, important information from the publication of the decade 1990 – 1999 in geoheritage conservation was extracted during the stage of in-depth reading of primary articles. By building a comprehensive query, we were able to identify a large set of papers, 14 948 in total: 1245 in Scopus, 13 280 in Google Scholar and 423 in Science Direct (Figure 6). The findings were retrieved in order of relevance from each database and stored in different spreadsheets.

The screening for relevant articles started with the exclusion of duplicates, papers not written in English and papers unlikely to answer the research question. To include a paper, its title had to address any nature conservation issue with respect to geology, geomorphology or geoeducation. The paper was excluded from in-person reading if the title did not clearly relate to our study. After this stage, we had the title, keywords, and abstracts of 2478 papers, from which we selected the most relevant 200 papers for collecting data and a control pool of a random 200 papers.

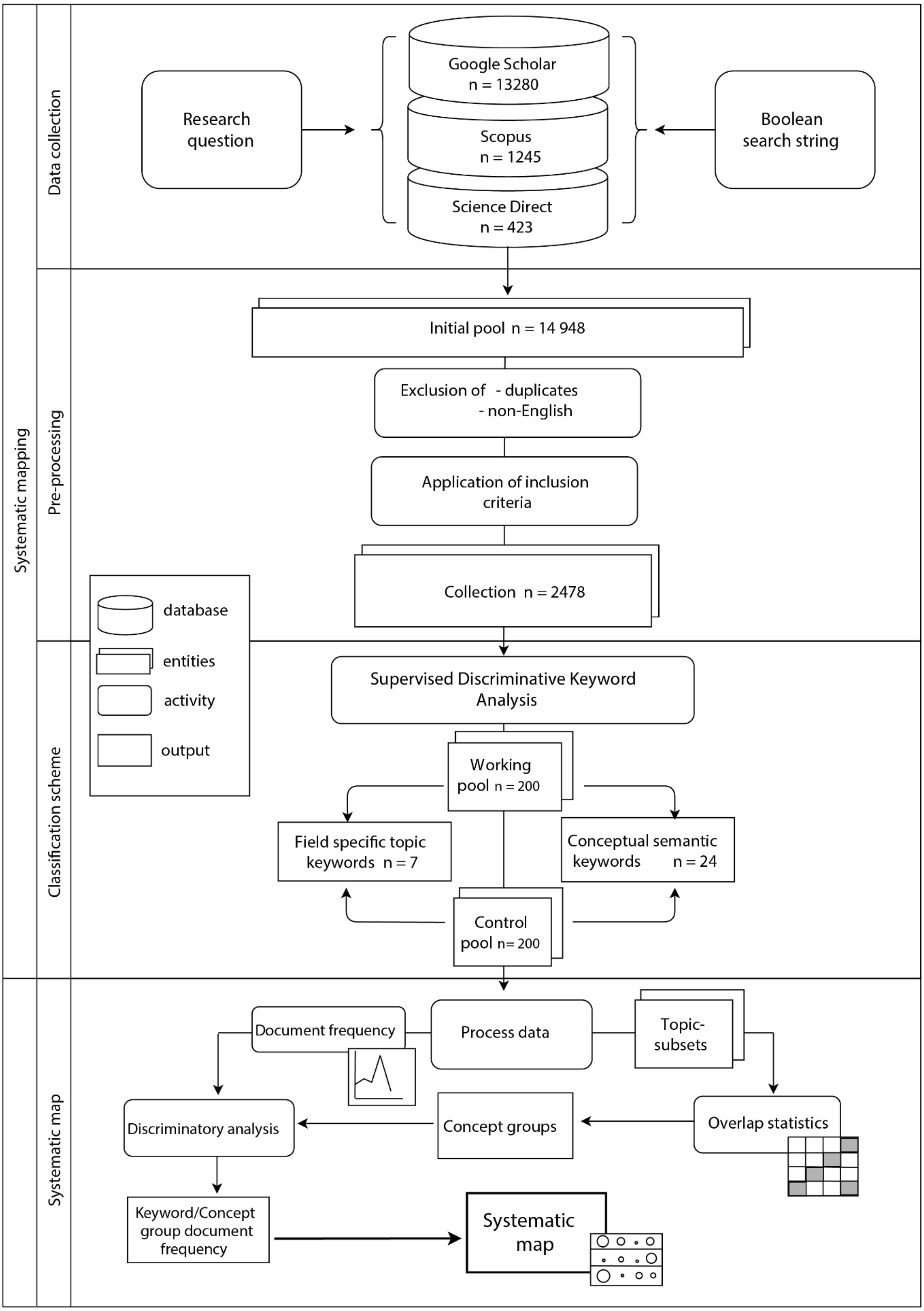

Figure 7 Systematic mapping process

The mapping procedure followed a *Supervised Discriminative Keyword Analysis*. The retrieved articles were collected and stored in order of relevance. We took a working pool of the most relevant 200 articles to collect training data. Training data consisted of keywords for two distinct areas of interest: field-specific topics and conceptual semantics (Figure 7). The first step was to record all domain-specific words with their counts by screening the 200 titles and author keywords. We separated them into two classes, one for words indicating a topic and another for conceptual semantics. This technique resulted in 7 topic keywords and 24 conceptual semantic keywords. Unsupervised techniques might require less time, but they are not suitable for recognition in the sphere of semantics. To map the structure of the scientific discourse on geoheritage, we were looking for domain-specific connotations, such as `geoethics`(Di Capua et al., 2021a; Di Capua et al., 2021b; Peppoloni S & G., 2012). The low frequency of the word would not have allowed automated processes to pick up on it; however, its discriminating power to the field is extremely important. Recognizing the connotations of a relatively new domain is ultimately beyond the limit of fully automated search techniques or tools. We tested the accuracy of the collected topic and conceptual semantic keywords using the control pool. We found them to be uniform with the working pool regarding training data. For further analysis, we counted the frequency of each topic keyword and each conceptual semantic keyword in the collection. Document frequency is used in topic modelling when the aim is to capture the number of documents containing a particular term without interest in the importance of that term within one document. We next subdivided the collection by searching each topic keyword and storing the findings in topic subsets. For testing the reliability of the collected training data, we visualized the log-scaled frequency of documents containing the conceptual semantic keywords in the whole collection against them in individual topic subsets (Figure 8). Breaking down their presence topic by topic revealed the diversity of the geoheritage discourse.

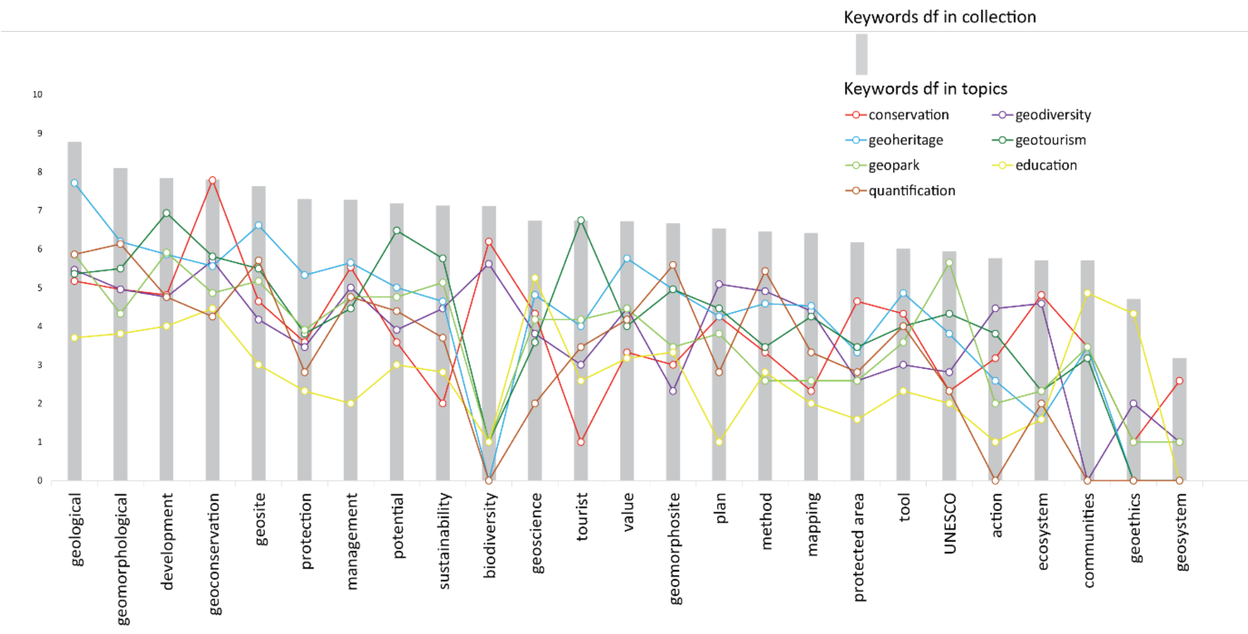

Figure 8 Log scaled document frequency (df) of keywords within collection versus within topics. Topic by topic analysis of the keyword allowed us to observe their discriminative role. The diagram depicts that geoconservation, biodiversity, protected area and geosystem are the most outstanding keywords in the subset of conservation; geological, geosite and value in the subset of geoheritage; UNESCO, development, sustainability in the subset of geopark; geomorphological, geomorphosite, method in the subset of quantification; plan, action, management, ecosystem in the subset of geodiversity; tourist, potential in the subset of geotourism; and geoscience, communities, geoethics in the subset of education.

The procedure led to *overlap statistics* and *discriminatory analysis* based on the training data. Our null hypothesis was that topic keywords co-occurring more often than expected by chance, forming a concept group within the realm of geoheritage. To explore which topic keywords form these concept groups, we ran overlap statistics employing pairwise comparison (Figure 9). Overlap values are the number of identical papers in two compared topic subsets. We merged the topic subsets accordingly into four concept groups that served as the basis for mapping the literature into concepts. The observed secondary relation between quantification and geotourism was noted and unfolded during the interpretation stage.

	geoheritage	geotourism	geodiversity	geopark	conservation	quantification	education
geoheritage	**915**	127	84	127	112	136	38
geotourism	127	**646**	64	129	77	73	40
geodiversity	84	64	**594**	56	127	80	18
geopark	127	129	56	**498**	56	63	26
conservation	112	77	127	56	**493**	30	30
quantification	136	73	80	63	30	**363**	12
education	38	40	18	26	30	12	**168**

Figure 9 Overlap statistics among topics. Topics with highest overlap are considered strongly associated. These strong associations form the concept groups, the subjects of interpretation analysis.

For the *discriminatory analysis,* we took the document frequency (df) of each conceptual keyword (C) and the number of documents (d) in each concept group (G). To measure how the proportional makeup of these keywords can change the context, we computed their discriminative weights. These weights were calculated to measure the keywords` ability as concept discriminators.

$$w_{ij=} \frac{\max(dfC)}{dfC_i} \times \frac{\max(dG)}{dG_j}$$

Where the weight (w_{ij}) of a given keyword within a given concept group equals the multiplication of: the fraction of the highest *df* counted for conceptual semantic keywords ($\max(dfC)$) to the *df* of the given conceptual semantic keyword (dfC_i) and the fraction of the number of documents of the biggest concept group ($\max(dG)$) to the given number of documents in the given concept group (dG_j).

$$DVx_{ij} = w_{ij} \times x_{ij}$$

We named the weighted *df* values of a given conceptual semantic keyword within a given concept group (x_{ij}) the discriminative value (DVx_{ij}). The DV of x was used for mapping the literature (Figure 10.) into a systematic map.

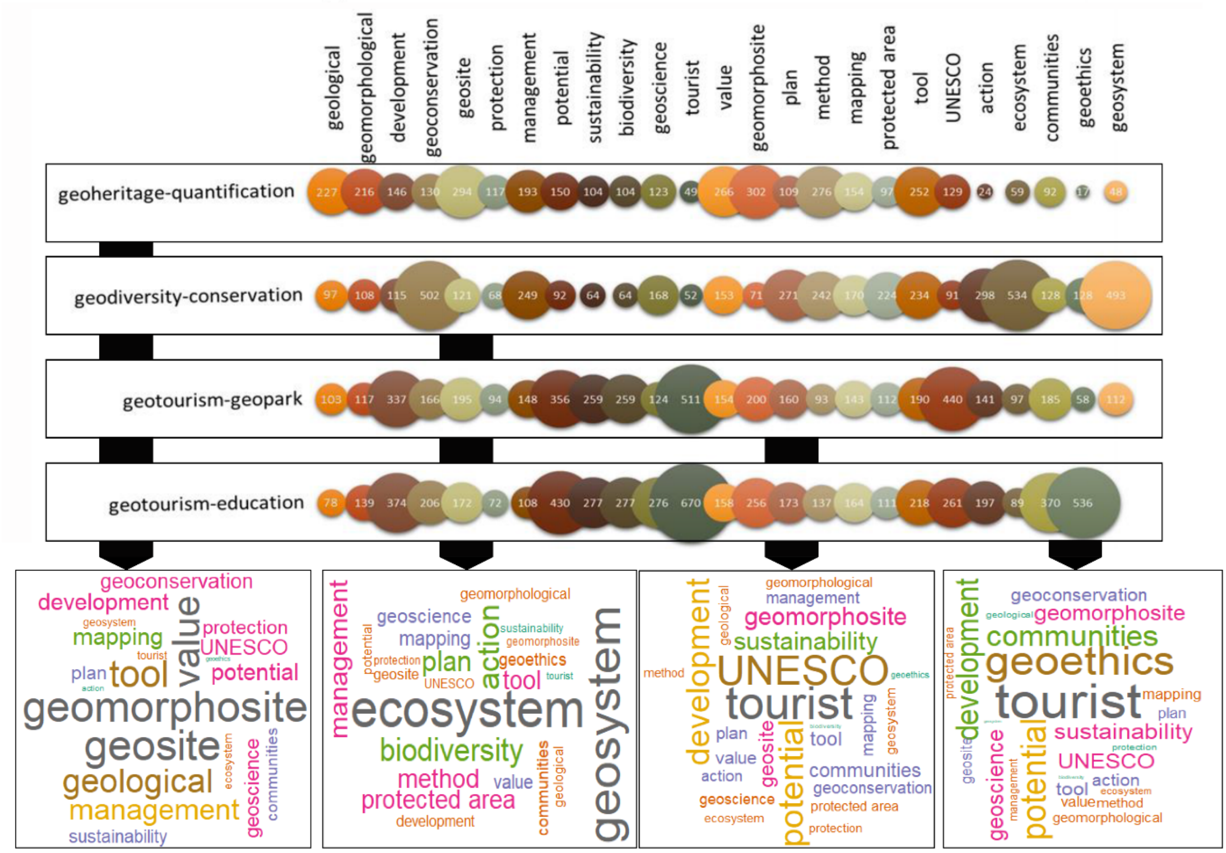

Figure 10 Visualisation of a systematic map with corresponding word clouds

The systematic mapping process allowed us to answer our research sub-questions: (q2) What are the main research fields (topics) concerned with geoheritage conservation? (q3) What are the keywords that best describe the geoheritage discourse?

The systematic map is an x-y scatterplot with bubbles in the concept group and keyword intersections. The size of a bubble is proportional to the weight of the keyword within a conceptual group.

The interpretation stage resulted in the conceptual characterisation of the four identified groups (Figures 10 and 11.) by analysing the proportional makeup of keywords. Additionally, a secondary screening was undertaken by searching to identify the most discriminative keywords. With that knowledge, we were able to extract primary studies from each concept group. In total, we identified **70 primary publications** contributed the most to our interpretation of the conceptual patterns.

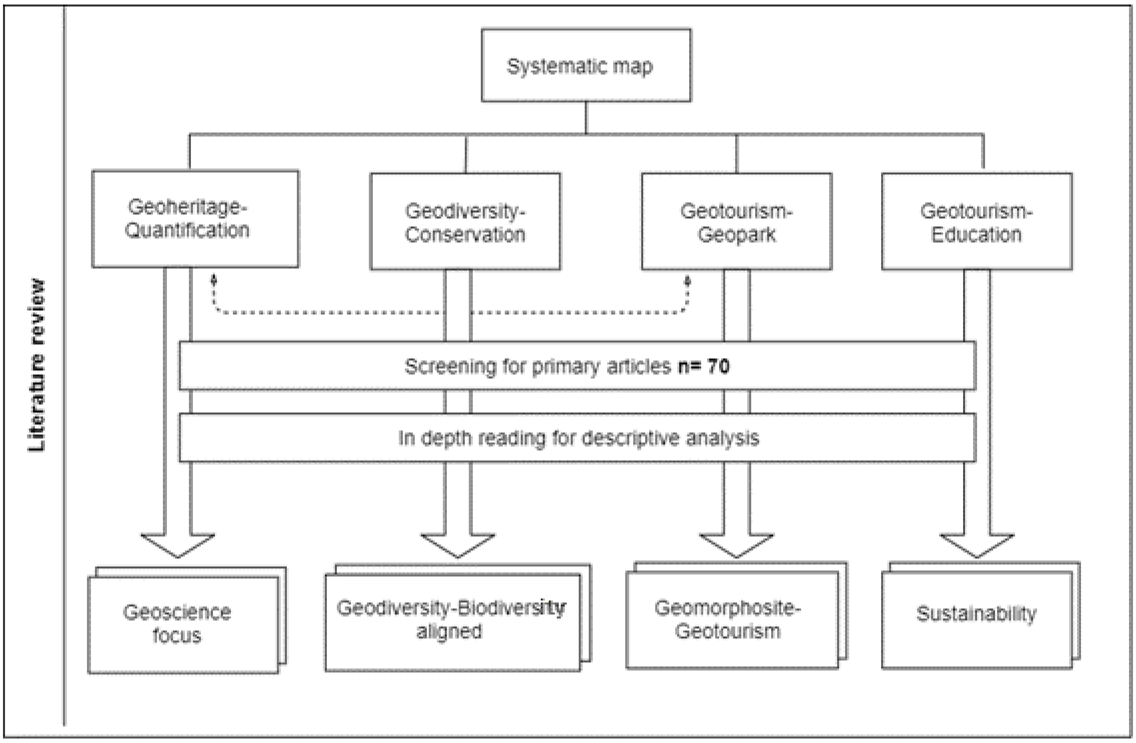

Figure 11 Process of the literature review for the characterization of the identified concept groups

4.3. Results

The results of the systematic mapping allowed us to answer our main research question. (q1) What are the identified conceptual patterns in geoheritage conservation? We identified four concept groups. Then, with an inverse approach, we started screening the titles falling in the given concept group, selected the titles corresponding to the word cloud, and filtered their relevance to our research question by reading the abstract. They were included in the primary articles if the in-depth reading confirmed their contribution to the conceptual discourse. We chose a paper as the primary article if it addressed the lack of conceptual agreement and proposed determination of the scope and scale of geoheritage. We were particularly interested in articles including critical acknowledgement of a different combination of the rationale for the scope of geoheritage. While the main goal of our study was to map out key concepts, we also aimed to identify the weaknesses of each concept, giving rise to very different angles and, in some cases demonstrating they could be delaying the formation of universally accepted principles.

During the in-depth analysis, we focused on investigating the secondary relationship between geotourism and quantification. Primary publications included review papers that addressed gaps in geoheritage quantification with the primary purpose of geotourism. Review papers have an inherent role in clarifying the state of knowledge and identifying research able to explain the forming of a new node in the literature between quantification and geotourism.

4.3.1 Earth Science

The most relevant keywords that our study identified from the titles falling in this concept group are *geological*, *geomorphological*, *geosite*, *geomorphosite*, *value*, *method*, *and tool.*

Geosite, as a term, is commonly used to refer to the subject features of geoheritage conservation in general (Brocx & Semeniuk, 2007; Fassoulas et al., 2012), whereas the term geomorphosites is used when the observable processes are from the field of geomorphology (Pelfini & Bollati, 2014; Reynard, 2009; Reynard et al., 2016b).

A debated question within the earth science community is the weight of aesthetics versus the weight of scientific contribution in evaluation models. One of the most problematic areas from this aspect is the mining sites. It can be difficult to measure the significance of old mines and quarries relating to earth science because they more often focus on their importance to human and cultural history. Cultural relevance is still better understood than the importance of informing visitors about geological processes at geosites that may be less favoured for recreational purposes (Marescotti et al., 2018; Ruban et al., 2018). These geosites are valuable educational assets, yet protecting their accessibility and longevity is difficult. A study from López-García et al. (2011b) depicts the problem through a case study on protected mining areas. Abundant mines provided insight into otherwise hidden geological processes in the Mazarrón and Cartagena–La Unión district, Spain. Exposed rock formations provide unprecedented materials for earth science research and education. While the mining sites are protected, this is to explicitly promote cultural heritage; little recognition is given to their geological heritage value. As a result, important geoheritage sites remain underutilised and at risk of loss (López-García et al., 2011b).

Firmly set geographical boundaries placed on geoheritage features can cause confusion. Brocx and Semeniuk (2007) offer a simple solution, stressing the geological aspect as the only way to facilitate sustainable conservation. For education, the scale - crystals, outcrops, cliffs, terraces - should not matter if the geosite represents any component of earth science (Brocx & Semeniuk, 2007; Brocx & Semeniuk, 2010; Brocx & Semeniuk, 2011b).

The sovereignty of earth science in geoheritage stems from project GEOSITE, a framework to inspire actions to preserve scientifically outstanding elements of geodiversity (Wimbledon, 1996; Wimbledon et al., 1998). The project was linked to the World Heritage System and later taken over by the International Union of Geological Sciences (IUGS). The aim and principles of this project were to register significant European geosites. Inclusion criteria were extended to relevant views of local communities and regional scientific importance. A centralised working group was formed to ensure scientific rigour for evaluation. GEOSITE aimed for a balanced coverage between countries (Joyce, 2010b).

In undertaking geoheritage conservation, the IUGS, in a joint effort with UNESCO, set up a working group in 1995 (Global Geosites Working Group) to collect not only European but a global list of geoheritage sites. ProGEO was assigned the task, leading to a surge in European geoheritage conservation activities. Erikstad (2008) urged international site status conservation measures to facilitate strong international support for geoconservation. The first unifying project, The Global Geopark Network, was formed by UNESCO in 2004 to promote geological, natural and cultural knowledge exclusively through engagement with local communities. Notwithstanding the magnitude of such collaboration, UNESCO labels remain selective and are unlikely to fulfil the need for a systematic international network of geosites at local to regional scales (Erikstad, 2008). Following up on the initiatives mentioned above, Brilha (2016) proposed a conceptual framework of geodiversity, geoheritage, and geoconservation, reinforcing the principles of the GEOSITES projects (Table 2).

Table 2. The principles of GEOSITES project (Wimbledon, 2011)

	Principle	*Essence*
i	Geoconservation is fundamental to the prosecution of geological research, education and training.	Geoscientists notice that geoconservation is a vital necessity when a key site is damaged or lost.
ii	Key to conservation as a whole.	Geology underpins all landscape and biotic nature. Biodiversity is determined by geodiversity.
iii	The geological story, time and scale are continuing sources of wonderment to earth scientists and the lay public.	The conservation of geosites encourages and fosters geologic research.
iv	Geosites and terrains establish the geologic record.	Understanding the importance of geologic records creates respect and appreciation for the need of conservation.
v	Only geologists can compile a global geosite inventory that produce a balanced coverage between countries and regions.	To justify the significance of localities for promoting greater knowledge of geology amongst the broader public.
vi	Global inventory allows a comparative assessment.	Without it the designation of global sites is much harder and open to criticism for not being based on an objective examination of the global picture (which is the major driver of the ongoing debate today).
vii	Avoid selecting just a few superlative localities and ignoring the time matrix.	In putting together a global listing, it is necessary to have representation not only of processes and features, but also to exemplify these through geological time.

These principles (Table 2) did not achieve consensus. Conservation experts from the environmental sciences prefer an approach that incorporates geoheritage conservation into biodiversity conservation using an aligned evaluation methodology. According to this approach, the success in geoheritage conservation lies in future cooperation among scientists from a wide spectrum of conservation areas (Anderson & Ferree, 2010; Erikstad, 2013; Hjort et al., 2012; Schrodt et al., 2019). They propose that geology and geomorphology define the patterns and hot spots in biodiversity. Therefore geoconservation should put a higher emphasis on their interrelatedness.

4.3.2. Call for aligned conservation methods for geo- and biodiversity

The most relevant keywords that our study identified from the titles falling in this concept group are *geoconservation, management, plan, method, protected area, tool, action, ecosystem, and geosystem.*

Kozlowski (2004) describes geodiversity as the perpetual basis for the increasing biological diversity during geological history. The development and survival of life are highly dependent on geophysical conditions. If we want to maintain the balance necessary for resilience, there is a need to implement the two major global programmes: 1) conservation of biological diversity and 2) conservation of geodiversity.

Geodiversity in recent conservation planning constitutes the geophysical conditions of inhabitants and connectivity. The outstanding features of geodiversity are not yet recognised as equally important elements of protection as the species living on it. This is due to the fact that the protection of biotic elements has a long history and, therefore, a better-understood status in conservation initiatives (Crofts, 2014). Despite the huge body of research about the benefits of implementing geoscience in all environmental policies, practitioners argue that inequity between the biotic and abiotic conservation measures jeopardises sustainability (Brilha, 2002; Comer et al., 2015; Crofts, 2014, 2018; Crofts & Gordon, 2015; Gordon et al., 2018b; Gray, 2008c, 2018; Prosser et al., 2011). Sustainability is an overarching scientific discipline dependent on an integrated knowledge of geosciences and other environmental and social sciences. Geodiversity, relatively recently recognised as a branch of conservation, should be put in the context of current conservation policy frameworks and established as a fundamental component of conservation (Gray et al., 2013; Zwoliński et al., 2018). Although biodiversity conservation has an impregnable purpose of protecting life, we acknowledge still unresolved conceptual questions (Groves et al., 2002; Rands et al., 2010; Wilshusen et al., 2002). Arguments questioning the place of geodiversity in biodiversity conservation have their fundamental counterpoints that explain the need for exclusive geoconservation principles, as visualised in Table 3. The pivot point is the perceived necessity to decide between ecocentric or anthropocentric perspectives (Kopnina et al., 2018). Geodiversity includes resources for a provision that may conflict with the principles of biodiversity conservation, but it can coexist with geoheritage conservation. For this reason, geoheritage conservation should be considered a standalone branch of the discipline.

Table 3. Arguments why geodiversity should be assessed along with biodiversity and counterpoints why geodiversity itself deserves undivided attention for conservation through geoheritage

	Arguments	*Counterpoints*
i	The usage and conceptualization of geodiversity is incosistent (Boothroyd and McHenry, 2019)	Due to the specific interest of each individual evaluating the geoheritage there are differences in terminology (Erikstad, 2013; Kozlowski, 2004; Serrano and Gonzalez-Trueba, 2005). The GEOSITES project set up a centralized working group and guiding framework to prevent confusion. The GEOSITES principles are still valid and should be reinforced (Díaz-Martínez et al., 2016)
ii	There are major knowledge gaps in predicting how different forms of geodiversity influence biodiversity patterns across spatial and temporal scales (Zarnetske et al., 2019)	The criteria used by geologists in the mainstream geodiversity studies differ from those used in by the biodiversity and geodiversity communities (Ibáñez et al., 2019)
iii	Integrating geodiversity and biodiversity at a landscape scale is applicable to key issues such as habitat and natural system responses and adaptions to climate change (Bruneau et al. 2011)	All biological ecosystems are dependent of geodiversity. At the same time geodiversity merits conservation for its own considerable values (Hjort et al., 2012)
iv	Majority the literature specifically recognizes geodiversity as a supporting stage for the spatial differentiation of biodiversity values and as primary contributor to ecosystem services (Boothroyd and McHenry, 2019).	The ecosystem function is dependent on specific geosystems that delivers ecosystem services. This interdisciplinary application is not always referenced in discussions centred on geoheritage and geotourism (Thomas, 2016)

The ambiguity in applications of the term geodiversity constrain its present use as a working concept. Discussing geodiversity outside of geoscientific disciplines would result in validating broader applications. For example, geodiversity elements should be quantified according to their relationship with the spatial distribution and abundance of species (Boothroyd & McHenry, 2019). Hjort et al. (2015) further elaborated how geodiversity is crucial for sustaining species and ecosystems, thereby encouraging a fully integrated and unified approach to geo- and biodiversity.

In contrast, it is difficult to incorporate small scale geoheritage objects or processes, such as minor and localised volcanic eruption sequences, because they are perceived to have little relation to biodiversity conservation. Strict linkage of geodiversity to biodiversity risks the loss of geoheritage sites of non-protected domains like active mining areas or urban development areas. (Del Monte et al., 2013; Gravis et al., 2020a; Gravis et al., 2020b; Habibi et al., 2018; Marescotti et al., 2018; Valdez, 2018).

Mocior and Kruse (2016) reviewed the educational values of landscapes, mainly through geoheritage evaluation methods, and concluded they are too weighted towards geology specifically and would benefit from addressing ecological values encompassing all elements of nature and their interactions. As an example, "geological age" or "number of interesting geological features" could be transformed by removing the specifying adjective "geological". On that matter "ecological value" should not be considered as an additional criterion (Kubalíková, 2013; Pereira et al., 2007) but one of the fundamentals (Bollati et al., 2015; Bollati et al., 2013). This demonstrates that education is one of the ecosystem services that should be incorporated into the quantification of ecosystem services.

4.3.3 The concept of geomorphosites, the leading resource for geoparks

The most relevant keywords that our study identified from the titles falling in this concept group are *development, potential, tourist, and UNESCO.*

There is a strong relationship between the keyword geomorphosite and the concept relating to geotourism and geoparks. Geotourism is one of the core activities of geoparks that stimulate sustainability (Farsani et al., 2011a). To date, geomorphosites are more attractive for geotourism purposes (Pelfini & Bollati, 2014). If the socio-economic benefit is the main goal, geomorphosites have an aesthetic advantage over geological sites.

The examination of respective review papers demonstrates the pervasiveness of this concept. Results show (Tables 4 and 5) an elevated recognition of geoheritage in the context of geotourism. More than half of the review papers narrow geotourism down to a specific factor, geomorphology. Promoting geoheritage as aesthetically pleasing landforms serviced by facilities catering to tourist demands and recreational purposes attracts the public (Office of World Geopark, 2004). The resultant benefit of preserving geoheritage is its potential positive effect on the local economy. Renowned researchers have devoted entire articles and books to clarify the principles of geotourism (Dowling, 2008; Hose, 1995; Hose, 2000; Hose, 2010; Newsome & Dowling, 2006).

According to Ollier (2012), geotourism takes place mainly within natural or wilderness areas, which in turn conceptually reduces the vital role of geological exposures in road cuts and quarries that are often considered of no aesthetic value. A conceptual argument is implied in the promotional material of National Geographic, defining geotourism as the tourism that sustains or enhances the distinctive geographical character of the place – its environment, heritage, aesthetics, culture, and well-being of its residents (National Geographic). This approach ignores one of the main objectives of raising scientific awareness. National Geographic magazine is described as the `bellwether nature publication in the USA, translated to over 40 local-language editions, global circulation of around 6.7 million that has been advertising environmental issues over the past decades (Ahern et al., 2012; National Geographic Boilerplates, 2015). Undoubtedly, residents' environment, heritage, aesthetic values, culture and well-being are the major winners of any conservation activities. However, by stressing these factors and excluding others, the original quest for protecting extremely informative exposures of past geological processes, or a geosite of spiritual value based on centuries to millennia of community engagement (Gravis et al., 2016), will ultimately lose the battle against human demolition (Del Monte et al., 2013; Gravis et al., 2020b; Ruban, 2010).

Kubalíková (2013) found that ethical and social principles of geotourism are often neglected, and the motivation is often economic profit. Štrba et al. (2015) highlighted the problem of arbitrary and ad hoc interpretation of geoheritage, resulting in varying assessment methods making it impossible to compare (therefore validate) competing for geoheritage nominations. Ólafsdóttir and Tverijonaite (2018) noted that research on the effect of geotourism on geological knowledge and engagement with local communities is scarce, and this scarcity makes it difficult to improve educational material and the well-being of communities. Mucivuna et al. (2019) mainly addressed the technical issues of the evaluation methods, noting they generally lack clarity on objectives, criteria and consistency in weighting and formula applied. Despite differences in problems raised through their findings, proposed solutions always include the reduction of subjectivity, either through eliminating fuzzy criteria such as aesthetics or the unification of the methods where comparability results in objectivity.

Through this approach, it is widely acknowledged and recognised that UNESCO is a ‘brand’ that strictly protects its integrity by delivering features that are the most unique of their kind under the designation of World Heritage Sites. As the tentative list increased in parallel with the desire to protect more and more geosites, a system was instigated to bundle the features into one geographic subdivision to enhance their significance and for the purposes of education, management and monitoring.

Table 4. Summary of the review protocols review papers used

Year	Aim	Review strategy	No. studies included	Scope
Comănescu et al. (2012)	To create the most efficient method for quantifying the value of geomorphosites.	Screened worldwide known methods of evaluation and applied them on a group of geomorphosites. Final scores were compared.	no. 8: Pralong 2005, Reynard 2007, Coratza 2005, Bruschi 2005, Serrano 2005, Pereira 2007, Zourous 2005, Erhartic 2010	Geomorphosites for geotourism
Kubalíková (2013)	To compile criteria set best facilitate geotourism.	Screened significant assessment methods used for geotourism purposes and analysed their criteria against the concept of geotourism.	no. 7: Pralong 2005, Reynard 2007, Coratza 2005, Bruschi 2005, Serrano 2005, Pereira 2007, Zourous 2005	Geomorphosites for geotourism
Štrba et al. (2015)	To compare selected geosite assessment methods to prove that further research is needed for geotourism planning and management.	Six types of quantitative methods were selected. Each method was tested on the same group of geosites. Final scores were compared.	no 6: Baca & Schuster,2011; Bruschi et al.,2011; Fassoulas et al.,2012; Pereira et al.,2007; Reynard et al.,2007; Rybar, 2010	Geosites for geotourism
Ólafsdóttir and Tverijonaite (2018)	To systematically review the scientific literature on geotourism and analyse the research trends in geotourism.	Systematic search, selection, and categorization of studies for clear, reproducible results.	256 papers	Geotourism
Mucivuna et al. (2019)	To analyse how the evaluation methods developed and to compare them.	International database search by the keywords of 'geomorphological heritage', 'geomorphological site' or 'geomorphosite'.	71 scientific papers	Geomorphosites

Table 5. Findings and conclusions of the review papers

Year	Selection criteria	Evaluation criteria	Findings	Proposed solution	Discussion
Comănescu et al. (2012)	Assessment methods known worldwide.	Deviation of obtained scores within one assessment method.	N/A	Equal importance to scientific, ecological, aesthetic, cultural, economic value and management value.	It is not compulsory that geomorphosites with the highest scientific value must also have high values for additional criteria.
Kubalíková (2013)	Numerical assessments of geomorphosites.	Presence of scientific, cultural and economic value.	Methods should follow the principles of geotourism with the values of scientific, educational, economic and added.	Reduce criteria difficult and subjective to measure such as aesthetics.	All the methods cannot be used for geotourism purposes - some of them are not equilibrated and they are focused unilaterally, so they do not meet the principles of geotourism.
Štrba et al. (2015)	Quantitative assessments of geosites.	Possibility for uniform assessment method	Lack of uniform assessment method with criteria of rarity, representatives, integrity, accessibility, ecological value and economic value.	Reduction of the subjectivity of assessing person by uniform assessment (1) establish independent team of specialists and laics (2) establish a web-based online assessment form	Necessary to focus on the research of the most suitable and universally applicable assessment criteria
Ólafsdóttir and Tverijonaite (2018)	Studies directly related to geotourism.	Summary	(1) Lack of research on visitors to geotourism destinations to facilitate the preparation of geologic information. (2) Actual contributions of geotourism to the wellbeing of local communities are currently in very short supply.	Empirical knowledge concerning: (1) visitors\` preferences and motivations (2) main management challenges (2) positive and negative impacts of geotourism on geoheritage and local communities.	Sustainability is one of the primary objectives of geotourism which should be achieved through geoeducation.

Mucivuna et al. (2019)	Studies directly related to geomorphological heritage assessment.	General aspects, quantitative or qualitative evaluation.	(1) ignoring the purpose of the evaluation when adapting them (2) lack of clear procedures questions the reliability and replicability of qualitative evaluations (3) lack of clarity in criteria (4) no consistency in the weighting and formula applied	Applying and discussing strengths and weaknesses of previous methods to improve existing methods rather than creating many new methods.	The different ways of presenting results can lead to misinterpretation because some methods present the values separately, while others present the global value, including the use and potential threats.

4.3.4. Community involvement for sustainability

The most relevant keywords that our study identified from the titles falling in this concept group are *development, potential, tourist, communities, and geoethics.*

Ecosystem services are defined as the benefits nature provides people (Danley & Widmark, 2016). Geoheritage as a constituent of ecosystem services would be established as essential to humanity by its inclusion under the umbrella of ecosystem services through recognition of the term geosystem services (Gray, 2008b). Ecosystem services play a major role in 41 of 169 targets of the Sustainable Development Goals (Wood et al., 2018). The study of van Ree et al. (2017) aimed to debunk the place of geosystem services in ecosystem management. They found that geosystem services are significantly underrepresented in contemporary studies. The conceptualisation of ecosystem services has been driven predominantly by biological and ecological scientists, interpreting biodiversity and ecosystems as underpinning all dimensions of human, societal, cultural, and economic well-being (Folke et al., 2016; van Ree et al., 2017).

The Sustainable Development Goals prompt all countries to achieve 17 broad development goals by 2030 (United Nations, 2015). Gill (2017) presented a matrix to visualise geologists' role in helping achieve Sustainable Development Goals. The study identified that earth materials, processes and management support 12 of 17 goals (71%), earth science skills and practice support 10 of 17 goals (59%) and the synthesis clearly demonstrates geologists have a role in achieving all 17 of the Sustainable Development Goals (Gill, 2017).

An emerging view is that sustainability science needs to be integrated into the earth sciences (Stewart & Gill, 2017). The exact definition and value of geoheritage might be under debate. However, its contribution to sustainability from varying perspectives is undeniable, as well as the contribution geologists can make to resilient communities (Stewart & Gill, 2017). Gray (2011) published his analysis demonstrating the lack of application of geosciences in the global environmental solution frameworks and introduced the term geosystem services. To highlight the significance of geodiversity, he used the classification of the Millennium Ecosystem Assessment (2005a) and presented the place of geodiversity in four classes of ecosystem services; **i)** regulating Earth system cycles, **ii)** provisioning physical resources, **iii)** supporting and forming soil and land, **iv)** cultural and community engagement through platforms such as geotourism, **v)** knowledge of the earth sciences for understanding, monitoring and forecasting.

4.4. Discussion

The significant body of geoheritage conservation literature forms a conceptual network with four major theme nodes. The characterization of these four key nodes as concepts revealed (Figure 11) that geoscientific knowledge governs the course of events in geoheritage conservation (Figure 12).

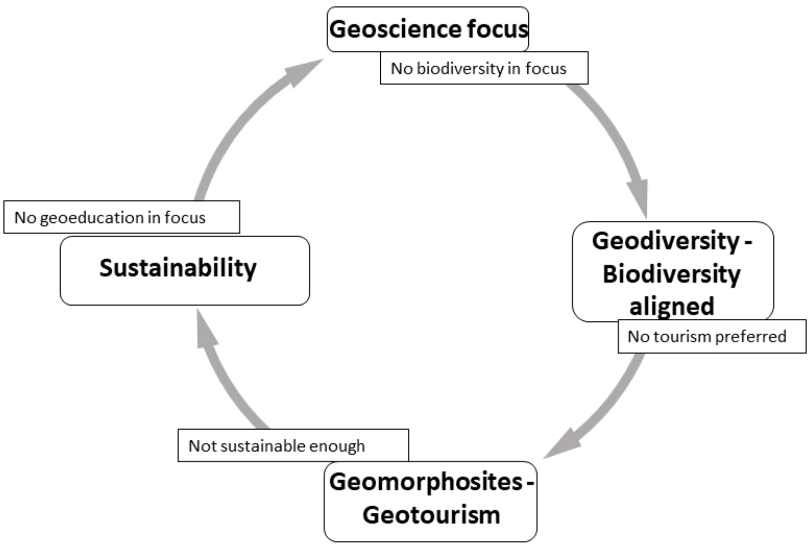

Figure 12 The circular nature of the four key concepts identified in our systematic mapping

Below we discuss our findings from the systematic mapping from four main aspects ‘purposes and principles`, `role of education`, `decision-making challenges` and `participatory geoconservation`.

4.4.1. Importance of geoscience

The purposes are to promote and strive for the protection of geoheritage by principles that deliver earth science knowledge and generate geotourism. However, the purposes and principles present an inherent conflict between conservation and tourism. Recognising the responsibilities embedded in the overarching concept of geoheritage, there is an urgent need for uniting them and achieving a balance between protection and promotion. The geodiversity concept based on the biodiversity framework has brought geoheritage closer to the long-practised guidance of biodiversity conservation.

Within the biodiversity framework, the mere existence of a species is just for protection; there is no morally acceptable debate over the value of life. This drives the argument back to the conflict between conservation and tourism; in protecting species or sensitive habitats, strict measures are applied, for instance, severe limitation of visitors. In effect, geoheritage does not require strict protection to be able to offer public access. However, an instrument for organising geoheritage is necessary. Geoparks are the most effective mediators to promote and protect geoheritage. Geoparks facilitate the promotion, access, networking, community engagement, and consequently, economic growth and sustainable development. However, geoheritage conservation and geoparks are shown to be a significant gap in the Sustainable Development Goals agenda (United Nations, 2015).

Awareness about geoheritage is growing through geotourism as an emerging global activity channelled by geoparks (Dowling & Newsome, 2010; Dowling, 2011; Ruban, 2015). The geopark system is coordinated by the dominant international organisation UNESCO under the name of the Global Geopark Network (http://www.globalgeopark.org/). The support of international governing bodies and national governments may give rise to smaller-scale geopark networks. For example, China created a hierarchical system of regional, national and international (UNESCO) geopark networks (Xun & Milly, 2002). This strategy supports bottom-up initiatives and allows for a graduated growth from a regional practice toward the rigorous UNESCO requirements. Regional geoparks prepare communities for the attention and responsibilities the UNESCO label invokes. Geoparks are vastly superior in protecting geological heritage, balancing economic and tourism development, and educating the public. (Bailey & Hill, 2010). The declaration of UNESCO (2016b) targets the geoparks toward the general public to enhance laypersons` awareness of geology. This includes facilitating an understanding of geologic timescales and periods through the global geopark network, as they are the best option for informing the public about the entire Earth's history. Global geoparks should offer appropriate interpretations about geologic time, but they are often located only in the most accessible locations. Geoparks need to be taken together as well to represent the length and significance of each geologic era and eradicate bias towards certain geologic periods (Ruban, 2016b).

4.4.2. Toward quality science education

This study mapped education as the connection between all environmental disciplines. Education is also the key to knowledge-induced sustainability and resilience to environmental hazards. According to Mata-Perelló et al. (2012), geology is one of the most influential factors in human development, as it determines the evolution of societies and can inform answers to the challenges of urban growth and high quality of life. UNESCO (1998) referred to the birth of socio-geosciences as an unavoidable milestone in human development, given the influence of geological resources and geological-based risks to society. Socio-geoscience is an emerging discipline addressing sustainable development with respect to the population and environment. Mata-Perelló et al. (2012) proposed reclassifying geological resources into extractable and non-extractable. Under the non-extractable group, we find the scientific, cultural, heritage, didactic and recreational subcategories. They put scientific knowledge at the top of the hierarchy because it may reduce and mitigate geological risks by increasing policy impact. There is a growth in small-volume disasters that could be prevented by more effective local actions that prioritise the principle of mitigation (Puiguriguer, 2007).

Societal utilisation of resources in an unsustainable manner is causing irreversible changes affecting many fundamental aspects of human life. We do have the knowledge and the potential to make changes to sustain the economy while eradicating global problems through wise management of geological resources, reducing risks, and promoting equitable social development. Geoscientists need to be encouraged to be involved in discussions around sustainable development (Mora, 2013; Stewart & Gill, 2017). Geoscientists are well equipped to develop more sustainable practices by informing society about the varying manifestations of Earth processes at different spatial and temporal scales (Gosselin et al., 2013).

4.4.3. Geoheritage of unprotected areas

The implementation of geoscientist participation processes into conservation planning and providing space for indigenous co-participation in geoheritage conservation ventures is important for the democratisation of natural values. However, geoheritage values are often overlooked in unprotected areas (cities, mines, archaeological sites, infrastructure sites, and indigenous sites). With the extent of overlaps in protected area designations, these geoheritage features can be out of the sight of policymakers. At a global scale, a quarter of the protected terrestrial network, and under a fifth of the global marine network, is protected by two or more designations (Deguignet et al., 2017). The most common overlap is between one or several national designations, with at least one international designation risking conflicting objectives among different governing bodies. Doubled or tripled designations are particular in western China and need more attention to avoid unclear management objectives, imbalance in regional geopark distribution and inefficient use of funding (Wang, 2007).

The literature on geoheritage is very vocal about the hierarchical relationship between bio and geodiversity (Ibáñez et al., 2019). In the case of conflicting objectives, this means geoheritage is inevitably placed at a disadvantage. Moreover, geoheritage carrying very high scientific values outside protected areas gets overlooked (Gravis et al., 2020a)).

The idea of geoparks unites the principles of different conservation goals that give a fair share of importance to biodiversity. For that reason, very often, geoparks share at least part of their territory with areas for conserving nature, wildlife, or relics of human history. But, unfortunately, that can result in a shift of focus from the integration of geoscience or the role of geoscience in cultural development and result in unbalanced educational material across disciplines (Megerle & Pietsch, 2017).

The operational guidelines of the Global Geopark Network (Office of World Geopark, 2004) express the strong statement that no destruction or economic transaction based on the geological value of a global geopark will be tolerated, except for scientific or educational purposes. Geoparks must reflect the principles set by the Sustainable Development Goals. Setting sustainability as an essential practice for economic development and management structure results in a geoheritage evaluation from locals` perspective, presence and needs. Thus, investing in geoparks contributes to the development of tourism and related actions through the enhancement and promotion of geoheritage. Encouraging active participation in the geopark operation revalidates and revitalises the values of the territory`s heritage. Furthermore, a global geopark must work within a network leading to cross-cultural collaboration and new by-products linked with geoheritage and cultural heritage (Patrick et al., 2010). These principles often conflict with the management policies of national parks or protected areas that often require strict protection.

In research presented by Wilshusen et al. (2002), biodiversity protectionists argue that: **i)**biodiversity protection is a moral imperative, **ii)** conservation linked to development does not protect biodiversity, **iii)** harmonious, ecologically friendly local communities are myths, and **iv)** that emergency situations require extreme measures. These points are sharply at odds with policies of a geopark that address several issues such as: **i)** people in rural areas suffer from economic decline, **ii)** the need for educational programs that employ inventive communication techniques, **iii)** and geological landforms may be either ignored or appreciated only for their aesthetics. The main conflict arising from establishing geoparks within already protected areas is that the latter exert restrictions on land use. At the same time, the former encourages locals to engage in more traditional industries and to be an integral part of management promoting sustainable geotourism.

4.4.4. Relationships among major factors of geoheritage conservation

A participatory process is an emerging approach in the form of bottom-up consultation and involvement of local communities. It is considered beneficial to earn UNESCO Global Geopark status (Bailey & Hill, 2010). However, on the one hand, it is not always appealing to locals due to the fear of sudden popularity or the possible effects on indigenous sacred elements. And on the other hand, UNESCO geoparks must deliver international significance (Adie, 2017a), and no deviation from this rigid quality standard is accepted. Remote rural communities often have no capacity to carry that expected quality. To enable geoconservation in areas of all backgrounds, national geopark networks should be encouraged through a process whereby communities would receive attention gradually and take advantage of ample time to adapt to geopark goals.

While geoparks safeguard our geoheritage, we question whether that should be the only conservation goal. There will always be areas where a geopark may not be culturally or occupationally suitable or simply lacking the required capacity. However, these sites are recognised and inventoried due to the strong geoheritage movement within the geoscientific world. Additionally, a robust framework for a convention would guide landowners for a geoheritage favouring operation, for example, a privately owned quarry in a geologically significant area. Re-establishing the GEOSITES program within the International Geoscience Program could be a suitable starting point for a bottom-up community-based framework to protect single geosites of local, regional, or national importance.

The GEOSITES project set the objective of compiling an international list of each region's representative geological sites. Geoparks or geotrails may not require strict protection status, but they should be subject to a strict process driven by local communities and promoting cultural integrity. This would be a significant instrument towards more comprehensive nature conservation in countries where the government may already support national geoparks. When the only option is for local initiatives to strive towards the goal of UNESCO Geopark status, they, unfortunately, need to prove a special local and biotic significance of the area, which may be a significant burden and obstacle to any form of lesser protection. UNESCO was established on principles of culture, flora, fauna and geodiversity, and these are inseparable, as they should be. Communities lacking opportunities or resources (both financial and human resources) for developing and instigating a geopark plan would greatly benefit from the GEOSITES project. As Ryan and Silvanto (2011a) noted, UNESCO's list of World Heritage Sites as the "coveted brand and seal of approval" is clear that it will not allow all of a region's representative geological sites to dilute this quality. However, a global list of purely geologically/geomorphologically significant sites can provide the basis for the evolution of a geopark plan or simply facilitate access to individual sites that may be threatened. To operate a geopark, people need to identify themselves as related to the area. As the geopark idea was born in the era of growing acknowledgement of the importance of sustainability, we agree that it should facilitate the rise of local communities, with concepts such as biodiversity, cultural significance, and geodiversity inextricably connected. When locals and their associated businesses manage a geopark, a sense of pride for the culture and nature in the region will be restored. GEOSITES has the potential to be a "brand" for geoheritage as "UNESCO "has come to be widely recognised for cultural heritage. Unfortunately, as discussed earlier, the program stopped despite the serious need for it. Protecting individual outstanding geodiversity features depends on countries' conservation strategies, which may be well-developed in certain countries such as New Zealand.

The Auckland Volcanic Field provided topography and fertility for a unique culture to grow and develop into an indigenous culture significantly different from the Pacific Island culture from which it originally evolved (Anderson, 2009). This culture is recognised in New Zealand's bicultural governance through the Treaty of Waitangi, though the Western cultural paradigm remains dominant. Māori culture is acknowledged as significant and important, and as a living, dynamic, and evolving culture, it has adapted many of its elements to remain relevant and important in modern society (Mead & Mead, 2016). The Māori worldview reflects the Western concept of sustainability through a holistic approach that sees humankind inseparable from nature and its ecosystems rather than existing outside or above the natural domain (Marsden, 2013). Māori values are strongly intertwined with geoscientific values and give significance to outstanding geological/geomorphological features based on self-identity and the unbreakable relationship between people and the land. Geoscientific research in Auckland takes place in a bicultural context, and institutions are required to develop a grounding for indigenous knowledge. Māori values also shape the ethics and principles that shape decision-making and interactions with the environment at both physical and spiritual levels (Mead & Mead, 2016). The Māori worldview and its associated ethical principles and values provide a basis for what is valued and define the information required to establish what is significant and how to prioritise values among natural resources (Harmsworth & Awatere, 2013). Geoparks were established to promote such holistic, interconnected relationships with nature based on a rich traditional knowledge base developed through centuries of occupation. The Auckland Volcanic Field and its power to shape the social landscape should be understood in more far-reaching terms. It sets an unprecedented example of two radically different cultures not only coexisting but attentive and concerned about one another.

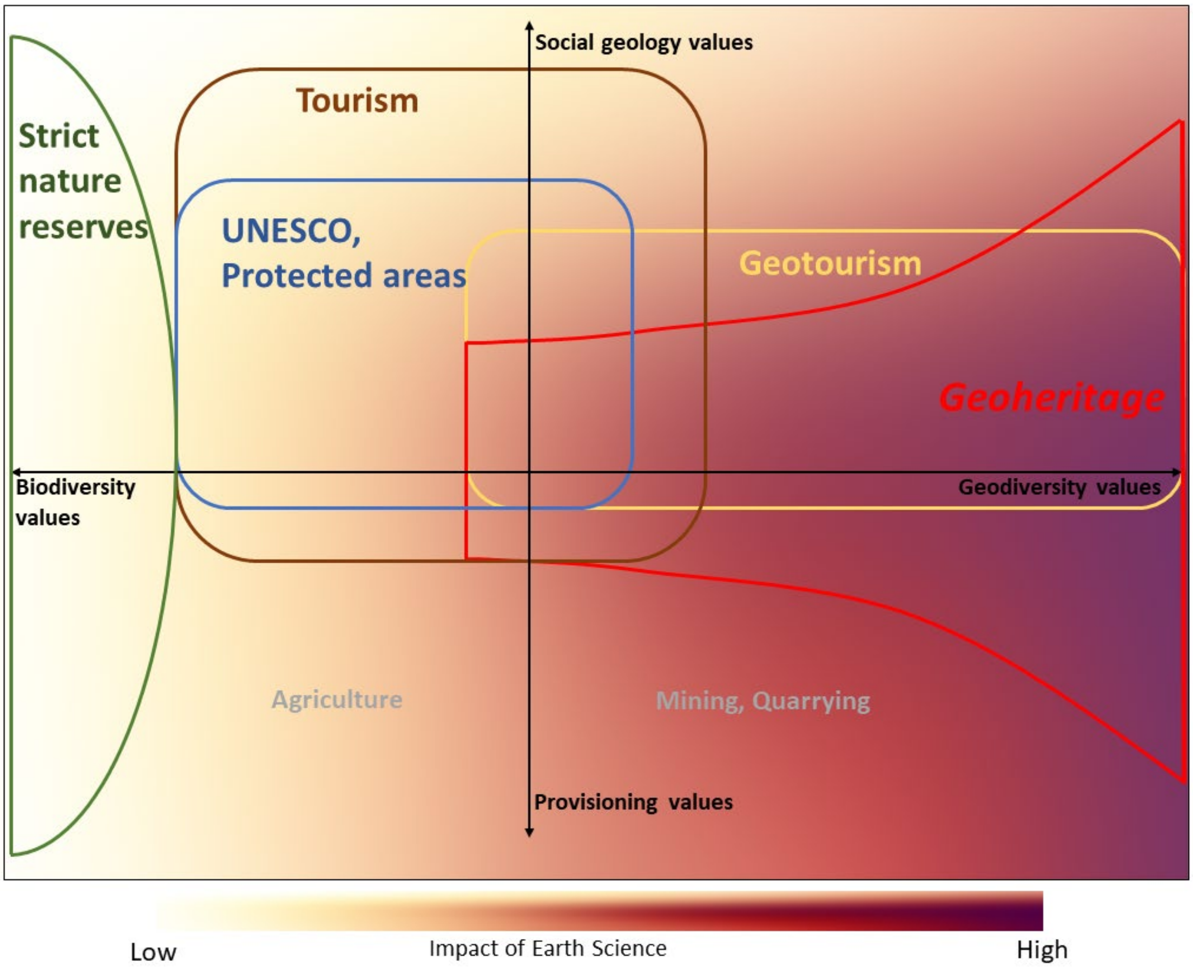

Figure 13 Relationships between major factors of conservation that influence the establishment of the scope and scale of geoheritage in geosystem services.

We designed a chart (Figure 13.) to break down geoheritage across primary values and variables of conservation and tourism. The chart promotes an understanding of the scope of geoheritage in the broad framework of geosystem services. The x-axis is the intrinsic conservational value, ranging from high biodiversity value to high geodiversity value, with a moderate value of both in the middle. The y-axis is the geosystem services value, ranging from a high provisional value to a high social geology value. Provisional values are the extractable geological resources, and social geological values are the associated educational and historical values of the natural elements providing nonmaterial benefits for society (aesthetics, recreational or cultural quality of the landscape). High intrinsic geodiversity values coincide with high Earth Scientific impact, resulting in high geoheritage occurrences. The high intrinsic value correlated with high geoheritage values stretches widely along the spectrum of geosystem services as they get featured within mines, quarries, and cultural landscapes. Conversely, with the decrease in geodiversity value, biodiversity values appear, and multi-designated areas occur. Believing in the inherent right for outstanding natural features to exist, geotourism is separated from tourism but not as a true superset of geoheritage. Geotourism, as interpreted today, is seen as an activity to engage with geoheritage but is slightly shifted toward classic tourism due to the necessary acknowledgement of tourist demands (high social value, aesthetics, tourist facilities).

Protected areas and UNESCO World Heritage Sites focus dominantly on biodiversity and their amenity values. The role of geodiversity is more acknowledged on the side of provisions of habitat and food to wildlife. Endangered species require extreme measures managed under the category of strict nature reserves defined by the World Commission on Protected Areas. The curve of strict protection drops when human needs for agricultural land or unique experiences of social landscapes overwrite the highest level of conservation status. Other protection statuses, such as UNESCO or category II-IV Protected Area also generate a large share of tourism (Dowling & Newsome, 2010; Dowling, 2011).

4.5. Conclusion

A systematic mapping study of geoheritage conservation across three decades of practice was considered necessary to address key concepts in the literature that were overlapping and at the same time forming a foundation for conflict between competing interests and ideals. The results of this study provide a structured understanding of the state of geoheritage. The identified keywords of the main body of geoheritage literature were shown to be depicting four major strands of conceptual thinking: **i)** geoscience focus; **ii)** call for aligned conservation methods for geo- and biodiversity; **iii)** the concept of geomorphosites, the leading resource for geoparks; **iv)** emphasis on community involvement for sustainability.

Assigning value to geoheritage will depend on their perception if left to individuals. Perception on what we value is a private experience. It is ultimately beyond any measurement technique or tool. Without our capacity to objectively measure and compare the values assigned by perception, policy makers cannot build them into conservation planning.

Our responsibility is to facilitate the survival of the relics and landscapes telling the story of the Earth's history beyond the limits of human perception of value, which remains unstable. Additionally, we have a duty to counteract preventable losses while considering potential benefits for local communities. A unified perception can be achieved if geoscientific facts are taken as the basis for the scope and scale of geoheritage. Science is built on evidence that individual experiences cannot change.

It is a great challenge to find agreement on subjective values, but necessary to open up further opportunities for efficient geoheritage conservation. In order to meet the challenge, we need to understand all the conceptual proposals involved with geoheritage conservation. Understanding the reasoning behind different concepts will lead to better cooperation between practitioners of varying scientific background. This will require a concerted effort on the part of policy makers to do more to understand and advance geoheritage conservation. Working with local communities, authorities, planners, and decision makers is crucial for sustainability and long-term adaptation strategies. The Geoscientific community therefore must shift its attention toward conservation matters and engage in the geoconservation-geoheritage-sustainability discourse, thus confirming principles and guidelines that will lead to successful local initiatives. In the meantime, it is also important to ensure that those initiatives place prime importance on the outstanding geoscientific value, the principal factor of geoheritage. This paper is a stepping-stone to that consensus as it summarizes the full spectrum of geoheritage related standpoints and concerns in addition to illuminating. the often-underrated complexity of geoheritage conservation

Chapter 5. *Validating the Conceptual Framework*

In this chapter, we investigate the underlying trends of successful geoheritage implementation through statistical analysis of countries with the highest trackable geoheritage interest. This chapter introduces correspondence analysis (CA) to the field of geoheritage to obtain information on how certain indicators bundle together and multiple correspondence analysis (MCA) to detect sets of factors which determine positive geoheritage conservation outcomes. Finally, the chapter presents ordination diagrams that visualize correlations among determinant variables translated to links between socio-economic background and geoheritage conservation outcomes.

Supplementary data for the Chapter are in Appendix C.

Chapter Contents

This chapter is based on a published paper:

Németh , B., Németh , K., Procter (2021). Informed Geoheritage Conservation: Determinant Analysis Based on Bibliometric and Sustainability Indicators Using Ordination Techniques. *Land, 10*, 539.

<u>Participating authors:</u>

Boglárka Németh, (data collecting and processing, analysis, manuscript writing and editing)

Károly Németh, (manuscript editing and discussion)

Jon N. Procter, (manuscript editing and discussion)

Chapter 5. Informed geoheritage conservation: determinants analysis based on bibliometric and sustainability indicators using ordination methods

5.1. Introduction

Determinant analysis (Hughes et al., 2008) is a detailed examination of the factors affecting the course of geoheritage conservation and reviews the relationships among these factors. Bibliometrics and sustainability are an interesting confluence of indicators to be the basis of the determinant analysis. The measurable aspects of environmental, economic and social sustainability are assessed against the bibliometric productivity of researchers. The performance of their output provides the informing linkages on what determines the objectives and direction of geoheritage conservation taking place around the globe (Maghsoudi et al., 2018; Nazaruddin, 2017; Németh & Moufti, 2017; Őrsi, 2011; Poiraud et al., 2016; Sallam et al., 2018; Santos et al., 2017; Štrba, 2018; Szepesi et al., 2016). Understanding these latent factors is key to optimising the subjectivity inherent in the assessments of the significance of natural features. In exploratory data analysis, the approach is summarising a data set's main characteristics. This study uses an unconstrained ordination method to represent relationships in a low-dimensional space. The model orders value so that similar variables are near each other and dissimilar variables are farther from each other (Borcard et al., 2011).

Most geoheritage practitioners aim to simplify the complexity and describe these environments through their most representative occurrences. Geoheritage sites and geological sites are part of the Earth as a system and serve as educational tools (van Wyk de Vries et al., 2018). However, the determinants or conditions of an environment where geoheritage features are successfully conveyed to the public are yet to be discovered. The determinant analysis is used to identify factors of interest and to review the linkages among the factors.

Geoheritage studies have multiple objectives that make multi-criteria decisions difficult. To date, the best practice is the creation of a geoheritage inventory by earth scientists (De Wever et al., 2015; Díaz-Martínez et al., 2016; Djurović & Mirela, 2010; dos Santos et al., 2016; Fuertes-Gutiérrez & Fernández-Martínez, 2010; Hicham et al.; Pereira et al., 2015). Due to the lack of a universal conceptual background, there are ongoing inventions of novel and hybrid inventory methods (Pereira & Pereira, 2010; Pralong, 2005; Reynard et al., 2007a; Rybar, 2010; Serrano & Gonzalez-Trueba, 2005; Warowna et al., 2016; Zouros, 2007).

Geoheritage assessment methods have a certain level of inherent subjectivity, one of the main concerns of geoheritage studies (Bollati et al., 2015; Ibáñez et al., 2019; Mucivuna et al., 2019; Ollier, 2012; Valdez, 2018). In cases where geoheritage exists in specific areas, such as a growing city, decisions on what value can be considered have to be made. Geoheritage value is not directly measurable, which inherently links subjectivity to the evaluation. A robust analysis of the state of knowledge is a convenient tool to remove subjectivity from evaluations and can ratify liability for minding geoheritage by authorities, organisations, and landowners. Decision-making is the process of making choices by identifying a decision, gathering information and assessing alternative resolutions. The stronger the case of a resolution, the higher the chance of its implementation.

Statistical exploratory methods are established in other disciplines like ecology, biology, sociology, and psychology (Blasius & Greenacre, 2006; Greenacre, 2006; Hill, 1974; Zoderer et al., 2019). Ordination is the collective term for multivariate techniques – that are abundantly used in ecology – that arrange sites along the axis on the basis of data on species composition (Braak, 1995). Ecologic systems are complex: one of the modern world's biggest challenges is quantifying ecosystems as part of sustainability measurement. This challenge is very similar to that of geoheritage; in fact, geoheritage appeared in literature as 'geosystem services' (Gordon & Barron, 2013; Gray, 2011). Ecosystems consist of many interacting biotic, abiotic and geoheritage components. Geoheritage encompasses a range of interactions of abiotic, societal, economic, and biotic factors that would require a universal best practice guide to be well understood.

The priority needs for quantitative procedures for examining vegetation as a continuum prompted the development of ordination techniques (Austin, 1985) years before geoheritage made its appearance in the scientific literature (Anonymous, 1991). Ordination methods quickly made their way to other multi-disciplinary fields where stakeholder perspectives are the subject of the research (Burke et al., 1992). These are the adequate methods to find underlying structures and relationships in a qualitative-quantitative dataset (Zoderer et al., 2019).

When trying to get a comprehensive view of the content of scientific activity in order to inform stakeholders, the most traditional method is the analysis of the scientific publications with the construction of performance indicators (Bauin et al., 1991). Bibliometric markers are a powerful tool for science policymakers. They monitor research and the assessment of the scientific contribution of authors as well as the tracking of knowledge evolution on research hotspots to inform science and public policy (Derrick & Pavone, 2013; Larivière et al., 2013;

Narin et al., 1994). Bibliometric performance indicators combined with environmental indicators provide insight beyond scientific activity and imply sets of optimum conditions for the high scientific performance of a field (Chinchilla-Rodríguez et al., 2015; Van Leeuwen et al., 2003). Performance indicators can be defined and quantified during link analysis; link counts are used as indicators or measurements of the level of influence and performance of people, domains, or nations. These `evaluative link analyses` rank studies according to their influence (Borgman & Furner, 2002).

The ability of metrics to represent complex information about research in an accessible format is overlooked in geoheritage and other scientific fields (Derrick & Pavone, 2013). Geoheritage studies draw attention to the corrupting effect of inherent subjectivity (Kubalíková, 2013; Štrba et al., 2015). The heavily biased field is expected to reach the level of reliability required by decision-makers after three decades of practice through the adaptation of proven instruments from other disciplines that tackle similar issues. A scoping study explored all approaches to geoheritage conservation as the first step in cleaning up the field and comprehensively synthesising evidence (Németh et al., 2021a). A meta-analysis of the literature identified four concepts. These approaches are rooted in the same maxim; however, they cover different value systems (Anderson & Ferree, 2010; Brilha, 2016; Crofts, 2018; Gray et al., 2013; Patrick et al., 2010). The development of four different concepts suggests a stronger socio-economic influence on geoheritage conservation. While socio-economic background has its place in the frame of geoheritage, its uncontrolled influence will jeopardise core conservation intentions.

This critical study serves to intensify geoheritage conservation implementation into all agendas in isolation from socio-political perspectives. Surveying the literature and collecting background data on the experts created a robust database for further analysis of relationships to determine geoheritage determinants. The main goal of this research is to find a correlation among different types of world development indicators with bibliometric data on geoheritage to find those key factors. The research set three objectives to achieve its goals. The first objective is to recognise countries with an elevated interest in geoheritage conservation through citation analysis. Next, the study looked for indicators of geoheritage interest and relevant socio-economic background. The final and main objective is to report directions of geoheritage implementations and their determinants at a global and local level by tracking correlations among indicators.

The expected outcomes of this study are identifying the optimum conditions for geoheritage growth that strengthen geoheritage instruments for successful implementation. The evolution of the field of geoheritage is best understood by its characterisation and comparison at different scales. The research collected data at a global scale and, in the end, narrowed it down to a case study of Auckland Volcanic Field (New Zealand) in order to understand further challenges present at a local scale. New Zealand is a country of 268 021 km2, geographically distant from the next inhabited land yet still globalised, as is reflected in the multiplied amount of shares of trade, finance and migration in total in the OECD countries (NZ member since 1973) in the past 30 years (OECD, 2006; OECD, 2020). The country safeguards its indigenous values while participating in major international agreements. Conservation strategies are based on addressing global issues to preserve the bicultural identity that refers to indigenous Māori and the polyethnic communities resulting from European migration (Mead, 2003). The urban expansion of Auckland occurs on an actively researched monogenetic volcanic field under the principles of sustainability (Hayward et al., 2011b; Hopkins et al., 2020). Auckland, the study area, encompasses all the components of geoheritage and provides an unprecedented example for an overarching approach to conservation.

5.2. Indicators at the global scale

Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs (Holdgate, 1987; Lélé, 1991). Sustainable development has been successfully adopted worldwide and gradually impregnates all functions of national and provincial governments (Griggs et al., 2013; Nilsson et al., 2016; Pearce et al., 2013; Sachs, 2015). Sustainability is the new paradigm of development.

The concept of sustainable development is derived from the Holdgate (1987) report of the Brundtland Commission (World Commission on Environment and Development). Its main concern is an alienated society from natural-geological environments and basic human nature (Ghai & Vivian, 2014; Loorbach, 2010; Vejre et al., 2010).

Geoheritage conservationists' direct attention toward the overlooked intangible values of the non-living and their fundamental role towards achieving sustainability (Crofts, 2018; Lazzari & Aloia, 2014; López-Gamero et al., 2011; Roders & van Oers, 2011; Wimbledon & Smith-Meyer, 2012). Therefore, sustainable development also means that any experience of the past handed over to the present is secured to be obtainable for future generations. In other words, landforms and geological features deemed to be significant to the geographical location must be secured for future generations to utilize as educational tools for knowledge and understanding of basic characteristics of the site, hazards, and their role in cultural belonging.

The people who are the object of development must be addressed; those who have the right to preserve their cultural identity and their own community by eradicating poverty through a sustainable environment and political development. However, economic growth always brings the risk of environmental damage as it puts increased pressure on land resources. When the concept of sustainability guides policymakers, the development will not necessarily work to ensure that the ecological roots are nurtured (Holdgate, 1987). The concept of geoheritage is to unite an inanimate environment and human societies to pursue resilience through recognition that provides for coherence within communities. Outstanding landscape elements reduce the feeling of losing control and provide a powerful attraction for understanding the nature of geological processes. Yet, there are no explicit policies addressing these outstanding occurrences of geodiversity.

Sustainability also means resilience. Resilient communities understand their environment and potential hazards. Geoscience education through geoheritage is an explicit normative framework for achieving an overarching understanding of hazard characteristics. The Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework for Disaster Risk Reduction 2015-2030, 2015) is an instrument created by the United Nations that provides concrete actions for societies of Member States to build the resilience of communities to disasters. The agreement outlines four priorities, of which the first one is "…the understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Such knowledge can be used for risk assessment, prevention, mitigation, preparedness and response" (New Urban Agenda, 2017). Urban areas are more vulnerable due to the high population density, and geoheritage is more likely to have been destroyed in the development of urbanized areas. Geoheritage conservation and resilience building go hand in hand with sustainable urbanization, and it should be particularly mentioned in such international agreements on hazard mitigation. Through rigorous scientific methods, this priceless knowledge is derived from important geological and geomorphological sites (geoheritage). Their rapid loss through intensified landscaping undermines the capacity for accurate hazard forecasts.

New Urban Agenda was adopted as a global framework for achieving sustainable urbanization. The United Nations Human Settlement Programme (UN-Habitat) for human settlements and sustainable urban development envisioned the document as a guideline for urban development. The Agenda "supports science, research and innovation, including a focus on social, technological, digital and nature-based innovation, robust science-policy interfaces in urban and territorial planning and policy formulation and institutionalized mechanisms for sharing and exchanging information, knowledge and expertise, including the collection, analysis, standardization and dissemination of geographically based, community-collected, high-quality, timely and reliable data disaggregated by income, sex, age, race, ethnicity, migration status, disability, geographic location and other characteristics relevant in national, subnational and local contexts" (New Urban Agenda, 2017). Although the geoheritage principle completely fits into this description, there is no mention of the importance of protecting outstanding geological sites.

5.3. Indicators at a local scale: Auckland Volcanic Field

Rapid urbanization and housing problems are not the only priority areas of urban planners in Auckland, the metropolis built on the Auckland Volcanic Field. Biculturalism implies integrating indigenous streams and protecting customs, values, and spiritual lands. The first people to arrive in New Zealand were ancestors of the Māori and probably arrived from Polynesia between 1200 and 1300 AD and inhabited lands of perfect conditions, such as the volcanic cones of Auckland. The first European settlers arrived in the nineteenth century, and modern urbanization took place during the twentieth-century quarrying away not only iconic volcanoes but as well cultural belongings (New Zealand Geopreservation Inventory, https://services.main.net.nz/geopreservation/; Te Ahukaramū Charles Royal, 2020).

Māori people believe they are related to the natural world – the earth, the birds, and the trees. Prestigious elements of the environment are the ancestors of humankind; therefore, every aspect of existence shares an intimate relationship with people. At its root, this view of the world is the projection of human qualities onto the natural world (personification) (Te Ahukaramū Charles Royal, 2020). Until the contact with Europeans, Māori lived in rural areas. As a result, they have lost contact with their original hapū (community) and iwi (tribe) in urbanised areas. This way, urban youth could reconnect with the tribes of their ancestors (Rāwiri Taonui, 2020). Their value system and connectedness to ancestors and nature must be included in all political systems and governmental functions to be preserved for future generations (Satterfield et al., 2013).

Auckland is predicted to take up to 60 per cent of New Zealand`s population growth over the next 30 years (Auckland Governance Reforms, 2009). The strategic plan for regional growth must meet the standards of international best practices in an effectively integrated spatial planning system. In order to achieve successful geoheritage conservation within the Auckland area, the policy framework must fit into this strategic direction of integrated spatial planning and be drawn from both indigenous identity and international best practices. Strengthening existing linkages between spatial planning and geoheritage is essential for the integration otherwise, competing for policy goals such as conservation and opportunity costs could potentially dominate geoheritage efforts (Auckland Governance Reforms, 2009).

In New Zealand, the term "outstanding natural features" is used to refer to geoheritage, as it appears in the Resource Management Act (Resource Management Act, 1991) (RMA). The Act is the blueprint that every related function of national, regional, and local governments is based upon in alignment with corresponding international obligations.

In essence, the compilation of the Geopreservation Inventory was carried out under the principles of the RMA and its coastal management regime, the New Zealand Coastal Policy Statement (New Zealand Coastal Policy Statement, 2010) (NZCPS). The purpose of NZCPS is to state policies to achieve the purpose of the RMA. Policy 1.1.3: it is a national priority to protect (a) significant representative examples of each landform which provide the variety in each region, visually or scientifically significant geological features and (b) characteristics of special spiritual, historical or cultural significance to Māori.

Auckland Council today face the challenge of prioritising geopreservation action over economic growth. The Inventory highlights all the landforms and geological sites the scientific community has deemed important. However, present decision-making has gone through scientific development and resulted in complex spatial planning systems to calculate precise areas of interest. The increasing demand for land surfaces makes it necessary to produce evidence-based assessments of the value of significant landforms and outstanding features. Satisfying principles of geoheritage conservation with relevance to indigenous values while sustaining economic growth became an advanced task in the metropolitan area of Auckland. Elaborately designed geopreservation assessment tools are hence indispensable and must start with an analysis of the key factors that dominate geoheritage conservation all around the globe.

5.4. Methods

This research resulted in the compilation of a report on the determinants of increased geoheritage activity. Three data types were collected: citing articles and academic output, geographic data on protected areas and geoparks, and world development indicators (Figure 14). In addition, information on a country's scientific orientation and dynamism and its impact on the national and international community serve as a tool for describing emerging theories, methods, orientations, and conservation outlooks (Okubo, 1997).

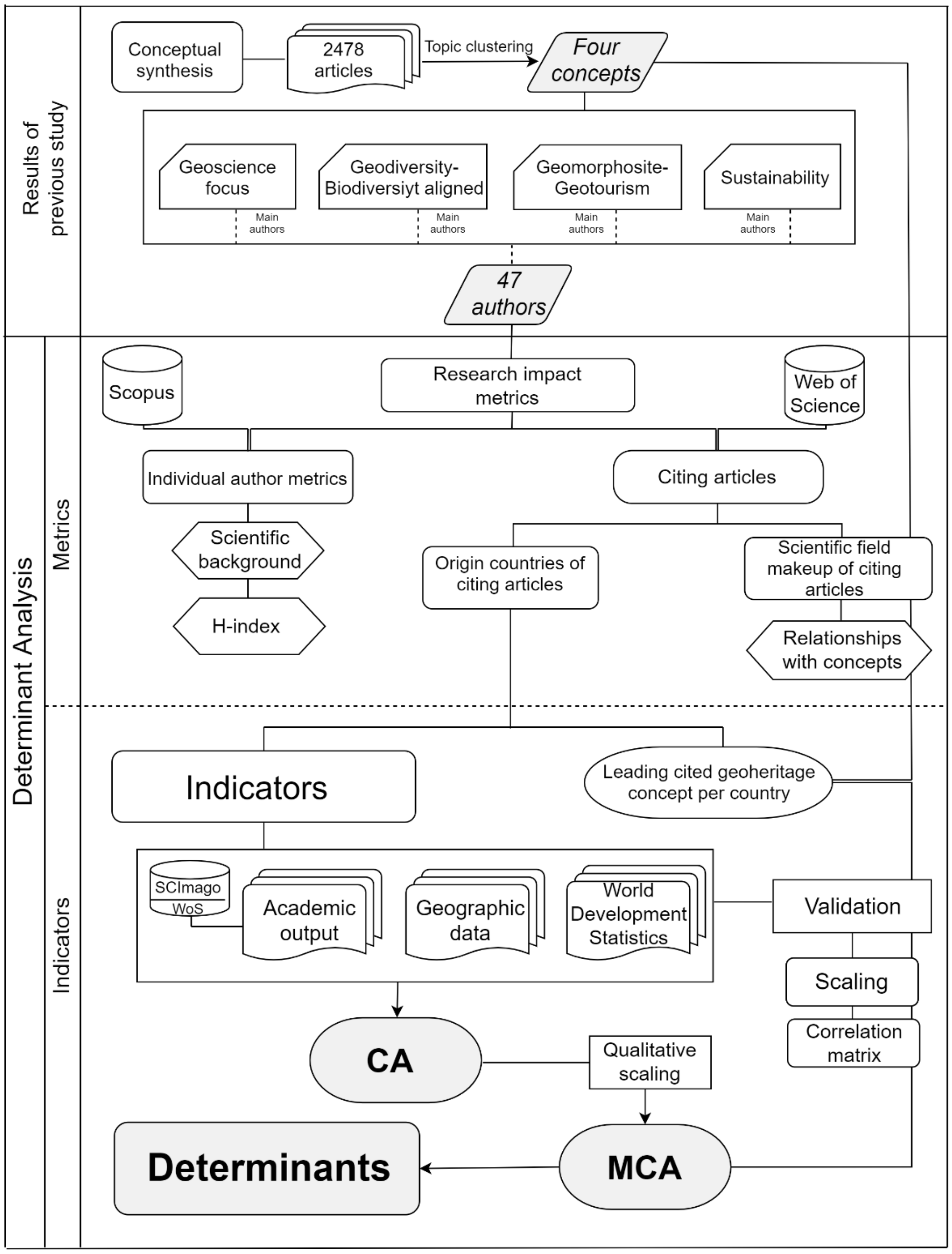

Figure 14 Flowchart of the research process

5.4.1. Indicators

Our approach to measuring scientific performance and extracting determinants in high-achieving countries started with research metrics analysis. Proven practice for such analysis is the use of online databases such as the Web of Science and Scopus for scientific publications (Durieux & Gevenois, 2010; Merigó et al., 2015; Okubo, 1997; Van Raan, 2006). Author metrics were extracted from Scopus (Scopus, 2020) and citing articles were extracted from the Web of Science (Web of Science, 2020) through research impact metrics tools of these online databases. The subject authors of this study are considered to be the major advocates within the scientific discourse on achieving global agreement on the quantification criteria of geoheritage or geodiversity (Németh et al., 2021a). The author's name conducted the search in the full database of Scopus and Web of Science with no minimum time period until 2020. We built two databases, one on the authors` background and H-index extracted from Scopus and another on the origin countries and scientific background of the citing documents collected from Web of Science. During the summarising period, the citing countries entailed two criteria of inclusion; to cite at least one of the works of the 47 selected authors and to have at least 15 documents citing one or more of the selected authors. These countries are the units of our determinant analysis.

To explore patterns between countries' scientific productivity compared to their geoheritage performance, we extracted data that is based on publications from the SCImago Journal & Country Rank that develops scientific indicators for journals and countries from the Scopus database. The ranking site is useful for analysing and comparing scientific domains (SCImago). Earth Scientific output and the geoheritage-related studies made up the academic indicators in our determinant analysis.

Biodiversity conservation is strongly associated with geodiversity conservation; therefore, World Protected Areas were chosen as one of the two geographic indicators (Yale Center for Environmental Law + Policy - YCELP - Yale University et al., 2012). The percentage of protected areas was calculated in ArcGIS software. The year of extraction is 2018, and the final data is expressed as a percentage of the country's total land. The data is retrieved from data.worldbank.com based on the world database of protected areas where the compilation and the management were carried out by the United Nations (Environment World Conservation Monitoring Centre) that is available for download through the Protected Planet website: protectedplanet.net. The World Database on Protected Areas is the most comprehensive global dataset of areas registered under the IUCN Protected Area Categories I-IV, including national parks, wilderness areas, conserved community areas, nature reserves, marine reserves and so on. Furthermore, the count of geoparks of each country and the year of UNESCO Geopark designation was extracted from the website: http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks. A number of geoparks, the major measurable manifestation of geoheritage conservation, were added as the second geographic indicator in our research of geoheritage determinants.

Databases on countries' performance in other functions of society provide a tool to discover, compare, predict and attack inequality in the world. World Bank Group, an international organisation, affiliated with the United Nations, offer a tool for measuring sustainable development through the measurement of the wealth of nations (World Bank, 2014). The country-level community well-being indicators are drawn from the publicly available World Bank Development Indicators. Eight variables are included as indicators of country development: population, urban population, urban population growth, urban land, total land, population density and international tourism receipts. The countries identified through the Web of Science as having elevated interest in the scientific communication of geoheritage were compiled into an `interest group` to attain data on our chosen world development indicators.

Worldbank.com provided an incomplete dataset of urban land cover. To recover missing data for countries Austria, Czech Republic, Hungary, Serbia and Slovakia, we used the online database of the European Environment Agency (https://www.eea.europa.eu/data-and-maps) stored as `Artificial Surfaces` which calculation was based on data from Copernicus Land Monitoring Service – Corine Land Cover (www.land.copernicus.eu) from years 2012-2018. This data is more recent than that of the 2010 world.bank.com. However, for the sake of our study on finding influencing factors to geoheritage decisions, the level of inaccuracy caused is statistically insignificant for the final result. This is due to the low land take of urban and other artificial development in the 39 European countries reaching only 0.1 % between 2006 and 2012 (European Environment Agency, 2017). Furthermore, the urbanisation rate has slowed down even more from 2012 to 2018, taking 200 km2 less land per year in all European countries (European Environment Agency, 2019).

More than half of the world's people are currently living in cities, which is predicted to expand to about two-thirds of the world's population by 2050 (Razmjoo, 2019). As the urbanisation process keeps growing, it is crucial to measure and monitor the development to meet sustainability goals. Understanding indicators allows urban planning to align with the global targets of sustainability by pinpointing present conditions. These tools are very important to influence all sectors, from energy -, land use-, and social well-being policymaking to biodiversity and geoheritage conservation strategy setting.

We developed indices from the publicly available world bank data to increase insightful indicators. We added three indices; the number of international arrivals per 1000 people, tourist density, and trade openness, each explained below.

The arrival number is an index of international arrivals per 1000 people of the country's population. The index expresses the capacity of tourists to enhance communities' economic well-being. If the number of arrivals is low compared to the host population, then fewer individuals or communities can benefit from tourism. On the other hand, it is more likely to significantly impact micro, small- and medium enterprises when the number of annual arrivals is relatively high. For the sake of analysing influencing factors in geoheritage designation, we use 60% of the given local population as a margin to judge the number of visitors as high or low.

The tourist density index is developed to obtain the countries` capacity to distribute tourists. A larger number of tourists concentrated in small geographic areas puts pressure on authorities to implement conservation rules and policies and create designated areas for sustainable tourism. Hence these authorities are likely to have an elevated interest in promoting geological sites. The equation used is Annual international arrivals/Population * 1000/Total land.

Trade openness and quality of economic growth have cointegration, a long-term, stable relationship, as shown by a case study in China (Kong et al., 2020a). Another study showed that the long-term relationship between trade openness and economic growth is positive, and they tend to move in the same direction (Obeid & Awad, 2018). The question is whether there is an influence on developing geoheritage conservation by the level of international trade. It is said that international trade lower barriers toward faster economic progress. Indirectly, international trade openness contributes to a natural increase in international tourism flow. Hence the importance of analysing whether trade openness is an important influencing factor in geoheritage development. Transnational tourism helps communities to restore their well-being. Studies confirm that changes to the countryside have coincided with a growth in tourism, recreational needs, and activities in rural areas (Beeton, 2006). However, communities exist in cities. Based on the explored dynamics of ecotourism, urban geoheritage can direct tourism development in all geographical areas toward a balance between community-driven and operator-driven tourism. Policy changes have also led to an increase in ecotourism by opening previously restricted areas and increasing environmental program funding opportunities (Beeton, 2006).

5.4.2. Correlation matrix

The indicators collected very different datatypes. It is important in statistical analysis to unify the datatypes. The scaling option for us was interval scaling. The calculation of Cronbach`s alpha validated the reliability of the set intervals. In quantification theory, the general internal consistency reliability plays an important role in interpreting multiple-choice-like data (Cronbach, 1951). Cronbach`s alpha is indicated by α, and it attains its maximum of 1 when all variables are perfectly correlated with the total score. In other words, the score reflects reliability, that is, the degree to which the instrument is free from random error. To date, it can only measure internal consistency through correlations among test items. Introducing such practices leads to the ability to measure reproducibility, that is, the stability over time or the consistency of scores across valuers at a point in time. To calculate correlation, we used Spearman`s rank correlation (ρ) because it creates a new variable in order to rank-order the result and is proved to be the most robust with outliers (Taber, 2018).

5.4.3. Correspondence analysis (CA)

We use exploratory data analysis techniques to identify any systematic relations between variables. The correspondence analysis (CA) method is an unconstrained ordination method that orders individuals characterized by categorical values on multiple variables. CA works on categorical datasets that have been scaled into categories as a powerful tool for finding patterns in large datasets (Deschamps, 2017). This multivariate method is used for almost any data matrix with nonnegative entries that principally involves tables of frequencies of counts and analyses data without explanatory variables (Blasius & Greenacre, 2006). A particularly powerful technique to group our indicators in the reduced dimensional spaces to present the key insights on relationships. Ordination orders the individuals so that ones with similar profiles are near each other and dissimilar objects are farther from each other. It simplifies complex data and provides an exhaustive analysis of the data (Costa et al., 2013). The technique is appropriate for discrete variates. It is often considered a simple scaling method widely used by plant ecologists. Floristic data to which gradient analysis is applicable consist of occurrences of a number of species at numerous sites where certain species prefer certain habitat types and, therefore, can become indicators (Hill, 1974). The first stage for such gradient analysis is to scale along a known gradient; for example, a country with a score of 1 may be small in area, a score of 5 may be very large, and a score of 3 may be medium. In the interpretation of such data, a geometric approach has the most benefits. The rows and columns are assumed to be points in a high-dimensional Euclidean space redefined so that the principal dimensions capture the most variance possible, allowing for lower-dimensional descriptions of the data (Blasius & Greenacre, 2006).

5.4.4. Multiple correspondence analysis (MCA)

While CA shows the relation between variables, multiple correspondence analysis (MCA) analyses relationships within a set of variables, the interrelationships between the statements or categories of variables. MCA is the central analytical tool to embed qualitative data. MCA is applied to detect and represent underlying structures in our dataset to investigate influencing factors for geoheritage designation. Therefore, this analysis can explore whether there is an association between "high geoheritage-related citations" and a "high number of international arrivals". CA can only tell us whether all the categories of the same variable have a statistically significant correlation with any other variable. This method tackles the more general problem of associations among a set of more than two categorical variables (Greenacre, 2006). This unconstrained geometric approach is directly linked to data visualization.

5.5. Results

5.5.1. Individual author metrics

A previous study presented a robust instrument that leveraged the power of a meta-analysis of the scientific literature in the form of a scoping review (Németh et al., 2021a). It pinpointed the most influencing articles (no = 70), produced by 47 individual authors, that channelized the discipline of geoheritage into four characteristic leading concepts. These concepts are i) Observes the changes to complex Earth Systems (geosystems); ii) Deals with geodiversity that can be considered the stage upon which biodiversity acts; iii) Focuses on social interactions of geotourism and support networks of geoparks; iv) Study the connection of geosystems to communities, ethics and traditions and transnational policies and cultural interconnectedness. Breaking down geoheritage discourse into its elements is crucial for quality implementation. With an understanding of the state of geoheritage, it is possible to take single or dashboard indicators to guide and facilitate decision-making (Iddrisu & Bhattacharyya, 2015).

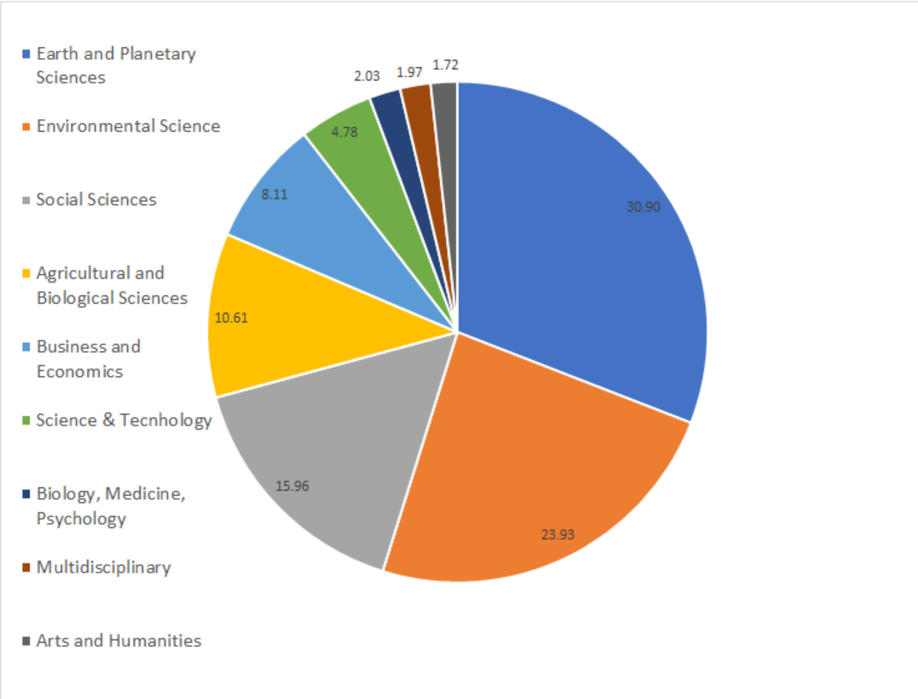

Figure 15 Background fields of the 47 authors influencing the most the conceptual evolution of geo-heritage conservation.

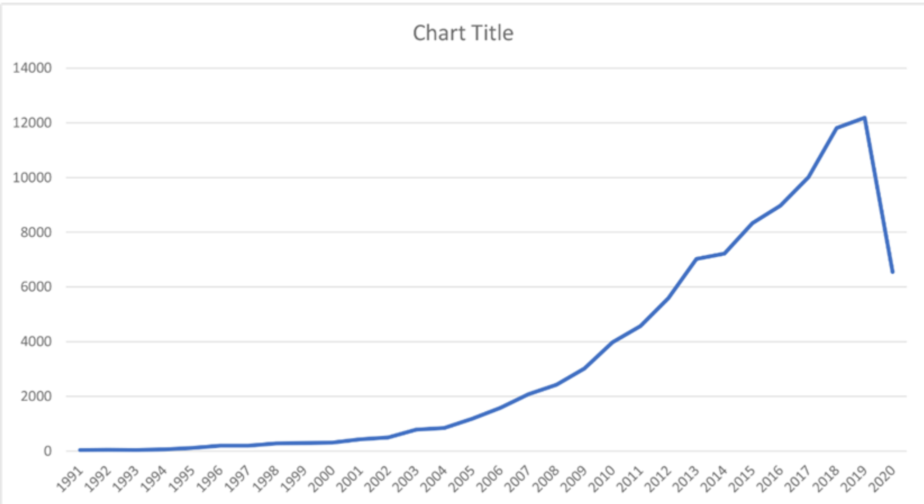

Figure 16 Cumulative citations (Y-axis) of the 47 authors since 1991. The citation number includes citations for all their published and co-published material available in Scopus online database.

Table 6. H-index of the authors listed according to their country of affiliation in 2020

Σ authors		**H-indexes of each author**											
United Kingdom	12	17	17	1	21	12	6	10	15	3	3	5	22
United States	8	12	17	12	8	10	8	14	15				
Australia	6	7	6	1	20	16	6						
Italy	4	22	14	13	21	13							
Poland	3	6	4	12									
Spain	3	12	4	18									
Iran	2	6	5										
Netherlands	2	18	6										
Brazil	1	2											
Canada	1	8											
China	1	2											
Czech Republic	1	6											
Finland	1	24											
France	1	3											
Germany	1	1											
Greece	1	13											
Iceland	1	13											
Norway	1	12											
Portugal	1	14											
Russian Federation	1	18											
Slovakia	1	8											
Sweden	1	98											
Switzerland	1	18											

Scopus offers author metrics to show the researcher`s performance. We were interested to find out what scientific background the influence of the 47 authors is coming from and where is the highest measurable impact of their research. We first looked at their h-indices that indicate their citation influence, which also indicates the most influential conceptual framework. For the research, we took a pool of 47 authors that were identified as the leading characters in the geoheritage conceptual evolution. Figure 15 shows the scientific fields these authors are experts. The main area is Earth and Planetary Sciences at ~31%, followed by

Environmental Science at ~24% and Social Sciences at ~16%. Agricultural and biological sciences (10.61%) and Business and Economics (8.11%) appear with a fair share revealing the multidisciplinary nature and permeability between areas of geoheritage research. The leading area is earth science, which is evidence for the scientific core nature of geoheritage conservation. The citation overview of the authors in question (Figure 16) presents a consistent growth from that point in the late 1990s when two of the very popular concepts on geosites and geomorphosites got published by Wimbledon (1996) and Panizza (2001). This period represents a milestone for development, and the works published in the early 2000s add a fundamental contribution to conceptualising geoheritage, creating a strong pattern still present today.

Hirsch (2005) proposed an index h, defined as the number of papers with citation number ≥ h, as a useful index to characterise a researcher's scientific output and quantify the cumulative impact. We organised the authors according to their affiliations and assigned H-indices (Table 6) to their countries. This index shows us the countries which provide a contribution to geoheritage conservation. The highest impacts on the field are derived from the United Kingdom, United States, Australia, Italy, Spain and Poland. We keep this data as control data to validate our results in geoheritage interest, one of the academic indicators of our study.

5.5.2. Citing articles

We hypothesise that the analysis of the background of the received citations reflects the interest in geoheritage. To collect these data we used the online database that provides research impact metrics, the Web of Science (WoS). We analysed the background of the authors who generated the citation count by their main scientific areas and countries of origin.

The analysis of given cumulative citations produced a list of 54 countries that are the subjects of our further data collections. The countries with the largest numbers of citing articles of geoheritage conservation-related works form the entities our study proceeds to derive underlying trends. Figure 17 compares these countries` rankings in terms of their scientific output, respectively, in all scientific fields, in earth sciences, and in citing geoheritage authors. The rank in each column is based on the total number of articles published in 2018. We were interested to see if we could identify a linear relationship between earth science and geoheritage research.

The United States and China are the most fruitful publishers of science research (Lepori et al., 2019). Figure 17 suggests that increased earth scientific research within a country does not necessarily increase geoheritage publications. Earth scientists should be encouraged to translate their findings and specific knowledge into geotourism education material and nominate outstanding outcrops of their study area for geoheritage evaluation. There is a tendency for authors to cite scientists from shared cultural backgrounds. Compared with the authors` H-index analysis, the highest-impact countries are ranked to have the highest geoheritage interest. The United States and the United Kingdom did not change position compared to the rank column in earth sciences and all scientific disciplines. Australia, on the contrary, jumped over six countries and ranked in third place in geoheritage interest without showing any increased interest in earth sciences compared to all sciences. Spain and Italy showed a very similar trend.

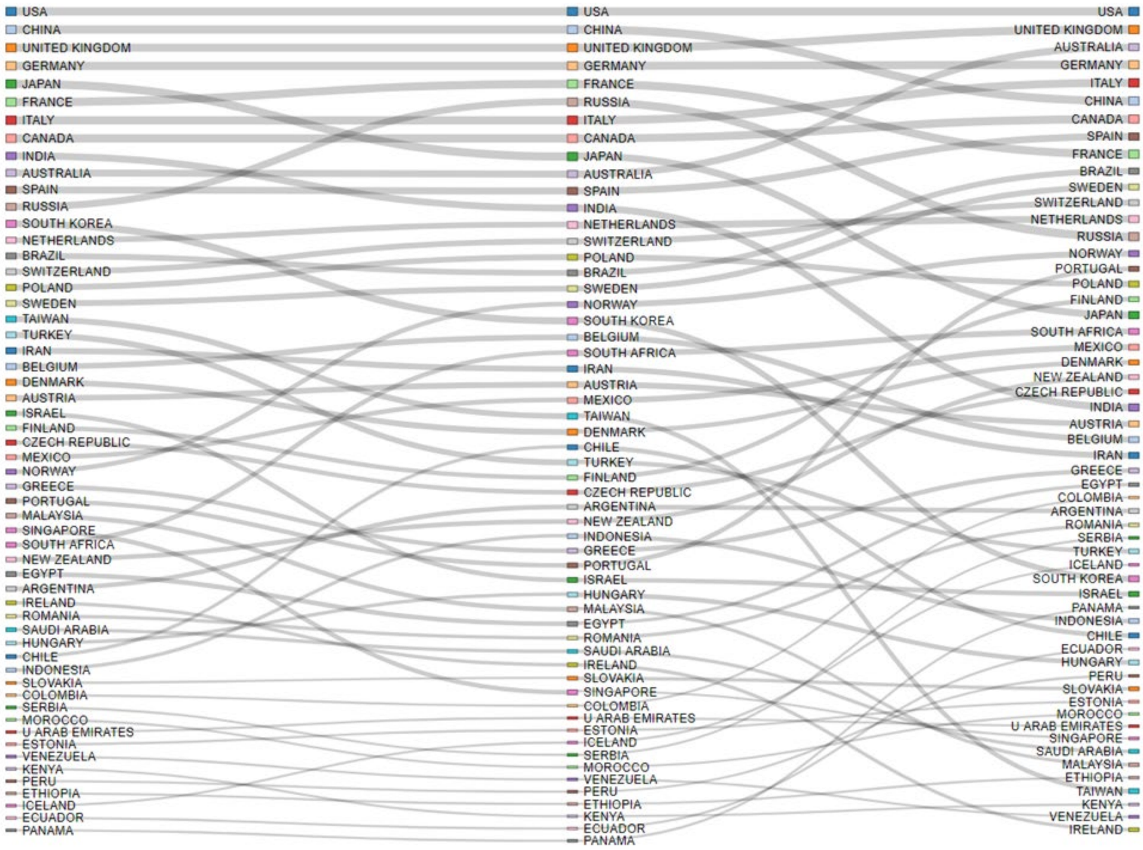

Figure 17 The three columns display the countries extracted through the bibliometric analysis. All columns are rankings according to their scientific output (1) at all scientific subject areas from SCImago, (2) at earth science and (3) at Geoheritage (third column). The width of the arrows is proportional to the flow rate. For a detailed explanation, please refer to the main text.

	Concept1	Concept2	Concept3	Concept4		Concept1	Concept2	Concept3	Concept4
ENVIRONMENTAL SCIENCES	1776	2964	698	5480		0.864472	1.170424	0.311276	1.340257
GEOLOGY	2910	1766	1629	2368		1.783096	0.877869	0.914503	0.729059
PHYSICAL GEOGRAPHY	1309	1060	728	1923		1.385757	0.910354	0.706091	1.022883
SCIENCE TECHNOLOGY	405	508	443	1311		0.807018	0.8212	0.80875	1.312593
BIODIVERSITY CONSERVATION	321	1081	69	470		0.878882	2.40109	0.173084	0.646581
ENGINEERING	151	438	262	662		0.530382	1.248083	0.843132	1.168341
SOCIAL SCIENCES	43	214	3884	751		0.046713	0.188597	3.865682	0.409925
WATER RESOURCES	246	218	165	829		0.896662	0.644625	0.55101	1.518265
LIFE SCIENCES	364	373	240	444		1.361314	1.131678	0.822338	0.834333
HEALTH CARE SCIENCES	67	188	457	242		0.373231	0.849606	2.33239	0.677357
MATERIALS SCIENCE	56	636	648	129		0.20259	1.866567	2.147764	0.234487
AGRICULTURE	171	280	174	302		0.980319	1.302226	0.913909	0.869917
FORESTRY	265	268	78	233		1.668609	1.368991	0.449972	0.737164
MARINE FRESHWATER BIOLOGY	156	134	29	503		1.008565	0.702815	0.171775	1.63398
GEOCHEMISTRY GEOPHYSICS	242	115	79	399		1.54021	0.593772	0.460653	1.27596
BUSINESS ECONOMICS	5	104	80	492		0.039019	0.658407	0.571974	1.929161
PUBLIC ADMINISTRATION	28	0	34	455		0.287818	0	0.3202	2.350019
ZOOLOGY	63	377	5	21		0.718465	3.487897	0.052242	0.120333
DEVELOPMENT STUDIES	0	68	4	280		0	0.832865	0.055329	2.124056
URBAN STUDIES	27	37	24	242		0.434811	0.483388	0.354104	1.958177
EVOLUTIONARY BIOLOGY	92	93	14	100		1.635188	1.340973	0.227977	0.893057
REMOTE SENSING	150	85	34	26		2.702218	1.242239	0.561165	0.235343
FISHERIES	11	47	2	203		0.222274	0.77046	0.037026	2.061061
ANTHROPOLOGY	138	35	39	39		2.92184	0.601177	0.756527	0.414898

Figure 18 The chart depicts relationships between the main background subjects of citing articles and the four main concepts of geoheritage conservation. Concept 1 = Earth science focus, Concept 2 = Geodiversity-Biodiversity aligned conservation, Concept 3 = Geotourism, Concept 4 = Sustainability

Regarding Web of Science background field categories, Environmental Sciences produced the highest number of citations, with Geology in second place. By grouping the citation count according to the authors' concepts was derived from we could gain insight to further trends in geoheritage conservation. Ratio normalized counts (Figure 18) uncovered special interests within concepts. Certain fields, such as remote sensing and anthropology, show an increased interest in concept 1, characterized by earth science, compared to the other concepts. Zoology and biodiversity conservation are rather interested in concept 2, the joint evaluation of biodiversity and geodiversity. Social sciences and health care sciences cited authors dealing with concept 3 on geotourism. Sustainability as concept 4 was the biggest interest of fisheries, urban studies, and development studies, which simultaneously validates our interpretation of sustainability.

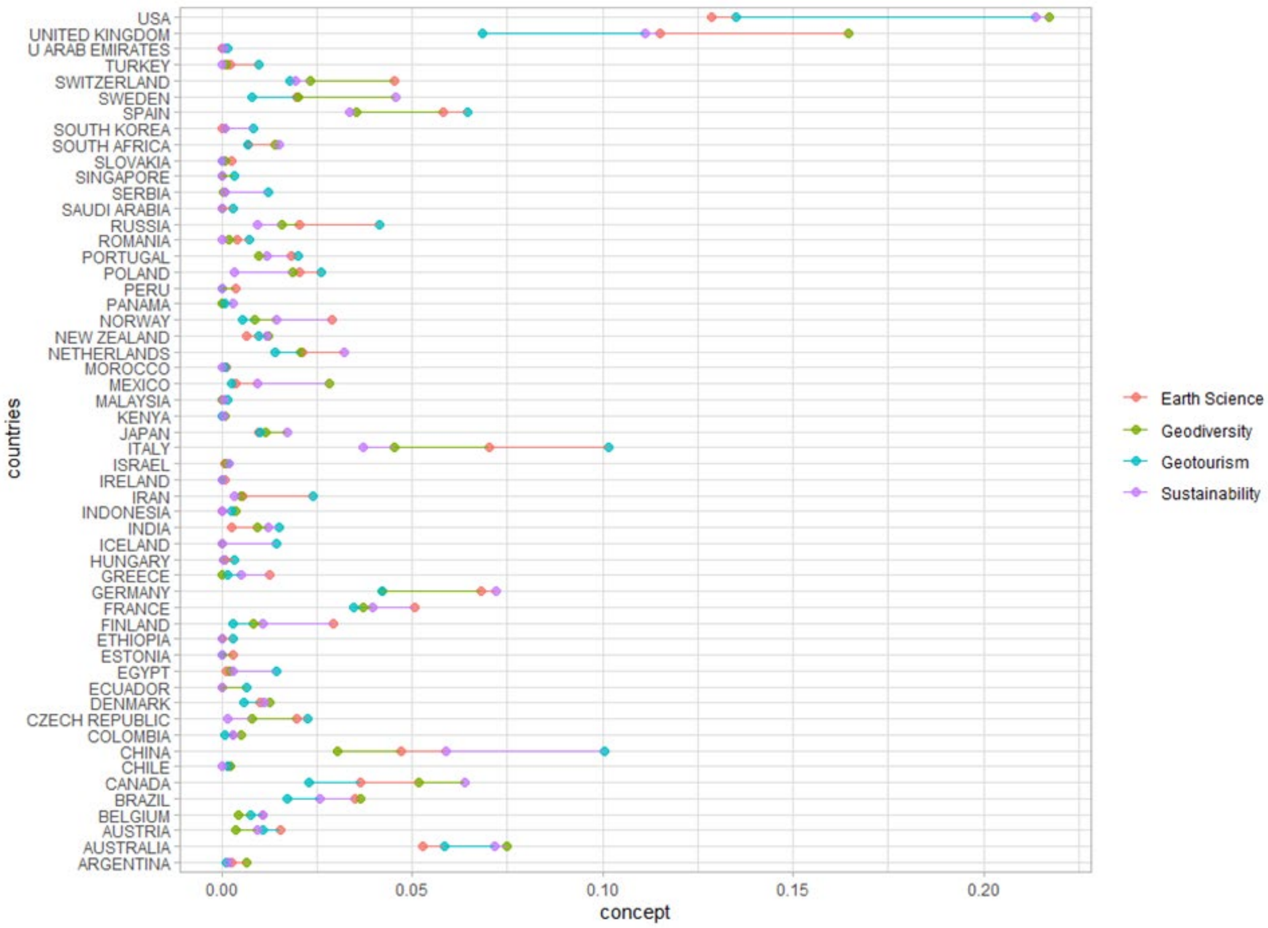

Figure 19 This figure provides information on the relation of the origin countries of citing articles and the four different concepts. The dots indicate the normalized value of citations generated by the country toward the different concepts.

The last part of the analysis of the citing articles divided its countries per their leading choice of concept (Figure 19). The value resulted from the highest normalized count of citations generated by the given country toward the four different concepts. The first three countries, the United States, United Kingdom and Australia, in the geoheritage interest ranking, had cited authors publishing on the relationships between geodiversity and biodiversity. Although the number one interest is in geodiversity, the following interest for these leading countries is very different; while in the United Kingdom, earth sciences are the next, in the United States and Australia, it is sustainability. China`s biggest interest is in geotourism, with geodiversity in the last place, Canada has sustainability in the first place, and geotourism comes last. Italy, Spain, and Portugal appear with the exact same interest pattern; geotourism and the first place with earth sciences right after and sustainability come last. This pattern suggests a special acknowledgement of educating the geotourists.

The most obvious assumption would be that the type of interest in geoheritage is driven by the country's size and societal demand. To understand how certain countries` preference is formed in geoheritage or geodiversity conservation, we introduced further indicators to the study to be able to derive evidence-based conclusions on the major drives in geoheritage interests.

Single indicators provide simple ways for interpretations encompassing less subjectivity and bias and other synthesis errors inherent in composite indices (Böhringer & Jochem, 2007; Iddrisu & Bhattacharyya, 2015). However, single indicators are only suitable for the measurement of unidimensional issues.

5.5.3. Indicators

International agreements relating to environmental protection are based on a convention that countries commit to and create a framework aligned with their socio-economic background. International committees are established to monitor and ensure these changes are taking place. To date, geoheritage conservation does not have a standard measurement tool.

Despite the complexity of geoheritage conservation, the starting point in evaluating features is always the scientific knowledge derived from it. Unfortunately, geographic areas that are distant from scientific hot spots (scientific hot spots understood here as regions where persistent earth science research has been performed over a prolonged time and is of global interest) or not of current scientific interest (areas which were in the focal point of earth science researches in the past, but today they are considered as areas where "nothing left" to research) will be less likely listed on any geoheritage inventory. The intensity of scientific research depends on the governing regime and the level of support science institutions receive. Scientific output can be a great indicator in the geoheritage measurement tool once the number of sites is listed and released in a global database. It could be interesting to see whether a rise in a certain field in a given country increases the number of listed geoheritage sites. In this study, we analyse the country's performance in citing geoheritage works against earth science publications. The indicator, in our case, could be the outperforming production of geoheritage documents in relation to the output of Earth Scientific documents.

In 2004 Europe and China launched a geopark program to kickstart the publicisation of geoheritage conservation (Jones et al., 2007). Geoparks (Figure 20) have proved to be successful in contributing to sustainable development goals by revolutionising tourism, promoting local tourism businesses, and ensuring the protection of important geological sites and landscapes (Catana & Brilha, 2020; Williams et al., 2020). Hence UNESCO put it on its agenda to open new opportunities for propagation. The number and reputation of geoparks increased rapidly, and today they can be used as an indicator for geoheritage conservation measurement.

In addressing subjectivity in geoheritage evaluation, we have absolutely no tool to measure and compare the effectiveness of geoheritage conservation. The lack of geoheritage conservation policies means successful geoheritage conservation at the site level most likely would take place within already protected areas. However, there is no database on the number of geoheritage sites preserved and promoted over the years within protected areas.In addressing subjectivity in geoheritage evaluation, we have absolutely no tool to measure and compare the effectiveness of geoheritage conservation. The lack of geoheritage conservation policies means successful geoheritage conservation at site level most likely would take place within already protected areas. However, there is no database on the number of geoheritage sites preserved and promoted over years within protected areas.

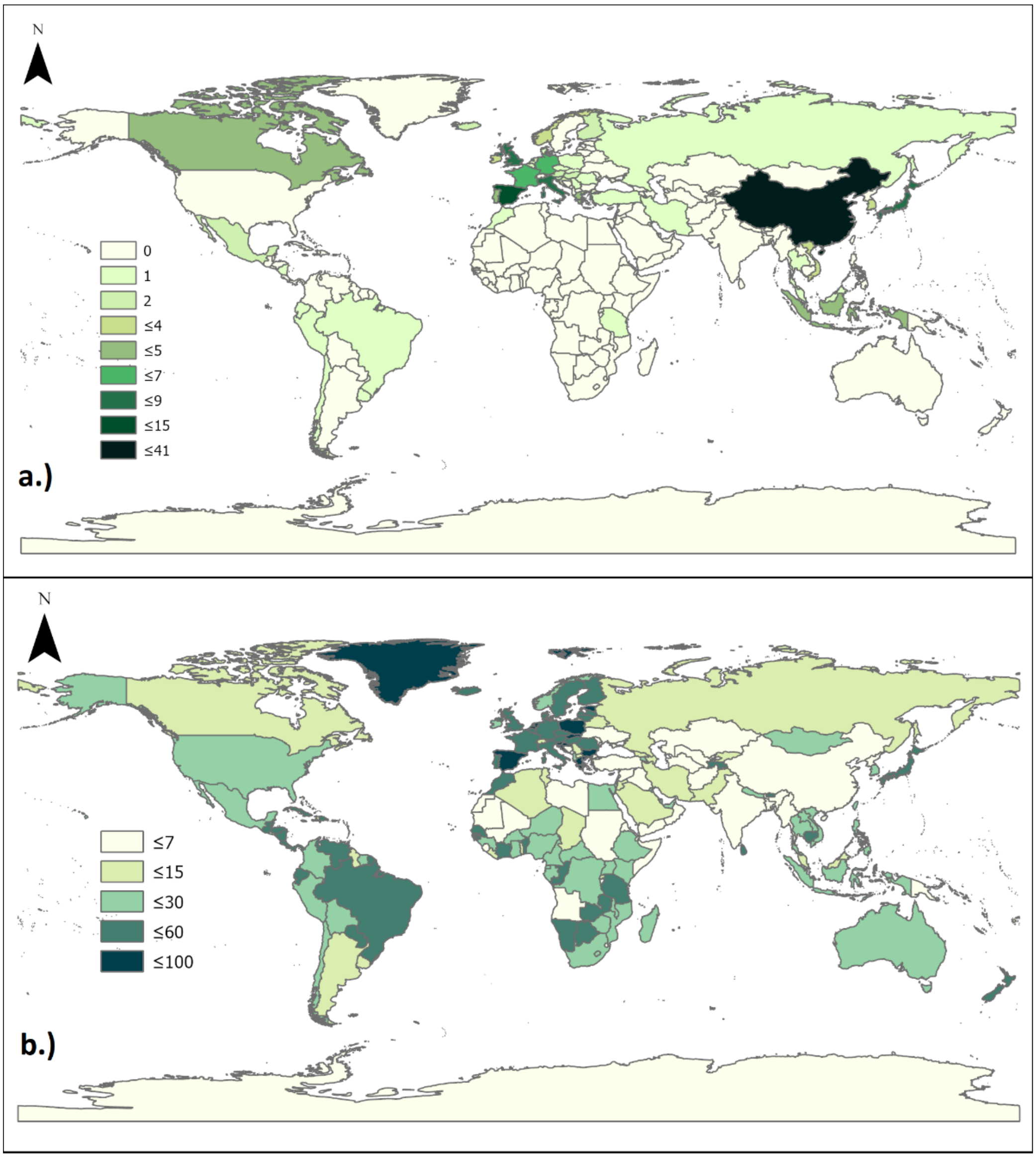

Figure 20 a.) A number of geoparks per country in the world in the year 2020 b.) Percentage of protected areas per total area of each country in the year 2020

The two maps show an interesting contrast. Countries with the highest number of geoparks appear to have a lower percentage of protected areas.

Visitation, when not as a form of business, will contribute to the tourism sector. Teaching earth science through experience and recreation cannot be part of the site's visitation unless the universities promote virtual field trips. Visitations affect the economy, and if regulated, it increases local development. Basic world development indicators (Table 7) can therefore unearth the optimal social-economic conditions that motivate decision-makers to pursue geoheritage conservation. Such economic effect is guaranteed in rural areas, but conservation activities often lead to opportunity loss in urban areas.

Table 7. Indicators to measure geoheritage effectiveness. Values were scaled from 1 to 5 to standardise the different data types for further statistical analysis

Indicators	**1 (very low)**	**2 (low)**	**3 (medium)**	**4 (high)**	**5 (very high)**
Population (million)	<7	7-20	20-100	100-330	1300-1500
Urban population (% of total population)	<35	35-55	55-75	75-90	90-100
Urban population growth (annual %)	<0	0-1	1-2	2-3	>3
Urban land (% of total)	<5	5-10	10-20	20-30	>30
Population density	<15	15-50	50-100	100-500	>500
International tourism, receipts (% of GDP)	<1	1-2.5	2.5-5.5	5.5-9.0	>9
GDP per capita (thousand US $)	<10	10-25	25-50	50-70	>70
Trade openness	<35	35-60	60-100	100-200	>200
Tourist arrivals (per 1000 people)	<75	75-400	400-1000	1000-2500	>2500
Tourist density	<10	10-80	80-200	200-300	>300
Total land (thousand km2)	<50	50-300	300-1000	1000-5000	>5000
Protected areas (%)	<7	7-15	15-25	25-35	35-40
No of geoparks	none	1-2	3-7	8-20	>20
Geoheritage citing papers	<50	50-400	400-1500	1500-500	>5000
Documents in earth science (Scopus database)	<5	5 -20	20-100	100-200	>200

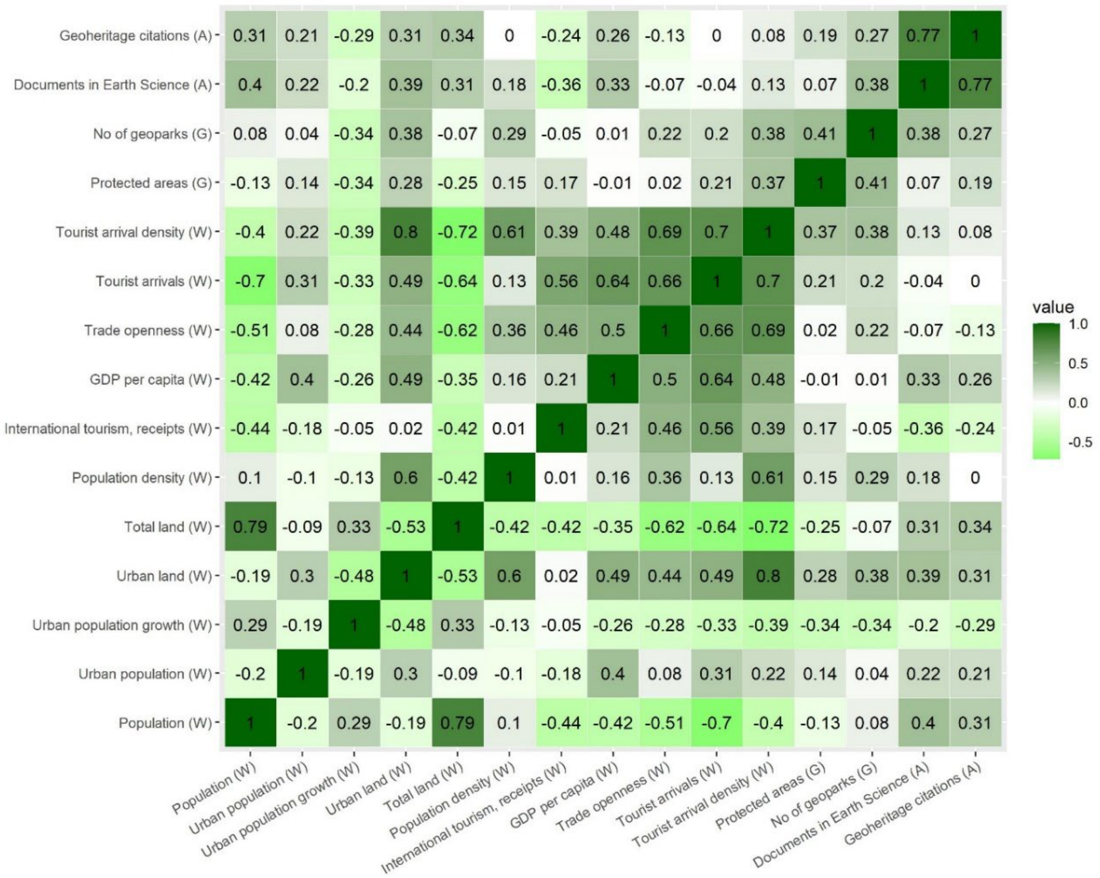

Figure 21 The matrix is built up by the correlation coefficient values of each indicator to detect the level they affect one another. The coefficient is based on their variance for all the studied countries Indicators of academic output are marked with (A), geographic data are marked with (G), and world development statistics are marked with (W).

The Cronbach`s coefficient α (Figure 21) was used to calculate the internal consistency of the scaling. The overall scaling reliability of the gradient values was robust, with $\alpha = 0.83$ (Taber, 2018). Correlation coefficients don't highlight one outstanding relationship that would connect academic, geographic, and world development indicators; therefore we continued the analysis looking for bundles that indicate determinants in geoheritage conservation.

5.5.4. Correspondence analysis (CA)

Several functions are available in the R software for computing CA; we used the package 'FactoMineR' and 'Factoshiny'. The inertia of the first few dimensions calculated by the coordinates of the points (Table 8) shows that there are strong relationships between variables and suggests that the first 3 dimensions are to be studied. The first three dimensions express

68.46% of the total dataset. 56% of total variability is explained by the plane of the first two dimensions. Due to the relatively high number of variables, the variability of the discarded dimensions cannot reveal reliable relationships. These lower dimensions represent the noise that comes from the heterogeneous construct of the data.

Figure 22 presents the indicator profiles representing the proportions belonging to each country category. In the first dimension, we have a bundle of population (Table 9) variables: Total land, Population and Urban Population Growth, and one bundle of tourism industry-related variables: Trade openness, Tourist arrivals, Urban land and Tourist density. In this dimension, Geoheritage citations and the number of geoparks remain closely linked and present an association with the bundle of population variables rather than the tourism industry variables.

In the second dimension, we can observe the bundle of geoheritage (Table 9) variables: Geoheritage citations, Documents of earth science, Number of geoparks, and interestingly joint variables of Urban Land. This dimension also joined the variable of International tourism receipts to the tourism industry bundle.

In the third dimension, Geoheritage citations are significantly associated with the Urban population and Tourist arrivals. Also, population density and urban land gained ground in the population bundle (Table 9).

Table 8. Correspondence analysis (CA) dimension discrimination measures. The numbers show the contribution of indicators in each dimension by the coordinates (calculated by the standard coordinates and singular values raised to a certain power) of the points.

Indicators	**Dim 1**	**Dim 2**	**Dim 3**
Population	-0.387	-0.003	0.172
Urban population	0.029	-0.007	-0.158
Urban population growth (%)	-0.219	-0.291	0.094
Urban land (% of total)	0.275	0.262	0.155
Total land (km2)	-0.459	-0.065	-0.069
Protected areas (% of total)	0.043	0.008	-0.008
Population density	0.089	0.002	0.29
International tourism receipts	0.13	-0.259	-0.063
No of geoparks	-0.009	0.149	0.094
GDP per capita	0.103	0.001	-0.132
Trade openness	0.198	-0.117	0.008
Geoheritage citations	-0.19	0.322	-0.167
Documents in earth science	-0.163	0.252	-0.05
Tourist arrivals	0.263	-0.097	-0.148
Tourist density	0.354	0.072	0.105

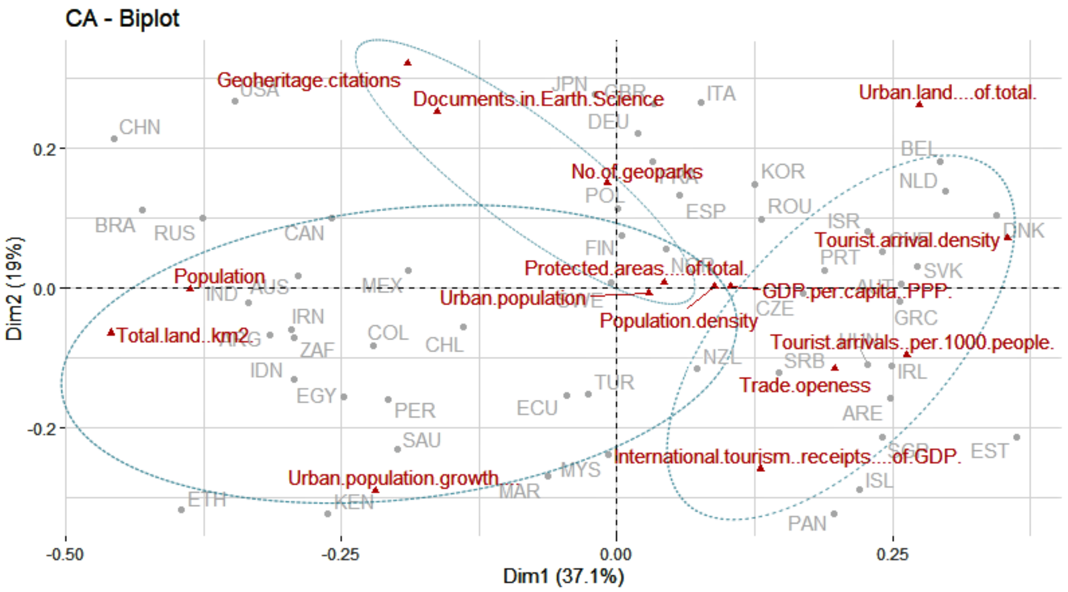

Figure 22 Correspondence analysis ordination diagram of the first two axes with countries (grey) and indicators (red); Ellipsoids illustrate the three identified indicator bundles.

Table 9. Identified indicator bundles. In the input matrix, the rows are the countries, and the indicators are the columns. When creating an ordination diagram, the data points displayed represent the countries and the indicators. These data points are organised so that similar observations are located closer to each other, and those that differ are farther apart.

Population bundle	Tourism industry bundle	Geoheritage bundle
Total land (km^2)	Trade openness	Geoheritage citations
Population	Tourist arrivals	Documents in earth science
Urban population growth (%)	Tourist density	No of geoparks
Population density	International tourism receipts	Protected areas
Urban land (% of total)	Urban land (% of total)	Urban population
Geoheritage citations		Urban land (% of total)
		Tourist arrivals

5.5.5. Multiple correspondence analysis (MCA)

Categories were not made for Urban land and GDP as they did not show statistical significance with any of the indicator bundles. The categories were assigned to the indicators based on the known gradient scaled values from CA computation to express the lower and higher range of the spectrum, the scores were split at the median and assigned to categories (Table 10) accordingly unless the value range of the indicator required three categories, where the medium scale was kept.

Table 10. Categories of indicators for multiple correspondence analysis.

Indicators	**Categories of indicators**			
Concept (supplementary var.)	Earth Science	Geodiversity	Geotourism	Sustainability
Urban population	rural	urban		
Urban population growth	negative	indifferent	prominent	
Protected areas	<15	>15		
Population density	scattered tourism	concentrated tourism		
International tourism, receipts	small tourism share	large tourism share		
No of geoparks	No	Yes		
Trade openness	closed market	open market		
Geoheritage citations	low geoheritage citations	high geoheritage citations		
Tourist arrivals	lower number of arrivals	high number of arrivals		
Tourist density	scattered tourism	concentrated tourism		
Total land area	small	medium	big	
Earth Scientific output	less significant	significant		

The individual factor map (Figure 23) shows the division of the countries in the multifactorial analysis plane. Countries are coloured according to bibliometric data of concepts. The Wilks test p-value indicates that the “concept” factors are the best separated on the plane, which explains best the distance between individuals. The confidence ellipsis around the categories for all the qualitative variables used. Apart from concepts, none of the development descriptors used in this study could distinguish the countries.

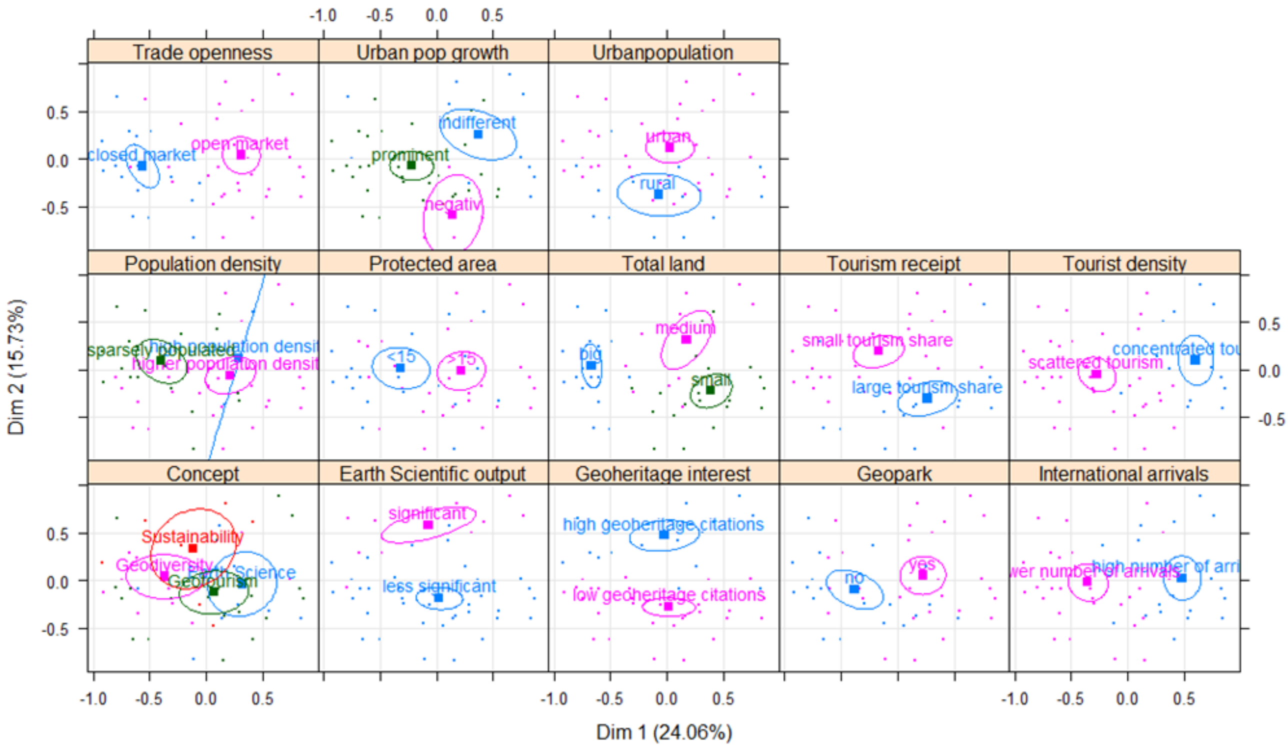

Figure 23 Individual factor map. The chart breaks down the relationship of values with the origin countries of citing articles separately for each indicator. None of the indicators creates well-distinguished clusters from the countries (represented by dots), meaning none of the indicators alone influences the course of geoheritage conservation.

Table 11. Multiple correspondence analysis (MCA) dimension discrimination measures. The numbers show the contribution of indicators in each dimension by the coordinates (calculated by the standard coordinates and singular values raised to a specific power) of the points.

Categories	**Dim 1**	**Dim 2**	**Dim 3**
no	-0.6914	-0.21107	-0.61507
yes	0.40669	0.124156	0.361807
<15	-0.5762	0.036882	-0.36361
>15	0.39613	-0.02536	0.249981
big	-1.2191	0.095424	-0.06502
medium	0.31453	0.710895	0.710553
small	0.70959	-0.50325	-0.38445
high geoheritage citations	-0.0445	1.069525	0.241772
low geoheritage citations	0.02619	-0.62913	-0.14222
less significant	0.0419	-0.4205	-0.09211
significant	-0.1321	1.326197	0.290501
rural	-0.1355	-0.84614	1.133691
urban	0.04296	0.26829	-0.35946
indifferent	0.66807	0.588311	-0.02177
negative	0.25884	-1.34325	2.138608
prominent	-0.4081	-0.16302	-0.25508
high population density	0.53148	0.264942	-2.26671
higher population density	0.38636	-0.13251	0.295789
sparsely populated	-0.727	0.202258	-0.27514
closed market	-1.0347	-0.17118	-0.01041
open market	0.56172	0.092929	0.005654
large tourism share	0.48245	-0.68441	-0.1501
small tourism share	-0.307	0.435535	0.09552
high number of arrivals	0.87086	0.061819	-0.40836
lower number of arrivals	-0.6461	-0.04587	0.302975
concentrated tourism	1.091578	0.227105	-0.36497
scattered tourism	-0.50154	-0.10435	0.16769

The first three dimensions of analysis express 51.9 % of the total variance. The lower inertia by the 0.95-quantile of random distributions suggests that only these 3 dimensions carry real information (Table 11). Accordingly, the description stands to these axes. The Cronbach alpha of 0.45 is low but acceptable in exploratory data analysis. It suggests a poor inter-relatedness between items (Kong et al., 2020a). During the construction of the dataset, the aim was to compare measurements taken from different disciplines to explore any potential relationship and to investigate major drives behind enhanced geoheritage activities. Geoheritage is a relatively new discipline that has not gained ground among scientific and economic disciplines. It has only started appearing on the policy-making agenda.

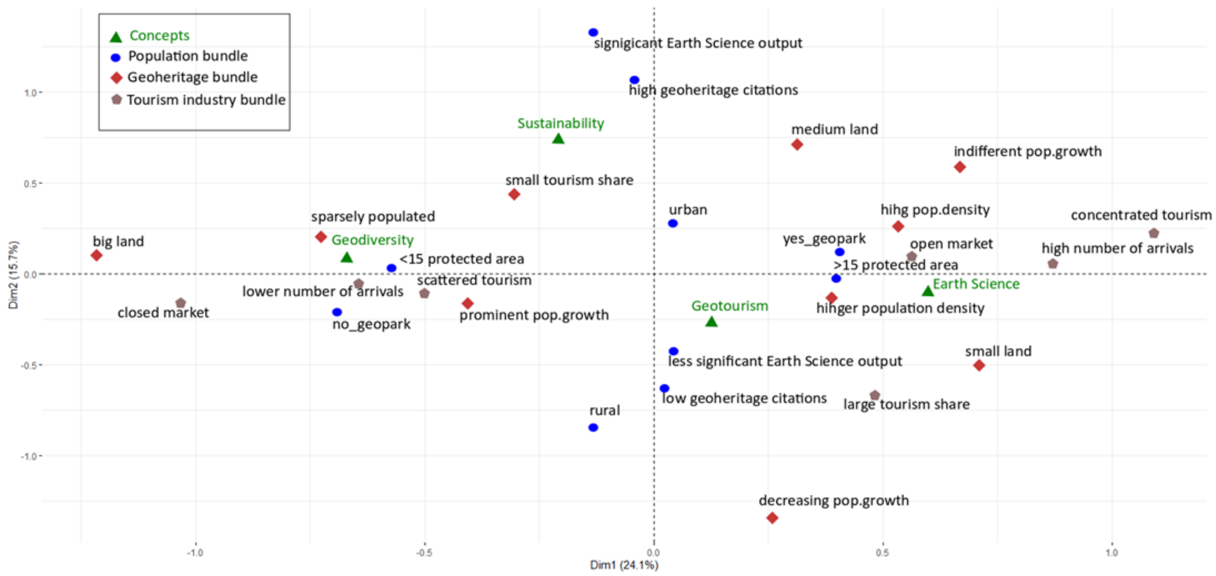

Figure 24 Biplot of the first two axes of the multiple correspondence analysis (MCA) illustrating the categories of the three identified indicator bundles with their associations with the four geoheritage concepts. The categories show the highest variation along the first dimension.

Table 12. Determinants of successful geoconservation as derived from multiple correspondence analysis (MCA)

Geoheritage bundle - Population bundle	
Geodiversity	Sustainability
"No" for geopark	*high geoheritage citations*
sparsely populated countries	*significant earth science output*
small tourism share	*small tourism share*
lower number of arrivals	*urban population*
big land	*medium land*
prominent urban population growth	*indifferent urban population growth*
scattered tourism	
closed market	
<15% protected areas	

Geoheritage bundle-Tourism industry bundle	
Earth science	Geotourism
open market	*rural population*
high number of arrivals	*lower number of arrivals*
concentrated tourism	*negative urban growth*
small total land	*medium land*
'Yes' for geopark	*'Yes' for geopark*
>15% protected area	*>15 protected areas*
higher population density	
large tourism share	

Based on each graphical depiction of the indicator categories (Figure 24), we were able to identify 3 opposing trends, 6 in total.

In dimension 1, the first result shows that an open market, a high number of arrivals, concentrated tourism, and small total land has a strong relationship and is associated with 'Yes' for geopark, higher population density, >15% protected area and large tourism share. Therefore, the concept of earth science was ordered into these categories.

The opposing result in this dimension, "No" for geopark, sparsely populated countries, scattered tourism, lower number of arrivals, closed market, and large land area shows a significant relationship and is associated with small tourism share, prominent urban population growth and <15% protected areas. The concept of Geodiversity was ordered into these categories.

In dimension 2, there is a strong link between the categories of the rural population, large tourism share, less significant earth scientific output and low geoheritage citations associated with negative urban population growth and small land area.

On the opposite side, we found stronger relationships among high geoheritage citations and significant earth science output associated with small tourism share, urban population, medium land area, and indifferent urban population growth. The concept of sustainability was ordered into these categories.

In dimension 3, relationships between the rural population, negative urban growth, “Yes” for geopark and>15% protected areas, and lower number of arrivals with medium land showed a trend but less popularity than the trends revealed by the first two axes. The concept of Geotourism was ordered into these categories. On the opposite side, a relationship was found among high population density, “No” for geopark, urban population, a high number of arrivals, <15% protected areas, and small land area.

5.6. Discussion

5.6.1. Determinant analysis at the global scale

Quality implementation requires reliability and credibility. Longstanding activities or a pressing issue will determine decision outcomes until these two factors are absent. Geoheritage conservation often means that the process originates from lower levels and proceeds upwards. Geoheritage areas do not require strictly controlled and limited human visitation. The geoheritage concept continues to gain popularity, with communities recognising the value of their natural features. Year by year, new geoparks appear in the network, involving an increasing number of scientists in the program. Global activities achieved a level that allows us to investigate what determines this evolution. The question is, what indicators can uncover such determinants? The primary purpose of the United Nations is to create numerous bodies to work towards the goals of solving international problems. The Sustainable Development Goals were launched in 2015 and became a core framework of national strategies. The Commission on Sustainable Development defined 14 indicator themes: poverty, governance, health; education; demographics; natural hazards; atmosphere; land; oceans, seas and coasts; freshwater, biodiversity, economic development, global partnership, consumption and production patterns. We chose the closest themes to geoheritage as indicators for our research. These are land, biodiversity, economic development and global partnership. Each country that adopted the Agenda 21 plan and Rio Declaration on Environment and Development committed itself to work towards sustainable development.

The limitation of a procedure based on scientific literature and research metrics is that it cannot see unpublished material, technical reports, or grey literature (e.g. literature appearing in magazines not listed on the Web of Science or Scopus or any major global science database). The survey also has not included scientific outputs published in non-English languages. We acknowledge that geoheritage conservation initiatives often take place in non-academic environments. Nevertheless, with the help of these countries` publicly available statistical data, trends in global practices can be extracted, and it can be understood how New Zealand measures up to international practices.

The citing articles` backgrounds are Earth Sciences, Environmental Sciences, and Social Sciences and Agricultural Science and Business and Economics, which explains the geotourism aspect of geoheritage. The citation of these authors steadily rose from the early `90s, which proves the scientific field achieved the data size that can unveil underlying trends and patterns in geoheritage practices. Knowing what drives policy-makers to put geoheritage on all agendas helps to adjust evaluation methods to provide adequate information for successful policy impact.

UNESCO took over the global network of geoparks, so they benefitted from a global network of exchange and cooperation. In the age of sustainability and conservation, there is an unprecedented number of bottom-up proposals for the UNESCO title.

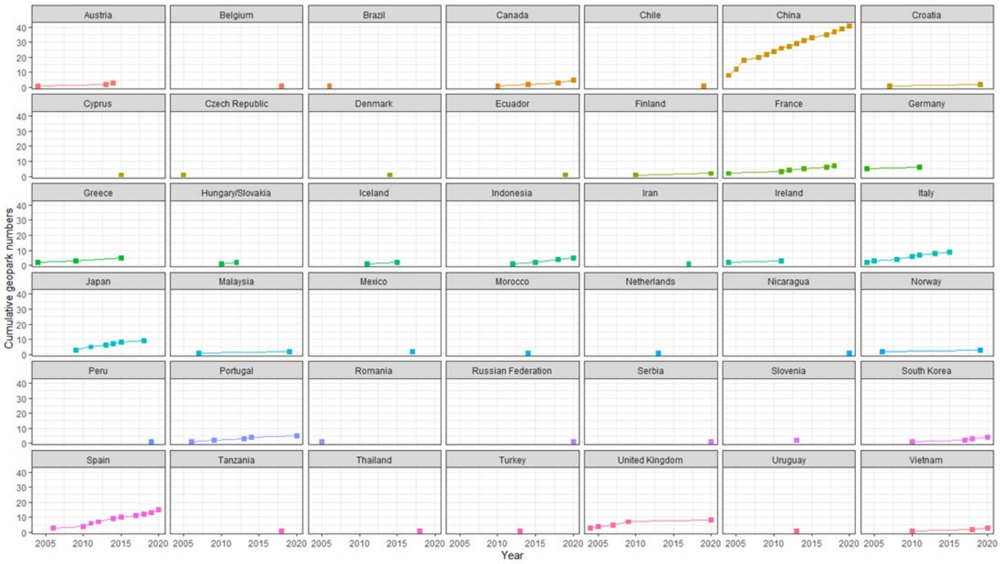

Figure 25 Cumulative number of geoparks in the world. The X-axis represents the year the geopark was established.

Figure 25 shows that most of the countries struggle to increase the number of geoparks, while China, Spain, the United Kingdom, Italy, France and Japan had more success with a continuous expansion of this form of geoheritage conservation. Today most countries have recognised the benefits of a geopark and wish to make an appearance on the UNESCO Global Geopark Network`s map. However, the evaluation process of the applications is very strict and follows a different approach to IUCN-protected area management. Communities hold their geological landscape in such high esteem and potentially omit the high-standard assessment practice required by UNESCO. Synthesis of the global state of geoparks sheds light on the approach they need to take to prepare successful applications.

Multivariance analysis enabled us to observe more complex relationships appearing around geoheritage conservation practices. Due to the nature of our study, this is not a robust instrument to measure and monitor geoheritage popularity but, on the one hand, to identify rising trends with time and prompt action for the creation of a universal framework that will prevent conflicting interpretations. On the other hand, the study aimed to understand the complexity of decision-making when the natural environment is at high risk of devastation. All conservation planning requires trade-offs. Geoheritage assessments cannot occur without including the demands of the local society and the limited resources of their land. However, when discussing conservation trade-offs, sustainability principles cannot be stressed hard enough. Approaches must consider the support of small and medium enterprises and the restoration of cohesive communities with a sense of belonging.

Basic indicators were chosen to first uncover basic trends. To consider further indicators, in-depth data collection is needed that is not necessarily publicly available from credible sources. Such work can only take place by an international working group under the umbrella of a non-governmental, non-profit organisation requiring contributions from practitioners from all around the world (UNESCO, 2013).

The derived sets of associated indicators formed four well-distinguished bundles (Table 12). They formed clusters by population, tourism industry, and geoheritage-related items. We could observe as well that with the formation of the population bundle in the bibliometric indicator, geoheritage citations appeared associated. This result suggests the particular proportion between the size of the population, land, urban land, and the pace of urban growth triggers enhanced interest in geoheritage research. The same theory applies to the economic effect of the number of international tourist arrivals that increases the opportunities to protect more areas. Conservation efforts are triggered by the witnessing loss of areas with outstanding geology or geomorphology. It is a very interesting observation that the GDP of the country does not link to any trend but rather links to the size of the rural population. Globally, low GDP reflects limited opportunities for local communities in rural areas. Addressing geoheritage conservation in these rural areas can improve local communities economically.

Analysing the formation of relationships within the categories offered further insight into the dynamics of geoheritage conservation. In effect, our analysis also supports the theory that high trade openness attracts more visitors and positively affects the economic aspect of the tourism sector. The first axis, dimension 1, ordered the existence of geoparks to this phenomenon, as well as the maintenance of a larger protected area network, a small land area, and higher population density. Countries with an overall intensified conservation strategy have a higher proportion of the population on land. These countries encountered the problem of land limitation and noted that society must learn to coexist with the environment in the best way possible. The globalised market and the high number of international arrivals lead to a more open approach to including geoheritage in nature conservation plans. At the same time, these circumstances seem to drive decision-makers to acknowledge and utilise the power of earth science education to generate sustainable tourism that can take place in geoparks. Our model ordered the concept of "earth science" to these conditions.

The category of `zero geoparks` bonded with categories of sparse population, scattered tourism opportunity, lower international visitors, and lower value of trade openness. Here the protected area network tends to be smaller *because of the growing* urban population. This suggests there is no land pressure nor social pressure to force conservation policies to be more inclusive in terms of geology. The arrivals use the existing facilities without risking adverse effects, and urbanisation has not yet exerted the level of pressure on policies that leads to changes. The concept of "Geodiversity" aligns the most with this state. The reason is that the primary focus is yet to shift from merely biodiversity, and geodiversity is looked at as a factor for more accurate biodiversity conservation measures *(*Alahuta et al., 2018; Anderson et al., 2010; Bétard et al., 2013; Comer et al., 2015).

With dimension 2 we arrived at our main interest, which is the level of interest in geoheritage conservation. It is no surprise that significant Earth Scientific research activity falls into this group. Other members of this group are small tourism share, urban population, medium land, and a very slow rate of urban population growth. The concept of sustainability falls in line with the categories. The lower contribution from the tourism sector to GDP and the lack of pressure to create opportunities for rural populations makes it less important to guide tourists or to create geoparks. At the same time, urbanisation is getting stronger, alerting scientists to research their geoheritage.

The opposite end of the axis showed us that a population living mostly in rural areas, receiving a large tourism share, and experiencing a decrease in urban population have low interest in geoheritage. Such a trend is possible in countries with small or medium land areas with a culturally strong and cohesive society with an authentic landscape that attracts tourists.

As there is no pressure to expand urban land, society does not experience the loss of its geoheritage features. Efforts primarily address overall economic growth without the weight of losing cultural identity or significant harm to the environment. These circumstances should not stop decision-makers from preventing the conservational issues prominent around rapid urbanisation.

Dimension 3 displays the least common relationships. Here we can observe the type of rural population with existing geoparks that have a lower number of arrivals. This is the case where attracting more visitors to the area to enhance the local economy will open ways for geoheritage practitioners to create geoparks. In these areas, however, there is no pressure to address geodiversity loss but to use aesthetically pleasing geomorphological features for promoting earth science education and geotourism. Therefore, our model ordered the concept "Geotourism" to this bundle.

Opposite to dimension 3, the last category is displayed, which includes the following categories: small country land area, no geopark, high population density, a high number of arrivals, and urban population. In such areas, urbanisation reached an extent where no organic landscape exists to preserve. Visitors here are interested in the built landscape with impressive technology and recreational landscaping. The landscape and geology that is buried under the urban landscape can be discovered in museums or exhibition centres (Fio Firi & Maričić, 2020; Kong et al., 2020b).

5.6.2. Determinant analysis at a local scale

This study sheds light on the underlying trends of geoheritage conservation. The increase in geoheritage publications suggests that the discipline has gained ground globally. However, it is possible that important geological sites and landscapes keep disappearing against developments at a local scale. To understand how trends change with the change of scale, we zoomed into our results and had a closer look at geoheritage determinants in an urban area. We selected Auckland, the city where all pressing issues are present with governance inclined to create a sustainable city for both western and indigenous communities by 2050. The unique volcanic landscape, paired with a unique socio-economic situation, provided a perfect textbook example for understanding the determinants of geoheritage conservation.

According to OECD standards, New Zealand is a relatively sparsely populated country (population density: 18 per km2). Its population density is relatively low but highly concentrated in the Auckland area. Conserving land is a challenging task and is determined by conflicts of interest. Cultural land and geoheritage sites are threatened by urbanisation, and the reserves and green spaces left for recreation and cultural purposes do not compensate for the rapid sprawl. Therefore, there is no better place to conduct a case study and contribute to the world with information on which gaps need to be closed to achieve the status of geoheritage conservation.

From a geopark perspective, New Zealand has no UNESCO Global Geoparks. Despite that, recognised scientists are involved in the construction of geopark proposals interestingly away from the "expected" locations considered as conservation and tourism hot spots such as the Central Volcanic Plateau in the North Island or the Rotorua geothermal areas (Dowling, 2018; Migoń & Pijet-Migoń, 2016). New Zealand has a pending application for the Waitaki Whitestone Aspiring UNESCO Global Geopark in the South Island (Waitaki District Council, 20018). The country's cultural values are invaluable to the world (Dowling R., 2018). However, the slower rate of historical events and lower population density limits the cultural aspect of an otherwise geologically unique area shaping a social landscape such as Auckland.

OECD tourism policies highlight the need for coherent and comprehensive approaches. One of the main focuses is rethinking tourism through a sustainability lens (OECD, 2020). There is a growing argument that tourism success is measured by visitor numbers instead of by its contribution to local economies and other advantages to tourist destinations. However, there is no standard response to these problems, and the OECD Tourism Committee still reports a failure to adequately address the worth of tourism for destinations (OECD, 2020). New Zealand took additional steps to integrate sustainability into tourism through a program managed by New Zealand's tourism industry association, "Tourism Industry Aotearoa", developed by industry for the industry. The aim is to achieve sustainability for every New Zealand tourism business by 2025 (https://www.sustainabletourism.nz/).

New Zealand has a set of categories between sustainability and geodiversity. It is sparsely populated, but the country strives to create opportunities for rural communities without undermining community well-being. Also, the country regionally experiences immense pressure from rapid urbanisation, especially in the Auckland region. According to our analysis, New Zealand measures up to international practices and stands out (Figure 26). It shows special interest towards saving geoheritage features of science and indigenous values; however, it is a difficult and complex process to achieve with numerous obstacles (Gravis et al., 2017; Gravis et al., 2020b). In the Auckland Volcanic Fields, scientists work together with indigenous representatives to create a peaceful environment for all communities (The Auckland Plan, 2018). Value systems can evolve and merge, and one does not need to suppress the other (e.g. cultural values to scientific values). Along with the strong measures to preserve cultural identities, Auckland aspires to pursue internationally agreed goals on geodiversity, biodiversity, and sustainability (Auckland Conservation Management Strategy, 2014).

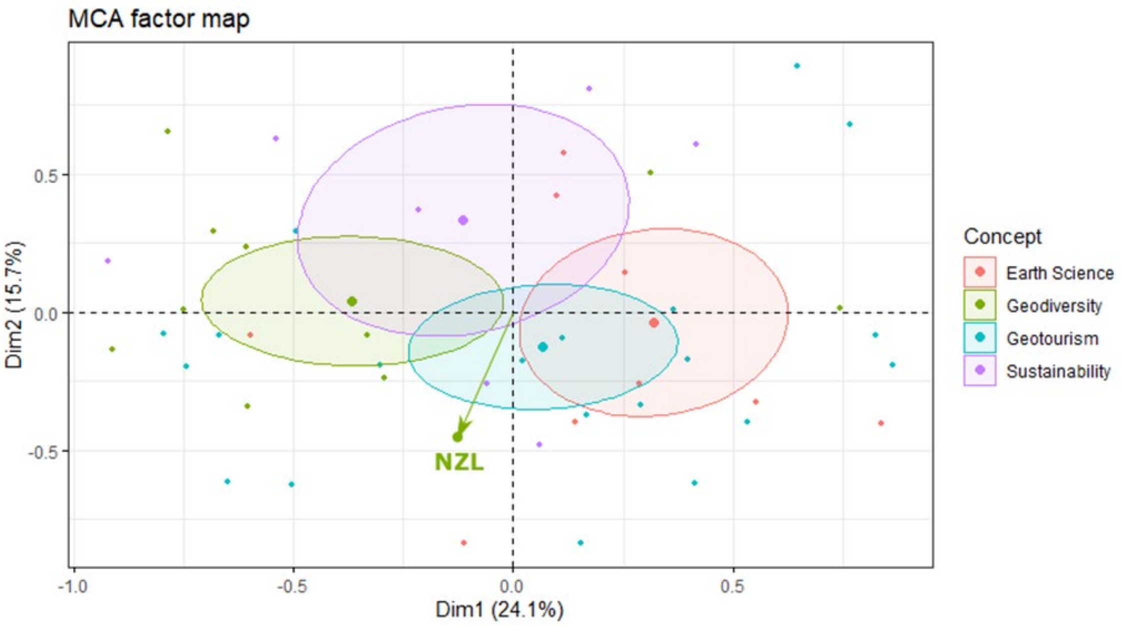

Figure 26 MCA factor map of the concepts and their position to New Zealand (NZL). The angle between row points and the central point of confident ellipsoids gives a measure of their correlation. The farther the angle from 90° the closer the relations are. The angle between NZL data point – Geodiversity centre point and NZL data point – Geotourism centre point is similar suggesting that New Zealand geoconservation strategy favours them both.

Regarding conceptual background analysis, New Zealand cited geodiversity/biodiversity authors the most. However, this diagram (Figure 26) suggests that data point position of New Zealand is located at similar angles to two concept centres, sustainability and geotourism. This means environments with such complexity as Auckland cannot simply include geoscientific significance in the urban planning agenda. Instead, concepts of the existing regulatory framework (tourism, biodiversity, sustainability) will have to take over.

The humanitarian governance of Auckland not only seeks opportunities to implement geoheritage conservation but also to shape the outlook of global patterns toward holding a diversity of nature and culture in their highest regard.

5.7. Conclusions

Monitoring and reporting geoheritage conservation changes is essential for effective and long-lasting management. However, management of geoheritage conservation is constrained by the absence of an internationally accepted framework. We aimed to relieve constraints by connecting links between socio-economic background and geoheritage conservation. Citation analysis of the most influential academic discourse is a powerful tool for the recognition of countries with an elevated interest in geoheritage conservation. The main objective of this study was the comparison of the academic activity and development metrics within these countries to unearth the factors that allow for extensive geoheritage conservation.

The results of the determinant analysis and the finding of the metrics research show clearly some key factors determining the successful implementation of geoheritage conservation. Indicators derived from the geoheritage-related academic activity and world development metrics show patterns towards a shift to other conservation disciplines of strong international agreement on objectives and goals such as the sustainable development goals or the IUCN red list of threatened species. Socio-economic needs and geographic conditions play strong roles in how and where geoheritage conservation can progress. It is also shown that international conventions create the credibility needed for positive decision outcomes that are potentially made at the expense of economic growth.

There is currently no tool to measure and monitor the change in geoheritage conservation areas. The absence of a framework to quantify the improvement or decay in conservation makes it impossible to create credible reporting and applications for conservation. Not all areas face the pressure of rapid geoheritage loss. An area specifically dedicated to the protection of biodiversity has associated natural values awaiting recognition; however, geoconservation cannot take place in isolation. Even though society exploits resources all over the world, the fate of geoheritage features should not be left to chance. Within and outside of protected urban, industrial, and agricultural areas, geoheritage can be protected without introducing restrictive laws and policies, and all types of activities can advance. Also, we observed that without the pressure of creating new opportunities or saving rapidly disappearing natural environments, geoheritage interest and the enthusiasm to build geoparks decreases. The results show that countries with higher geoheritage interests tend to have a larger protected area network. This is evidence that geoheritage conservation is dominantly taking place in already protected areas. That serves the goal of promoting earth science in general but also generates a misconception about opportunity loss when the geoheritage feature is situated in close proximity to developed areas.

To comprehensively understand our world, it is important to zoom in and understand how global trends manifest themselves locally in the Auckland Volcanic Field and how local problems relate to global patterns. It is impossible to establish an overarching agreement without acknowledging the interdependence of places and the variety of scales. The identification of relationships between microscale and macroscale phenomena is imperative to solve conservation concerns. New Zealand conservation strategies resonate with three of the four concepts of geoheritage conservation and call for further studies to accelerate the pace and scale of sustainable development. A small change at the local level can result in large differences at the global scale; therefore, locals need to understand not only their place in the big picture but their crucial role.

This research project has demonstrated the importance of a common goal for implementation strategies in geoheritage conservation. How the identification of geoheritage conservation determinants could positively influence conservation outlook at the local scale needs to be analysed in detail. Further research needs to have a closer look at the conservation status of geological sites of high geoscientific significance and the geological sites of high cultural and recreational value at the Auckland Volcanic Field. This could influence further success in quality implementation and generate further interest from geoscientists to mediate geoheritage promotion and valorisation.

Chapter 6 *Geospatial Analysis for Spatial Decision Support*

This chapter investigates the use of Big Data (FlickR), Geopreservation Inventory and Geographic Information Systems for identifying the geoeducation capacity of tourist attractions. The underpromoted important geoeducation sites can be mapped and added to the spatial database Auckland Council uses for urban planning through landform classification using the Topographic Position Index and integrated with geological and inventory data. Using a Geoeducation Capacity Map can help resolve conflicts between multiple objectives a bicultural, metropolitan city council needs to tackle in the planning of upgrading open spaces and providing for the growing demand for land.

Supplementary data for the Chapter are in Appendix A and C.

Chapter Contents

This chapter is based on a published paper:

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Chapter 6. Visitation rate analysis of geoheritage features from an earth science education perspective using automated landform classification and crowdsourcing: a Geoeducation Capacity Map of the Auckland Volcanic Field, New Zealand

6.1. Introduction

Whilst the natural environment is disappearing under growing cities and their landscaping activities (Auckland Governance Reforms, 2009; Gu, 2010; Jiao, 2015), scientists introduced a new conservation challenge, the protection of geoheritage. The elements of geology and geomorphology provide a connection between the population and abiotic nature. They not only provide knowledge about past geological processes but also allow us to make predictions for future events and their effect on human societies. Having to look after our geoheritage is the product of modern society`s lifestyle. It was a non-existent concept in cultures to quantify the value of geological conservation simply because primordial societies were part of the natural environment, including its abiotic component; hence human society was interconnected and part of the natural environment (UNEP, 2011). Since the industrial revolution, an accelerated separation of human society from its natural environment polarised our habitats, and rapid loss of natural habitats took place (Brooks et al., 2002; Hoekstra et al., 2005; Pongsiri et al., 2009; UNEP-WCMC, 2015; UNEP, 2011). This process in recent years reached the level to identify and develop strategies for the preservation of not only the biological elements but also the non-living environments. The value of geological features was only characterised (mostly in a semiquantitative manner) when a site was a subject of extraction for raw material. The geomorphology of various geosites was only valorised when aesthetics functioned as a draw to the attraction of tourists on a scale that boosted local and national economic development.

Today geoscientists are to change the disposition of geology and add an important angle to it that focuses on geoethics (Di Capua et al., 2021b). However, due to pressing global issues and the cruciality of running an economy, various levels of authority require measurable and quantifiable evidence of the values of abiotic nature before expanding activities considered only indirectly as a profit-generating activity (e.g. recreational aspects, tourism or geoeducation) (Ruban et al., 2018) at the expense of industrial-social development (e.g. quarrying, housing development, landscaping). This conflicting interest within geological and geomorphological elements has generated their inclusion into the ecosystem services framework (Gray, 2012) to specifically analyse the full values of abiotic nature provided for human society. In this conceptual framework, a new term was designated to express the abiotic nature's services for humanity: geosystem services (Fox et al., 2020; Gray, 2011; van Ree et al., 2017). Geoheritage is considered a new, educated recreational activity under the scope of conservation science that serves tourist demand to a reasonable level. In effect, justification for geoheritage goes beyond recreation and open space experience, it is fundamental for geoeducation, resilience, sustainability, geotourism and community building through local to global geoparks. All these attributes are non-quantitative, and there is no directly measurable indicator that would safeguard their existence in a rapidly growing urban area. However, visitation is a great strategy with a variety of measurable short- and long-term benefits to communities that can lead to successful geoheritage conservation (Justus et al., 2009; Németh et al., 2021b).

Visitation is highly associated with tourism and is considered a tertiary industry (Fick et al., 1991; Hassan, 2000; Leiper, 2008). The first question of non-experts will be, therefore, what is the benefit for a city if they hold back lands from revenue generation (Beretic et al., 2019; Duarte et al., 2020; Gordon & Barron, 2012; Lim, 2014; Moreira et al., 2021; Štrba et al., 2020). This is the major shortfall preventing quality implementation, as education, awareness, and resilience are not measurable in profit. Although achieving direct profit in the short-to-medium term is possible by utilising allocated geosites through geotourism. For instance, co-development of protection policies that involve cooperation and involvement of local communities can generate "revenue" that can be measured indirectly. In the long-term, the benefits are in the establishment of a resilient society against global challenges. The ultimate goal of geoconservation (geoeducation, community building, resilience) fits perfectly within the concept of a more holistic, transdisciplinary and global aspect of sustainability. Sustainability was originally developed on the conceptual basis of ecosystem services hence the radical focus on biotic elements of the environment. Geoconservation puts forward geoscience as one of the essential building blocks for the conceptual framework of sustainability (Elliott & Hanson, 2003; Lukes et al., 2021; Manduca & Kastens, 2012; Pringle, 2014).

Urban areas attract visitors for a myriad of reasons. In pursuit of valorising geoheritage worldwide, cities are in an advantageous position. There is less pressure received from economic status toward attracting visitors, and more emphasis can be placed on guiding arrivals to locations of high geoeducation interest. The significance is in the combination of experiencing many phenomena with a unifying theme as opposed to an individual item that might not in itself be regarded as sufficient to influence tourists` willingness to visit (Leiper, 1990). Hong Kong UNESCO Global Geopark generated sustainable tourism and revitalised traditional culture (Wang et al., 2015; Yeung, 2013). Such dynamics encouraged local people to take part in geoconservation activities and naturally formed the main force of geoconservation (Wang et al., 2015). Geoparks in cities have the advantage of satisfying multiple objectives such as conservation, education and recreation. While visitors enjoy leisure activity, they also learn about the significance of geology and how their behaviour is altered toward protecting rocks and landforms (Ng, 2014). Geoparks of rural areas face the challenges of promoting geology in a way that increases the willingness to travel to the area. Different activities are developed, such as geo-educational games (Sütő et al., 2020), multimedia presentations (Henriques et al., 2012) or the creation of GEOfood, that delivers quality and connects the food and raw materials with their place of origin (Rodrigues et al., 2021).

Tourists possessing environmental knowledge of their destination often make more educated decisions when visiting hazardous areas and naturally grow respect for the local environment and community and seek authenticity over marketing(Cohen, 2002; Maslow, 2013; Yeoman et al., 2007). The increased awareness will feed grassroots initiatives. The steps for building a new geopark include interdisciplinary research and expert collaboration, stakeholder identification and involvement, evaluation of the geoheritage sites, strategy development for sustainable tourism, correlation with local projects, providing training for the locals, designing educational materials and activities (Andrasanu, 2010; Liberatoscioli et al., 2018; Tomić, 2011).

Education as the main objective brings an extra dimension to geotourism. Tourism only allows certain geographical locations to be considered, geotourism ultimately should be everywhere, including housing or industrial areas (AlRayyan et al., 2019; Caironi et al., 2019; Capdevila-Werning, 2020; Comentale, 2019; Habibi et al., 2018; Pelfini et al., 2018; Polck et al., 2020; Portal & Kerguillec, 2018; Wolniewicz, 2019). Quarrying away geomorphology opens a door for another type of geoheritage. Open-pit and underground mining sites potentially are windows into the geology under the surface and the history of geological processes (Gioncada et al., 2019; López-García et al., 2011a; Prosser, 2018). Strong measures implemented features revealed during the operation of a quarry that leads to cooperation between conservation agency, mining, quarry or landfill operator (Prosser, 2018). Tourist attractions and geotourism destinations overlap. That overlap accounts for a great percentage of successful implementation. A tourist attraction is largely evaluated on a cost–demand–competitiveness triangle (Hu & Wall, 2005; Leiper, 1990). Geotourism destinations primarily focus on conserving their artefacts of present and past geosystems and helping tourists form geoscience habits of mind (Farsani et al., 2014; Newsome et al., 2012).

Since the creation of social media, crowdsourcing has been applied to the fields of marketing (Gatautis & Vitkauskaite, 2014; Whitla, 2009), urban planning (Brabham, 2009), sustainability (Certoma et al., 2015), tourism (Sigala, 2015), public policy and government (Lehdonvirta & Bright, 2015; Prpić et al., 2015), medicine (Brabham et al., 2014), bioinformatics (Good & Su, 2013), higher education (Solemon et al., 2013), disaster risk (Besaleva & Weaver, 2013), and product development (Djelassi & Decoopman, 2013). A specific type of crowdsourcing is applying volunteered geographic information available through photo-sharing platforms. FlickR is one of the most popular platforms for such data extraction (Alivand & Hochmair, 2017; Zielstra & Hochmair, 2013). The data is mostly used for analysing regions of interest (Cai et al., 2014; Shafique & Ali, 2016), tourists` spatial behaviour (Höpken et al., 2020), people`s activities (Kisilevich et al., 2010), movement patterns (Chareyron et al., 2013; Kádár & Gede, 2013b), or event detection (Chen & Roy, 2009).

Landform classification is purely based on geographic information that strengthens the case of the geoconservation inventory. It is important nationally for policy-level implementation and internationally for comparison and achieving status at international organisations on geoconservation. Weiss (2001) developed a completely automated landform classification method using the topographic position index. The method facilitates land use planning by combining precision landform information with relevant geographic or qualitative data in a geographic information system. The method allows for the aggregation of spatial and qualitative data. The classification of landforms aggregated with spatial qualitative and/or quantitative data is a powerful tool for planning such as climate adaption planning (Theobald et al., 2015), prediction of landslides, wetlands distribution (Ma et al., 2010; Riley et al., 2017; Woo et al., 2008), understanding site-specific management units (Mieza et al., 2016), or simply the study and analysis of landforms (Skentos, 2018; Trentin & de Souza Robaina, 2018).

The main subject of our research is the geoeducational value of the geoheritage features in the Auckland Volcanic Field. The volcanic field hosts Auckland, the biggest city in New Zealand. The same cones hold high cultural values, and have been subjects of settlement across New Zealand`s human history. The question of this study is to what extent geoheritage sites serve as geoeducational material for the public, as most volcanic features of the Auckland Volcanic Field coincide with the open space areas of Auckland city (Hopkins et al., 2020). This report is important for decision-makers because it indicates the migration of geoheritage principles to other burning and more understood issues (e.g., strengthening cultural heritage, sustainable tourism, sustainable development, and community involvement). Auckland (population: 1.5 million) is the economic capital of New Zealand, facing a severe housing affordability crisis in the world, leading to rising numbers of homelessness (Demographia, 2021; Wetzstein, 2019). The answer to our research question was attained through four objectives: (1) To identify strengths and gaps in existing legislations relevant to geoconservation, (2) to identify the degree of grassroots initiatives, (3) to define what geological or geomorphological features receive visitation, (4) to derive geoeducational value of the non-visited geological or geomorphological sites to depict current bases of promotion.

6.2. Disposition of formal decision instruments

The first objective of this research is to analyse the current policies and other formal decision instruments to understand the directions of conservation strategies. The Auckland Volcanic Field is a major geological feature of the North Island. Its geological feature as being a monogenetic volcanic field that is still considered to be actively created a general interest in volcanic hazard studies (Agustín-Flores et al., 2015; Deligne et al., 2017; Hayes et al., 2020; Hopkins et al., 2020; Kereszturi et al., 2017; Linnell et al., 2016). In addition, the studies that have highlighted its size, age range and preservation potential made it a globally relevant volcanic field that strongly impacted our understanding of volcanic field evolution. Using Thomson Reuters's Web of Sciences All Database until 16 September 2021, searching for papers for topics named Auckland Volcanic Field yielded 184 results, 95% published after 2000. This collection of scientific papers has a Hirsh-index of 36, indicating that the global community is also reading these published scientific reports and is likely influenced by their results. Currently, there is one governance authority (The Tūpuna Maunga Authority) for 14 out of the 53 edifices due to the varying ownership status (Hayward, 2019). The Resource Management Act administered by the Ministry of Environment is the only jurisdiction that cuts across organisational boundaries. The Resource Management Act guides regional and local environmental policies with the ambition to promote sustainable management of natural and physical resources.

New Zealand is generally considered an example of success in its transition into a sustainable bicultural economy with an ambition to restore native land cover. Prioritisation of conservation approaches includes the need for the identification of geoheritage along with their relationship to the Māori culture and the indigenous land cover. However, it is still a challenge for policymakers to put forward a clear set of geoheritage targets in the lack of community involvement. As long as responsible bodies cannot make evidence-based decisions, the implementation of the geoconservation inventory will be on hold despite the ambition of decision-makers to follow a holistic conservation plan that includes all aspects of the geo-ecosystem with special relevance to their cultural relations (Destination AKL 2025, 2018; Németh et al., 2021a; Pressey et al., 2017). Much of natural resource management is focused on biodiversity species models, and policy recommendations are based on their conservation without accounting for the role of geosystem services.

The Resource Management Act in New Zealand is the main law that sets out principles and priority areas for regional authorities for the development of detailed strategies and plans working toward a common target and a sustainable future. It is clear that New Zealand has adaptive governance and is inclined toward sustainable solutions and that the ambition is to keep the country as close to its natural state as possible for future generations and to keep development disturbance to the minimum (Auckland Conservation Management Strategy, 2014; Auckland Council, 2016; Auckland Governance Reforms, 2009; Auckland Regional Council, 1999; New Zealand -Aotearoa Government Tourism Strategy, 2019; New Zealand Coastal Policy Statement, 2010; New Zealand Geopreservation Inventory, https://services.main.net.nz/geopreservation/; The Auckland Plan, 2018; Wright, 2016)

6.2.1. Conservation strategies and urban planning

The Auckland Volcanic Field (Figure 27) was one of the first areas that provided significant habitat for early Māori arrivals. The region had a rich, friable, volcanic soil well suited to kumara growing. From about 1300 CE, Māori used cones as their living environment. There is evidence of systematic gardening and usage of storage pits and canoes around the volcanic field that is of high cultural value today (Boswijk & Johns, 2018; McCoy & Ladefoged, 2019; Pool, 2013; Ryks et al., 2016). By about 1700 CE, the population of some thousands made the region the most densely settled area of New Zealand in Māori times; it remains so today (Stone, 2001). Urban planning became crucial after the industrial revolution when the population boom caused serious public health issues. Areas lacking urban planning outgrew their sewage systems resulting in discharged waste products into water supplies that spread diseases like cholera. This was a problem even in ancient Rome, but with the number of large cities expanding dramatically, the importance of urban planning became a global imperative and has now expanded to include amenity and conservation matters. Any matters of national importance must be researched and communicated to decision-makers, and geoeducation is no exemption.

The responsible agencies for the volcanoes vary among council, conservation, education, facility management; Tūpuna Maunga Authority – Tūpuna Taonga o Tāmaki Makaurau, Auckland Council, DOC, and private ownership; however, organisations strictly follow the principles set out by the government.

There is an open opportunity in the legal framework for quality geoconservation implementation. For the law to fall into place, responsible agents must create a strategy with a clear target, objectives and set of choices. This is widely researched (Brilha, 2016; Németh & Moufti, 2017; Pelfini & Bollati, 2014; Pereira & Pereira, 2010; Pralong, 2005; Reynard et al., 2016a; Reynard et al., 2007b; Ruban, 2016a; Višnić & Began, 2016; Wimbledon, 2011) but not yet established for geoheritage. The reason is the lack of convention on the full range of applicable values. However, the responsible agents for such tasks are the local and regional councils, who require evidence for bottom-up proposals to get policy-level support.

Every related strategy includes a call for proposals on making New Zealand and its fastest-growing city, Auckland, sustainable and nature-friendly (Auckland Conservation Management Strategy, 2014; Destination AKL 2025, 2018; New Zealand -Aotearoa Government Tourism Strategy, 2019; The Auckland Plan, 2018).

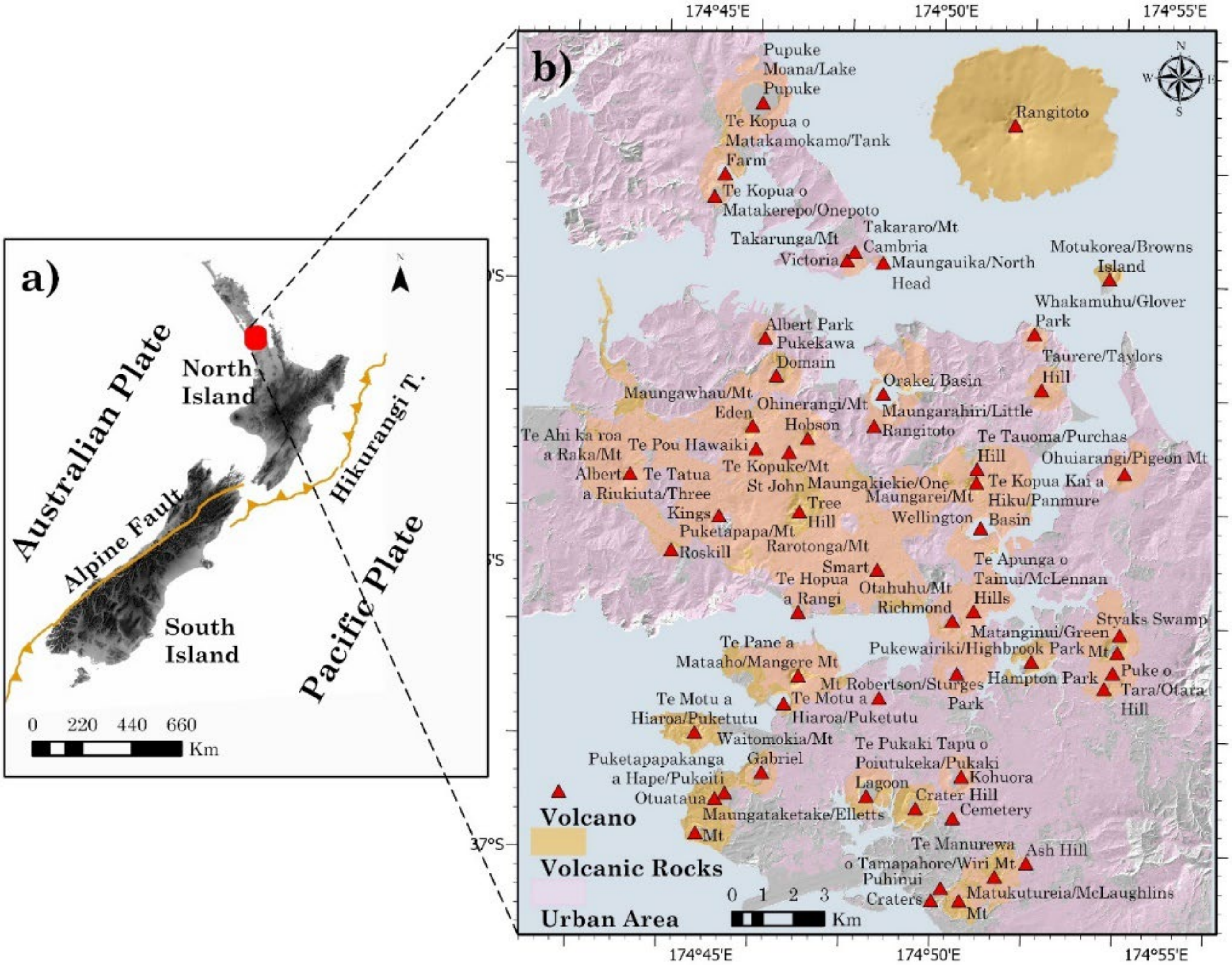

Figure 27 a) New Zealand on a digital terrain model with the location of the study area. Hikurangi Thrust is the surface manifestation of the oblique subduction front along the Pacific Plate going under the Australian Plate b) The map shows the 53 recognised volcanic centres of the Auckland Volcanic Field. The Māori names of the volcanoes are shown first followed by their respective English names.

The Auckland Plan (2018) is a spatial plan that sets targets that complies with the Resource Management Plan. It summarises the main challenges the region faces today and organises them into six outcomes. These outcomes are to increase community well-being and the liveability of the city. One of the outcomes targets environment and cultural heritage, but the plan for implementing environment and cultural heritage has no explicit section for geoconservation. However, it opens opportunities where evidence-based proposals can fit. The supporting strategies and plans are for growing a greener city, restoring indigenous biodiversity, reducing waste and recycling more, restoring and protecting the sacred volcanoes (ancestral mountains) renowned by Tūpuna Maunga Authority, for managing assets of stormwater, water-care and open space and last for safeguarding Hauraki Gulf.

Destination Auckland (2025) sets directions for Auckland`s visitors' economy for a more sustainable future economically, socially and environmentally. This plan is issued to make sure tourism management aligns with the outcomes detailed in the Auckland Plan. Auckland is the gateway to New Zealand, with more than 2.6 million international visitors each year before the pause on international travel caused by the COVID-19 pandemic. The challenge is to encourage visitors to help protect and improve Auckland`s geological heritage, unique identity and cultural heritage.

6.3. The study area

AVF is situated on the North Island of New Zealand on a continental crust about 400 km to the west of the Hikurangi Margin subduction zone (Hopkins et al., 2016; Seebeck et al., 2014). There is one more intra-plate volcanic field south of AVF called South Auckland Volcanic Field (active 1.6 – 0.5 Ma) (Briggs et al., 1994), and toward the south, there are some slightly older basaltic volcanic fields such as the Ngatutura and Alexandra Volcanic Fields (active 2.7 – 1.5 Ma) (Briggs et al., 1989). Several distinct young Pleistocene to Quaternary volcanic fields are peppered across Northland, interestingly with a few very young, potentially Holocene scoria cones. The Auckland Volcanic Field (AVF) has erupted at intervals of thousands of years over the last 250,000 years. The last eruption, Rangitoto, occurred 600 years B.P. at least two distinct eruptive episodes apart of about 50 years from each other (Linnell et al., 2016), very likely witnessed by early Polynesian arrivals (Brothers & Golson, 1959; Newnham et al., 2018). The AVF is considered to be still active (Hayward et al., 2011b). Magmatic and phreatomagmatic eruptions produced ~53 small volcanic centres (Agustín-Flores et al., 2014; Agustín-Flores et al., 2015; Kereszturi et al., 2014; Németh et al., 2012). Scoria cones, lava flows, maars, tuff cones and tuff rings build up the volcanic landscape on top of early Miocene marine sediments (Hayward et al., 2011b; Leonard et al., 2017).

Spatial-temporal patterns and the volume of magma suggest that the AVF is at an early stage in its evolution, and further eruptions could occur (Allen & Smith, 1994). However, the young age and ambiguous spatial patterns in distribution make it problematic to determine the likelihood and associated risks of future eruptions (Cassidy & Locke, 2010). Promoting geological sites is extremely important because Auckland City, with a population of over 1.5 million, covers the entire field. Mitigation of a natural disaster is achieved by effective communication and education from geoscience communities. Residents and visitors need to understand volcanic hazards and the reasons for the unpredictability of potential next eruptions. This form of volcanism exposes residents to unpredictable volcanic hazards (volcanic ash, lava flows, pyroclastic flows, lahars, and debris flows) in cities situated in close proximity (Kereszturi, 2012; Lindsay et al., 2010; Sandri et al., 2012).

The area is on the UNESCO World Heritage tentative list (https://whc.unesco.org/en/tentativelists/). Even though basaltic scoria cones and maar craters are common volcanic features in the World, the Auckland field stands out as a unique volcanic field, among them being active under a metropolitan city. To mitigate volcanic hazards and establish resilience in local communities' extensive research has been carried out within the area that significantly amplified the scientific value of the given volcanic edifices. Furthermore, the subtropical regional climate gave the commonly barren, brown, reddish scoria cones a solid green cover with an aesthetic value.

The Auckland Volcanic Field is researched from multiple geoscientific angles (Allen & Smith, 1994; Cassidy & Locke, 2010; Deligne et al., 2017; Hayward, 2015; Hopkins et al., 2020; Hopkins et al., 2016; Leonard et al., 2017; Seebeck et al., 2014; Sprung et al., 2007) and its geoeducation potential is highlighted in several case studies (Gravis & Németh, 2016; Gravis et al., 2017; Gravis et al., 2020b; Hayward, 2019; Hayward et al., 2011a; Hayward et al., 2011b; Nemeth et al., 2017; Procter & Nemeth, 2017). The concern over the disappearing outcrops and culturally worshipped geological sites can cause unrest in the local communities (Gravis et al., 2017; Gravis et al., 2020b). Evidence advancing successful implementation by local decision-making bodies is imperative and can be executed using the power of GIS techniques providing clear boundaries of high to low geoeducational value areas.

6.4. Methods and Results

6.4.1. Formal decision instruments and community endeavour

Through the first objective of analysing current formal decision instruments, we have concluded that New Zealand has adaptive governance and is inclined toward sustainable solutions. The ambition is to keep development disturbance to the minimum (Auckland Conservation Management Strategy, 2014; Auckland Council, 2016; Auckland Governance Reforms, 2009; Auckland Regional Council, 1999; New Zealand -Aotearoa Government Tourism Strategy, 2019; New Zealand Coastal Policy Statement, 2010; New Zealand Geopreservation Inventory, https://services.main.net.nz/geopreservation/; The Auckland Plan, 2018; Wright, 2016). The Resource Management Act is the main law that sets out principles and priority areas (Table 13) for regional authorities for the development of detailed strategies and plans.

Table 13. Legal Instruments placing priority on important matters of Culture and Nature Conservation.

Resource Management Act (Resource Management Act, 1991)	The Act calls upon to recognise and provide for the matters of national importance: The *preservation, protection* of coastal environment, wetlands, lakes, rivers, areas of indigenous flora and fauna, of *outstanding natural features* and landscapes and of historic heritage from inappropriate subdivision, use and development. The relationship pf Māori and their culture and traditions with their ancestral lands, water, sites, wāhi tapu (sacred place) and other taonga (treasure). The maintenance and enhancement of public access to and along the coastal marine area, lakes and rivers. The protection of protected customary rights.
Reserves Act: Scientific Reserves (Reserves Act, 1977)	Its purpose is to have effect, in relation to reserves classified as scientific reserves, for the purpose of protecting and preserving in perpetuity for scenic study, research, education and the benefit of the country … types of soil, geomorphological phenomena and like matters of special interest.

Auckland Regional Policy Statement (Auckland Regional Council, 1999)	Auckland`s sense of place is also defined by its volcanic field of which the volcanic cones are the most well-known features. Their identification as Outstanding Natural Features recognises that they are of geological and scientific significance in their own right, as well as having amenity values and being of particular spiritual value to iwi of the region.
Open Space Provision Policy (Auckland Council, 2016)	Treasure Auckland`s Parks and Open Spaces by protecting and conserving them and improving people`s ability to understand and appreciate their value and significance.
Destination Auckland 2025 (Destination AKL 2025, 2018)	Because everything is connected, the only way we can ensure the sustainability of any particular subsystem of our region is by adopting a holistic approach. "If planned and managed well", the Executive Director of UN Habitat said recently, "Cities can be the main tool for sustainable development and a solution to many of the challenges our planet is facing today."

Legally there is much appreciation for conservation values, and bottom-up approaches are much appreciated, even encouraged. Long-term plans and strategies are all firmly targeting sustainability and effective collaboration of stakeholders.

The second objective was the investigation of the degree of community sensitivity to the topic and the magnitude of work invested in the subject. Auckland volcanoes were considered highly among early inhabitants. The small volume of regular landforms provided shelter and fertile land. Scoria cones provided a surface easy to landscape for shelter building, vegetable gardens and storage pits. Human occupation of the area suggests the existence of admiration of the local features. A literature review and interviews of experts in the area revealed the existence of an online available, open-source Geopreservation Inventory (Figure 28). The inventory not only contains the significant geological and geomorphological features of the Auckland Volcanic Field but a comprehensive collection of significant outcrops, fossil sites and landforms of all geological and geomorphological processes selected on the basis of research, education, tourism, recreation and aesthetic values. The metadata includes the assessment of their importance; (A) of international scientific, aesthetic or educational value, (B) of national scientific, aesthetic or educational value, (C) of regional scientific, aesthetic or educational value. This classification was later formed as an important attribute for the analysis of the geoeducational capacity of the Auckland Volcanic Field.

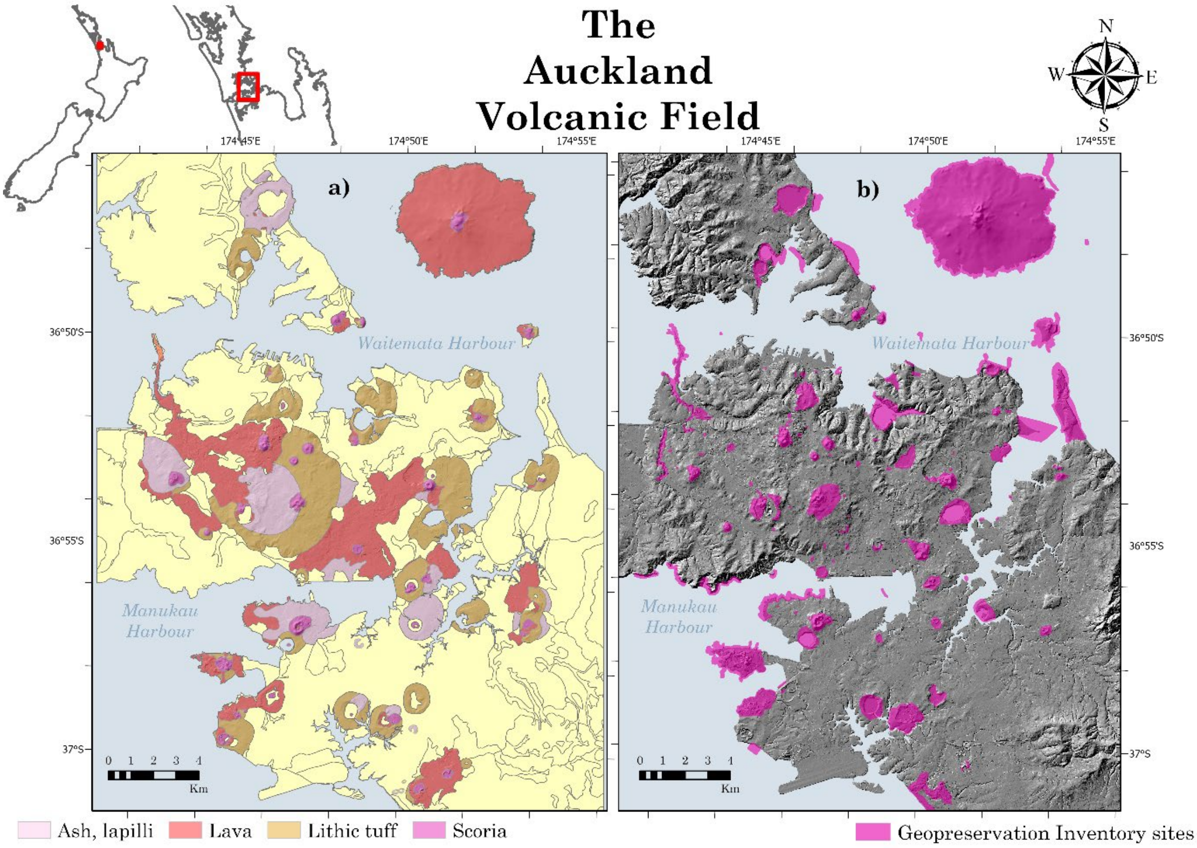

Figure 28 a) Geology of the Auckland Volcanic Field modified from GNS QMAP Programme Dataset – Geology of the Auckland Urban Area 1: 50 000 GIS data (Kermode et al., 1992) "Ash, lapilli": fine to medium grained magmatic explosive products accumulated beyond the scoria cones. "Lava": undifferentiated lava flows, mostly rubbly pahoehoe, aa and subordinate pahoehoe surface texture types. "Lithic tuff": accidental lithic clast-rich fine grained pyroclastic rock formed due to explosive phreatomagmatic eruptions. "Scoria": highly vesicular magmatic explosive eruptive products of typical Strombolian style eruptions. b) Geopreservation Inventory (**http://www.geomarine.org.nz/NZGI/**), which was compiled using the information provided voluntarily by New Zealand`s Earth Scientists. The database lists the best representative examples of geologic features, landforms, and fossils discovered and studied up to date. The map displays the volcanic sites that fall into the study area extracted from the online available, open-source geospatial database of the Geopreservation Inventory.

6.4.2. The mapping

The third and fourth objectives required data acquisition and analysis. The Auckland Volcanic Field correspond to the metropolitan area of Auckland. Volcanic edifices are typically easily distinguishable from the surrounding topography and are essentially surficial representations of underlying magmatic systems. There are ~53 landforms within the Auckland Volcanic Field that have erupted during the Quaternary. Besides the typical cone-shaped volcanoes, here are also ~33 other monogenetic geoforms, mostly broad tuff rings or shallow maars. From a geoheritage aspect, we would like to know all the individual aspects of each volcano that can help drive further inquiry. The main goals of our project are first to extract the topography of the different edifices and then to order and visualize them to understand their scientific and educational significance. To do this, we used automated landform classification aggregated with geological and Geopreservation Inventory maps. Landform classification is an important factor as it defines the rarity of a given landform and as well provides scale for decision-making.

6.4.2.1. Boundary

To see which features receive visitation, we extracted the boundaries of volcanic edifices. We determine edifice boundaries from topography by terrain attributes. We postulate that the highest slope areas correspond most to coastal and volcanic edifices. We first calculated the topographic slope of the AVF using a 1-meter resolution Digital Elevation Model (DEM) derived from LIDAR point-cloud data captured by airborne sensors, available through the LINZ Data Service (https://data.linz.govt.nz/). We generate a filtered map of areas that have slopes higher than a threshold value (10° slope) (Figure 29). Afterwards, we distinguished contours that follow an elliptical shape. Boundaries of the landforms were not added to the analytical process because they were created to understand the overlap of a built-in area with the volcanic landforms (Figure 30).

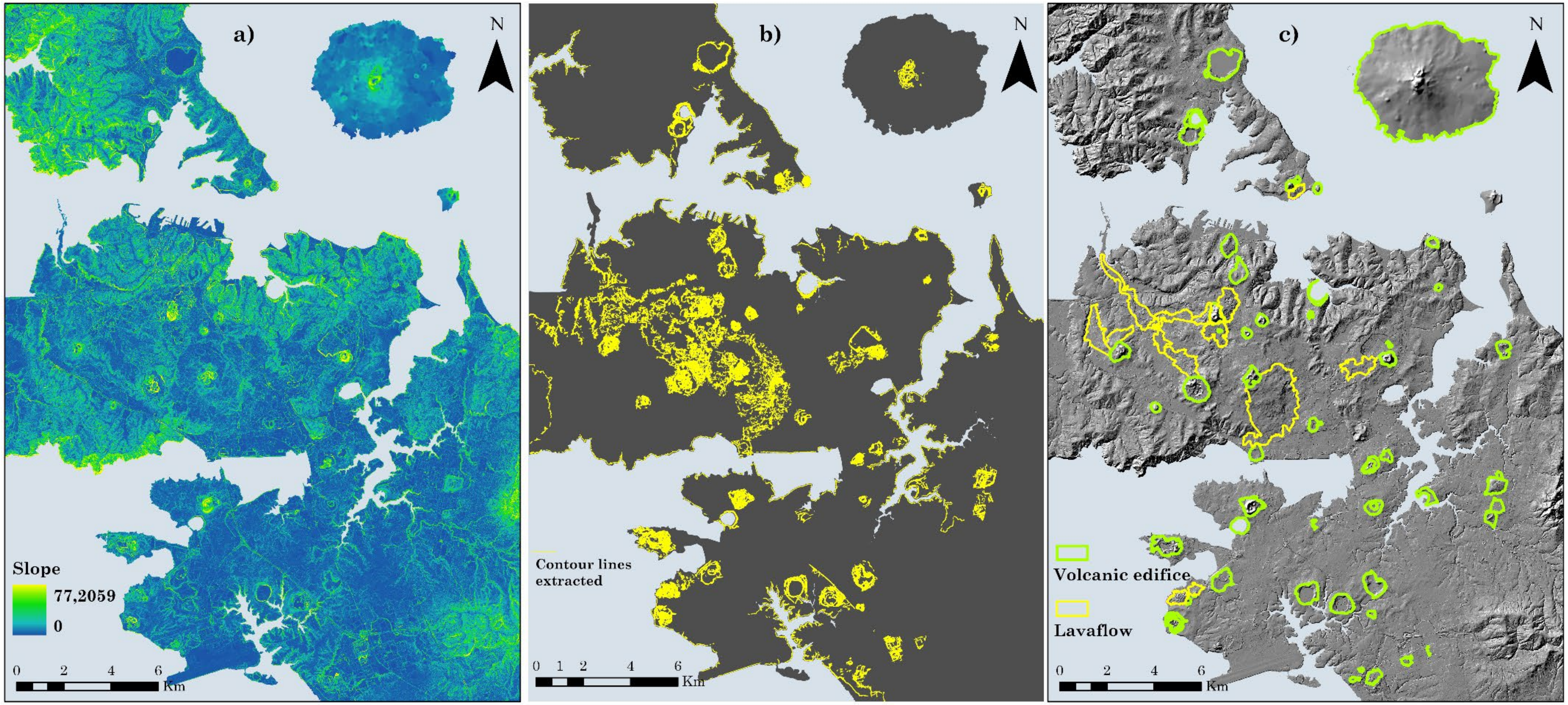

Figure 29 Edifice boundary extraction for the Auckland Volcanic Field using ArcGIS Pro software package to analyse and process spatial data. A) Topographic slope b) Filtered map of the slope of volcanic surface higher than a threshold value extracted from the built-in ArcGIS Pro statistical analysis tool c) edifice boundaries.

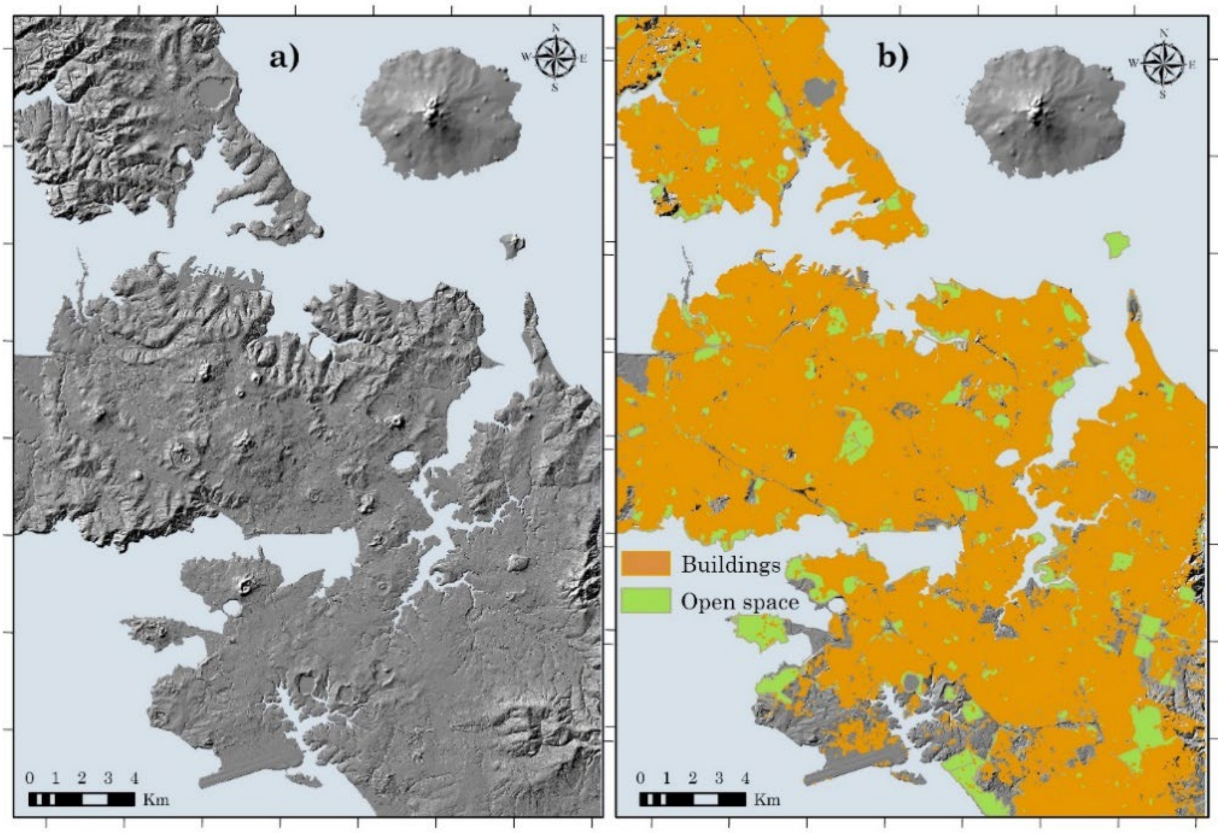

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Figure 30 a) Grayscale 3D representation of the Auckland Volcanic Field`s surface with vegetation and objects extracted (1m DEM built from LiDAR point cloud provided by LINZ Data Service **https://data.linz.govt.nz/**) b) open space areas and buildings of Auckland city (data provided by LINZ Data Service **https://data.linz.govt.nz/**). Open space means any open piece of land which offer important opportunities for sport and recreation and are accessible to the public (excludes private land).

Analysis of what has been achieved in terms of geoheritage conservation, up to date resulted in the identification of the Geopreservation Inventory. The boundary of landforms did not match the boundary of the geoconservation areas in the inventory (Figure 31). A comparison with the land use database revealed that the Geopreservation areas are adjusted to the boundaries of open spaces of the city.

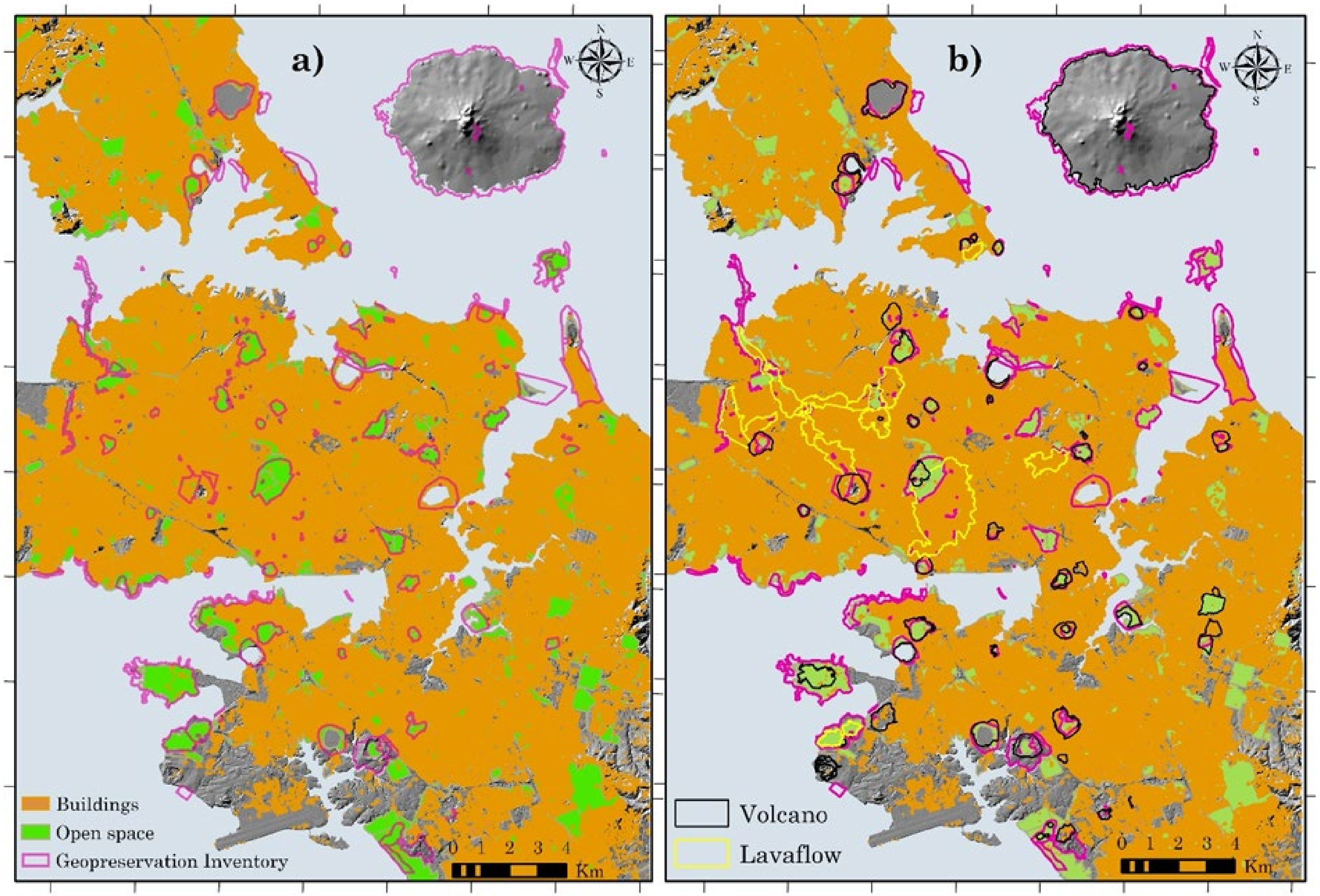


Figure 31 Comparison of boundaries to visualise the impact of urban sprawl on the Auckland Volcanic Field. a) Building outlines in orange colour represent the urban sprawl. The green polygons are the designated open spaces by the Auckland Council. Pink lines represent the outstanding natural features of the Geopreservation Inventory. b) The map depicts the edifices boundaries in yellow and black colour in comparison to open spaces and Geopreservation Inventory items. The aim of this map is to visualise the loss of volcanic edifices by the urban sprawl.

The map shows that the boundaries for the items in the Geopreservation Inventory are somewhat adjusted to the boundaries of open spaces. There is no evidence yet that urban planning practices incorporated geoheritage as a factor during multicriteria decision-making. The boundaries of volcanic edifices do not correspond with open space, it shows the loss of geoconservation area. However, good environmental management in urban areas of Auckland has saved many volcanic cones from being quarried away. Quarry scars often increase the geoeducational value of a landform by giving insight into the geological processes that took place during the formation of the edifice. Our calculation for edifice boundaries is based on a digital elevation model produced from a LiDAR point cloud image 2013. LiDAR data is collected as a point cloud of individual points reflected from the surface, including buildings and trees. To produce the digital elevation model, these buildings and vegetation were stripped away, that slightly altered the slope rate.

6.4.2.2. Classification

Simply by calculating the difference between the cell elevation value and the average elevation of the neighbourhood around that cell, we classify the landscape into slope position and landform category. We used the 1-meter resolution DEM to calculate the basic algorithm, called Topographic Position Index (TPI). The algorithm uses the annulus neighbourhood for the average elevation. Positive TPI values represent locations that are higher than the cell average around them (ridges). Negative values represent locations that are lower than their surroundings (valleys). Values near zero are either flat areas or areas of constant slope (Weiss, 2001). We were curious whether, within volcanic landforms, quarry scars, craters, outcrops and tuff rings are categorized into different landform classes.

TPI calculation is inherently scale-dependent. Scale can become an apparent issue as craters of monogenetic volcanoes can be too small (a few tens to hundreds of metres across); they blur into the topography dominating their environment at a scale of a kilometre. We calculated TPI at the scale of 100 m applying radii of 5 (inner pixel radius), and 10 (outer pixel radius) and separately calculated TPI at the scale of 500 m applying radii 8 (inner pixel radius), 15 (outer pixel radius) to the formula provided by Weiss (2001):

$$\boldsymbol{tpi} < \boldsymbol{scalefactor} > = \boldsymbol{int}((\boldsymbol{dem} - \boldsymbol{focalmean}(\boldsymbol{dem}, \boldsymbol{annulus}, \boldsymbol{irad}, \boldsymbol{orad})) + .\boldsymbol{5} \quad (1)$$

Diameters of craters and tuff ring in the AVF start at 100 m. The average high of scoria cones is >150 m. The average scoria cone diameter is 500 m. The landform characteristics are calculated separately at 100 m and 500 m resolution using the focal statistics tool. For the best outcome, we combined the 100 m and 500 m scales.

We standardized the TPI grids to allow craters to be distinguished following the formula provided by Weiss (2001):

$$\boldsymbol{tpi < sf >_{stdi} = int\left(\left(\frac{tpf < sf > -mean}{stdv}\right) * 100\right) + .5} \quad (2)$$

For the breakpoints, we chose the standard deviation as the basic unit. Next, the standardized TPI values were used to classify the field into slope position classes. For enhancing the classification of volcanic landforms, we used additional topographic metrics, slope and non-standardized TPI at a 100 m scale (Theobald et al., 2015) so from the basic landforms, ridges, upper slopes (shoulders), lower slopes (foot slopes), valley bottoms (toe slopes) we can add craters, tuff rings and scoria cones (Table 14). A slope threshold of 6° was used to distinguish between flat areas and open lava flows.

Table 14. Landform classes by slope position and volcanism-relevant features. The breakpoint among classes shows the slope position based on Weiss (2001) from the negative values of deeply incised streams and valleys to the positive values of upper slopes and ridges and the rolling morphology in between. In our study, we adjusted these breakpoints to optimise the classification for monogenetic volcanic landscape. TPI100stdi and TPI500stdi are the standardised TPI calculated at 100 m and 500 m. TPI100 is the non-standardised TPI at 100 m scale (to classify deep craters and quarry scars).

Slope position	**Volcanic landform**	**Class**	**TPI100$_{stdi}$**	**TPI500$_{stdi}$**	**TPI100**	**Slope**
Cliff	Exposure	**0**				**>50°**
Deeply incised streams	Deep crater	**1**	**≤ -100**	**≤ -100**	**≤-10**	
Deeply incised streams	Quarry	**2**	**≤ -100**	**≤ -100**	**>-10**	
Mid-slope drainages	Lava drainages, tuff ring	**3**	**>-100, <100**			
Plains	Explosion crater (maar)	**4**	**>-100, <100**			**<6°**
Open slopes	Lava flow	**5**	**>-100, <100**	**>-100, <100**		**>6°**
Upper slopes, mesas	Tuff ring	**6**	**>-100, <100**	**≥100**	**>-1, <1**	
Upper slopes, mesas	Shallow or open crater	**7**	**>-100, <100**	**≥100**		
Ridges	Cone, Ridges	**8**	**≥100**			

The accuracy of distinguishing volcanic landforms can be improved. Future work is to introduce the ruggedness index as a secondary classification factor to move the different landforms to the right classes with higher accuracy. However, for the geoeducational capacity map, we need the summary of the different identified landforms by the TPI algorithm. We used the volcanic landform classes to calculate their extent in order to assign weights to given classes.

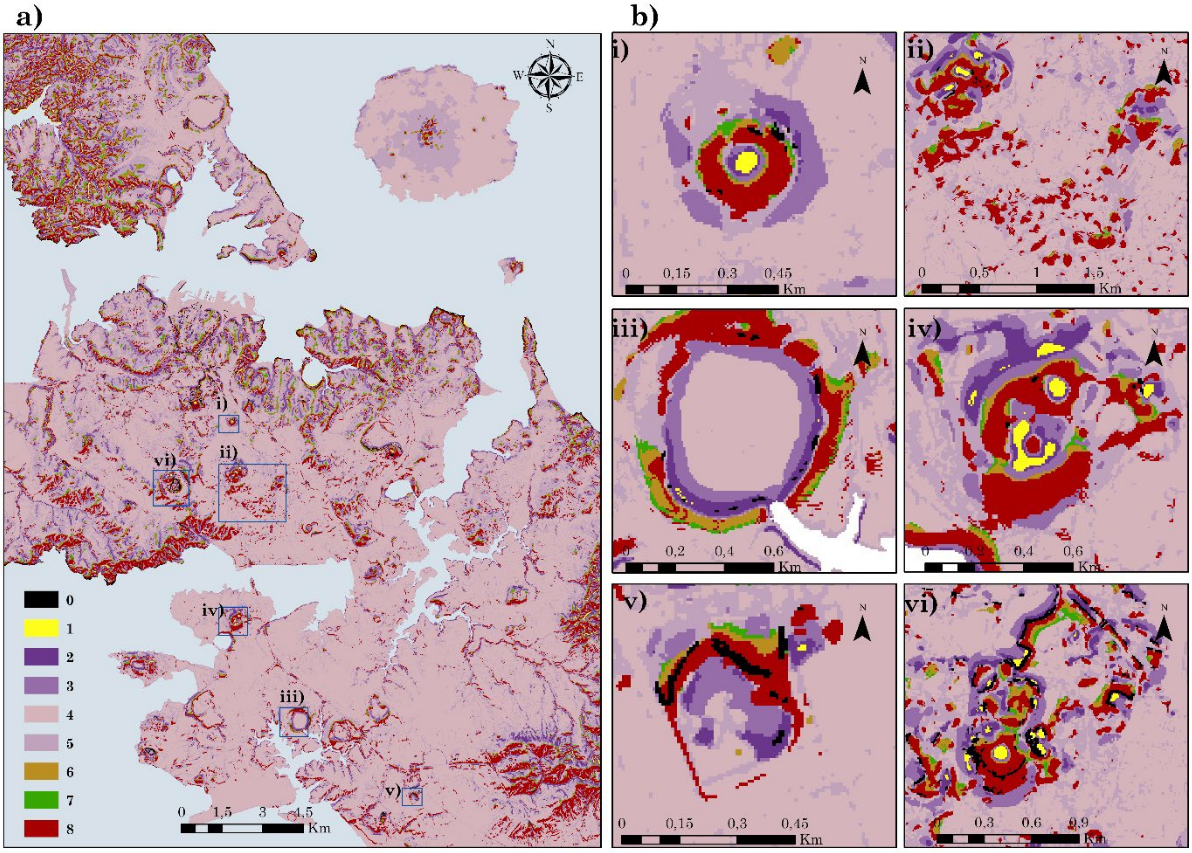


Figure 32 a) Landform classification using the Topographic Position Index of the Auckland Volcanic Field using the criteria and the number codes shown in Table 15. The method applied was based on Weiss (2001) and modified threshold values to distinguish slopes characteristic of monogenetic volcanism. b) i) Mt Saint John scoria cone with steep crater. ii) One Tree Hill lava flow. iii) Pukaki maar with a tuff ring. The white area as the estuary. iv) Mangere Mt tholoid in main crater and a second steep crater. v) Wiri Mt quarry face. vi) Three Kings scoria cone with quarry scars and crater.

By identifying the main topographic attributes of the elements of a landform, it is possible to automate the classification of geomorphology (Figure 32) of similar geological features and promote comparability for objective geoheritage evaluation.

To map the visitation rate, we leveraged the vast amount of data generated by the public and available for research purposes on the internet. Crowdsourcing is the practice of obtaining a large amount of information about people`s habits via the internet. Volunteered geographic information is geospatial content generated by visitors using available mapping platforms on the internet (Goodchild, 2007). Flickr is a safe platform for volunteered geographic information. It is based on the data visitors store on the cloud and agrees on the use of the metadata for research. Flickr has been used for a long time to analyse visitation patterns and interests. The high level of representativeness of Flickr data is discussed in numerous studies (Chen &

Shaw, 2016; Huiskes & Lew, 2008; Kádár & Gede, 2013b; Lieskovský et al., 2017; Sun & Bhowmick, 2010). There is a low level of inaccuracy involved due to the known errors (atmospheric error, user clock error, orbital error, multi-path error, etc.) of built-in geographic position systems; however, the location correctness of geotagged Flickr images are reliable (Senaratne et al., 2013). The technology offers a large amount of cheap and instant data. The data exposes gaps in promotion instruments as well as being useful for monitoring behaviour changes generated by the quality implementation.

The most useful social media site is Flickr (compared with Panoramio, Geograph) for the visitation analysis because it is the photo-sharing site with the most photographs uploaded due to its social networking factor (Antoniou et al., 2016; Kádár & Gede, 2013b). The most popular photo-sharing sites provide an application programming interface (API) to access the photo storage database. APIs offer the possibility to download geographic data within a given bounding box.

Geographic coordinates were integrated into a GIS environment to visualise the photo distribution by placing a dot on a map at each image`s location. In the case of Auckland, the major tourist attractions are recognisable at first sight. Along with the city centre, the volcanic cones are the most favourable places among photographers based on the number of photos taken at a given location. The data also clearly shows the pathway to the top of the volcanoes. Fishnet tool was used to construct a polygon grid to cover the dot print features. Spatial join analysis counts the number of photographs taken within each grid polygon. The last step of geoprocessing is to convert this polygon feature to a raster dataset in order to determine the tourist hotspots. Hotspots are the places that attract most of the 'sight-seers" (Fernández et al., 2016; Jacobsen et al., 2019; Neuts & Nijkamp, 2012; Yagi & Pearce, 2007).

6.4.2.3. Analysis

Geoeducational capacity is the depth of information which can be deprived, observed, or attained at a position displaying features of the earth system. For the calculation of the Geoeducation Capacity Map, we used the landform classification, geology and geopreservation maps. Each map was individually transformed into a low to high-value map and aggregated to show geoeducation capacity. The items in the Geopreservation Inventory (**http://www.geomarine.org.nz/NZGI/**), beside a detailed description of their scientific attributes, are marked according to their level of importance; 'A' of international scientific, aesthetic or educational value, 'B' of national scientific, aesthetic or educational value, 'C' of regional scientific, aesthetic or educational value. We simply transformed the importance marks into weight classes; '1' presenting non-volcanic features, '2' presenting 'C' importance items, '3' presenting 'B' importance and '4' presenting 'A' importance. For the geology map and landform classification, we calculated the spatial extent of each rock type and landform class and weighted them based on their amplitude (Table 15). Our supposition was that the smaller the spatial extent, the rarer the rock type/landform class, hence receiving the highest weight.

Table 15. The calculated extents and their assigned weights of the geology classes, Geopreservation Inventory classes and landform classes. Landform classes are explained in Table 14. Geology weights are derived based on the geographic extent of the rock type, the rarest rock type is assigned the highest value (scoria is assigned weight 4, ash is assigned weight 3, tuff and lava is assigned 2). Geopreservation Inventory weights are derived based on the importance defined in the inventory 3 being internationally important (marked as "A" importance in the inventory), 2 being nationally important (marked as "B" importance in the inventory) and 1 being regionally important (marked as "C" importance in the inventory). Landform classes weights are derived from the TP index based on the geographic extent of each class. The rarest class is assigned the highest weight that is 8. The class with the largest geographic extent is assigned the lowest weight that is 1.

	Geology					**Geopreservation Inventory**				**Landform Classes**								
	Scoria	**Ash and Lapilli**	**Lithic Tuff**	**Lava**	**Non-Volcanic**	**Importance \`A\`**	**Importance \`B\`**	**Importance \`C\`**	**Non-Volcanic**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Extent (km^2)	5.7	23.9	39.8	61.5	283	N/A	N/A	N/A	N/A	2.4	23.6	220	97	39.9	1.7	12.4	11.7	5
Weight	4	3	2	2	1	4	3	2	1	8	4	1	2	3	9	5	6	7

The following steps were executed using the zonal statistics tool to calculate the geoeducational value's magnitude. For each map, we used a 100 m grid cell to count the number of units and added together the weights of the different types of units of geologic, landform and geopreservation. The classification method for the Geoeducation Capacity Map (Figure 8) used the natural breaks (Jenks) method.

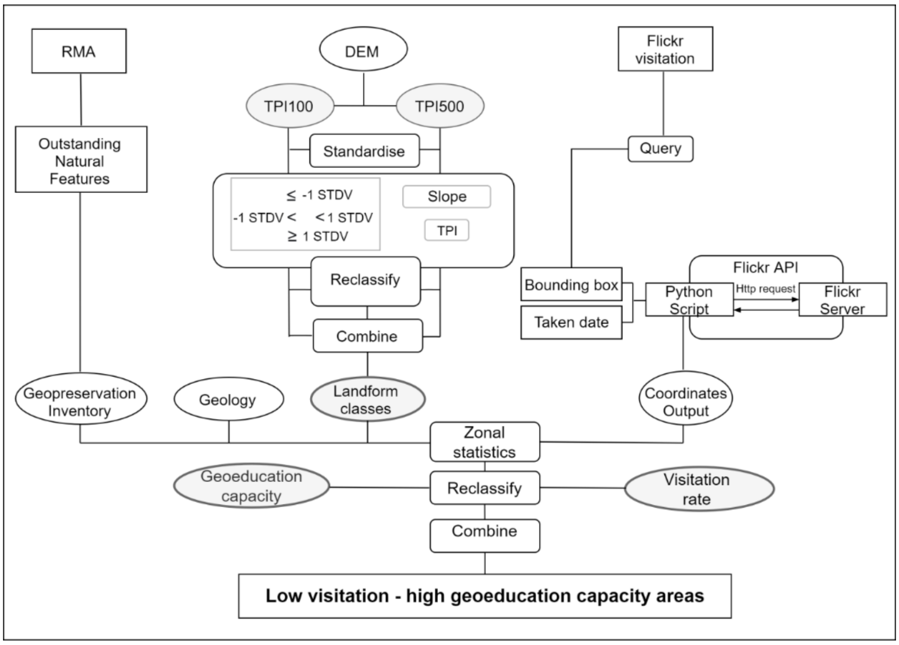


Figure 33 Flowchart of the methods and materials used for the analysis. The four take-off points of the study were the basis of all environmental matters the Resource Management Act (RMA), the collection of significant geological sites in New Zealand (Geopreservation Inventory), the Digital Elevation Model of the Auckland Volcanic Field (DEM) and coordinates of photos taken within the bounding box of Auckland Volcanic Field extracted from FlickR (Flickr Visitation). The analysis continued in three consecutive stages. First, the landscapes were categorised into `Landform classes` using Topographic Position Index (TPI) on two different scale ranges (TPI100 and TPI200). In the second stage, the representative layers of expert`s knowledge, geology map and Geopreservation Inventory were processed into layers compatible with the acquired layer on Landform classes. Next, we used GIS multicriteria decision analysis to generate the `Geoeducation capacity` map from the aforementioned map layers. In the third stage, the photo taken coordinates acquired from FlickR were organised into low to high visitation categories resulting in a `Visitation rate` map. The results of the three stages were combined into the map of underrated geoeducation capacity areas with high scientific value. All the processes above used the analytical power of ArcGIS.

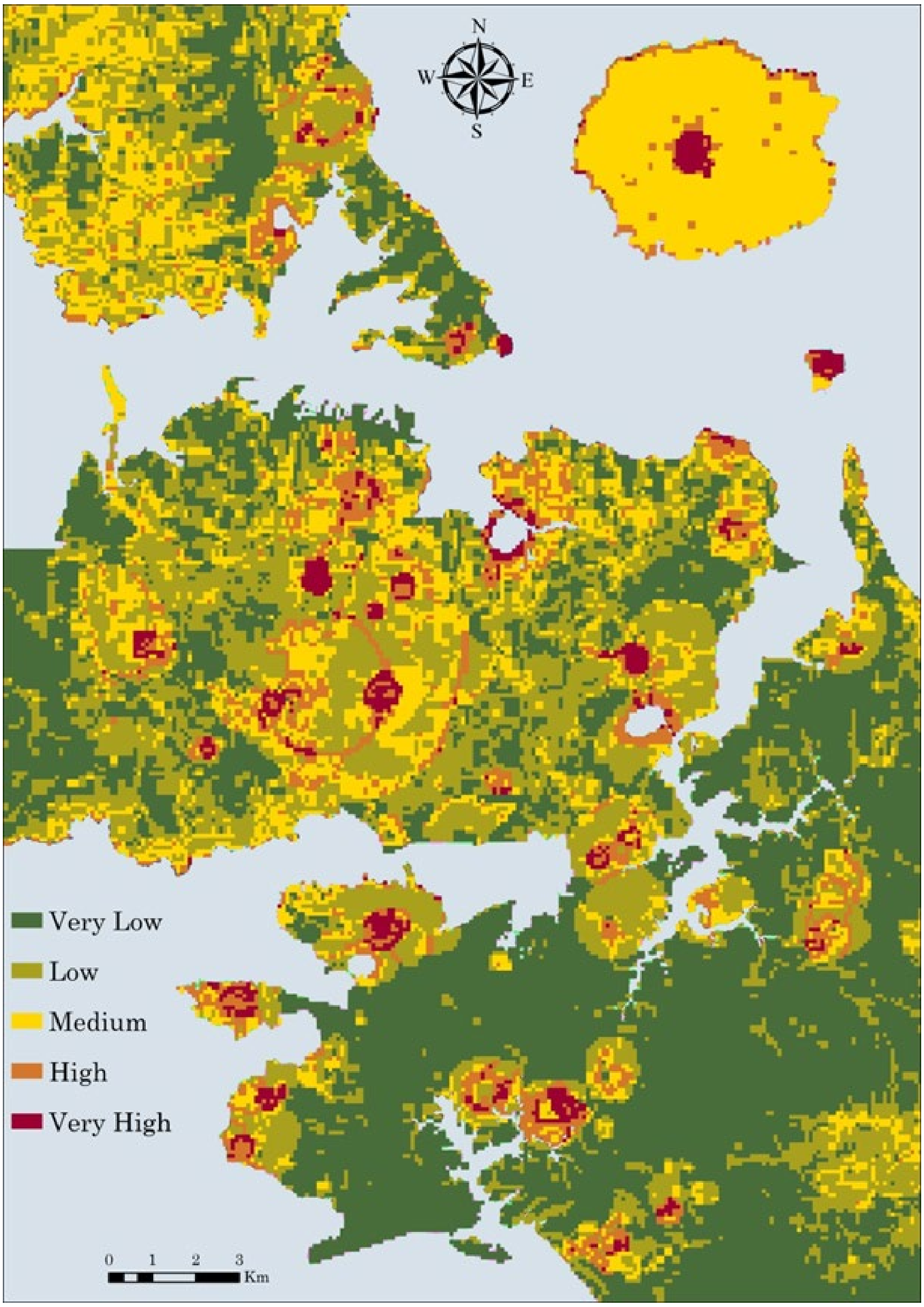


Figure 34 Geoeducation Capacity Map. Very low to very high values result from the GIS multicriteria analysis. We aggregated three map layers: geology, Geopreservation Inventory and landform classes. Standardised weights were assigned to the different classes of each map layer. The extent of each class calculated the weights for the geology map and landform map. The smaller the extent of a geological class or a landform class, the rarer that class is. The weights for Geopreservation Inventory were provided, ranging from international to regional importance. The aggregation of the map layers was based on variety.

We took the Flickr coordinates extracted from the cloud to analyse the visitation rate of the highest geoeducational features. We used FlickR API to return the metadata of photos within a bounding box of specific latitude, longitude, and accuracy (for all available dates until the end of 2021). We affixed the data with the spatial joint tool to form a spatial perspective. By counting pictures taken within a 100 m grid, we produced a raster of high to low visitation areas. To reduce the effect of the highly skewed distribution of visitation caused by the popularity of the cities downtown, we ran a log transformation on the joint count data. The high visitation cells on the grid needed to be expanded to 200 m to reduce the error resulting from the majority of the photos taken at the top of the landforms. The buffer was executed to cover a generalised diameter of a scoria cone (200 m). To test the representativeness of crowd-sourced information, empirical information was collected from New Zealand`s official data agency Statistics New Zealand. To enable the comparison, the social media information was downloaded in time periods corresponding with the empirical data on the monthly international visitor arrivals to New Zealand. The information from Flickr photographs corresponds well with empirical information about where and when people go (Appendix 2).

For the final map, we deducted the high visited high geoeducational values from the geoeducational capacity map to highlight underrated and underpromoted areas (Figure 35).

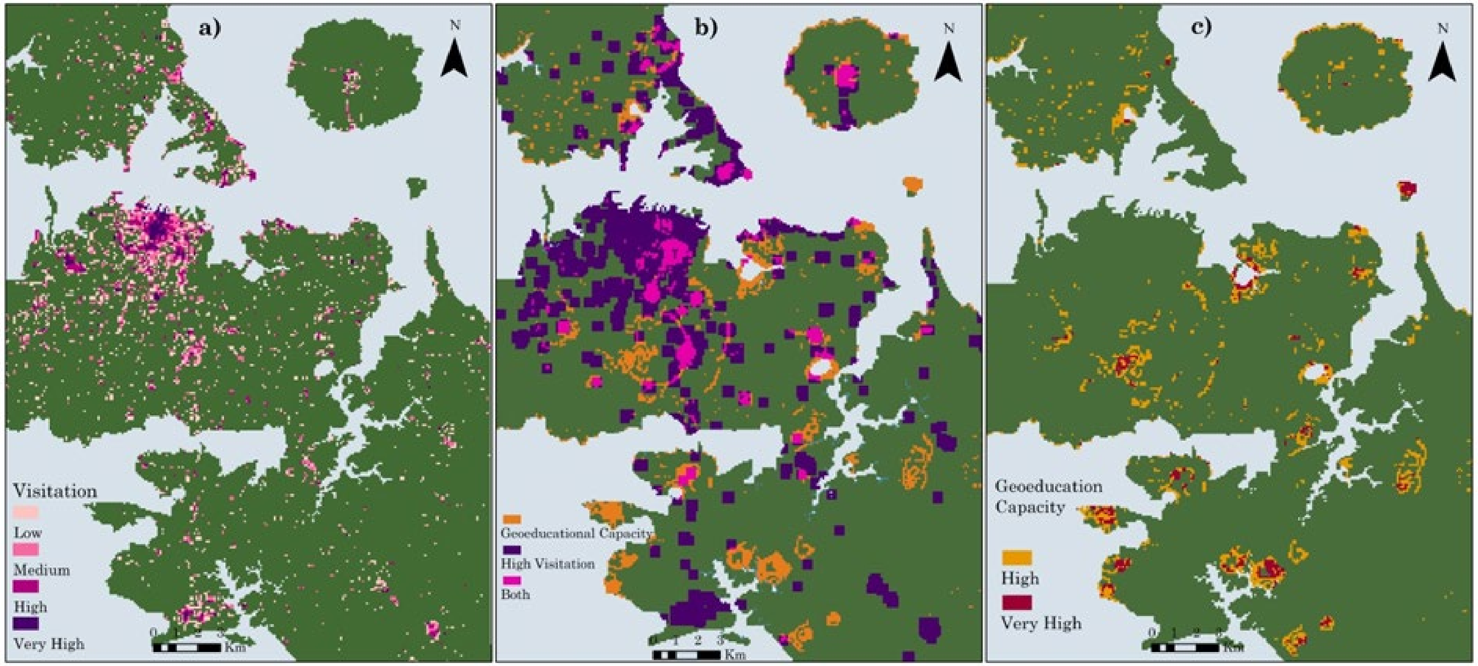


Figure 35 a) FlickR visitation rate b) Flickr visitation compared to high geoeducation capacity cells. In this map, geoeducation capacity is converted to Boolean categories and combined with the Flickr visitation rate layer. Yes, shown by the colour yellow, where 'medium', 'high' and 'very high' capacity is present. No, shown by the colour green, where 'low', 'very low', or 'not detected' is the cell value. Visitation cells, shown by the colour purple, present 'medium' to 'very high', and the not visited cells, shown by the same colour green as the 'low' to 'none' geoeducation capacity, present 'low' and 'null' cell values. The overlay function produced the areas where Boolean visitation and geoeducation capacity overlaps, colour pink. The purpose of the map is to find areas that need to be prioritised for conservation and promoted as high-value geoeducational sites. c) This map shows the high and very high geoeducation capacity cell only clipped with the visitation layer. This is to highlight the 'low visitation/high geoeducation capacity' areas.

6.5. Discussion

6.5.1. GIS techniques to strengthen the geoheritage case

GIS techniques deliver an ability for users to construct repeatable models. The repeatability of an evaluation method is one of the main criteria for achieving the reliability necessary for quality implementation (Malczewski, 2006). In addition, spatial techniques allow new potential geoheritage sites to be part of evaluations by calculating values for each cell within a given area (Jankowski et al., 1997).

The topographic Position Index creates an accurate map for `rarity` that is the main criterion layer. The technique is developed to classify landforms for further analyses and is utilised mainly in ecological decision-making tasks such as biodiversity modelling (Amatulli et al., 2018; Wood et al., 2011) or assessment of soil-moisture (Dyer, 2009; Parker, 1982; Riley et al., 2017), or habitat suitability (Galparsoro et al., 2009; Hook & Burke, 2000) to mention a few.

The topographic Position Index technique is used to classify the landforms. This means clearly defined boundaries and the opportunity to break down a landform into smaller landform features. This increases the likelihood of implementation by giving opportunities for the identification of sites with the highest potential. Once the exact locations of the highest information are pinpointed in GIS, the map can be inserted into land use planning. This step is a prerequisite for the promotion of geological heritage in urban settings.

GIS multicriteria analysis is widely used in site selection exercises, for example, wind farm site selection (Szurek et al., 2014; Van Haaren & Fthenakis, 2011), agro-industrial complex (Sahnoun et al., 2012), industrial site selection (Eldrandaly et al., 2003), parking site selection (Jelokhani-Niaraki & Malczewski, 2015), investment site selection (Siejka, 2017), landfill site selection (Bahrani et al., 2016) or for the detection of land use suitability for example in urban extension (Chen, 2014; Mosadeghi et al., 2015; Svoray et al., 2005), citrus management (Zabihi et al., 2019), agricultural land use (Janssen & Rietveld, 1990), land management (Joerin & Musy, 2000; Nguyen et al., 2015), for biomass residues (Colantoni et al., 2016), rainfed farming (Kazemi & Akinci, 2018). GIS multicriteria analysis is a very useful technique in hazard mapping such as multihazard mapping of landslides, floods and earthquakes (Skilodimou et al., 2019), forest hazards (Gigović et al., 2018), hazards in site selection (Ahmadisharaf et al., 2016), forest fire risk (Huyen & Tuan, 2008) also in socio-economic fields to analyse deprivation (Bell et al., 2007), urban water demands (Panagopoulos et al., 2012), climate change (Mokrech et al., 2012), forest landscape restoration preferences (Uribe et al., 2014) or to map zones in groundwater recharge (Chenini et al., 2010), landslide hazard zonation (Bera et al., 2019; Rahamana et al., 2014), protected area zoning (Zhang et al., 2013) or to create multi-objective land allocation (Gilbert et al., 1985; Hajehforooshnia et al., 2011; Ligmann-Zielinska et al., 2008; Matthews et al., 2000; Zhang et al., 2016). These applications require precise modelling that underlines decision-making. Conservation of geological and geomorphological features gain objectivity by using GIS modelling. Multicriteria decision analysis is versatile, allowing for multiple objectives to be considered and having all the alternatives on record. The main constraint of non-GIS-based geoheritage evaluation is the level of subjectivity and the inability to provide multi-objective solutions.

6.5.2. Geoeducational capacity map in Urban Planning

Value criteria in geoheritage assessment lack clarity in a decision-making environment. This study aims to shed light on the overlaps between the values of different conservation branches. Therefore, this study encourages future studies to shift evaluations to geographic information systems for comparability and reproducibility.

Tourism, recreation and geoconservation have to overlap though contradicting objectives, all targeting the outstanding geological/geomorphological features. When the opportunity is limited, decisions favour objectives that are supported by a firm framework. That is where our study plays a crucial role. In New Zealand, it is of national importance to conserve nature and cultural authenticity. Therefore, the constant development of a geoconservation framework that adapts the newest urban planning methods and incorporates the increasing amount of valuable but latent online data is imperative. Urban planning in Auckland is carried out in GIS; therefore, our study is quickly and effortlessly implementable into future planning exercises. Decision makers understand the value of geoheritage (Pelfini & Bollati, 2014); however, with a low percentage of geoheritage features being already a popular tourist destination, it could seem practical to exert geoeducation around these features. Our map shows the areas that receive no visitation and carry very high geoeducational capacity. These areas are now on record and less likely to be overlooked if there is an opportunity to protect further geoheritage features.

6.5.3. Geoeducational capacity map in indigenous knowledge system

Local communities ideally live in harmony with their environment and assign myths and legends to their geology and geomorphology. Significant geological and geomorphological features are the basis of the spiritual well-being of the locals. Humans are bonded with nature into an intertwined system where people are the guardian of the environmental manifestation of the ancestry of all living. Scientific knowledge of the environment develops hand in hand with indigenous knowledge and worldview creating a moral obligation for geoconservation. Communities are attached to geology and geomorphology scientifically and spiritually, which is globally an underrated element of sustainability and quality of life (Amberger, 2001; Bailey et al., 2010; Gravis et al., 2016; Gravis et al., 2017; Panizza, 1992). With the open opportunity in the legal framework for quality geoconservation implementation, we can achieve that sustainable development and holistic conservation. Our map provides clarity on the geographical locality and extent of the scientific capacity of these features. The engagement of iwi representatives is the next step that will close the gap between `western` and `indigenous` knowledge. Our map provides a common ground for all the stakeholders and serves as an instrument in this spatial decision-making issue. The maps cannot tell the spiritual value of the community's natural features. However, maps are crucial for identifying features that are sacred or otherwise valued by the community. Maps are powerful tools for solving multi-objective decision-making problems. A geoeducational capacity map provides decision-makers with alternatives and the most optimal combination of features for conservation under multiple objectives.

6.5.4. Improving the geoeducational site network in Auckland

Geoheritage value presents a range of values, including aesthetics, viewpoints and intactness of geomorphology. In an urban environment, these values are the basis of recreation. Even though this is a great advantage for geoconservation, these values are not the basis for education. From a geoeducation aspect, the scientific value should be assigned a higher value than the aesthetic value. From this aspect, the Geopreservation Inventory proved to be very useful in raising awareness as it has triggered further community initiatives. The geological sites are used by local tourist agencies (https://www.geotrips.org.nz/map.html) to create geo trails and guided tours. Their work needs to be promoted and inserted into promotional materials of Auckland. Walking through Auckland as a visitor, however, there is very little promotional material. Some geoheritage features receive high visitation without tourists understanding their destination and rather using the volcano for the view. The most visited locations, like Mt Eden, are nearly completely lacking information on volcanism, and overall, there is only very basic geoeducational material in situ. The existing motive for visitors to engage in the view from the top of a volcanic cone is an advantage in drawing attention to volcanic processes. Strategically placed information panels spark curiosity to discover the story of the volcanic field as a whole and visit outcrops with lower aesthetic value.

The Geoeducation Capacity Map is useful because it presents information about the world in a simple, visual way. It facilitates the promotion of geological information and the value of geoeducation for resilience, future research and hazard mitigation. It also promotes the advancement of educative boards and instruments that generate interest in the non-geologically inclined public. Geoeducational capacity represents scientific value, whereas geoheritage value represents cultural, recreational and scientific value.

6.5.5. Big data analysis as decision making support tool

Volunteered geographic information can be used for analysing the patterns of visitors and patterns of their movement. Temporal data in the future will help monitor changes in tourist behaviour and evaluate marketing techniques. It is a very important emerging tool in modern urban planning. To map where tourists go is crucial in deriving motives. Motivation is generated by promotional materials that can be manipulated toward geoeducation. The uncovered patterns of visitation show the strongest pull motives within Auckland. These visitation patterns placed against the geoeducation map show the gap areas needing to be addressed (Figure 36). The ability to estimate visitation rates without survey data accelerates the process of quantifying the tourist value of a certain volcanic site. Raster data shows the exact number of photos within a square of 100mx100m, that is, the average size of the Auckland volcanoes. High-value raster polygons are tourist hotspots. The display of the exact locations within the polygons helps the optimum emplacement of promotional and educational materials.

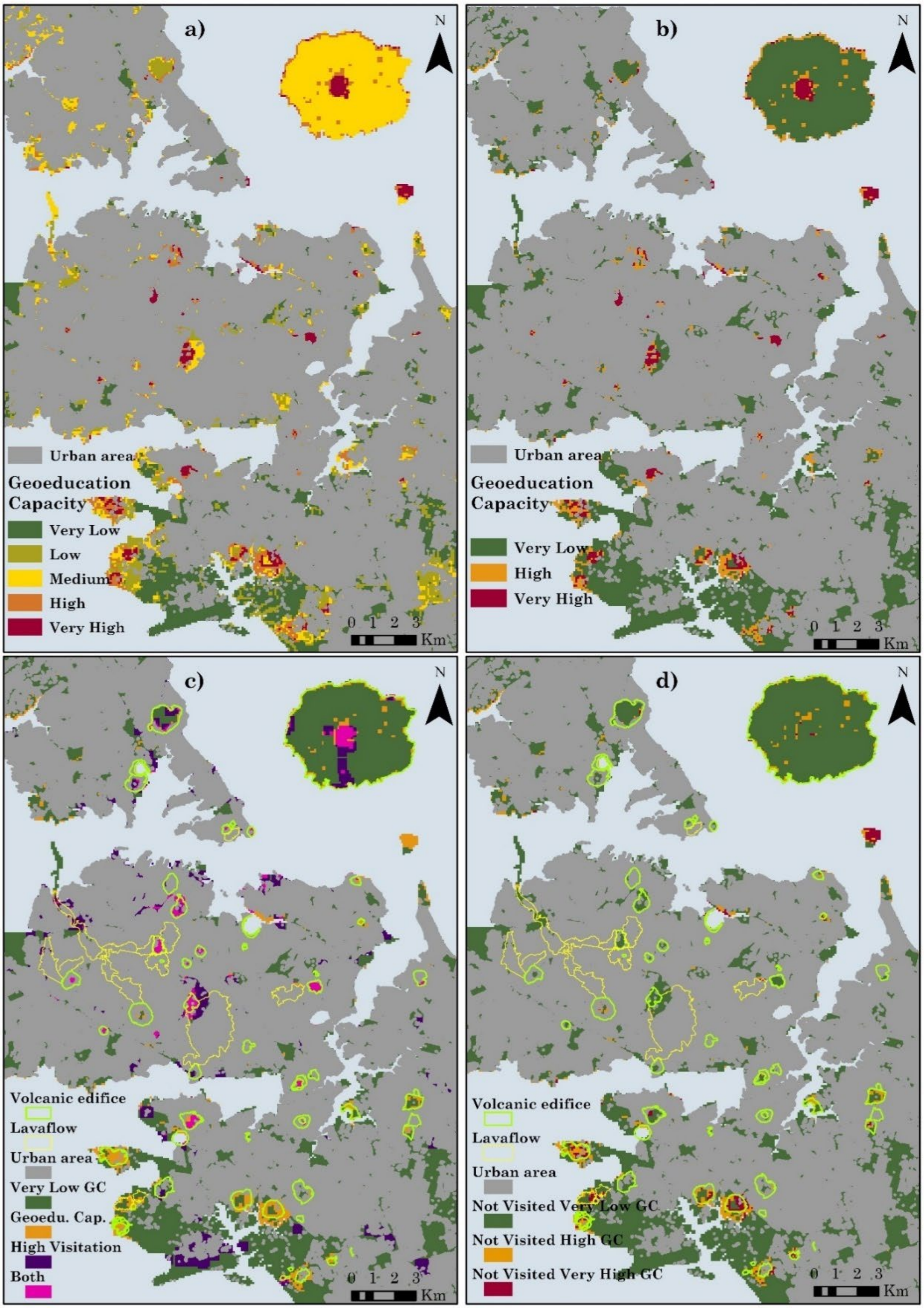


Figure 36 a) Geoeducation Capacity Map with urban area b) This map shows the locations of 'high' and 'very high' geoeducation capacity areas that are not covered by buildings in the urban area. c) The buildings of the urban area placed over the geoeducation capacity and visitation depict the exact area available for the promotion of volcanology. Edifice boundaries are necessary to better understand the threat of geoeducation values. d) The map only shows the 'high' and 'very high' geoeducation capacity areas with the urban area.

6.6. Conclusion

Legislation in Auckland, New Zealand, allows for an upgrade in geoheritage conservation. Sustainable development and community involvement are very important national matters. These are as well among the main supporting arguments for geoheritage conservation. As a rapidly developing city, Auckland is searching for solutions to ensure the community can keep a connection with nature. Natural features of the highest cultural importance are safe under the ownership of the local community. However, the area being geologically active, natural features of high geoeducational capacity need to be promoted in order to achieve high resilience to geohazards within the community.

A robust evaluation instrument is necessary to create policies that protect and promote high geoeducational capacity features. Achieving a high-quality geoheritage conservation implementation is critical to achieving the desired outcomes in the Geopreservation Inventory. The Geopreservation Inventory results from local geoscientists who expressed concern about the loss of the geoheritage in the urban area as early as the 1980s (http://www.geomarine.org.nz/NZGI/). This extensive work represents the expert's knowledge. This study inserts this expert knowledge into a suitability map to demonstrate a robust instrument that aids spatial decision-making. The suitability map is technically a capacity map. Therefore, it was important to find evaluation units that could be assigned to the expert knowledge. We used automated landform classification by applying the Topographic Position Index to attain objective units for our decision-making instrument. GIS-based multicriteria decision analysis aggregated the information into the Geoeducation Capacity Map. Such analysis reveals the feasibility of expanding recent geological conservation strategies toward geoeducation. Modern GIS techniques eliminate the subjectivity level that often jeopardise geoconservation plans from implementation.

Understanding visitation patterns facilitates recognising and promoting overviewed high geoeducational capacity areas. Furthermore, comparing visitation dynamics with the geoscientifically important areas optimises decision-making and planning processes and points out gaps and unrecognised opportunities.

A comprehensive network of geoeducational sites within a city that stretches across a geologically active area is an effective field education tool. As a result, the general public will achieve a better understanding of geological hazards and an overview of earth scientific research and their importance. This conceptual direction fits perfectly with a current UNESCO IGCP Project 692, "Geoheritage for Geohazard Resilience" [http://www.geopoderes.com/].

Present-day geopreservation locations do not necessarily overlap with those areas that are visited or have some geological value from a morphological and volcanology perspective. The overlay of the Geopreservation Inventory that is marked following urban development boundaries and edifice boundaries shows that there is still extensive geology to protect and promote. Geology is important not only for geoeducation but as well for community well-being.

Chapter 7. *Discussion*

This chapter proposes a GIS synthesis of the GIS data layers and provides models for mapping multiple objectives in geoheritage conservation. It also describes how data integration into GIS could be used in land use planning.

Supplementary data for the Chapter are in Appendix B and C.

Chapter Contents

The Discussion chapter is planned to be submitted to the Geological Society of London Special Publications "Visages of Geoheritage" volume in 2022 February.

Chapter 7. Discussion

It is imperative today to make geoheritage conservation an essential part of all environmental standards and operational procedures. Geoheritage conservation secures the preservation of in situ geoheritage elements, especially in an urban environment such as Auckland. Geoheritage in Auckland is strongly associated with both indigenous culture and textbook geology of monogenetic volcanism and can play an important role in hazard forecasting and risk mitigation. However, to date, there has been a lack of policy or any planning tools based explicitly on the current geopreservation inventory. Here we present an approach for supporting policy-making informed by a spatial multicriteria analysis that has long been used in an environmental decision supported by multi-layer mapping. A systematic literature review was undertaken to define the most accepted assessment criteria used in geoheritage evaluation. We identified 6 criteria for the base spatial layers of our analysis, highlighting the most suitable areas for geoheritage conservation. For cultural conservation, we used available archaeological shape files, indigenous land ownership data and elevation data (the volcanic cones had multiple roles in the life of the first settlers, the ancestors of the Māori). GIS multi-objective land use planning is an effective procedure for solving complex planning and preservation objectives. It allows for outcomes based on quality data and analysis while minimising compromise and conflict between values.

7.1. Conceptual background

An analysis of peer-reviewed literature revealed four major conceptual themes: geoscience as the prime value underlying geoheritage; aligned conservation methods for geo- and biodiversity; geomorphosites as key features of geoheritage conservation; and geoheritage of local communities in favour of sustainability (Németh et al., 2021c).

One of the most influential works that clearly distinguishes the scientific value from other values in geoheritage valorisation is Brilha's (2016) work proposing a framework of geosites and geodiversity sites. The former recognises scientific values, while the latter recognises other values, including cultural, touristic, and economic values, as the main parameters. Therefore, all geosites contribute to geodiversity, but only those considered to be geoheritage elements carry outstanding scientific value. The others may be considered to be of special interest in the context of other fields, hence not defined as geoheritage *sensu stricto*. On the other hand, geodiversity sites subject to geodiversity index-based assessment have primarily focused on the investigated region's scientific values (Serrano Canadas & Ruiz Flano, 2007; Ruban, 2010; Pellitero et al., 2011; Araujo & Pereira, 2018; Betard et al., 2018; Brilha et al., 2018). Geodiversity considers all the abiotic elements of the lithosphere (and, to some extent, the hydrosphere and atmosphere) in a broad sense and can be viewed as the foundation (Gray, 2018) underlying the ecosystem functions. Hence it is the foundation for biodiversity and cultural diversity and defining foundation of human society and its history (Alahuhta et al., 2018; Brilha et al., 2018; Fox et al., 2020). Geodiversity mapping aims to reveal areas rich in features or unique within the encapsulating landscape. These maps assist geoconservation-related decisions. Murray Gray devoted a great deal of his work to defining the geodiversity paradigm. He says in multiple publications (Gray 2008b, a; Gray 2011, 2012; Gray et al., 2013; Gray 2018c, a, b; Gray & Gordon, 2020) that geodiversity is a vague term, as it is used widely in varying contexts.

The geomorphosite approach was introduced recently (Panizza, 2001; Panizza, 2009; Panizza, 2011; Panizza, 2018) and strongly supported by the Italian Geomorphological Community (Bollati et al., 2012; Bollati et al., 2015; Bollati et al., 2020). It traces its foundations to the mountainous landscape of Italy, with a long history of an artistic culture unfolding against the background of a well-known and aesthetically valuable landscape. It is no wonder then that geomorphology against this background informs theory about tourists and their special attraction to geomorphosites. It may also be considered that a geomorphologist will only apply the scientific criterion to value judgements of landscapes and encourage stakeholder involvement for the aesthetic and socio-economic evaluation of said landscapes and features. Geomorphology is largely the result of the underlying geology, shaped by complex interactions between the environment and unfolding processes such as weathering and erosion. Closer investigation at an outcrop scale will tell a story of past landscapes and a geological history compressed into a succession of various rock types assembled through diverse geotectonic processes and impacted by climatic and biogenic influences acting over long time scales (Brocx and Semeniuk 2011a, b; Bruno & Perrotta, 2012; Brilha, 2016; Habibi et al., 2017; Kubalikova et al., 2017; Németh et al., 2017).

A need for natural resources may influence humans' desire for knowledge about abiotic nature, but it also can help in building resilient societies in the face of natural disasters. Therefore, geoeducation, therefore, should be a significant factor in shaping geotourism ventures; however, an understanding of geologic units and processes may not be the motivating factor in visiting natural features. Rather is more likely to be for their aesthetic value. For most people, dramatic aesthetic values inherent in a mountain landscape would function as a more appealing drive to visit a site than the geological history or processes behind their origin. The hunger for geoscientific knowledge must be triggered by far-reaching geoheritage promotion and education, as seen in Hong Kong Global Geopark (Fung & Jim, 2015); Jeju Island Geopark, the volcanic wonder of Korea (Woo et al., 2013); Japan`s Izu Peninsula Geopark with its geosystem approach (Chakraborty et al., 2015); and the well-studied and researched Novohrad-Nograd Global Geopark crossing the border of Hungary and Slovakia (Szepesi et al., 2017). In line with local social-economic interests and cultural values, tourist-attracting activities can be an important association with geoheritage features.

The diversity of geoheritage concepts makes it difficult to identify the level of agreement over criteria used for geoheritage assessment. The idea of geoheritage value currently varies in a rather wide spectrum, which can result in shortcomings when applying multi-objective decision-making. Additionally, it may encourage misinterpretation and risk economic and utilitarian principles from a profit-driven tourist industry being the overriding values in any decision-making.

In our research, we address the question of how to be transparent in choosing objective and relevant criteria for assessing a region for geoheritage designation. Therefore, this work aims to extract and systemise the scientific literature and use statistical tools to find consistency, encouraging systematic definitions and agreement on all proposed geoheritage values.

7.2. Geopreservation in Auckland

Auckland is the largest city in New Zealand by population, economic output and global significance and is a significant hub in the SW Pacific socio-economic region. Auckland is recognised as a major settlement site of the early Polynesian migration, agriculture and urbanisation located on an active Quaternary monogenetic volcanic field. Auckland has a mild oceanic-sub-tropical climate that provides an ideal modern touristic hub providing sailing opportunities, sandy beaches, multicultural city experiences, and wineries. A breath-taking urban landscape over the Central Business District (CBD) with a futuristic cityscape can be viewed from high points in a monogenetic volcanic landscape with many recreational parks located on volcanic cones. These values clearly provide an opportunity for Auckland to be a global example of city-based geotourism with high potential geoeducation values observed at many sites, as highlighted in our study on the geoeducation capacity based on geoheritage values of the Auckland Volcanic Field (Németh et al. 2021b). Locals may understand the possibility of a future volcanic eruption; however, this does not translate to understanding variations in eruption styles, specific volcanic hazards, and necessary actions to take for mitigation.

Determining Volcanic Risk in Auckland (DEVORA) (https://www.devora.org.nz/) is a collaborative research programme led by senior volcanologists and geology students to conduct research on the historical volcanic eruptions, present processes, hazard prediction, evacuation and geoheritage conservation (Kereszturi et al., 2012; Hayes et al., 2018; Hopkins et al., 2021; Németh et al., 2021a). Spatial-temporal predictions of a new vent opening have long been the subject of research based on the detailed geological knowledge of past eruptions accumulated over the past decades (Searle, 1964; Bebbington & Cronin, 2011; Le Corvec et al., 2013; Brand et al. 2014; Ang et al., 2020). Knowledge exchange in an active geologic area is crucial for building resilience and mitigating risk. However, fast-paced landscape modification and urban sprawl are rapidly destroying sites holding valuable research material that is necessary for improving the accuracy of natural hazard predictions.

A case study was conducted to observe relationships between visitation and geoeducation in a geographically confined, nationally significant, and highly populated geological region, the metropolitan region of Auckland and its underlying monogenetic volcanic field (Németh et al., 2021b). Local Councils have multiple objectives for conservation, including tourism, recreation and geoconservation. The problem is that these overlapping objectives may be based on contradicting values when applied to outstanding geological/geomorphological features. Geospatial evaluation reveals areas in a defined unit (100x100m) subject to conflicting values resulting in poor outcomes for geoheritage and potential geoeducation. Socio-economic priorities may not allow for prioritising geoeducation values at present; however well-supported research and reporting can assist in opening future opportunities for landscape-scale geoheritage conservation. Auckland Council faces three key challenges, including 1) high population growth, 2) ensuring that wealth is shared equitably amongst all Aucklanders, and 3) that environmental degradation is kept to a minimum and reversed where practicable.

Although there is extensive work to date describing geological sites in the Auckland Volcanic Field (Hayward, 1989; Hayward 2001a, b; Hayward, 2007; Hayward et al., 2011; Gravis et al., 2017; Hayward, 2017; Hayward, 2019a; Hayward, 2019b; Gravis et al., 2020; Németh et al., 2020; Németh et al., 2021a; Németh et al., 2021b; Németh et al., 2021c; Németh et al., 2021d) to register, systematic and science-based recognition of the geoeducational importance of the geoheritage sites still awaits. A recently established online database, the New Zealand Geopreservation Inventory (http://www.geomarine.org.nz/NZGI/), provides a comprehensive, searchable database which is freely accessible. This inventory describes abundant Geosites and their associated geological information within the greater Auckland area, which can be displayed on an interactive map. While this is a valuable development in providing basic geological information to a wide audience, its effectiveness and usage have yet to be established through research. Large-scale investment is required in Auckland to provide for estimated population growth of 720,000 people with 313,000 houses and 263,000 jobs over the next 30 years (The Auckland Plan 2018), putting ever-increasing pressure on preserving any geological feature (Németh et al., 2021d).

Effective policies must be based on good data and analysis. The capacity to collect, process and draw relevant conclusions from a variety of data sources is vital to developing effective policies and vital to the all-important feedback loop between implementation, monitoring, and evaluation.

The volcanic cones of Auckland are currently on the UNESCO tentative list (Walker, 2014). The nomination is a Serial Site comprised of 21 sites. They are nominated under criteria (iv) outstanding example of a landscape which illustrates significant stages in human history and (viii) representing major stages of Earth`s history.

The proposed volcanic sites were accepted under the mixed cultural and natural heritage site criteria. The Auckland Isthmus is a key landscape element hosting a series of volcanic sites formed through various volcanic eruption styles over the past 250 000 years, with scoria cones dominating the Auckland landscape. The cones supported a long period of Māori settlement, use and occupation (Stone, 2002; Stafford, 2008). Each cone was surrounded by large areas of rich volcanic soils, which formed the basis of highly productive gardening systems. Most slopes and summits were modified by Māori with terraces, ditches, banks, pits, forming gardening, food storage, and defence systems. UNESCO describes it as a significant cultural landscape located within the volcanic landscape. Although not unique as a collection of small basaltic scoria cones and maar craters, the Auckland field has an unusual diversity of features (full range of vents, explosion craters, evolved cones, and lava shields) (https://whc.unesco.org/en/tentativelists/5120/).

The evaluation methods used to date have proved useful; however, we suggest the need for supporting GIS analysis to satisfy the evidence required for well-informed decision-makers.

Without supporting evidence, it is impossible to effectively incorporate geoheritage values into urban land use planning. The first step is to identify the legal capacity for implementation, the level of interest, relevant ongoing programs, presently defined targets, and ongoing obligations.

A geopreservation inventory is necessary to highlight locations and conditions of geosites and collate all relevant information necessary for any planning period and decision-making. This goal must be followed up with a strategy clearly outlining how this service knowledge will be delivered to the population as a knowledge bank of the history of the Earth derived from geological research (Gray, 2011).

Apart from the high demand for urban and industrial development land, Auckland is also under a bicultural legislative system that must be considered in any geoconservation, geoeducation and geotouristic ventures. Some items of the existing New Zealand Geopreservation Inventory are acknowledged to hold high cultural values. Work is currently underway for a programme for the protection of Tūpuna Maunga/Geoheritage and includes measures such as on-site interpretation/storytelling with the installation of generic signs; development of an information centre and comprehensive interpretation using signs, notice boards, visual aids, and interactive Undertaken by the Tūpuna Maunga Authority (2016) this work recognises and engages visitors, highlighting the significance of the feature and their cultural history. Also, projects for education, events, commercial activities, volunteer programmes, pest management, biosecurity and biodiversity expansion are prioritised for completion in a timely schedule. The multi-faceted programme is sound and aligns with all aspects and objectives of geoheritage conservation.

The existing New Zealand Geopreservation Inventory created by the experts in their field suggests; however, our research demonstrates that the boundaries of landforms in some cases may not match the boundaries of geoconservation areas in the inventory (Németh et al. 2021b). This applied in cases where we identified high geoeducation capacity areas and the boundaries of each cone in order to understand how urban development may have had a negative effect on the integrity of the volcanic landscape. A comparison with the land use database revealed that the geopreservation areas are aligned with e boundaries of open recreational spaces of the city.

7.3. Indigenous community of Auckland

Ancient wisdom carried through generations is kept alive by the communities` attachment to their physical area. Each specific community within the natural world (e.g., western or traditional society) has specific strategies and traditions to maintain its link to its physical space. Geology is a major foundational element of local knowledge systems that are strongest within communities still following traditional ways of life and maintaining an understanding of abiotic nature's processes and natural rules. Therefore, communities care about and recognise the significance of their local geology and geomorphology. On a global scale, the main practical actions focus on the conservation of culture and biodiversity. International organisations play an important role in promoting and facilitating activities to manage and preserve the diversity of life and culture, thereby facilitating the achievement and maintenance of peace among different cultures (1992 Rio Convention on Biological Diversity, 1973 Washington Convention on International Trade in Endangered Species, 1979 Bonn Convention on the Conservation of Migratory Species and Wild Animals, 1972 UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage). Everything, both physically tangible and culturally intangible, is built on and shaped by landscapes with distinct geology and geomorphology; hence geoconservation aims to protect the outstanding elements of this `*everything*`. Additionally, the sense of connection and affiliation of local communities to their abiotic environment can result in sustainable behaviour of locals (Kawagley & Barnhardt, 1998; Amberger, 2001; Ens et al., 2012; Stephenson et al., 2012; Athayde et al., 2017; Carr, 2020; No'kmaq et al., 2021).

Let's consider local communities as guardians of geoheritage, incorporating natural wisdom on geological processes into modern society. The respect and daily care of local communities will be gradually elevated over time. Geoheritage conservation is paramount within the natural flow of knowledge of preserving and learning to live sustainably with abiotic nature. Geoheritage values are not only preserved within the relics of the vast history of Earth, but these values can also contribute to the pride of local communities in feeling an emotional, spiritual, and physical connection to l the land.

Pacific communities have very strong links to their ancestral lands and pride and a sense of place in belonging to their land. This sense of the land is an independent socio-cultural aspect of Pacific communities particularly, and it is an independent cosmovision from how external visitors may view the same landscape elements. However, visitors benefit from listening to the stories of the land and engaging with the vision of indigenous communities. As archaic or primordial societies that may be considered relatively intact display a culture that reflects internal feelings toward being part of their land, societies that are more detached from those ancient links may be seen as alienated and disconnected from the land and its associated cultural connections. Visitation plays an increasing role in keeping indigenous people's worldview strong in a bicultural society such as New Zealand, as it justifies their existence as a unique group of people with specific cultural values and a cosmovision reflecting the biotic and abiotic environment. Achieving high-quality geoheritage implementation is critical to achieving the desired bicultural outcomes in respect of maintaining cultural well-being and ongoing scientific research based on geoeducation. It is inevitable for quality implementation that we organise the divergent development of geoheritage conservation into a sound conceptual framework along with key factors affecting the feasibility of implementation.

In the case of the Auckland Volcanic Field, the boundaries of the existing geopreservation inventory, out of necessity and practicability, are adjusted to the boundaries of spaces protected from urban expansion (e.g., open spaces, parks) within the metropolitan area of Auckland. However, without a conceptual framework on the geoheritage/geoconservation values and their services, the case for geoscientific importance weakens, especially if one is unable to document the already lost areas.

In this chapter, we provide a narrative summary of the key issues associated with geoheritage valorisation, geoconservation and geoeducation of the Auckland Volcanic Field. In addition to exploring the indigenous perspective of geoheritage, we outline strategies and planning instruments currently active in the Auckland region. This overview will be followed by a newly developed GIS-based analysis of the region. In each spatial study, the topographic information is based on a LiDAR Digital Elevation Model (DEM) that was attained from the LINZ Data Service (https://data.linz.govt.nz). The spatial statistics were calculated using ArcGIS software's built-in geostatistical tools. GIS multi-objective land allocation methods (Hajehforooshnia et al., 2011) are used to create an objective record of the existing geoheritage features and geoheritage subtypes such as scientific, geoeducational, cultural or geotouristic. In some cases, areas may display a combination of these values.

Other fields like conservation biology have built GIS into measuring and analysing biodiversity and habitat to deliver exact, comparable, transparent geographic information for decision-making in practical conservation (Boggia et al., 2018). Using these methods, it has been demonstrated that roads across habitats can significantly lose animals. To mitigate this, specific crossing points, for example, can be built into infrastructure projects, and GIS suitability maps can be used to precisely place them to maximise their value (Cetin, 2015). In addition, habitat evaluation benefits from large-scale GIS analysis, such as linking landscape data with population viability (Akçakaya et al., 1995), designing core zones in biosphere reserves based on suitable habitats (Li et al., 1999), or identifying wildlife habitat linkages (Clevenger et al., 2002). In a comparable way, GIS models are suitable for a transparent, systematic and holistic geoheritage assessment.

7.4. Relevance of applied criteria by the indigenous community of Auckland

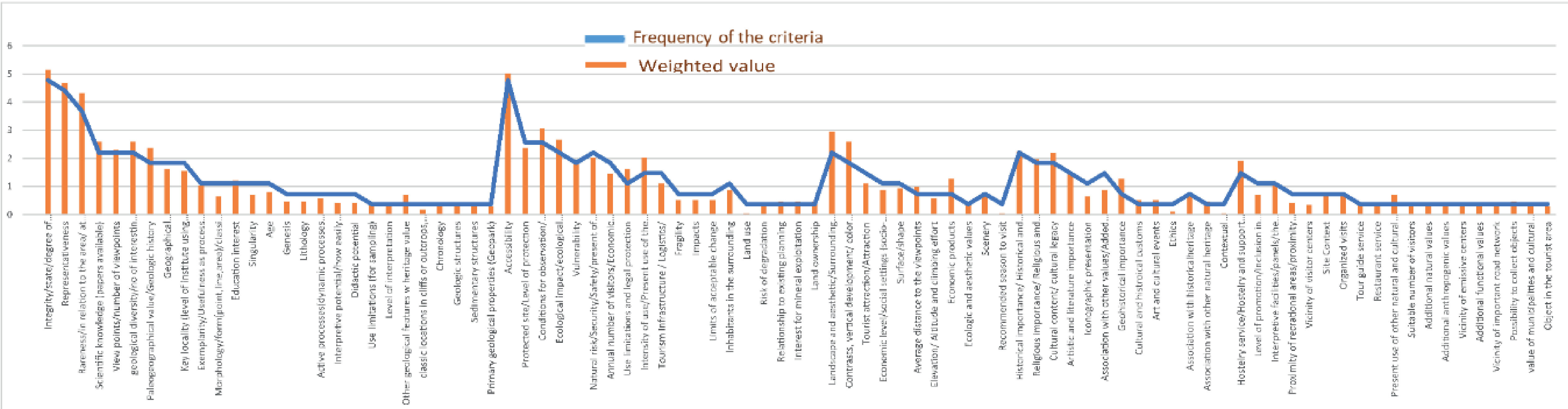
Upon examination of value pathways, it can be seen that indigenous communities may determine the value of their volcanic edifices differently from the general western perspective, and it appears that some areas fall under conflicting conservational objectives from a policy-making perspective. The Tūpuna Maunga Authority has developed a set of plans and policies to guide how the Tūpuna Maunga are valued. The value set accurately describes what geoheritage means for society and how to treat it respectfully. Full details of the indigenous value system for the management of geoheritage can be found in the integrated management plan of Tūpuna Maunga (ancestral mountains). The main goals of the management plan are to create places to host people and rekindle the sense of living connection between the Maunga (mountains, the highest order of sacred) and the people; to give expression to the history and cultural values of the Tūpuna Maunga; and to actively nurture positive relationships (Tūpuna_Maunga_Authority, 2016). Assessment criteria are defined according to these goals, for example:

- Restore and recognise the relationship between the Maunga and its people
- Treat the Maunga as taonga tuku iho –treasures handed down the generations
- Encourage culturally safe access
- Encourage activities that are in keeping with the natural and indigenous landscape
- Promote a connected network of Tūpuna Maunga.
- Preserve the visual and physical integrity of the Maunga as landmarks of Tāmaki.
- Strengthen ecological linkages between the Tūpuna Maunga.
- Maunga tū mauri ora, Maunga tū makaurau ora / if the Maunga are well, Auckland is well
- Rekindle the sense of living connection between the Maunga and the people.

7.5. Assessment criteria analysis

Criteria validation through extracting evaluation instruments has long been used in healthcare practices (Ogles et al., 2001; Prinsen et al., 2016). The systematic review processes were able to propose a core criterion set, resulting in an agreed standardised set of outcomes that could be measured and reported, thereby eliminating uncertainty over their relevance. In addition, consensus-based standards were released for the selection of health measurement instruments. GRADE assessment provides a structured way to consider key factors that may increase or decrease confidence in the synthesised findings of a body of evidence and provides statistical tools for judging the risk of bias and assessing the certainty of evidence (https://www.nhmrc.gov.au/guidelinesforguidelines/develop/assessing-certainty-evidence).

For our multi-criteria analysis, we needed to find criteria with the highest level of agreement. Based on a literature review, the most relevant authors were selected. We collected all criteria from the published instruments of the selected Authors. Each author (or instrument) was assigned a weight based on the number of citations their publication received as of 2019. The Authors' weights were assigned to every occurrence of each criterion. The weighted occurrences were added up and normalised for the final ranking of all assessment criteria found in the literature (Table 16).


Frequency of the criteria
Weighted value

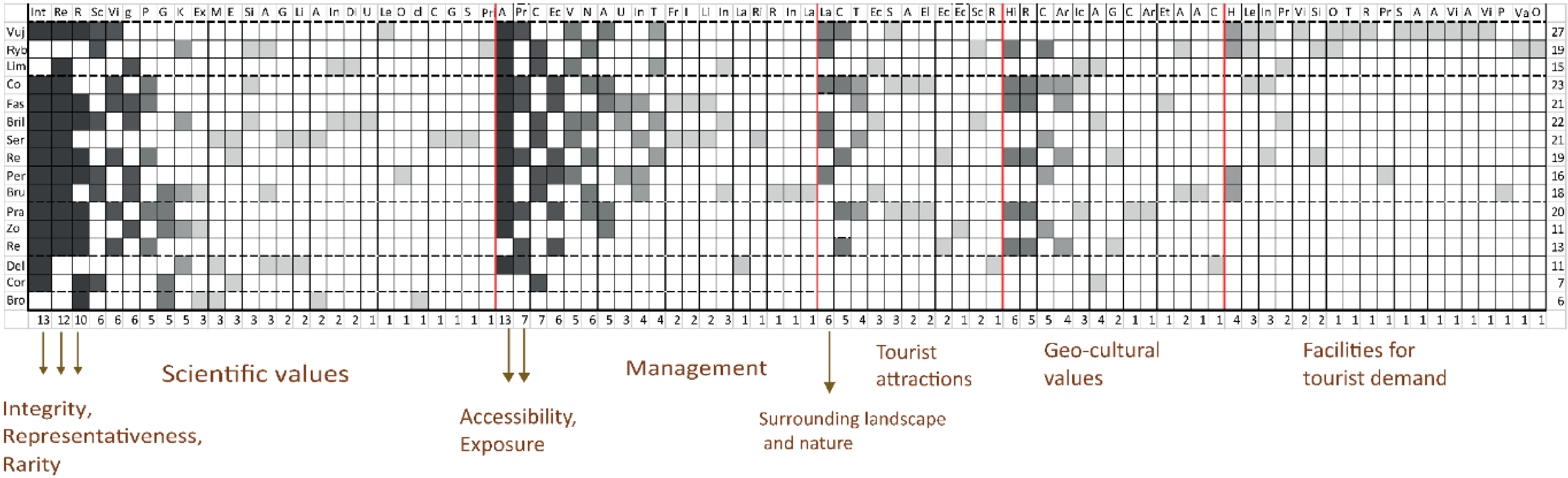

Scientific values
Integrity,
Representativeness,
Rarity
Accessibility,
Exposure
Management
Surrounding landscape
and nature
Tourist
attractions
Geo-cultural
values
Facilities for
tourist demand

Figure 37. Level of argument in value criteria used in evaluation instruments. On the left short side of the matrix are abbreviations of the first 3 letters of the author`s names who published the assessment method and the criteria. Each criterion used in these assessment methods was then extracted and summarised. On the matrix`s long right side are the extracted criterion`s first letters. On the short right side is the number of criteria the given author used in the instrument. Finally, the long left side of the matrix shows the number of occurrences (frequency) of the given criterion. These numbers represent basically the number of citations the published assessment method received.

The relevance of each criterion can be defined by calculating a metric for the level of agreement. Evaluation instruments may be inherently subjective based on the practitioner. By their aggregation, the evaluator's real level of bias can be demonstrated, and the weakest components can be eliminated. Populating the analysis from the scientific literature allows for internal consistency and a global agreement metric. Internal consistency means agreement among the creators of the instruments, and global agreement means the derived citation metric of the article that has published the evaluation instrument. For the readability of the criteria, the bar chart corresponds to the matrix`s columns (Figure 37).

Table 16. The first 30 value criteria ranked by their calculated weights

Weights	Criteria
5,141537	**Integrity/state/degree of conservation/current condition/conservation status**
5,025997	**Accessibility**
4,679376	**Representativeness**
4,332756	**Rareness/in relation to the area/ at national level/significance**
3,061814	**Conditions for observation/ Visibility/Exposure**
2,946274	**Landscape and aesthetic/Surrounding landscape and nature/location in the landscape/ Landscape difference**
2,657423	Ecological impact/ecological value/ecological interest
2,599653	Scientific knowledge (papers available)
2,599653	Geological diversity/no of interestin geomorph. Features/diversity of elements
2,599653	Contrasts, vertical development/ color contrast/Environmental fitting of sites
2,368573	Paleogeographical value/Geologic history
2,368573	Protected site/Level of protection
2,310803	View points/number of viewpoints
2,253033	Historical importance/ Historical and archaeological relevance
2,195263	Cultural content/ cultural legacy
2,021953	Natural risk/Security/Safety/present of potential threat
2,021953	Intensity of use/Present use of the geomorphological inerest/Activities that can be carried out
1,964183	Religious importance/ Religious and metaphysical relevance
1,906412	Hostelry service/Hostelry and support services
1,848642	Vulnerability
1,617562	Geographical distribution/Area/Extent/scale of geoheritage feature

1,617562	Use limitations and legal protection
1,559792	Key locality (level of institute using it)/recognizability/type locality/interest level/Excellence (WHS)
1,444252	Annual number of visitors/Economic potential
1,444252	Artistic and literature importance
1,270942	Economic products
1,270942	Geohistorical importance
1,213172	Education interest
1,097631	Tourism Infrastructure / Logistics/
1,097631	Tourist attraction/Attraction

7.6. GIS Multi Criteria Evaluation for geoheritage conservation and for cultural conservation

Multi Criteria Evaluation using reclassification and weighted overlay function was created for geoheritage conservation and cultural conservation areas. Geoheritage conservation map criteria scored ~3 and over in our criteria analysis were transformed into spatial layers. We ran viewshed analyses for the landscape value criterion (Figure 38). Observation points were the highest point of still-standing volcanic edifices (approximately half of the volcanoes have been partially or completely removed by quarrying).

The viewshed analysis allowed us to identify locations of the most extensive view over the volcanic field. Next, each map layer (Figure 39) was reclassified into five classes (Table 17), so an overlay analysis could be applied.

Table 17. Categorised criteria and the weights assigned to them for the evaluation of Geoheritage Conservation areas

Weight Assigned	5	4	3	4	5
Integrity (% of volcanic edifice situated within corresponding total open space area)	>80	80	60	40	<40
Representativeness (variety of landform classes)	9-5	4	3	2	1
Rareness (spatial extent of landform classes)	5	4	3	2	1
Exposure (distance from interest [m])	100	300	500	800	>800
Accessibility					
Bus routes (distance from interest [m])	100	300	500	800	>800
Bus stops (distance from interest [m])	100	300	500	800	>800
Landscape value (% of view over volcanic edifices to total viewshed)	>25	25	20	15	<10

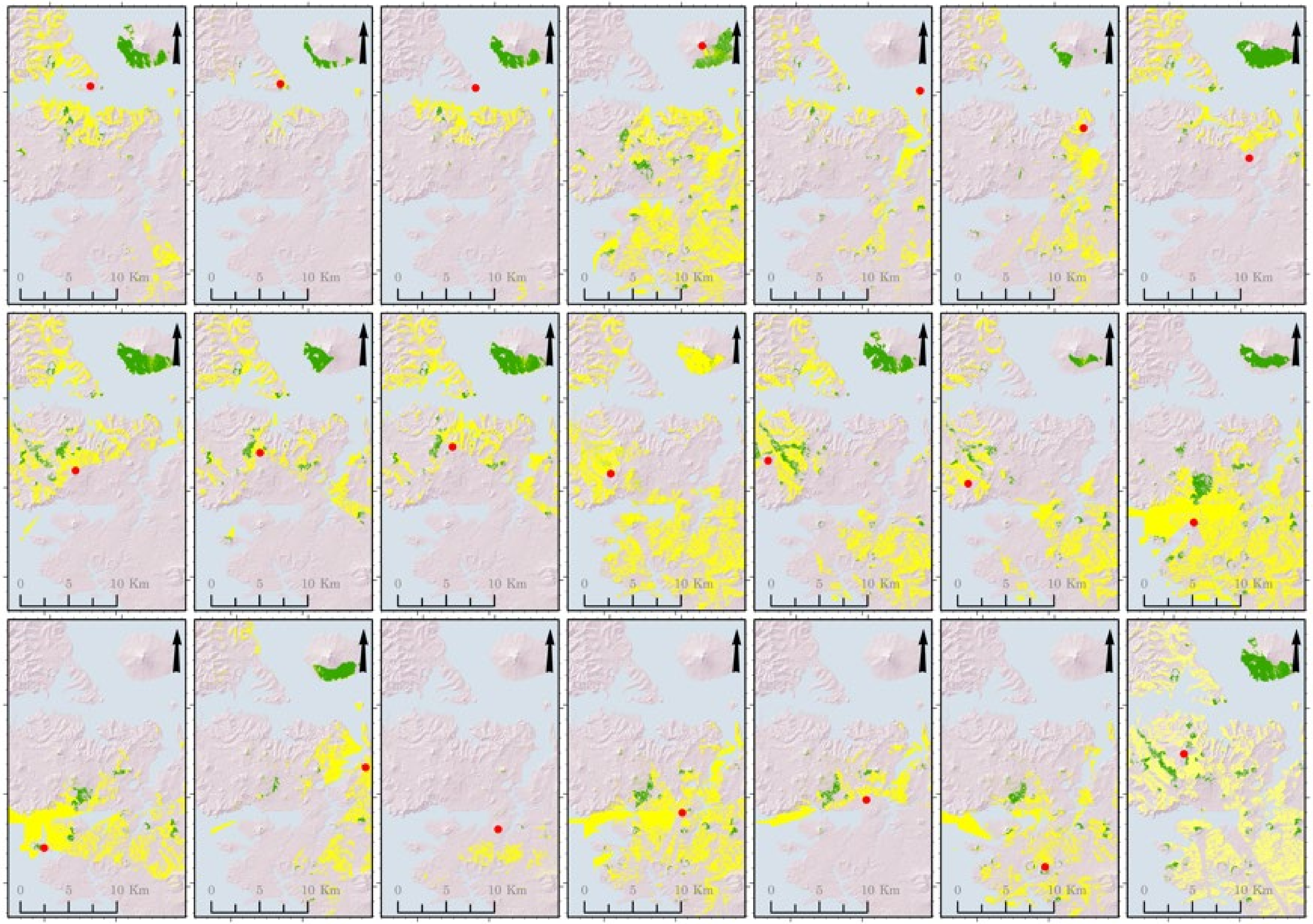


Figure 38. Viewshed analysis from elevated volcanic formations. Green colour shows the ratio of the view over the volcanic edifices. Yellow is the view over non volcanic edifices from the observer points. This viewshed analysis is the reference data for landscape value criteria in the MCE model. The observer points from where the viewshed was measured got assigned the value visualised in green colour in data form of percentage.

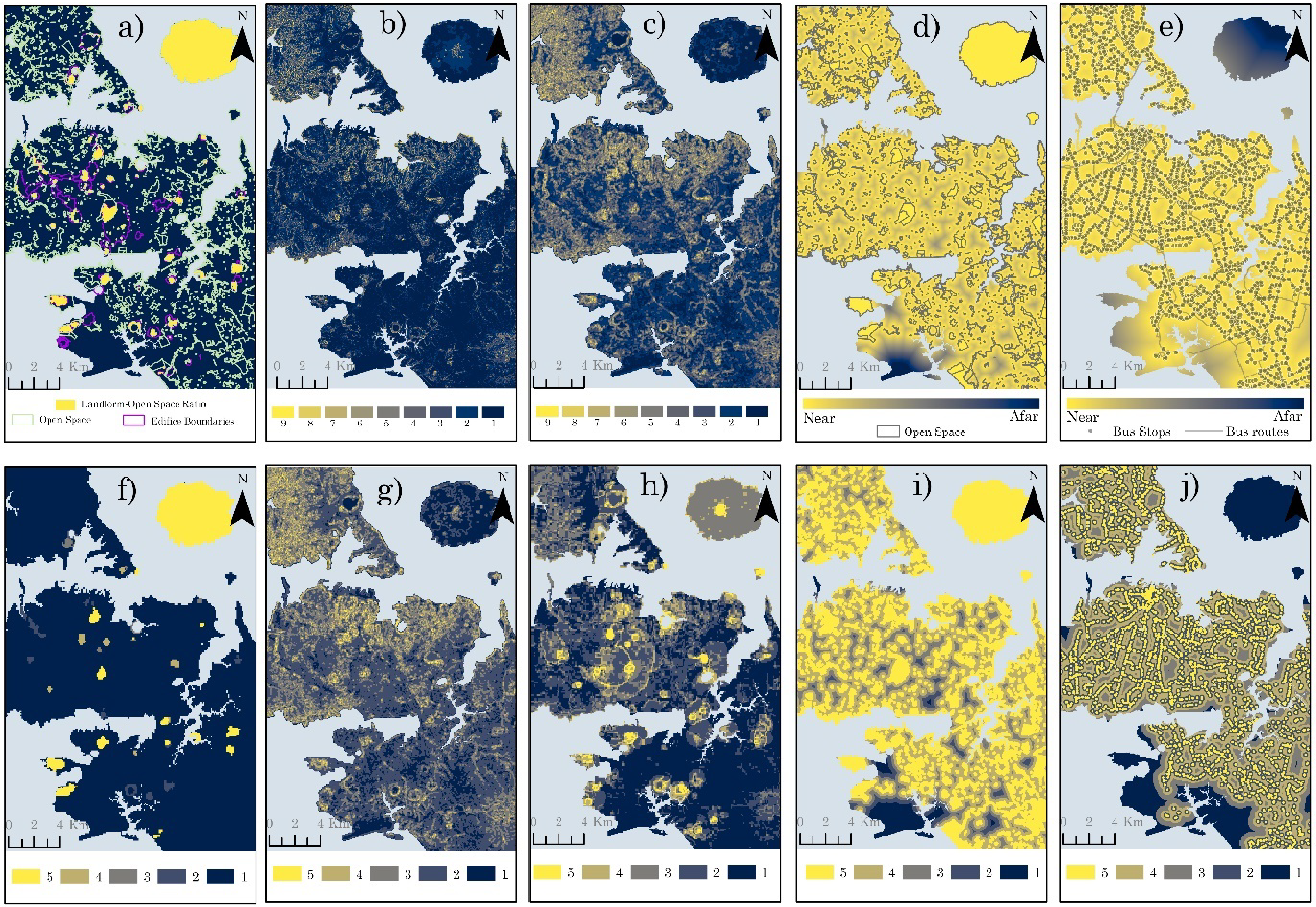


Figure 39. Criteria map to determine areas for Geoheritage Conservation. Top row is the spatial analysis of each criterion, the bottom row is their standardized equivalents a) Base map of Integrity calculation. The yellow patches outline the portion of edifice boundaries fall within open space areas. b) Base map of Representativeness calculation. The nine classes represent the variety (number of landform classes occurring within a 100x100m cell) of landform classes created by the Topographic Position Index. c) Base map of Rareness calculation. The nine classes represent the distribution of the landform classes derived from standardized multi scale Topographic Position Index maps. d) Base map of Exposure calculation. Near to far values represent the increasing distance from the open space area. It is self-explanatory that volcanic edifices are best exposed within open space areas of the urban expansion. e) Base map of Accessibility calculation. This accessibility map is the result of the overlay of two Euclidian distance map of bus stops and bus routes. Near to far values represent the aggregated distance from bus stops and the roads of bus routes. f) Reclassified map of Integrity into five categories with 5 being the highest weight. g) Reclassified map of Representativeness into five categories with 5 being the highest weight. h) Reclassified map of Rareness with 5 being the highest weight. The map is adopted from a previous study that determined the geoeducation capacity of the area. The geoeducation capacity value for each cell was attained through the aggregation of geology, geopreservation inventory and landform classification maps. Smallest to largest spatial extent determined the weight for the different categories that corresponds to what Rarity as criteria aims to achieve. i) Reclassified map Exposure with 5 being the highest weight. j) Reclassified map Accessibility with 5 being the highest weight.

For criteria to map cultural conservation (Figure 40), we used available data on archaeological sites, culturally significant landforms, and elevation (Table 18). The latest became a criterion because we postulate the cultural value increases with the elevation because of the multiple purposes for which the hills were used (defence, village, terraced gardens, food storage etc.). On the one hand, the indigenous belief system identifies hills and mountains as our ancestors, and high strategic value was placed on the volcanic cones for pre-European settlement in the region.

The final maps maximised the suitability of lands for geoheritage conservation and for cultural conservation (Figure 41), which provides functionality to analyse geographic data.

Table 18. Multi Criteria Evaluation to identify Priority Areas for Cultural Conservation

Weight Assigned	**5**	**4**	**3**	**2**	**1**
Māori Cultural/Archaeological points					
Rasterized (number of points within 100 m cell)	4	3	2	1	0
Distance function (m from interest)	100	300	500	800	>800
Tūpuna Maunga owned landforms					
Distance function (m from interest)	100	300	500	800	>800
Hillshade					
Classified (m)	>200	200	150	100	<50

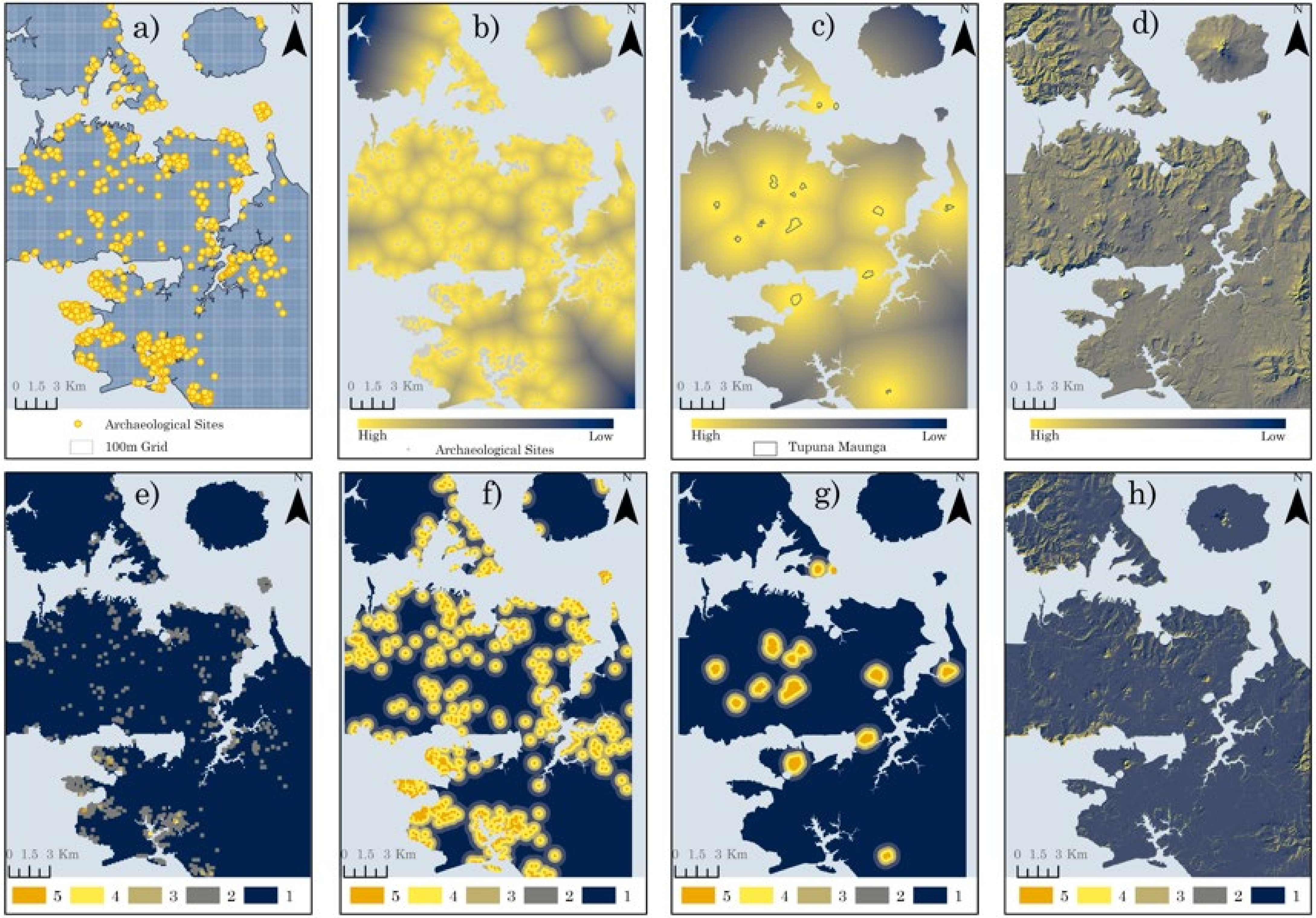


Figure 40. Criteria maps for the determination of areas for Cultural Conservation. The top row is the spatial analysis of each criterion, the bottom row is their standardized equivalents. a) Base map of archaeological (https://archsite.eaglegis.co.nz/NZAAPublic) hot spots. The number of points falling within a 100x100m cell established the weight assigned to each cell. b) Base map of the distance from archaeological points measured in meters. c) Base map of the distance from the Tūpuna Maunga (ancestral mountains) edifices. d) Base map of the elevation. e) Reclassified map of the archaeological hot spots. f) Reclassified map of the distance from archaeological points. g) Reclassified map of the distance from the Tūpuna Maunga edifices. h) Reclassified map of the elevation.

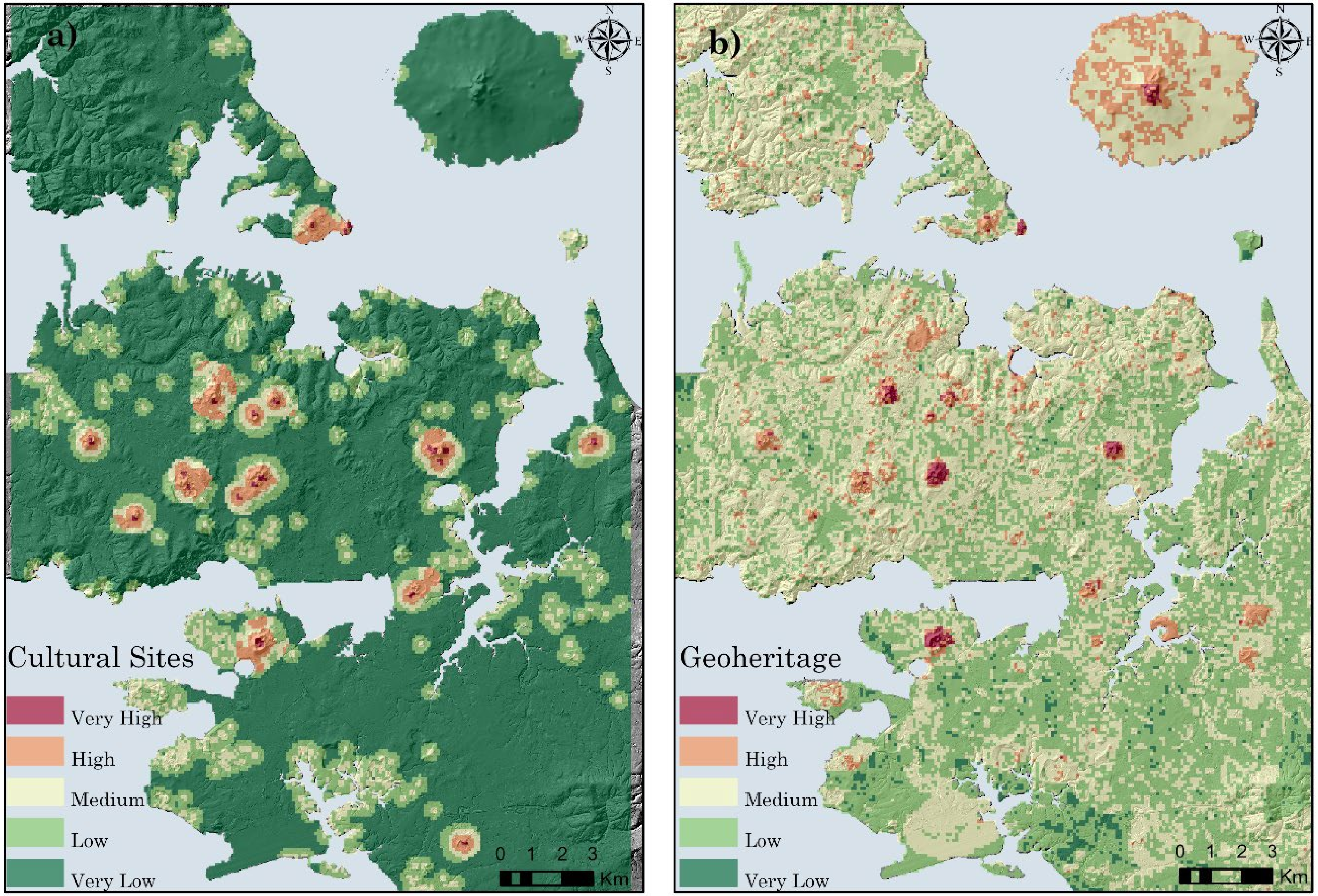


Figure 41. The results of the multicriteria evaluation. a) Areas to be prioritized for cultural conservation. b) Areas to be prioritised for geoheritage conservation.

7.7. Multi-Objective Land Allocation

The definition of objectives is a critical component of all decision-making processes. Multi-Objective Land Allocation (Figure 42) is not only a tool for assisting decision-making but can also provide evidence to resoling any disputes arising from conflicting objectives.

GIS-based Multi-Criteria Evaluation and Multi-Objective Land Allocation methods have the potential to provide objective tools to identify regions of high geoheritage values that require a formal geoconservation strategy. While we are unlikely to be able to overall slow urban and industrial expansion due to the socio-economic pressures Auckland faces in finding suitable housing and industrial regions, our methods allow us to explore a range of pathways to balance conservation needs and inevitable urban expansion and create a record of all existing features to be able to track the rate of their loss into the future.

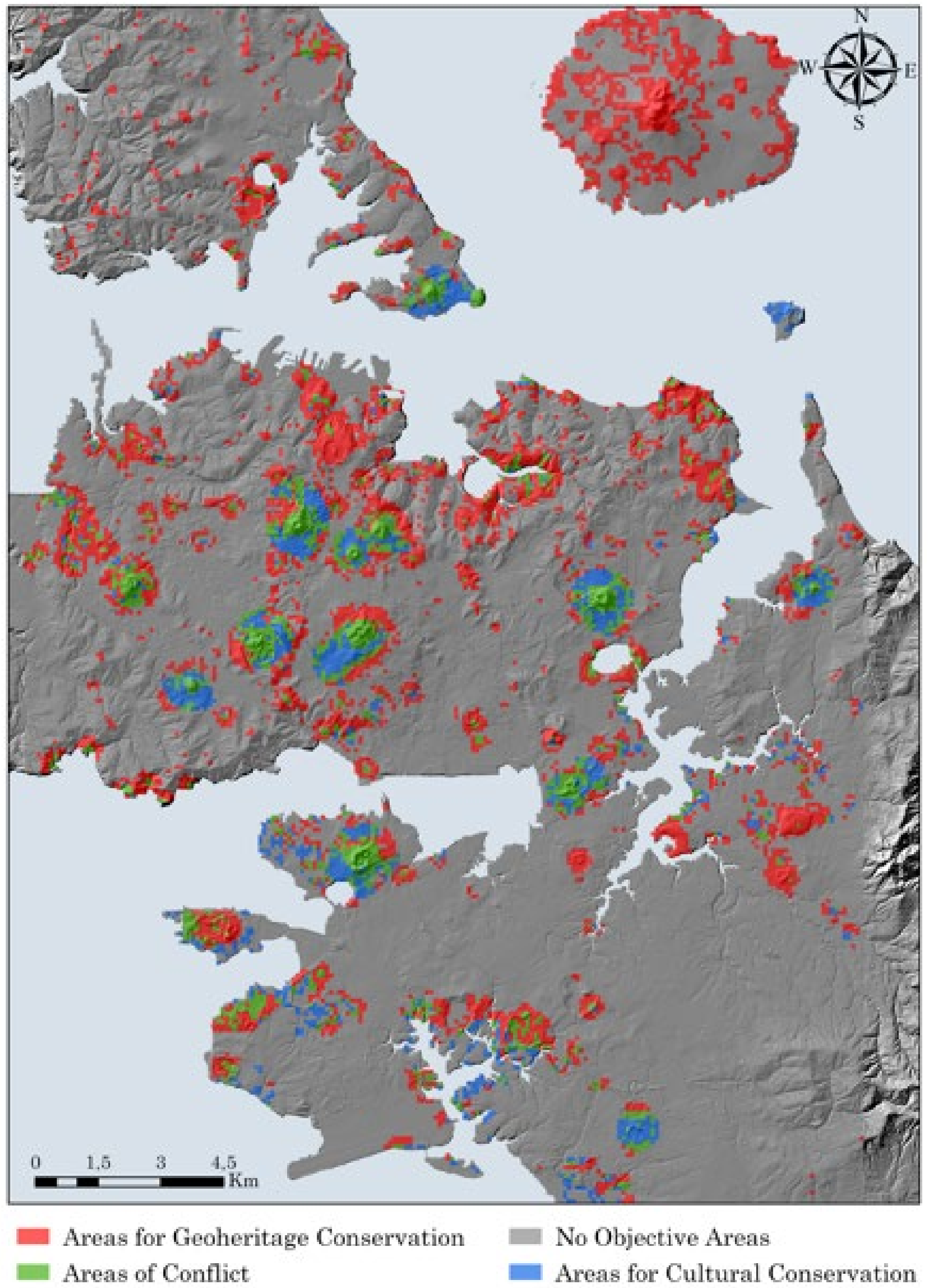


Figure 42. Multi-Objective Land Allocation. Red shows the areas of the highest value for geoheritage conservation derived from the multicriteria evaluation carried out for geoheritage conservation. Blue colour highlights the areas of the highest value for cultural conservation that as well were derived from the multicriteria evaluation for cultural conservation (Figure 4*0*). Finally, green colour delineates the equally important areas for both objectives, geoheritage conservation and cultural conservation and need further investigation on how to create a comprehensive management plan that satisfies all stakeholders.

7.8. Comparison of visitation intensity, geoeducation capacity and MCE – MOLA results

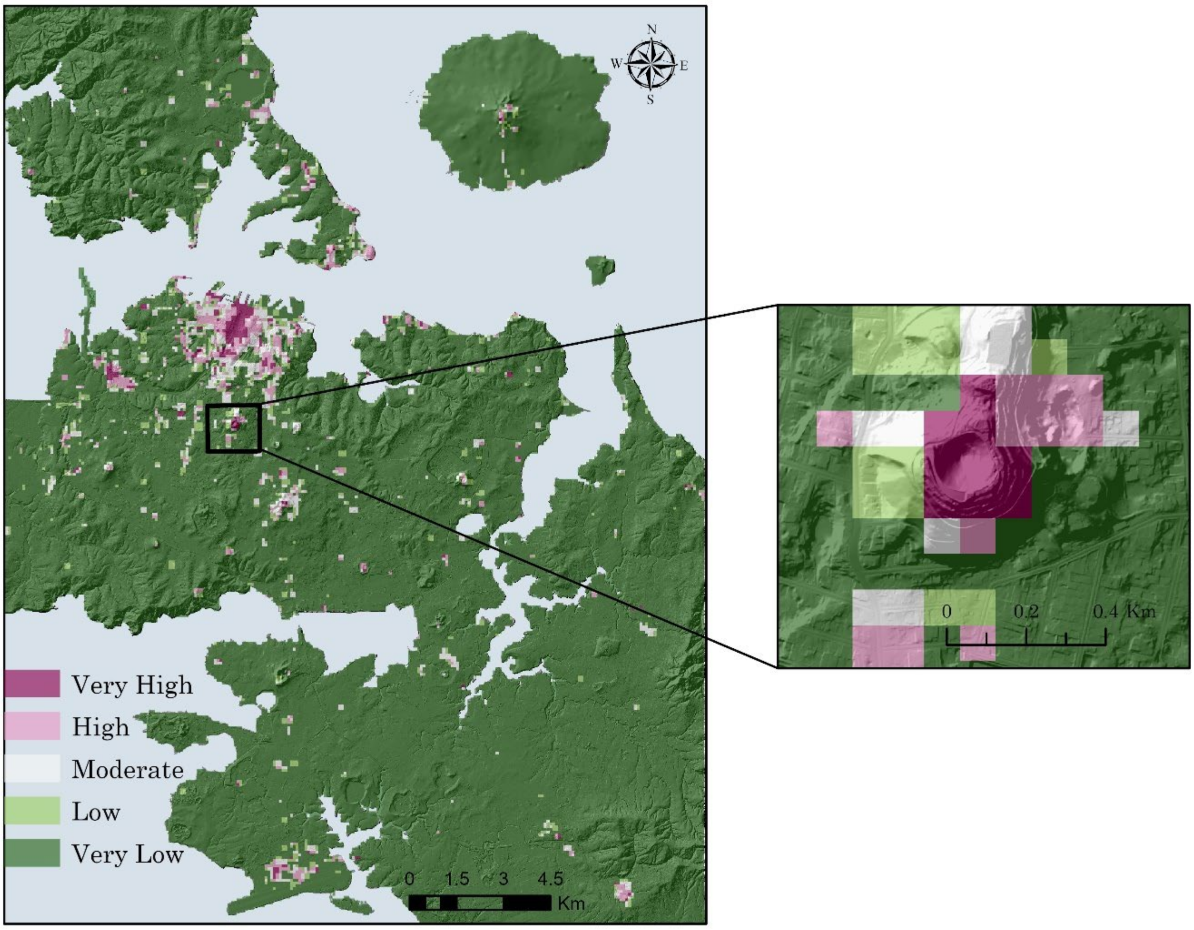


Figure 43. Visitation Intensity of Auckland city with Mt Eden in large scale. Mt Eden as a volcanic cone receives high visitation and it provides the best view over the volcanic landscape of Auckland (Németh et al. 2021b).

The visitation rate can be investigated through big data mining. The previous study utilised FlickR data (Figure 43) to identify the visitation intensity of 100mx100m areas (Németh et al., 2021b).

The base Digital Elevation Model (DEM) was attained from the LINZ Data Service (https://data.linz.govt.nz) that was derived from LIDAR point-cloud data captured by airborne sensors. The tourism system is a major contributor to the New Zealand economy (https://www.stats.govt.nz/topics/tourism). Tourism is New Zealand`s largest export industry. Tourism is not only a tertiary industry here, but also it seeks to bring social benefits across cities and communities, build deeper international connections, and enable other exporters and service providers to tailor and market their products and services to those markets. The main objective of Tourism New Zealand`s tourism marketing campaign is the international market, 100% Pure New Zealand, even during the COVID-19 pandemic. With restrictions on travel to New Zealand, international target audiences could be inspired by virtual experiences, for example, to showcase New Zealand while people unable to visit in person. (100%_Pure_New_Zealand 2020). While it remains unrealised to date, potentially, this provides an opportunity for the promotion of New Zealand's geoheritage values and sustainable community-based geotourism. (Gravis et al. 2020a; Gravis et al., 2020b).

Looking at geoconservation in the context of geoeducation, we see a clear picture of how the city would benefit from the protection of geologically and culturally significant features. Taking this as a given, we aim to provide a baseline of values for conservation and seek to objectively identify, delineate, and implement features for geoconservation. Geoeducation (Figure 44) must become an everyday facet of life in geologically active regions in order to increase resilience in the wider community. Our geoeducation capacity map (Németh et al., 2021b) shows where geoheritage has the highest educational value. The overlay of geoeducational capacity and visitation highlights the areas of high potential. However, we suggest priority needs to be given to these areas for community engagement, higher visitation in a sustainable and low-impact manner, and promotion of cultural, geological, and scientific values. This can be reflected in advocacy by relevant stakeholders, transparent decision-making based on sound data and analysis, and readily accessible records of all components underlying actions and decision-making.

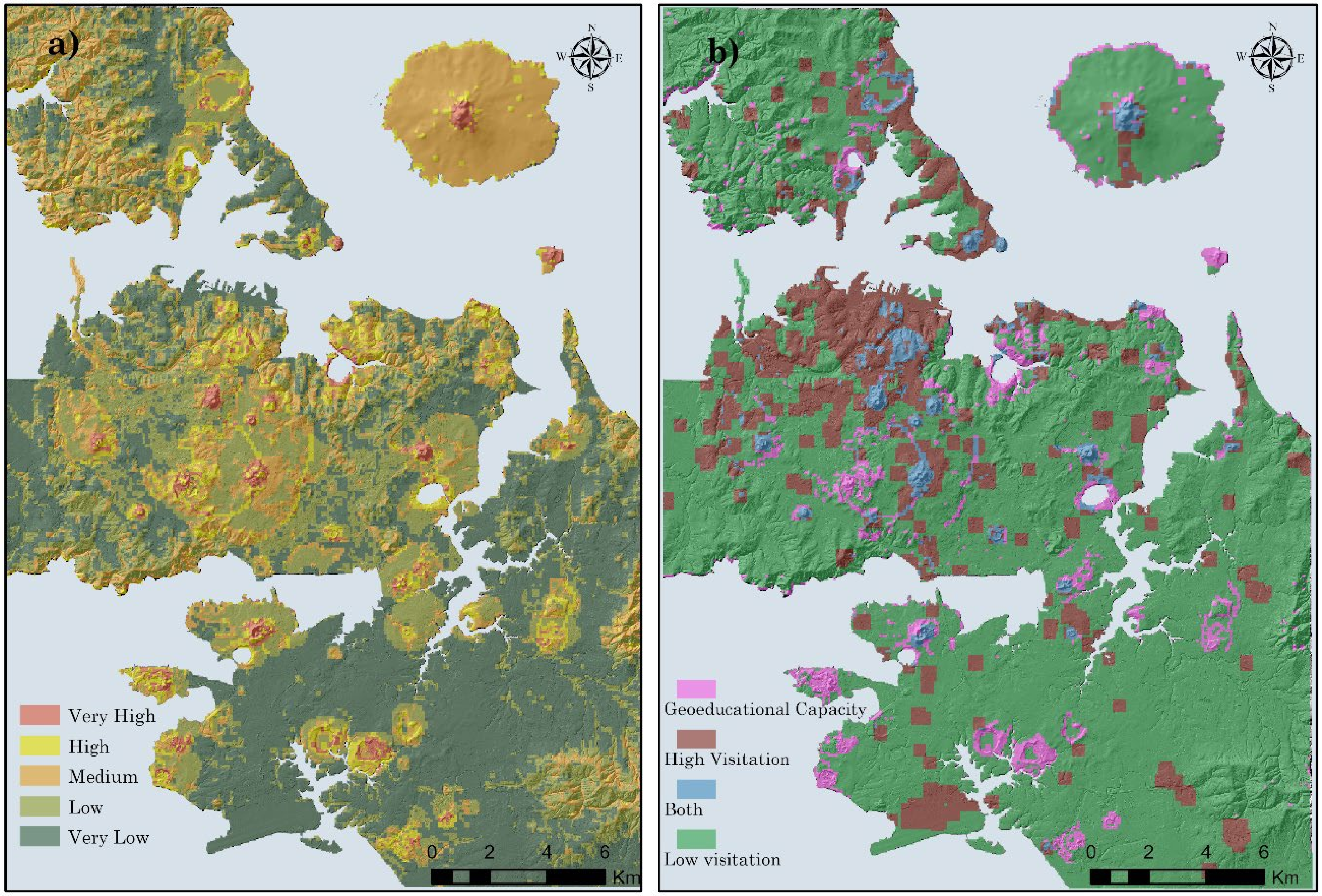


Figure 44. a) Geoeducation Capacity map. b) Visitation intensity map on high geoeducation capacity areas. The maps are the result of our study that combined topographic position index, geology and geopreservation inventory to identify high geoeducation capacity maps and compared it with the visitation rate that was acquired through big data analysis (Németh et al. 2021b).

Evidence shows that the first human settlers in New Zealand were the Māori, arriving from the Polynesian Islands (Hanson, 1989; McWethy et al., 2010). Their social system places people within the natural environment on an equal footing with all other aspects of the environment and land. Whakapapa (the line of descent from one's ancestors) places people in a wider context, and it is of note that all aspects of the environment, which in a western sense would be considered inanimate, also share a line of descent back to the highest deities. With this line of descent comes a responsibility as kaitiaki (guardian) of the total environment and specific sites, which may be considered wāhi tapu (sacred places) for several reasons. The description of indigenous people as tangata whenua (people of the land) reflects this multi-generational connection to the land, and it is of note that whenua, the noun for land, is also the noun for placenta in the Māori language. In the physical world, this connection is cemented by the placenta of a newborn buried at the place of birth. Failure to safeguard this natural environment can be seen in manifestations of the imbalance in the system in cultural alienation and complex intergenerational socioeconomic issues. In contrast, the scientific approach to life that our modern world is based on does not allow for observation of rules and sociocultural norms unless supported by empirical evidence observable in the physical realm. Nonetheless, based on scientific data and analysis, it is becoming increasingly apparent that hazard mitigation becomes futile without guarding and protecting our non-living environment. Furthermore, measures of healthy communities are becoming more and more linked to the level of connection to their natural environment.

Governed by a model combining indigenous and evidence-based worldviews. A excels in contributing to solving crucial and complex world issues. New Zealand promotes peace, security, trade, human rights, the end of hunger, health epidemics prevention, climate change, and enhancement and protection of the natural and indigenous environment. New Zealand advocates that the solution to these issues lies beyond the unilateral acts of individual countries and cultures and must be approached on a multilateral international basis.

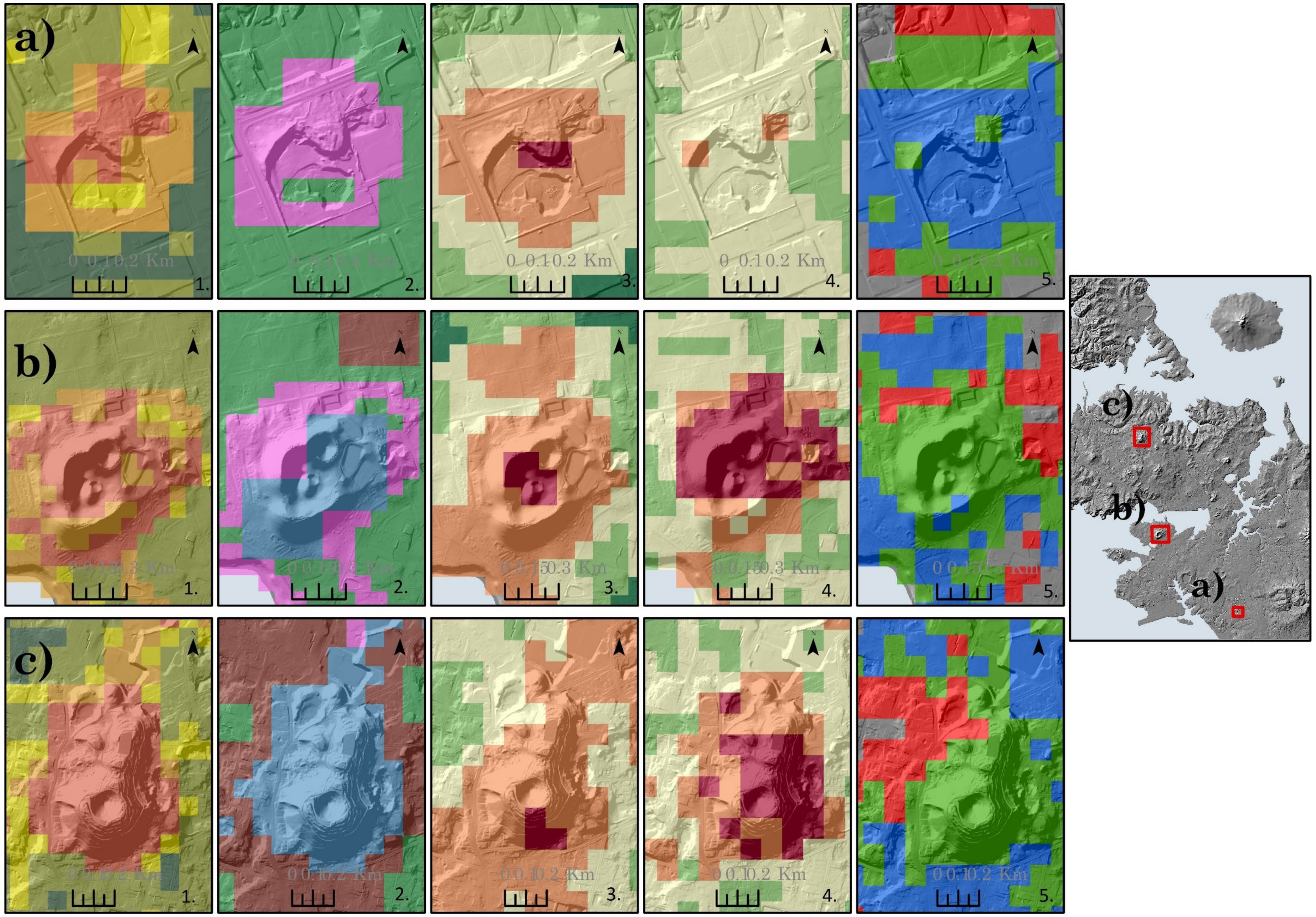


Figure 45. Comparison of Wiri quarry (row 1), Mangere Mt (row 2) and Mt Eden (row 3) by the geoeducation capacity (1), visitation rate (2), areas for cultural conservation (3), areas for geoheritage conservation (4) and Multi-Objective Land Allocation (5).

Using three volcanic sites subject to various levels of historical quarrying, we demonstrate significant changes to the locations and their impact on various aspects of heritage elements (Figure 45). We selected the three sites where the most dramatic changes and/or the highest geological, geomorphological and geocultural values provide a unique opportunity to test our approach.

The Wiri quarry in the southern part of the Auckland Volcanic Field was used as a raw material building site. After the cessation of the quarry activity, the location was used as a commercial waste dumping site, subsequently transformed into an industrial storage facility after the complete infill of the quarry pit. All this took place against a backdrop of remarkable geological features, the quarrying exposed in the remaining walls of a complex tuff ring/scoria cone complex. The sequence map of the Wiri quarry (Figure 45a) shows that it carries high geoeducational capacity. It does not receive any visitation, as it is now a privately owned industrial repository and storage facility. We can observe that it not only has geoeducational capacity but it also bears high cultural and geoheritage relevance.

Mangare mountain, just north of Wiri, has gone through some limited quarrying, but in recent times the location has been transformed into a local recreational park and the home of one of the first geoeducation and cultural centres explicitly affiliated with one of the volcanic cones, the Mangare Mountain Education Centre (https://www.mangeremountain.co.nz/). The sequence map for Mangere shows smaller land features of the whole edifice as holding high geoeducational value. This demonstrates the importance of the scale of specific features, as different scale delivers different information. The second map shows the high geoeducational capacity pixels as areas receiving high visitation. However, in this case, with the visitation cover, we need to apply a more practicable approach, as it does not mean that two-quarters of the landform is not visited. It means that the visitation hits a medium range, not generating enough coordinates to cover the landform as a whole. Locations within the Mangere landform have elevated cultural conservation value, overlapping with sites of elevated geoheritage conservation values.

Mt Eden is the most visited volcanic landform, one of the most well-preserved scoria cones in Auckland, and provides the best view over other volcanic landforms in Central Auckland, as revealed through our viewshed analysis. Archaeological sites have added high cultural conservation relevance to the cone's southern flank. From a geoheritage conservation perspective, the cone's middle to the northern part carries the highest values. Overall, the entire edifice is subject to conflicting values, but when looking at broken-down objectives, it is possible to create a comprehensive conservation management framework.

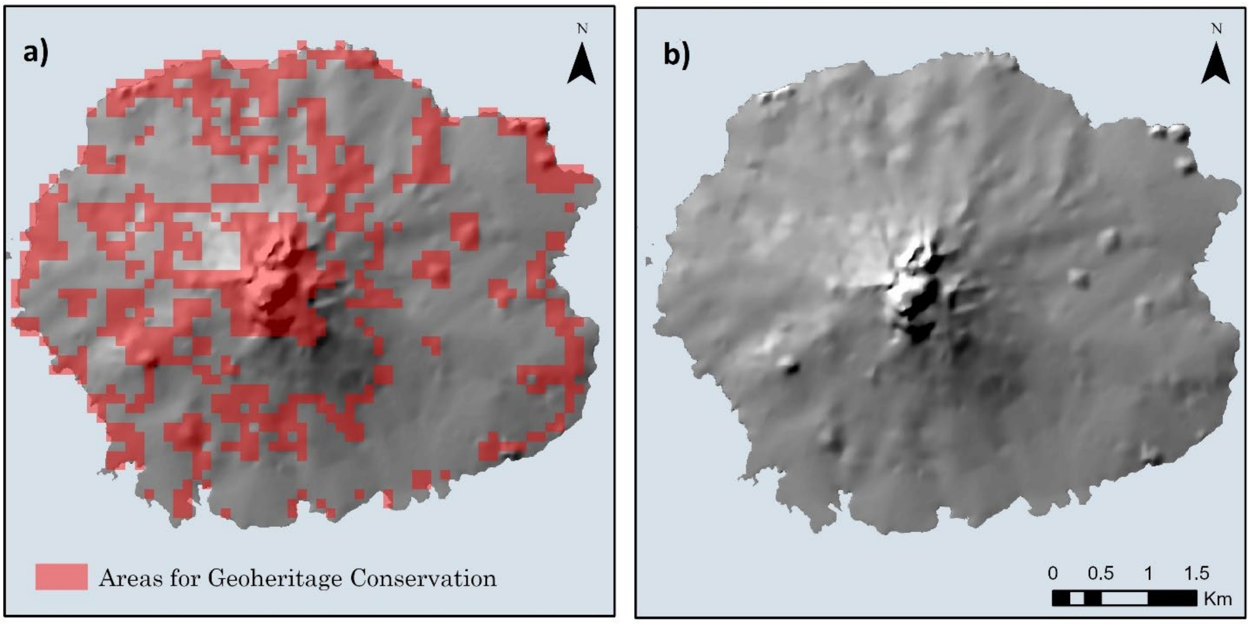


Figure 46. Rangitoto Multi-Objective Land Allocation (MOLA) (left) compared to its hillshade (right). Rangitoto was used within our evaluation because this location (a large compound lava shield with capping scoria cones) considered to have international significance and already established touristic ventures.

The map (Figure 45) allows us to explore a range of pathways and create a record of all existing features for the future to be able to track the rate of loss. Our study's main message is that an area's cultural and economic values can be accentuated in decision-making by applying our method. The more specific the objective is, the more distinguished units are defined. As we add objectives and criteria, an entire landform can become an area of conflict, causing difficulties in decision-making. However, when the task is to have an overall examination of the areas needing more attention, MOLA is a very effective tool. The example of Rangitoto (Figure 46) shows that the Topographic Position Index was able to pick up small features that can be outcrops or other surface features which might deliver important geoscientific information. The model at this stage is suggested as the basis of conservation planning and guidance for where ground truth work needs to take place.

7.9. Discussion

The difficulty of quantifying the benefits of protecting scientific values led to the inclusion of the values bringing benefits to society as understood today, such as cultural, touristic, aesthetic, recreational and biotic values. Geoheritage is inseparable from culture, tourism, or biodiversity. Geology and geomorphology have demonstrably influenced the development of human beliefs, indigenous communities' settlement patterns, and modern industrial societies' growth. Biogeography describes species distribution based on geomorphology and geological processes (Whittaker et al., 2005). Volcanic processes of the Neapolitan area at Campi Flegrei and Somma-Vesuvius (Italy) have played a fundamental role in urban development in terms of architecture, geohazards, and anthropic activities (Morra et al., 2010). Volcanic landscapes, in general, have attracted humans and deeply influenced the historical evolution of urban settlements due to the volcanic landforms, suitable geophysical properties for building, fertile volcanic soils, or simply the strategic value of solitary highly visible elevated volcanic cones reasons. Such settlements are a feature of Auckland and its volcanic landscape reflected in the Māori worldview and cultural connections to the land, and fortified shelters based on volcanic cones (pā) (Hargreaves, 1959; Stone, 2001; Davidson, 2011; Gravis et al., 2020). At Cuicuilco in Southern Mexico City, traces of volcanic impacts on the prehistoric environment can still be observed today (Cordova et al., 1994). Disasters can modify the present-day environment and create an unfolding narrative that will come to form the basis of future heritage values for coming generations and their resilience, as we can observe in Kilauea, Hawaii, where people choose to stay near the active volcano that provides them with geothermal energy to technological power systems (Brady, 2018; Holtorf, 2018).

However, as discussed earlier, we suggest that international conventions such as the World Heritage Convention are predominately weighted towards protecting cultural and biotic heritage. It is doubtless important that these values are given the promotion and protection they deserve, but this should be on an equal footing with values based on geoheritage, geodiversity, and geoconservation, values which only form a minor and secondary basis, if any, for current initiatives.

The main terms related to geoheritage are based on a range of secondary s concepts which may overlap, such as geosystem services, geodiversity, biodiversity, geotourism, and sustainability. Reviewing the scientific literature, it soon becomes apparent that a scientifically based, adequate and widely accepted definition of geoheritage and its associated concepts is readily grasped. Many questions emerge, not limited to but including interest 1) what specific and clearly definable abiotic elements are included in geoconservation; 2) should indigenous flora be a significant pillar of geoheritage conservation; 3) what is the unit of geodiversity, and how can we objectively define a region as being a high geodiversity area; 4) does geodiversity involve topography and other clearly defined qualities of specific habitats such as corridors falling within broader evaluations; 5) should an outcrop be described as a geomorphosite; 6) what is the value into protecting an important local outcrop for teaching and community engagement by local Earth Scientists; 7) is it morally acceptable that tourism demands should determine geoheritage outcomes; and 8) can a geopark be created without acknowledging and celebrating any outstanding cultural values. Questions raised should be applied to contemporary discussions, debates, and research around cultural diversity, biodiversity protection, niche tourism, and policy implementation, while acknowledging an overall concern for disappearing and highly modified landscapes that underly Earth Science research. We acknowledge that it is not helpful to consider any of the topics raised in isolation. A holistic and multidisciplinary approach to the theory, science, and philosophy behind geoheritage can help define this field more clearly. To date, interpretation can appear arbitrary and ad-hoc in its application, leading to the debate around foundational issues such as whether geoheritage should be based primarily on geology or geomorphology of features.

We have reached the 30th anniversary of the conference where `Geoheritage` was first mentioned (Anonymous, 1991). Since then, scientists all around the globe have decided t different concepts, ideas, theories, and evaluation methods. The concept of geoheritage has become organically incorporated into branches of geology and geomorphology and still developing related scientific topics such as geodiversity, geosystem services, and geoeducation. Sustainable geotourism, as our systematic mapping for a conceptual framework, has revealed. The amount of publication and data released can be considered the representation of all possibilities and options for geoheritage to be associated with. We consider this an ideal time to collect all ideas and form a solid conceptual framework, thereby preventing the continued expansion of what appears to be a "jungle" of related and overlapping concepts. Undeniably, a significant effect of geoheritage can shape potential economic opportunities in socioeconomically burdened areas, even if there is no current capacity. Scientific recording and research can be used to underpin opportunities for future generations, where outcomes remain readily accessible and engaging, and landscapes and associated features are treated as an asset for current and future generations. Destruction and modification of any geological evidence are essentially robbing future generations of our society of understanding hazards and risks in their own contemporary times. Landscaping can modify key geological features and evidence of geomorphological processes such as fault lines or anything underpinning further evidence for potential natural hazards (Fabbri & Chung, 2009; Cui et al., 2021).

In order to address the perceived subjectivity and rather low transparency of selection criteria, we suggest a need to address the systematisation of geoheritage. We acknowledge that subjectivity can be inherent, and each evaluator may have a different "instinct" for defining criteria depending on their background and field of expertise. Taken as a whole, attempts to define geoheritage and maintain integrity in methods can be seen as resulting in philosophy with subjectivity having a negative effect on rates of implementation. However, humans are inevitably a product of their environment, with values influenced by their physical environment, which can subsequently lead to a desire to conserve their geoheritage (Wachs, 1992). Overall, a community's view of geoheritage may be based on cultural and spiritual factors. In contrast, the scientific view of geoheritage may be based on strictly scientific values, often with a hint of bias to their own research area. Policymakers must understand the potential socioeconomic benefits of geoheritage and the lost opportunities when geoheritage is not an integral part of planning and policy implementation. All countries, regions, and cities will have different sets of priorities and imperatives that can shape instruments.

The industrial revolution and subsequent population expansion, and vast demand for resources have taken a significant number of natural resources, and their host rocks have removed any potential for geoscientific research. Today's geologists deal with geodiversity that, in many regions, is buried under buildings and streets or part of the built fabric of communities. Their knowledge about a region's exact history in terms of geology and associated processes relies on historical photos or historical teachings of late geologists. However, their knowledge is extensive and can be used to demonstrate which sites will hold the greatest value in preserving these stories for future generations. A sure way to destroy any evidence and potential value for future generations are to remove features at a landscape scale through quarrying, infill topography for landscaping, and removing geomorphic features for infrastructure, buildings, and recreation areas. This is where geoheritage could play an even more crucial role in human connectedness to nature (Vining et al., 2008; Zelenski et al., 2015). With effective and well-informed policies, these geosites can preserve, and if there is no current value for the touristic use of a geosite, they can still be recorded on a map or database, thereby ensuring that if future urban development takes place, their preservation will be favoured. It must be noted that geosystem services were recently defined and described to address unrecognised and undervalued geosites. Geosystem services progressively readdress the importance of balance between ecosystem services and abiotic nature but with a stronger focus on geodiversity. In pursuing an overarching sustainable philosophy and aligning with the ecosystem services model, this concept places the benefits of geological and geomorphological features for humans at the centre of evaluation (Gray, 2011; Bastian et al., 2015; van Ree et al., 2017).

The evaluation criteria of geoheritage align with the conceptual development of geodiversity estimates. Analysing the criteria used for evaluation reveals an interesting trend. The different concepts existing in the literature appear in our criteria set for evaluation. Well-elaborated evaluation methods can be cited in the scientific literature of this field, adapted for local and regional conditions, and combined with the influences of other disciplines, thereby continuing to influence and shape the development of a universally accepted metric and facilitating agreement on relevant and suitable criteria. Geoheritage conservation (geoconservation) can be shaped by predictions of the expansion of settlements, and expansion of infrastructure, thereby promoting and facilitating conservation measures. Additionally, it is important to analyse the most favoured pathways of tourists, connectivity of geological features, and boundaries of geomorphological edifices when planning geoparks or other means of practical conservation. There is an urgent need to utilise the best available techniques for optimising conservation efforts against urban/industrial development. It is not only important to prevent further loss of significant geoheritage features but also to encourage the discovery, promotion, and education of geological and geomorphological features (e.g., mining geoheritage, urban geoheritage, geoheritage of building stones etc.). Geoheritage conservation, however, does not have as well definable units as conservation biology. It is straightforward to measure different species and the number of individuals of the species, their life-supporting conditions and nutrition. In terms of geoconservation, units may be less definable, and boundaries of geological elements are less straightforward. Furthermore, it is as when modifying geology and extracting geological resources for development to conserve significant findings that may impose further constraints on the application of geoheritage protection.

Geoheritage conservation is a multidisciplinary study developed to build a bridge between geology and the practical issues of its conservation. The discipline involves geology, geomorphology, hazard mitigation, education, geopark-protected area- national park management, urban planning, land use planning, tourism, social sciences, and cultural heritage. The distribution of significant geological and geomorphological features across the globe recognises no national boundaries. The mapping and analysis of their geographic data and their cultural, biological, educational, or social relevance is a primary need of this discipline. Analytical tools provided by GIS software, such as overlay analysis, multi-criteria analysis, and multiple objective analysis, deliver large amounts of information on a global scale. This allows for collaborative research and decision-making across occupational fields, such as politicians, rangers, scientists, local community representatives and other stakeholders. GIS allows the discipline to fulfil its promise of providing a scientific framework for decision-making and delivering complex solutions for issues in practical conservation within urban settings.

With the collaboration of local representatives, historians, and geologists, further information can be fed into the GIS evaluation of the geoheritage sites in Auckland. Further steps are to create a spatiotemporal map of the use of the geological maps to enhance the cultural aspect of the study. The limitation of our study was the hyper-focus on the scientific value and the geoeducation capacity of the features as the major gap in conservation sciences. It was very important to address geoeducation in a standalone study to draw attention to the need to deliver comprehensible but advanced information on the local geological processes. Hazard mitigation in geoheritage conservation needs to be an independent objective, investigated to the deepest details before a multi-objective analysis is carried out in a region. This is particularly important in a geologically active area, where a volcanic eruption can potentially occur at any time. However, Earth Science should be understood as a system of processes in time and space only; therefore, the geoeducation in geologically inactive regions is just as important in the creation of a general understanding of Earth processes for everyone.

Chapter 8 *Conclusion*

This chapter summarises the major aspects of the conceptual framework and GIS data layers that were developed in this study to provide a synthesis of a new approach to geoheritage evaluation. Ensuring consistency in geoheritage conservation practices is very important for quality implementation.

Chapter Contents

Chapter 8. Conclusion

8.1. Objectives

Objective 1

To achieve conceptual clarity by creating the conceptual framework necessary for identifying the geoheritage elements of geodiversity in the Auckland Volcanic Field (AVF). To address the conceptual diversity, all available information on geoheritage concept proposals needs to be synthesized.

A preliminary literature review revealed the weaknesses of geoheritage conservation that stem from the novelty of the subject. Despite the existence of an extensive geoheritage inventory in the greater Auckland region, the recognition is slow and ongoing. However, the subject is emerging despite there being no common applicable methodology for evaluation criteria selection. A detailed literature review was intended to showcase the conflicts between geoheritage concepts and terminology that allow practitioners taking upon geoheritage assessment to pick and mix among options. Therefore, the objectives are often unclear that result in vaguely defined criteria. The complexity of the decision-making problem requires more rigorous methods that eliminate subjectivity that is detectable to a certain level in existing geoheritage procedures.

The way to evaluate and rank geoheritage items is through value criteria. The geoheritage assessment of a list of natural features hence depends on the applied set of value criteria. Unfortunately, there are wide different varieties of features and values that leave space for arbitrary interpretation and dilution of geoheritage vision. Practitioners identified sets of specific criteria that delineate the conceptual background. During recent decades, however, controversial assessments were carried out, jeopardizing the effectiveness of the extensive efforts of practitioners.

Objective 2

Investigate the underlying motives to achieve objectivity and reliability using advanced multivariate statistics. To seek correlation among different types of world development *indicators with bibliometric data on geoheritage to find key factors and report geoheritage implementations' directions and their determinants at the global and local levels..*

The primary purpose of the assessment is to help decision-making bodies in planning processes. What makes an assessment effective is how well the information is used. The information gained could determine future geoconservation activities and succeed in raising public awareness of geoheritage. Furthermore, it can assist the governance role and their decisions about increasing the chance of higher share from tourism revenues for locals, for providing resources for the employment of high standard educational and promotional tools to create a society with shared values in a diverse cultural environment. To achieve these objectives, we need a dynamic assessment instead of a criterion-referenced assessment that cannot be adjusted to society's dynamism.

The conceptual framework lays out the key factors (Jabareen, 2009) and seeks relationships between them (Chapter 5). Understanding the relationships is mandatory in order to provide an interpretative approach to social reality. As geoheritage is for people, it cannot discard the formed connection of geological features and communities. The purpose of a conceptual framework is to provide soft interpretations of intentions (Levering, 2002)

The analysis resulted in ordination diagrams that visualize correlations among determinant variables translated to links between socio-economic background and geoheritage conservation outcomes. Indicators derived from geoheritage-related academic activity and world development metrics show a shift from Earth Scientific significance toward disciplines of strong international agreement such as tourism, sustainability, and biodiversity.

Ordination methods are used in ecological multivariate statistics to reduce the number of dimensions and arrange data points so that similar observations are located closer to each other and those that differ are farther apart. Geoheritage designation is a new challenge for conservation planning. Quantification of geoheritage to date is used explicitly for site selection; however, it also carries the significant potential to be one indicator of sustainable development delivered through geosystem services. In order to achieve such a dominant position, geoheritage needs to be included in the business-as-usual model of conservation planning. Questions about the quantification process that have typically been addressed in geoheritage studies can be answered more directly by their relationships to world development indicators.

Objective 3

To calculate the extent geoheritage sites serve as geoeducational sites in the Auckland Volcanic Field, New Zealand. Investigate the feasibility of quantifying geoeducation capacity through the aggregation of automated landform classification with the values of recognized geoheritage sites. Application of GIS-based Multicriteria decision analysis (MCDA) based methods to objectively identify geoheritage sites and conflicting conservation for land use planning.

The Government of New Zealand has adopted Agenda 21, a comprehensive plan of action for sustainable development. Legislative bodies always set out regulations for industries to respect the environment and culture. The main body of environmental legislation, the Resource Management Act, calls for the protection of outstanding natural features and landscapes. Managing the use and development of such features is of national importance. Auckland is the biggest city and most rapidly evolving industrial district and needs to prioritise features that meet multiple objectives of protecting natural features. Auckland is built on an active volcanic field. The settlement within the region started with the Māori arriving on the land. Māori traditionally have their own resource management system to sustain natural resources for the future. Our study aims to expand on that knowledge and inform the wider multicultural community about the active geologic processes to enhance community resilience and well-being in Chapter 6. The key elements to achieve an overarching understanding of cultural groups, not only one another but the land they build their life on, are the geological and geomorphological features that provide the most insightful stories.

Auckland Volcanic Field in New Zealand stretches through the whole area of metropolitan Auckland, which helps preserve volcanic cones and their cultural heritage around its Central Business District (CBD). They are important sites for developing tourist activities. Geoeducation needs to become a significant factor in visiting geomorphological features, and it cannot be achieved without sound planning. Integrating Big Data (FlickR), Geopreservation Inventory, geology map and classified landforms led to identifying the geoeducation capacity of the frequented tourist attractions and areas of low visitation. The underpromoted, albeit important geoeducation sites are now mapped and ready to be added to the spatial database Auckland Council uses for urban planning. The use of a Geoeducation Capacity Map is a tool to resolve conflicts between multiple objectives of the bicultural, metropolitan city of Auckland.

Objective 4.

Apply the techniques and findings and build a model that takes into account the spatial character of the main evaluation criteria used in the literature and create spatial decision support by adopting the approach of coupling geospatial approaches between GIS and MCDA methods.

Visualization of geoheritage on maps is an excellent decision-making support tool. It provides the evidence needed to make geoheritage into a sound environmental conservation plan. GIS-based multicriteria decision analysis is an excellent tool to aggregate these maps into a suitability map that is instantly implementable into the GIS-based urban planning of Auckland. GIS is also an excellent tool for multi-objective land allocation that identifies areas where goal conflicts need to be handled in practice.

We built a spatial decision-making support instrument for the Auckland Council to ground the statistically significant results. Decision makers of Auckland face serious challenges in terms of balancing the facilitation of economic growth, maintenance of bicultural wellbeing and provision of land for growing housing demand. Geoconservation could play a crucial role in achieving sustainability. Practitioners understand it is more than possible to implement geoconservation as it does not require a change of operation; it requires a geoheritage-sensitive operation.

8.2. Future directions of research

- An indigenous framework for geoheritage conservation – Build in the principles of indigenous worldview relevant to geology and geomorphology. It is also, important to incorporate guidance from local iwis on protocols that visitors should follow. The geological features are not only sensitive to weather conditions but as well have sensitive spiritual perspectives. Our study outlines the complexity of geoheritage with all the existing views that need to be reviewed, expanded, and approved by iwi.

- Propose policies based on the concepts outlined in Chapter 1. Policy makers now understand the fields that include geoheritage conservation. Geoscience, geotourism, sustainability and biodiversity. All related policy statements and strategies must incorporate geoheritage conservation.

- Bring geoheritage features into the existing tourist network. Geotourism can be generated within tourism by distributing brochures. Based on the findings in Chapter 2, we now understand influencing factors. It is important to make use of these factors to achieve popularity for geoheritage. Auckland has the perfect infrastructure to build a geopark and has a very significant geological story to tell. It will not take much to create a geopark if policymakers create a new avenue for their existence that is independent of UNESCO (Xun & Ting, 2003). Based on the example of China (discussed in chapter 5), there are social, economic, and environmental benefits to creating a national network of geoparks whose distribution and geological settings and tectonism dominate characteristics. For example, China created a hierarchical system of regional, national and international geopark networks, which strategy supports bottom-up initiatives and allows for a graduated growth from a regional practice toward the rigorous UNESCO requirements.

8.3. Concluding remarks

Geoheritage conservation objectives depend on the socio-economical background of the country. The nature of geoconservation is to promote natural features so they receive a larger visitation flow. The purpose of such promotion is to reconnect society to its abiotic nature. Active participation of geoscientists in this process is very important to avoid a shift in focus from geoheritage conservation towards tourism demand (prioritising aesthetic features or features near tourist facilities). Attention has been paid to the paradigm that humans were once psychologically and physically closer to nature than residents of industrialized nations are now (Vining et al., 2008). In fact, the seemingly simple term ‘nature’ is not unequivocally defined (Zelenski et al., 2015). A simple definition of nature does not exist, so it is even harder to define the geological heritage of nature. The exact definition of geoheritage should be derived from the elements which constitute the conceptual framework. Now that we have unveiled all the existing theories put forward by the scientific community, we understand the definition of geoheritage. It serves society with knowledge, and as well it is the key to creating resilient societies with a sustainable lifestyles. Geoheritage must convey the geological history of the geographic region to the visitor and as well should reflect a sense of pride in the local culture. A study (Cronon, 1995) proposed the theory that in order to successfully protect the whole environment, not just a small part of it, humans must eliminate human-perceived barriers between themselves and nature. Others state (e.g. Schultz, 2000) that an individual`s level of concern for the environment is directly related to the sense of connectedness the individual feels with nature.

To mitigate confusion, the concept of geotourism emerged. However, ecotourism involves the business of attracting, accommodating and entertaining tourists that may negatively impact the promotion of high geoeducational value features such as outcrops in quarries or mines. The beauty of these outcrops lies in the story they tell us. Their key role in achieving sustainability is very important. Auckland is home to an increasing number of cultures whose common ground and a chance of connection is understanding the land they live on. Also, Auckland is an environment where policymakers create, maintain and update evacuation plans from volcanic hazards. However, it is very important to build a resilient community for these plans to take place successfully in case of a natural emergency. Geoheritage features are the tools to teach locals about the type of volcanism, the type of potential eruptions and the occurring hazards that could occur.

Our dynamic environment requires geoscientists to constantly study the area, constantly update predictions and fill research gaps. Their work must be supported by policies that protect outstanding natural features that provide the basis for academic studies. The idea of spatial decision-making support emerged because it prompts an instant understanding of what needs to be done and how. It shows areas of conflict with precise boundaries. An evidence-based approach to decision-making is more likely to achieve implementation as it is based on a combination of using critical thinking and the best available evidence. Spatial decision systems combine spatial and non-spatial data. Analysis and visualization functions of GIS compute the characteristics of a problem providing solutions and facilitating geoheritage assessment.

Our study postulates that geoheritage conservation should be set up in a way that prioritizes the right of future generations to experience geological and geomorphological features in their present state and to pass down the ability to them to research, learn and simply get connected to the Earth.

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APPENDIX A *Data mining*

APPENDIX A

To download the data this research use Flickr based on the comparative work of Kádár and Gede (2013) who tested the reliability of the downloaded data of different social media sites (Panoramio, Flickr). The photo-sharing sites provide an application interface (API) which provides access to the photograph database for web applications. These interfaces make it possible to use the shared photos and their metadata. It is one of the functions of these APIs is to download photograph data within a given bounding box that were used to collect the picture data of the area of the Auckland Volcanic Field. The metadata includes the coordinates of each photographs that allows for integration into GIS environment (Figure 1).

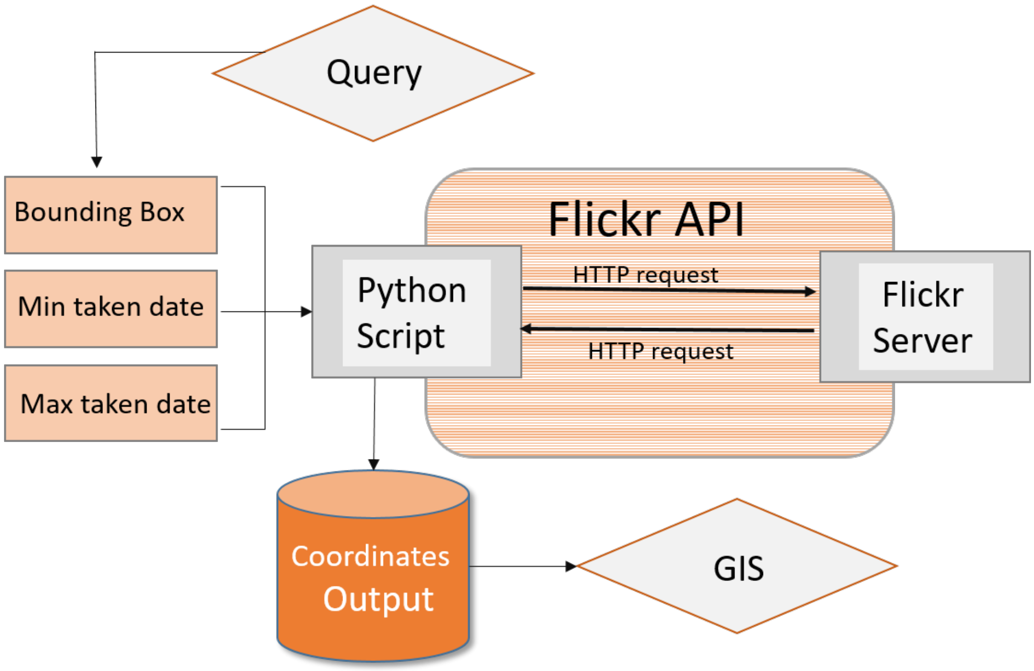

Figure 1. Working mechanism of the photo-downloading application

To test the representativeness of crowd-sourced information, empirical information was collected from New Zealand`s official data agency Statistics New Zealand. To enable the comparison, the social media information was downloaded in time periods corresponding with the empirical data on the monthly international visitor arrivals to New Zealand (Figure 2).

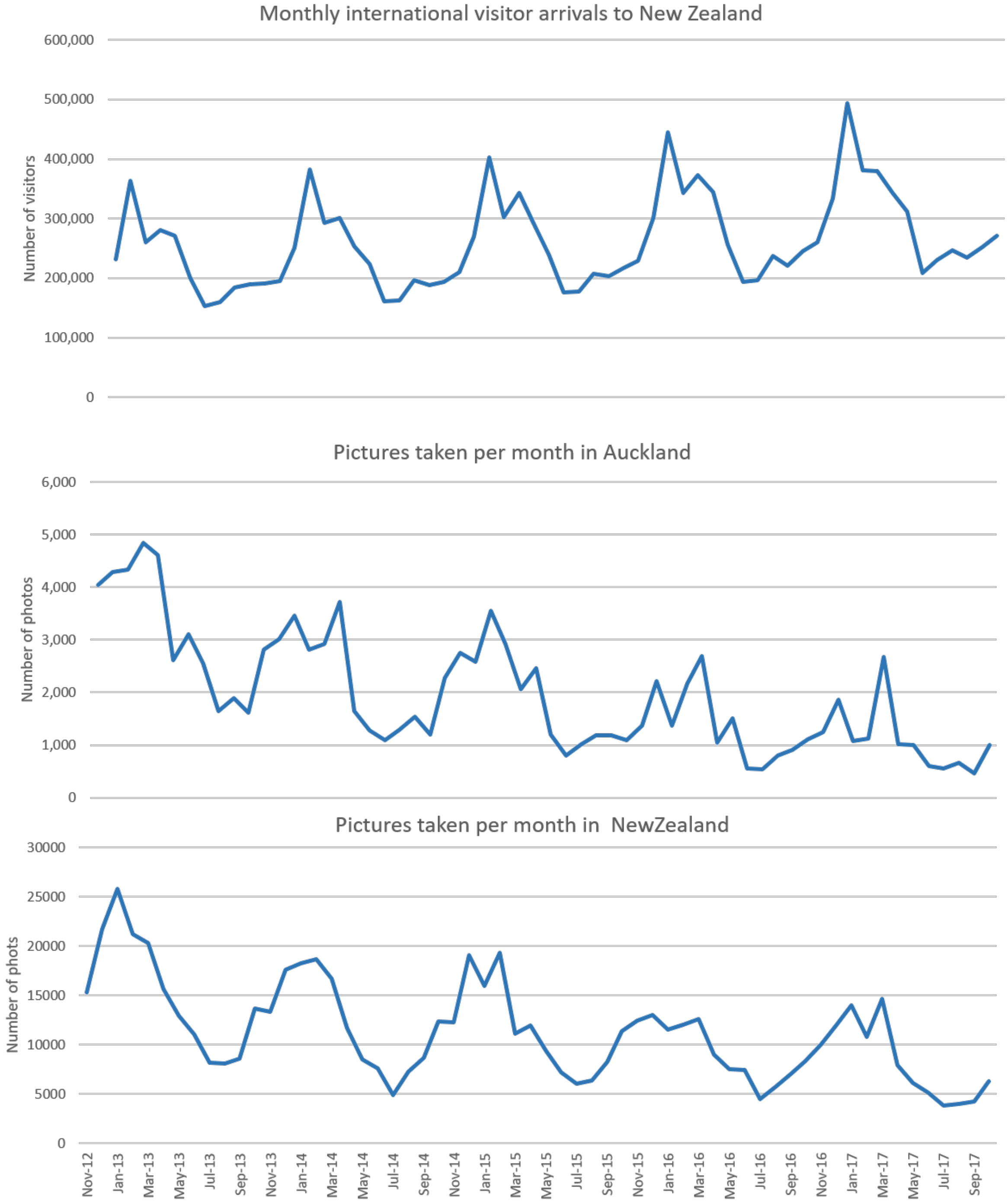

Figure 2. Corresponding trends depicting the temporal evolution of the number of visitors and the number of shared photos (Nov 2012-Sept 2017)

The information from Flickr photographs corresponds well with empirical information about where and when people go (Figure 3).

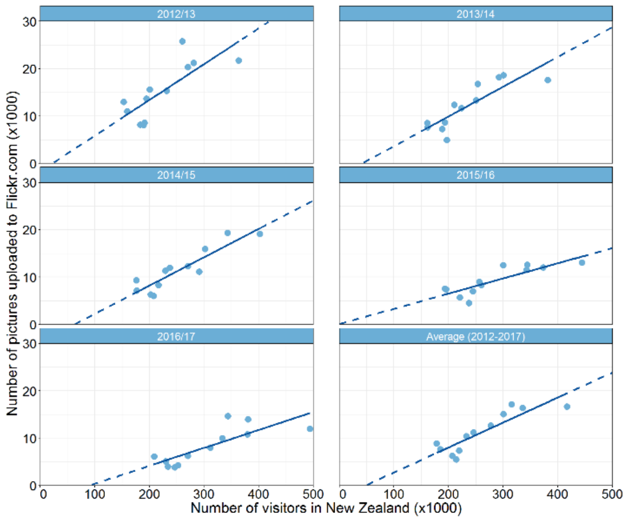

Figure 3. Statistical relationship between data from Flickr.com and Statistics New Zealand

Geographic coordinates were integrated into the GIS environment to visualize the photo distribution by placing a dot on the map at each image`s location (Figure 11). In the case of Auckland, the major tourist attractions are recognizable at first sight. Along with the city centre, the volcanic cones are the most favourable places among photographers.

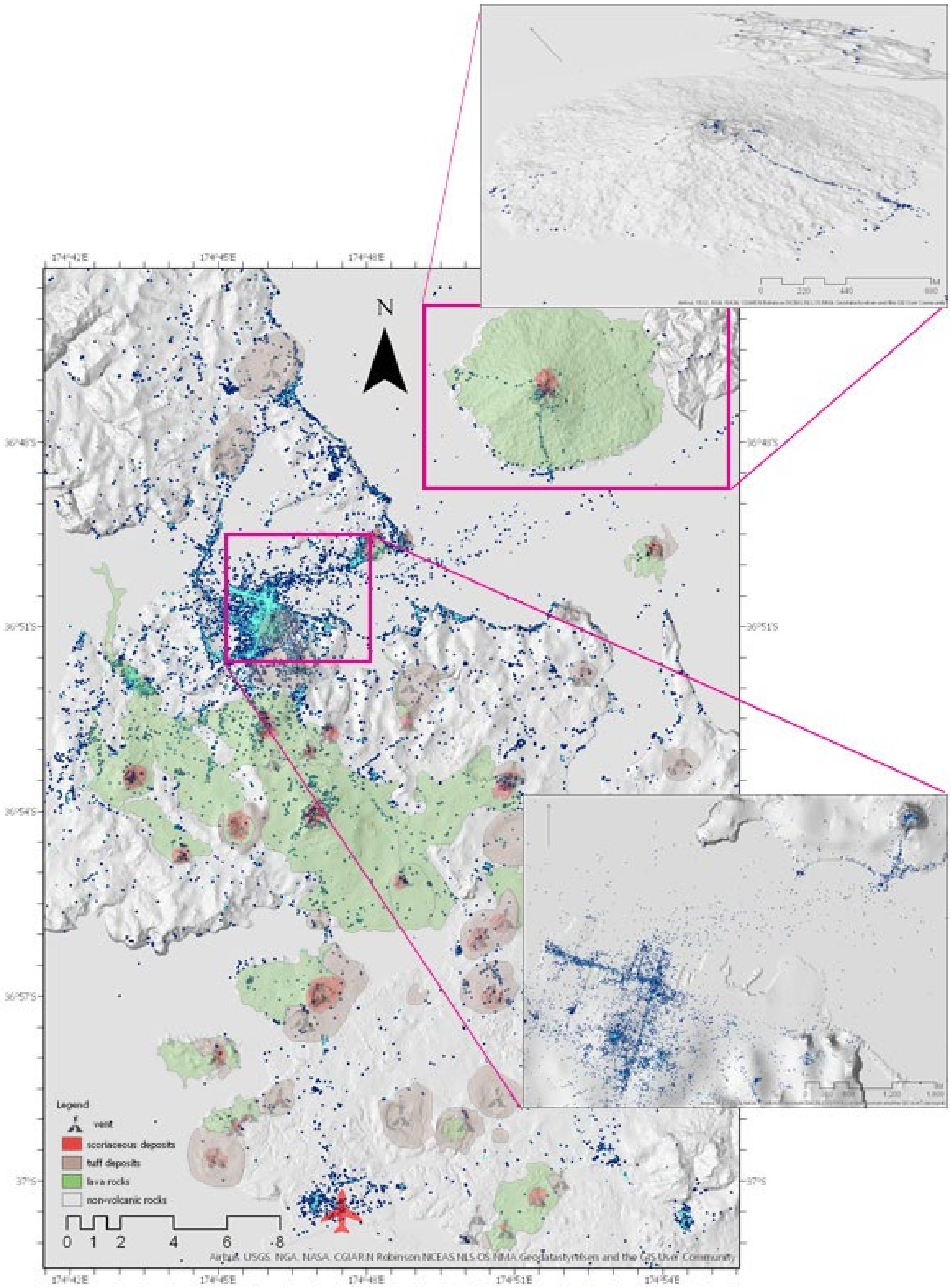

Figure 4. The distribution of photos obtained from Flickr (all photos taken until 2018) with the projection of Rangitoto Island (above) the city centre (below). Please note the FlickR photo taken data extraction was expanded until 2021 for chapter 6.

Fishnet tools were used to construct polygon grids to cover the dot print features. Subsequently conducted spatial join analysis counted the number of events falling within each grid polygon (Figure 4).

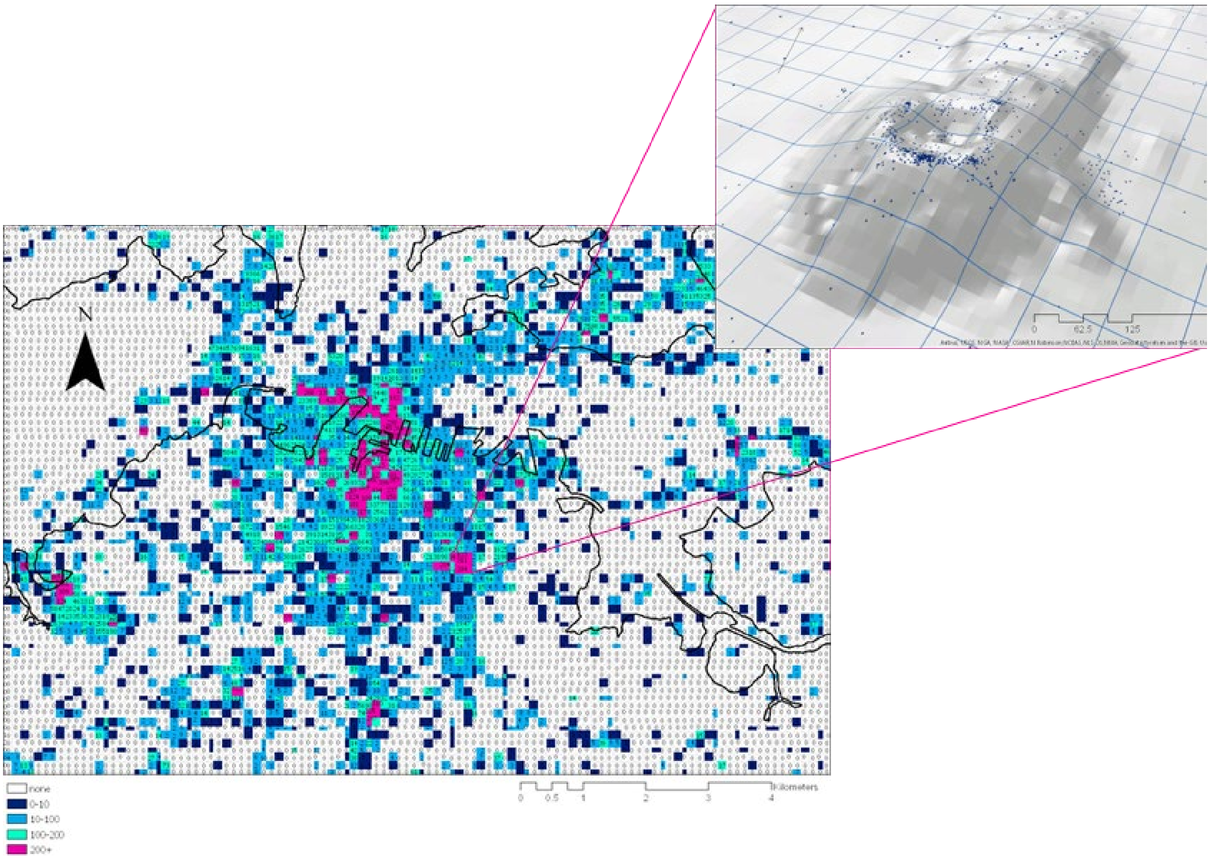

Figure 5 Tourist hot spots in the Auckland Volcanic Field and projection of the number of photos taken at the top of Mt.Eden, the most visited volcanic cone according to this big data analysis

The last step of geoprocessing was to convert this polygon feature to a raster dataset in order to determine the tourist hotspots (Figure 5). The rasterized map will be integrated into the geo-heritage evaluation process

APPENDIX B *Exhaustive list of geoheritage criteria extracted from literature*

APPENDIX B

Scientific values	Conservation management	Tourist attractions	Cultural Values	Facilities for tourism
Integrity/state/degree of conservation/current condition/conservation status	Accessibility	Landscape and aesthetic/Surrounding landscape and nature/location in the landscape	Religious importance/ Religious and metaphysical relevance	Hostelry service/Hostelry and support services/Value of provided services
Representativeness	Protected site/Level of protection	Contrasts, vertical development/ colour contrast	Historical importance/ Historical and archaeological relevance	Level of promotion/Inclusion in promotional materials and products/Availability of information about the object
Rareness/in relation to the area/ at national level/significance	Conditions for observation/ Visibility/Exposure	Tourist attraction/Attraction	Cultural content/ cultural legacy	Interpretive facilities/panels/the presence of study stations or points
Scientific knowledge (papers available)	Ecological impact/ecological value/ecological interest	Economic level/social settings (socio-economic indicators)	Artistic and literature importance	Proximity of recreational areas/proximity to recreational facilities
Viewpoints/number of viewpoints	Vulnerability	Surface/shape	Iconographic presentation	Vicinity of visitor centres
Geological diversity/no of interesting geomorphic features/diversity of elements	Natural risk/Security/Safety/present of potential threat	Landscape difference	Geo-historical importance	Association with other values
Paleogeographical value/Geologic history	Annual number of visitors/Economic potential	Average distance to the viewpoints	Cultural and historical customs	Inhabitants in the surrounding

Geographical distribution/Area/Extent/scale of geoheritage feature	Use limitations and legal protection	Elevation/ Altitude and climbing effort	Art and cultural events	Site Context
Key locality (level of institute using it)/recognisability/type locality/interest level	Intensity of use/Present use of the geomorphological interest/Activities that can be carried out	Economic products	Ethics	Organized visits
Exemplarity/Usefulness as process model/Reference site	Tourism Infrastructure / Logistics	Ecologic and aesthetic values	Association with historical heritage	Tour guide service
Morphology/form(point, line, area)/classic locations where Earth processes can be inferred	Fragility	Scenery	Association with other natural heritage	Restaurant service
Education interest	Impacts	Recommended season to visit	Added value	Present use of other natural and cultural interests
Singularity	Limits of acceptable change	Environmental fitting of sites	Contextual interest (culture, history, ecology)	Suitable number of visitors
Age	Land use			Density of population
Genesis, Lithology	Risk of degradation			Additional natural values
Active processes (dynamic processes operating)/Dynamics				Additional anthropogenic values
Interpretive potential/how easily illustrates geological aspects				Vicinity of emissive centres
Didactic potential				Additional functional values
Use limitations (for sampling)				Vicinity of important road network
Level of interpretation				Possibility to collect objects

Other geological features w heritage value	Object in the tourist area
Classic locations in cliffs or outcrops, where geological principles were first explained	
Chronology	
Geologic structures	
Sedimentary structures	
Primary geological properties	

APPENDIX C *Supplementary data*

available at:

https://drive.google.com/drive/folders/18UXbCmQfuB0kqa9-FTQXRd21LZ-C-aj5?usp=sharing

APPENDIX C

Appendix for Chapter 4

Papers used for describing each concept

- reviews table.pdf
- legal material table.pdf
- applied conservation table.pdf
- conceptual papers table.pdf

Keywording

- firstexclusion.xls
- keywording_classification.xls
- secondlevel_keywording_classification.xls
- thirdlevel_keywording_classification.xls
- documentation.pdf

Appendix for Chapter 5

Input data

- geopark_dataframe.xls
- indicators_table.xls
- outputs_scopus_wos_geoparksfromgis.xls
- rankings.xls
- worldbank_data.xls

Multi criteria analysis output

- CA results.xls
- MCA results.xls

Appendix for Chapter 6

Input data

- Shore_boundary_poly.shp (Bounding box vector layer)
- Urban_area_clipped.shp (Buildings within AVF vector layer)
- Open Space/Parks.shp (Recreational Open Space within AVF vector layer)
- Geopres/geopres_points.shp (Geopreservation Inventory Points vector layer)
- Geopres/geopres_poly.shp (Geopreservation Inventory Polygons vector layer)
- Geology.gdb
  - Correct_geology.shp
  - Geol_ash_lapilli.shp
  - Geol_lava.shp
  - Geol_lithictuff.shp
  - Geol_Scoria.shp
- Flickr/Allinone_till2021.shp (Extracted Flickr coordinates vector layer)
- Flickr/Flickr_clipped.shp (Extracted Flickr coordinates clipped to AVF vector layer)
- DEM_withRangitoto8m.gdb
  - DEM_clip (AVF mainland Lidar 1m DEM aggregated with Rangitoto Lidar 8m DEM raster layer)
- Raster.gdb
  - AVF_hillshade_shaped (Grayscale Digital Elevation Model created from 1m Lidar DEM)
  - Slope (slope raster layer)

Processing and Results

- tpi.gdb
  - TPI1 (TPI 100 m raster layer)
  - TPI2 (TPI 500 m raster layer)
  - TPIs1 (TPI 100 m standardised raster layer)
  - TPIs2 (TPI 500 m standardised raster layer)
  - mTPI (aggregated standardized TPIs)
- Classified_landforms.gdb (TPI raster layer)
- Landformboundaries.gdb

  - Contour_extracted.shp (edifice boundary slope analysis vector layer)
  - Landform_boundaries.shp (edifice boundaries result vector layer)
- weightscalculationfor_education_intensity.xlsx (excel table)
- flickr_visitation.gdb
  - flick_spatialjoin (processing raster layer)
  - flickr_visitation_density (visitation raster layer)
  - flickr_visitation_density_log10 (standardised visitation raster layer)
- geoedu_weights.gdb
  - geology_volcanoes_weights.shp
  - geopres_poly_weights.shp
  - geology_uniongrid (weighted geology raster layer)
  - geopres_uniongrid (weighted Geopreservation Inventory raster layer)
  - classes_weights (weighted TPI landform classes raster layer)
- Geoeducation.gdb
  - Geoeducation_intensity (geoeducation capacity raster layer)
  - Geoeducation_intensity_classes (classified geoeducation capacity raster layer)
- flickrVSgeoedu.gdb
  - flickr_versus_geoeducation (visitation and geoeducation aggregated raster layer)
  - flickrbuffered_versus_geoedu (buffered visitation and geoeducation aggregated layer)
- nonvisitedhighvalueareas.gdb
  - lowvisited_highvalueareas (visitation and only high geoeducation value areas aggregated raster layer)
  - buffered_lowvisited_highvalue (buffered visitation and only high geoeducation value areas aggregated raster layer)

Appendix for Chapter 7

Viewshed analysis

- analysis.gdb
  - point1.shp
  - point2.shp

    …up to:
  - point21.shp
- Viewshed2.gdb
  - Viewshe_DEM_1_Clip (raster layer)
  - Viewshe_DEM_2_Clip (raster layer)

  …up to:

  - Viewshe_DEM21_Clip (raster layer)

MCDA geoheritage map layers

- input_geoheritage.gdb
  - Parks.shp (Recreational open space vector layer)
  - Roads_AVF.shp (Roads within AVF vector layer)
  - BusStopLocations_Clip.shp (Public transport stops vector layer)
  - Allviewpoints_Buffer.shp (Observation points from viewshed analysis vector layer)
  - Classified_landforms.gdb (TPI classified landforms raster layer)
  - Geoeducation_intensity_classes (Geoeducation capacity raster layer)
  - Landform_boundaries.shp (Edifice boundaries result vector layer)
- MCDA_geoheritage.gdb
  - landform_boundaries_clip.shp (Edifice boundaries clipped with open space boundaries layer)
  - Geoeducation_intensity (Geoeducation capacity for Representativeness and Rareness layer)
  - EucD_park1 (Distance from recreational open space raster layer)
  - EucDist_roads (Distance from roads raster layer)
  - EucDist_busStops (Distance from bus stops raster layer)

- Reclass_EucDroad (Weighted distance from road for accessibility raster layer)
- Reclass_EucDstops (Weighted distance from public transport stops for accessibility raster layer)
- Reclass_viewpoints (Weighted distance from observation points for accessibility raster layer)

Result layers for final suitability map for geoheritage conservation

- Reclass_Integrity (Weighted portion of edifice falling within open space/Integrity raster layer)
- Reclass_Repres (Weighted variety of TPI landform classes/Representativeness raster layer)
- Geoeducation_intensity_classes (Weighted geoeducation capacity/Rareness raster layer)
- Reclass_EucDPark_visibility (Weighted distance from open space/Exposure raster layer)
- weighted_Access1 (Weighted Accessibility raster layer)

MCDA cultural value map layers

- input_cultural.gdb
    - Tupuna maunga.shp (Tupuna Maunga vector layer)
    - Maori_cultural_AVF.shp (Archaeological points vector layer)
    - AVF_hillshade_shaped (Grayscale digital elevation model created from 1m Lidar DEM)
- MCDA_cultural.gdb
    - Maoricult_SpatialJoin1.shp (Archaeological hot spot vector layer)
    - Maoricult_SpatialJoin1_PolygonToRaster (Archaeological hot spot raster layer)
    - EucDist_maoricult (Distance from archaeological points raster layer)
    - EucDist_tupu1 (Distance from Tupuna Maunga raster layer)

Result layers for final suitability map for cultural conservation

- Reclass_maoriRaster (Weighted archaeological hot spot raster layer)
- Reclass_EucDMaori (Weighted distance from archaeological raster layer)
- Reclass_EucDTupuna (Weighted distance from Tupuna Maunga raster layer)

- Reclass_hillshade (Weighted elevation raster layer)

MOLA

Mola_mcda_geoher_cult.gdb

- Weighted_MCA1 (MCDA analysis for geoheritage value raster layer)
- Weighted_Cultu2_reclass (MCDA analysis for cultural value raster layer)
- Combine_Geoh_Cult (Multi-objective land allocation raster layer)

APPENDIX D *Statement of contribution*

Note for examiners

MASSEY UNIVERSITY
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UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Boglarka Nemeth
Name/title of Primary Supervisor:	Prof Karoly Nemeth
In which chapter is the manuscript /published work:	Chapter 6

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Németh , B., Németh , K., Procter , J. N. (2021). Visitation Rate Analysis of Geoheritage Features from Earth Science Education Perspective Using Automated Landform Classification and Crowdsourcing: A Geoeducation Capacity Map of the Auckland Volcanic Field, New Zealand. In (Vol. 11, pp. 480): Geosciences.

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

- The percentage of the manuscript/published work that was contributed by the candidate: 80.00

- Describe the contribution that the candidate has made to the manuscript/published work:

data extraction from FlickR, edifice boundary calculation, visitation mapping, method development, landform classification and interpretation, geoeducational map mapping, writing and editing the manuscript

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Boglarka Nemeth Digitally signed by Boglarka Nemeth Date: 2021.12.10 20:38:45 +13'00'
Date:	10-Dec-2021
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Name/title of Primary Supervisor:	Prof Karoly Nemeth
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(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Németh, B., Németh, K., Procter, J. N., & Farrelly, T. (2021). Geoheritage Conservation: Systematic Mapping Study for Conceptual Synthesis. Geoheritage, 13(2), 45. 10.1007/s12371-021-00561-z

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

- The percentage of the manuscript/published work that was contributed by the candidate: 80.00

- Describe the contribution that the candidate has made to the manuscript/published work:

data extraction, keyword extraction, data synthesis, data modeling, conceptual interpretation, developing visualisation methods, conceptual mapping, writing and editing the manuscript

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Boglarka Nemeth Digitally signed by Boglarka Nemeth Date: 2021.12.10 20:39:19 +13'00'
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Name/title of Primary Supervisor:	Prof Karoly Nemeth

In which chapter is the manuscript /published work: Chapter 5

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(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Németh , B., Németh , K., Procter (2021). Informed Geoheritage Conservation: Determinant AnalysisBased on Bibliometric and Sustainability Indicators UsingOrdination Techniques. Land, 10, 539.

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

- The percentage of the manuscript/published work that was contributed by the candidate: 80.00

- Describe the contribution that the candidate has made to the manuscript/published work:

data extraction, data synthesis, data modelling, method development, application of multi variant analysis, interpretation of the statistical model, writing and editing the manuscript

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

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Name of candidate:	Boglarka Nemeth
Name/title of Primary Supervisor:	Prof Karoly Nemeth

In which chapter is the manuscript /published work: Chapter 7

Please select one of the following three options:

○ The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

○ The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

method development, data processing for mapping, MCA mapping, MOLA mapping, writing and editing

◉ It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Boglarka Nemeth Digitally signed by Boglarka Nemeth Date: 2021.12.10 20:38:15 +13'00'
Date:	10-Dec-2021
Primary Supervisor's Signature:	Prof Karoly Nemeth I am approving this document 2021.12.10 18:10:33 +13'00'
Date:	10-Dec-2021

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