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Inventory and Assessment of Geosites for Geotourism Development in the Eastern and Southeastern Lake Tana Region, Ethiopia

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Abstract

Geotourism is a niche form of sustainable tourism that focuses on the geological and geomorphological features of an area, and the associated culture and biodiversity. Geosites are important resources for geotourism development. The eastern and southeastern Lake Tana region in Ethiopia has several geosites with a potential for geotourism development. Despite the diversity of potential geosites and the strategic location of the area in the Northern Tourist Circuit of Ethiopia, only a few attractions such as Lake Tana and the Blue Nile Falls are currently being visited. The objective of this paper is twofold: to inventory geosites in the eastern and southeastern Lake Tana region and assess their potential for geotourism development; and to propose a geosite inventory and assessment methodology for geotourism purposes with adaptations from previous studies. Several studies were reviewed and finally nine of them used as the main references to prepare the criteria, indicators, and sub-indicators for this study. The indicators used for assessing the potential of geosites relate to scientific, educational, scenic, recreational, protection, functional, and ecological values. This research presents the first inventory of geosites in the Lake Tana basin. A first list of 120 geosites has been inventoried. Further screening and clustering resulted in 61 geosites, of which 17 are viewpoints. Among the major geosites are waterfalls, a lake with islands and island monasteries, a flood plain, caves and cave churches, lava tubes, a mountain (shield volcano), volcanic plugs, volcanic cones, rock-hewn churches, and viewpoints. Quantitative assessment of the geotouristic potential of these geosites revealed that clustered (complex area) geosites received higher scientific, scenic, and recreational value scores.

Keywords. Geoheritage . Geotouristic valorization . Sustainable tourism . Volcanic features . Lake . Waterfalls .

Introduction

It is now largely recognized that earth systems provide the resources for (geotourism) development (Asrat et al. 2012). Geology often determines natural scenery and landforms, the main attractions for geotourism. Tourism interest in geological features and landscapes is rapidly expanding (Newsome et al. 2012). Geotourism, which was rooted in England as a means to protect and conserve geosites (Hose 2011), is now an internationally developing academic, economic, and sustainable development field (Ngwira 2015) with considerable global growth potential (Hose 2011).

A review of the literature showed that there is no commonly accepted definition of geotourism. The first published definition was given by Hose in 1995 and focuses on providing interpretative service facilities to enhance visitors' understanding of the geology and geomorphology of a site (Dowling 2013). He revised his definition of geotourism as "the provision of interpretative and service facilities for geosites and geomorphosites and their encompassing topography, together with their associated *in situ* and *ex situ* artifacts, to constituency-build for their conservation by generating appreciation, learning and research by and for current and future generations" (Hose 2012). Another more geologically oriented definition of geotourism is by Newsome and Dowling (2006), who stated it as "tourism related to geology and geomorphology and the natural resources of landscape, landforms, fossil beds, rocks, and minerals, with an emphasis on appreciating the processes that are creating and created such features" (Newsome and Dowling 2006). The definition by Dowling (2013) emphasizes the sustainability nature of geotourism and encompasses biodiversity and cultural features. He defined it as an "emerging form of sustainable tourism with a primary focus on experiencing the earth's geological features in a way that fosters environmental and cultural understanding, appreciation and conservation, and is locally beneficial" (Dowling 2013). This paper adapted the definition and defined geotourism as "a sustainable form of tourism which primarily focuses on experiencing geological and geomorphological features (geosites) of an area, and associated culture and biodiversity". This more holistic approach to geotourism (which includes geological, biological, and cultural components) is the next wave of tourism (Newsome and Dowling 2018).

Geosites are the main attractions for geotourism. Reynard (2004) defined geosites as geological or geomorphological objects with scientific, cultural/historical, aesthetic and/or social/economic values. Fuertes-Gutiérrez and Fernández-Martínez (2010) developed a typology of geosites based on size, object shape and disposition, fragility, and vulnerability. With these criteria, they classified geosites as points, sections, areas, complex areas, and viewpoints. Geosites are defined in this study as geological or geomorphological features with one or more intrinsic values (i.e., scientific, educational, scenic, and recreational) as well as associated cultural and ecological value/s.

It has been argued that "a systematic and complete inventory of all tourist assets, their location, measurement, and potential … represents a basic condition for any tourist area" (Formica 2000). In fact, the inventory and assessment of geosites is a necessary requirement for geotourism development and management (Suzuki and Takagi 2018) and should be carried out before the development of potential geotourism destinations is planned (Vujičić et al. 2011).

Lima et al. (2010) argued that there should be a clear objective for inventorying geosites, which may include geoconservation, geodiversity promotion, and geotourism development. A review of the literature revealed that there are three important issues related to geosite inventory and assessment for geotourism development: (1) which criteria/indicators/sub-indicators to use for inventorying and assessment, (2) how to assess scenic beauty, and (3) how to determine the weights of the (sub-)indicators that will be used to inventory and assess geosites.

In relation to the first one, there is no single set of criteria/indicators/sub-indicators used in inventorying and assessing the potential of geosites for geotourism development. Different researchers have used different criteria. Despite the availability of several site inventories and assessments applied at different scales, the "criteria used for their selection are often unclear and poorly defined" (Brilha 2016). The geosite assessment methods were developed for varying purposes (such as geoconservation, geoheritage management, geotourism), as were the criteria/indicators/sub-indicators they use. There is also a difference in the classification or grouping of values/indicators/sub-indicators (for example, Vujičić et al. 2011 categorized "scenic value" under "main value" while Pereira et al. 2007; Reynard et al. 2007; Pereira and Pereira 2010 classified it under "additional value"; "ecological value" is categorized under "scientific value" by some authors such as Bollati et al. 2014, while others such as Pereira et al. 2007 and Reynard et al. 2007 grouped it under "additional value"). Furthermore, the scales they used for scoring are also different: they used three/four/five scales (e.g., Vujičić et al. 2011; Tomić and Božić 2014; Kubalíková 2013; Višnić et al. 2016; Suzuki and Takagi 2018).

The second issue is scenic beauty assessment. According to Daniel (2001), there are two approaches to assess scenic beauty: expert/design and perception-based approaches, termed by Lothian (1999) as "objectivist" or "physical" and "subjectivist" or "psychological" landscape quality assessment paradigms, respectively. In the first approach, a trained expert makes the assessment (Daniel 2001) based on formal knowledge (Tveit et al. 2012) and the application of selected criteria (Lothian 1999). On the other hand, the second approach involves "a rating of landscape beauty, usually represented by photographs, by a sample of actual/potential viewers [visitors]" (Daniel 2001). He argued that the perception-based approach is more reliable than the expert approach. Lothian (1999) proposed that only the subjectivist model should be used in scenic beauty assessment research. Vujičić et al. (2011) also suggested that scenic beauty should be evaluated by visitors. However, most, if not all, scenic beauty assessments of geosites in previous studies were based on the expert approach.

The third issue is setting the weights of the (sub-)indicators used in assessing the potential of geosites. There is no uniformity about assigning weights. For example, Pralong (2005) assigned equal weight to the four values (scenic, scientific, cultural and economic) he used, arguing that "there is no objective reason to think that a specific value is less important than the other one when we have to determine the theoretical tourist potential of a site". He used the mean of the four values for the final evaluation and ranking of tourist values of geosites. Similarly, others such as Vujičić et al. (2011) and Kubalíková (2013) did not set any weight for the (sub-)indicators they developed. On the other hand, many researchers assigned weights (Lima et al. 2010; Bruschi et al. 2011; Fassoulas et al. 2012; Brilha 2016). Some researchers set the weights by themselves while others allowed experts to determine these.

Schrodt et al. (2019) argued that "to advance sustainable stewardship, we must document not only biodiversity but [also] geodiversity [which includes geosites]". The studies carried out in the last 20 years mostly focused on methods related to geosite inventory, assessment and use for education and geoheritage purposes; they were also conducted on "already known sites and protected areas" (Brilha and Reynard 2018). They pointed out that there is a lack of research about geosites in some parts of the world, particularly in Africa, and the available studies focus on specific themes.

Ethiopia has many spectacular geosites. However, unlike cultural and historical attractions, geosites in Ethiopia are still undervalued by both the government and communities as a national heritage and tourist attractions (Williams 2020). The country lacks a systematic geoheritage evaluation strategy, and the efforts to promote potential geosites as geotourism destinations are limited (Asrat 2018). The studies related to geotourism conducted so far in Ethiopia are either general, focusing on the description of geology and/or geomorphology or geoheritage promotion and conservation issues at a national level (e.g., Billi 2015; Williams 2016; Asrat 2018; Williams 2020) or were carried out in specific parts of the country (e.g., Asrat et al. 2008, 2012; Mauerhofer et al. 2018; Nyssen et al. 2019; Megerssa et al. 2019; Nyssen et al. 2020). Empirical observations show that the Lake Tana region has several geosites with a potential for geotourism development. Despite this, little/no attention has been paid to geosite inventory and assessment. The only exceptions are Lake Tana and its island monasteries, and the Blue Nile Falls, which are already on the itineraries of tourists visiting Bahir Dar. Thus, the main objective of this study is to inventory geosites in the eastern and southeastern Lake Tana region as a basis for geoconservation and geoheritage management, and assess their potential for geotourism development.

In addition, the study also makes a methodological contribution. In general, the studies related to the inventory and assessment of geosites for geotourism development so far are not uniform in the three issues mentioned above: the criteria, indicators, and sub-indicators used; the weights of (sub-)indicators; and the scenic beauty assessment. Including all the necessary criteria/indicators/sub-indicators, allowing (potential or actual) visitors to assess the scenic beauty of geosites and setting weights for (sub-)indicators can help to better inventory and assess geosites for geotourism development. Identifying interesting features of geosites from (actual or potential) visitors' perspectives also has important implications for geotourism development. Moreover, the use of web-based data such as tour operators' itineraries, TripAdvisor reviews, and photos from Google Images and Instagram could provide more insights into familiarity of the geosites. The study in the eastern and southeastern Lake Tana region serves as a case study for the application of all these schemes and evaluates the practicality of the methodology to inventory and assess geosites for geotourism development.

Description of the study area

Asrat et al. (2008) described Ethiopia as an ideal "textbook" of geology and geomorphology. They argued that the country has diverse and unique geological and geomorphological features that are the basis of its major tourist attractions. Northwestern Ethiopia is a good example with rich geosites for (geo)tourism development. It is home to two of the country's nine UNESCO registered World Heritage Sites – the Lalibela Rock-Hewn Churches and the Semien Mountains National Park – which are in one way or another related to geology/geomorphology.

This research was conducted in the eastern and southeastern Lake Tana region, which lies in northwestern Ethiopia (Fig. 1). The area has several geosites with a potential for geotourism development. In addition, the region has rich cultural and biodiversity assets that are in one way or another associated with geosites, and hence can provide (an additional) reason for tourists to visit the area. Furthermore, the region is strategically located in one of the country's major tourist routes, namely the Northern Tourist Circuit.

The largest part of the study area lies within the Lake Tana basin, while the remaining part lies in the upper Blue Nile basin. The Lake Tana basin has been formed by lavas and shaped by tectonic forces and erosion (Poppe et al. 2013; Kebede 2013). With an area of ca. 15,100 km^2, it is the second largest sub-basin of the Blue Nile (Mengistu et al. 2017). It is also the "most economically, historically, politically and environmentally important sub-basin of the Upper Blue Nile River System" (Damtie et al. 2017). Because of its huge potential for socio-economic development, the basin has been identified as a major "economic corridor" of the country (Goshu and Aynalem 2017; McCartney et al. 2010). The Lake Tana area also has rich biodiversity and was registered by UNESCO as a Biosphere Reserve. Furthermore, it has thirteenth- and fourteenth-century monasteries housing important religious, cultural, and historical treasures.

Lake Tana and the Blue Nile River are the two most important water bodies in the study area. With an area of ca. 3,100 km^2, Lake Tana is the largest lake in Ethiopia, and the third largest in the Nile Basin. It holds 50% of the country's fresh water (Goshu and Aynalem 2017) though, once completed, the Grand Ethiopian Renaissance Dam (GERD) will hold more. The lake is ca. 84 km long and ca. 66 km wide and has an average depth of 9 m. Four permanent rivers: Gilgel Abay, Gumara, Ribb, and Megech (Fig. 1) contribute about 95% of the total annual inflow to the lake (Lamb et al. 2007; Chebud and Melesse 2009).

The Blue Nile is the only river that naturally flows out of Lake Tana (Fig. 1). There is another outlet to Lake Tana on the western side where the lake is diverted to the Tana Beles hydroelectric power plant. The Blue Nile is one of the longest rivers in Ethiopia and the main tributary of the Nile. It is Ethiopia's "best-known and most revered river" (Williams 2016), and the most important water body in northeast Africa (Firew 2014). The river is very important to the economies of Sudan and Egypt (Lamb et al. 2007), contributing the most water to the Nile River flow and ca. 95% of the mineral-rich sediments to the Nile Valley (Williams 2016).

The study area is not a single region such as a basin, a protected area or an administrative unit. Rather, it was selected in such a way that it connects two very important geosites in the Lake Tana and Upper Blue Nile basins: Lake Tana/Blue Nile Falls and Mt Guna. Potential geosites located between these two sites were inventoried. The study area includes six districts (Bahir Dar Zuria, Dera, Fogera, Libo Kemkem, Farta, and Guna Begemidir), Bahir Dar City Administration and Lake Tana itself (Fig. 1), and has an elevation ranging between ca. 1440 m a.s.l. (the Blue Nile River gorge) and ca. 4110 m a.s.l. (Mt Guna). The total coverage of the study area is ca. 9,750 km^2, of which ca. 3,100 km^2 is covered by Lake Tana. Potential geosites located in the eastern and southeastern part of the lake were inventoried and assessed.

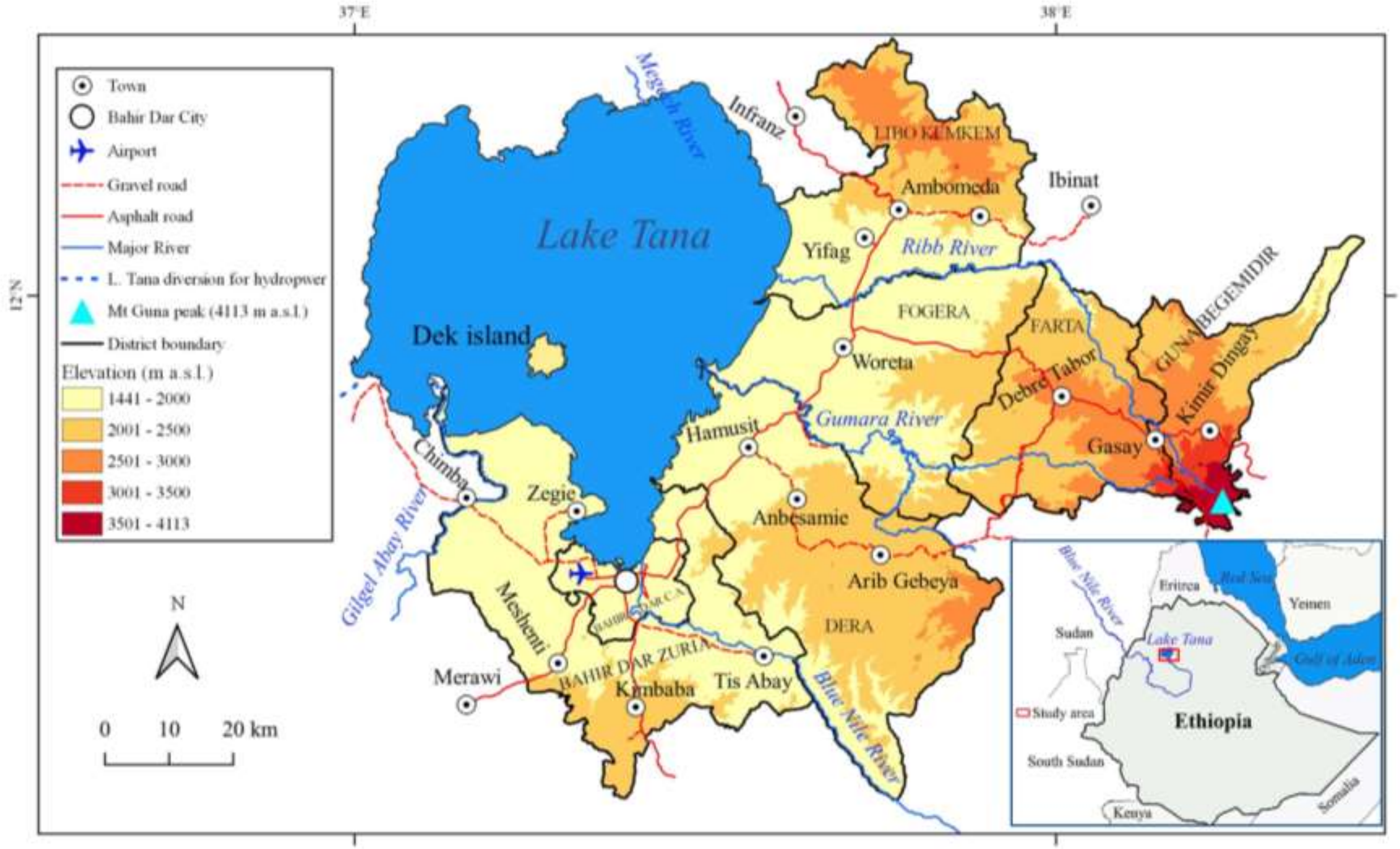

Fig. 1 Location map of the study area (Lake Tana, Bahir Dar City Administration and the six districts). Inset map shows location of the study area in Ethiopia.

The study area is dominated by Quaternary basalt flows and Ethiopian Flood Basalts, all younger than ca. 26 million years (Williams 2016). The area also has other geological formations (i.e., the Ethiopian Shield Volcanics: basalt, phonolite, trachyte, tephra, and ignimbrite) forming unique geomorphological features such as volcanic ranges, dikes, faults, grabens, volcanic plugs, domes, cinder cones, lava tubes, pahoehoe, shield volcanoes, river knickpoints resulting in rapids and waterfalls, and caves (for more information on the geology of the study area, reference is made to the geological map of the Lake Tana area by Williams 2016).

Materials and Methods

Pereira et al. (2007) identified six stages of geosite inventory and assessment: identification of potential geomorphosites, qualitative assessment, geomorphosite selection, geomorphosite characterization, numerical assessment, and analysis of results. On the other hand, Brilha (2016) identified five stages for the inventorying and assessment of geosites. These are (1) geological/geomorphological literature review and expert consultation, (2) listing of potential geosites, (3) fieldwork, (4) listing of geosites and characterization, and (5) quantitative assessment. It has been found that the steps developed by Brilha (2016) are more convenient, and hence were used for our geotourism study in the eastern and southeastern Lake Tana region.

Geosite inventory and selection

Based on the working definition of geosites given above, an initial list of 120 geosites was inventoried (Fig. 2). Three groups of geosites were inventoried:

A. Geosites with viewpoints: isolated places having intrinsic value (i.e. scientific, educational, scenic and/or recreational), as well as associated cultural and/or ecological value/s that belong to any one of the geosite typologies developed by Fuertes-Gutiérrez and Fernández-Martínez (2010) (i.e. point, section, area or complex area), which also serve as viewpoints;
B. Geosites without viewpoints: isolated places having intrinsic value, as well as associated cultural and/or ecological value/s that belong to any one of the geosite typologies developed by Fuertes-Gutiérrez and Fernández-Martínez (2010) and do not serve as viewpoints; and
C. Viewpoints only: sites where the locality for viewing has no intrinsic value necessary for geotourism but provides a panoramic view. Note that the site or landscape that is being seen should have intrinsic value (Migoń and Pijet-Migoń 2017). Viewpoints are classified as special types of geosites.

In this study, there is a difference in the scenic beauty assessment of geosites with and without viewpoints (“A” and “B” above). For the former, the scenic beauty score of the geosite itself or the surrounding landscape as seen from the viewpoint, whichever is higher, was taken; for the latter, the scenic beauty score of the geosite itself was taken.

As the study area is relatively large, the focus of inventorying was on geosites with and without viewpoints, and not on viewpoints. Hence, not all viewpoints in the study area were inventoried. The following criteria were used for inventorying viewpoints:

a. the site is a geosite in itself having intrinsic value as well as associated cultural and/or ecological value/s, and provides a panoramic view (which is category "A" above), or
b. the site is not a geosite in itself with intrinsic value, but provides a panoramic view and is located a maximum of ca. two kilometers from a city (town) or a road leading to another geosite.

For inventorying potential geosites in the eastern and southeastern Lake Tana region, fourteen governmental tourism and related offices were consulted. Four of these offices were contacted mainly because they have documented tourist attractions in their district, some of which are geosites. Interviews were conducted with the remaining ten offices, and documents describing tourist attractions in their regions, including geosites, were collected and analyzed. As the concept of geosite and geotourism is new in the study area, it was quite difficult for interviewees to identify which features may be considered as geosites (with a potential for geotourism). To solve this, the interviewees were shown photos of ca. 10 different types of geosites gathered from the literature so that they could easily understand which geological/geomorphological features are considered as geosites. In addition, a total of nine experts from academia (one geologist, two physical geographers, one archaeologist, two tourism professionals, two biologists and one natural resource management professional) and two local tour guides were consulted. Furthermore, literature related to geosites in the eastern and southeastern Lake Tana region gathered from offices and the web (including a geomorphological map of the study area) was reviewed. Google Earth was also used to identify certain geosites, especially larger features such as wetlands, volcanic domes, volcanic cones and volcanic plugs.

All of these inventorying tools resulted in an initial list of 120 potential geosites, including viewpoints (Fig. 2). Almost all of these geosites were visited during 36 field days. Further qualitative assessment of the geosites using criteria such as access limitation (private ownership, use for a religious purpose only and/or safety issues), proximity to other attractions, and/or whether the site shows special features compared to other similar geosites resulted in a final list of 84 geosites. Of these, 67 are geosites with and without viewpoints and the remaining 17 are viewpoints. Some geosites such as Lake Tana, the Blue Nile Falls and Canyons, Mt Guna and the Fogera flood plain cover a large area and have more than one individual geosite. In other words, they belong to the complex area geosite typology proposed by Fuertes-Gutiérrez and Fernández-Martínez (2010). As a result, for the convenience of assessment, clustering those that belong to these complex area geosites resulted in 61 geosites (15 geosites with viewpoints, 29 geosites without viewpoints, and 17 viewpoints) (Table 2 and Fig. 3). The assessments and discussions in the following sections are therefore based on these geosites. The geosites with and without viewpoints were coded numerically based on the sequence in which they were visited during data collection (Table 2). The viewpoints were coded numerically after the geosites with and without viewpoints, and followed the same procedure. The clustered geosites were coded alphanumerically. For example, Lake Tana was coded as "13" and its island monasteries/churches coded as "13A" and "13B" (see Table in S5 in the Online Supplement for the full list of clustered geosites).

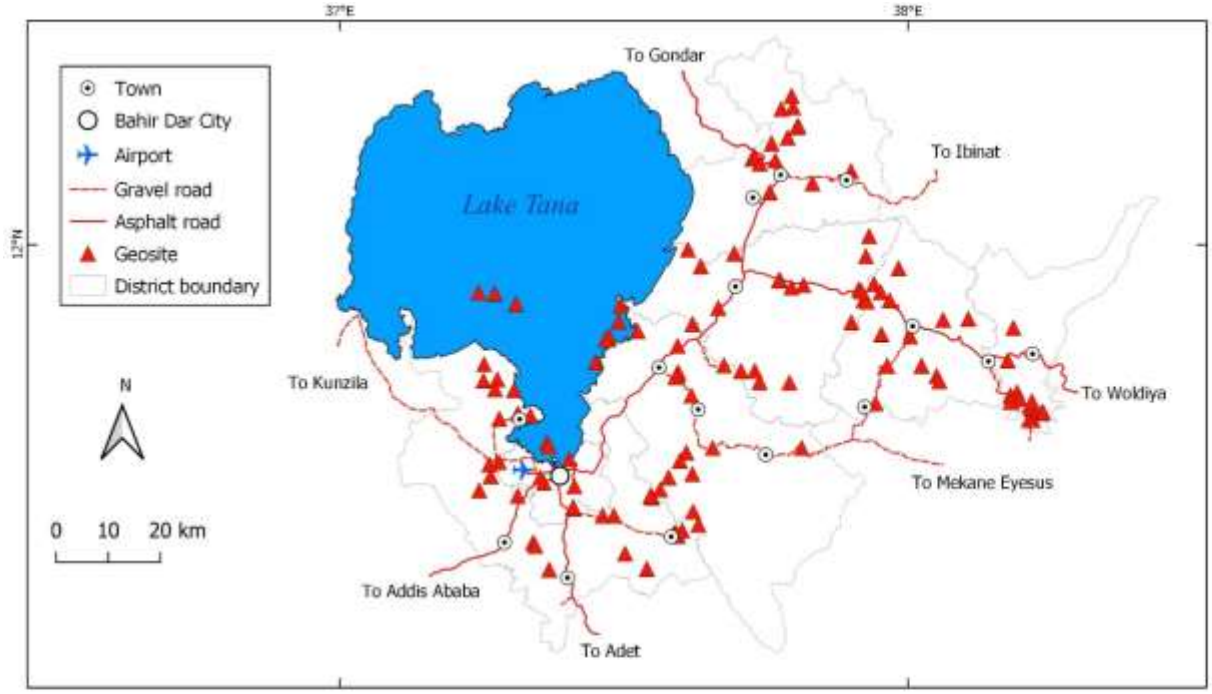

Fig. 2 Location of 120 geosites initially inventoried in the eastern and southeastern Lake Tana region (as some geosites are located close to each other, there might be overlapping)

Assessing the potential of geosites

Criteria for assessing the potential of geosites

It is difficult to directly apply the geosite assessment criteria developed during previous studies (e.g., Vujičić et al. 2011; Kubalíková 2013; Brilha 2016). The criteria need to be adjusted to the context of the study area. The methodology for this study (Table S1 in the Online Supplement) was developed based on available literature on geotourism and scenic beauty assessment, and on geosite inventory and assessment (mainly Daniel 2001; Pereira et al. 2007; Lima et al. 2010; Pereira and Pereira 2010; Vujičić et al. 2011; Fassoulas et al. 2012; Kubalíková 2013; Brilha 2016; Zgłobicki et al. 2019).

The objective of this assessment determines the grouping of the assessment indicators and sub-indicators under certain values (Mucivuna et al. 2019). As the main objective of this study was to inventory and assess geosites for geotourism development, two major groups of values (criteria) were used: main and additional ones. A main value is related to the intrinsic value of a geosite (the main reason for tourists to visit a geosite) and protection value. Hence, it consists of five indicators: scientific, educational, scenic, recreational, and protection, which are further subdivided into twelve sub-indicators (Table S1, Part I in the Online Supplement). Additional value refers to values that provide an extra reason for visitors to travel to and appreciate a geosite as well as factors that facilitate a visit to a geosite. Additional value has two indicators (added and functional), which consist of six sub-indicators (Table S1, Part I in the Online Supplement). For each sub-indicator, a five-point scale ranging from 0 to 1 (i.e., 0, 0.25, 0.5, 0.75, and 1), which is common in geosite assessment (e.g., Vujičić et al. 2011; Tomić and Božić 2014; Višnić et al. 2016) was used to rate the potential of geosites (Table S1, Part II in the Online Supplement). This 0 to 1 scaling is convenient for converting the assessment results into a percentage. Moreover, unlike studies that used three/four-point scales, the use of the five-point scale gives room to better discriminate geosites on the basis of their potential for geotourism.

In order to get an insight about which of the geosites are already known: (1) the tour operators' itineraries were reviewed; (2) TripAdvisor reviews about the geosites were counted; and (3) photos of the geosites in Google Image and Instagram were counted. Promotion and interpretation of the geosites that are already being visited frequently were also evaluated.

According to Migoń and Pijet-Migoń (2017), the specific procedures for assessing the potential of viewpoints and geosites vary in terms of both the number and type of criteria/indicators as well as the weighting of individual sub-indicators. The methodology developed in this study was for geosites (with and without viewpoints) only, and not for viewpoints. Hence, viewpoints inventoried in this study were assessed only for their scenic beauty.

Setting weights of sub-indicators and indicators

Weights were set for both sub-indicators and indicators. The weights of all sub-indicators were set by experts (Table 1). Experts were told that the objective was to assess geosites for geotourism development, and asked to keep this in mind when setting the weights. An Analytic Hierarchy Process (AHP) was used to determine the weights of sub-indicators for scientific, educational, and protection values. An AHP allows a pairwise comparison of (sub-)indicators to determine their level of importance or weight. It is carried out with "pairwise comparison judgments which are then used to develop overall priorities for ranking the alternatives" (Saaty and Vargas 2012). Six experts in geology and physical geography (KU Leuven) participated in setting the weights using a pairwise comparison of the sub-indicators of each indicator. However, the pairwise comparisons made by three experts were found inconsistent and hence were dropped. The weights set by the remaining three experts were used in this study. The average weights were then taken for determining the final weight of each sub-indicator. Scenic and recreational values do not have sub-indicators, and hence no sub-indicator weights were set.

Table 1 Weights of sub-indicators for scientific, educational, protection, added and functional values used to assess geosites

Scientific value sub-indicators	Educational value sub-indicators	Protection value sub-indicators	Added value sub-indicators	Functional value sub-indicators
Representativeness = 0.15	Interpretative potential = 0.25	Current conservation status = 0.4	Ecological value = 0.5	Direct access = 0.18
Geodiversity = 0.14	Quality of exposure = 0.75	Protection level = 0.14	Cultural value = 0.5	Travel time = 0.4
Rarity = 0.46		Fragility = 0.27		Proximity to other attractions = 0.09
Scientific knowledge = 0.25		Potential forces = 0.19		Means of transport = 0.33

Attempts to determine the weights of the sub-indicators for added and functional values using AHP was not successful due to the inconsistency of the experts' individual responses. As a result, a focus group discussion (FGD) was organized with seven experts from the Tourism and Hotel Management department (Bahir Dar University) to determine the weights (Table 1). The experts compared each of the sub-indicators in added value based on their importance for indicating the potential of geosites for geotourism development. The same procedure was followed for functional value sub-indicators.

As far as the indicators were concerned, equal weights were assumed for each of the five indicators of the main value (i.e., scientific, educational, scenic, recreational, and protection) of geosites. These indicators are in one way or another related to tourists' purpose of visit. Hence, setting varying weights for these indicators does not seem logical as the tastes of tourists with varying purposes of visit can also differ. For example, visitors traveling to a geosite for scientific/educational purposes might be more interested in the scientific/educational values than the scenic ones; or a tourist traveling for recreation purposes might simply be interested in the scenic beauty and recreational activities, and less interested in scientific values. On the other hand, the weights of the two indicators of additional value (i.e., added and functional) were determined using FGD by the Tourism and Hotel Management experts mentioned above. Added value received a weight of 0.24 while functional value received 0.76.

Quantifying the potential of geosites

Each geosite score for a given sub-indicator was calculated by multiplying the rating of the geosite on a five-point scale (Table S1, Part II in the Online Supplement) with the weight of the same sub-indicator (Table 1). Each of the five indicators (scientific, educational, protection, added and functional) was calculated as the sum of their respective sub-indicator scores. As mentioned earlier, the main value indicators were assigned equal weights. Hence, the main value is taken as the average score of its five indicators (scientific, educational, scenic, recreational, and protection). In addition, additional value is calculated as the sum of the weighted mean of added and functional value scores, as follows:

Additional value = (sum of added value sub-indicator scores × 0.24) + (sum of functional value sub-indicator scores × 0.76).

In this study, assessing the scientific, educational, and protection values of geosites (based on the assessment criteria in Table S1, Part II in the Online Supplement) by a group of experts was difficult mainly due to a lack of experts familiar with all the geosites. Hence, the first author of this research made the assessment and discussed the results with an expert in physical geography (KU Leuven) who is quite familiar with the study area. An exception to this assessment is the interpretative potential of geosites (belonging to the educational value), which was evaluated by three experts in Geology and Physical Geography (KU Leuven). They rated the interpretative potential (Table S1, Part II in the Online Supplement) of different types of geosites such as waterfalls, lakes, volcanic plugs, dikes, volcanic columns, caves, volcanic cones, and domes and hot springs on a five-point scale ranging between 0 and 1. The mean value of scores given by experts was used to determine the interpretative potential score of each geosite. In addition, the assessment of added and functional values was made by the first author due to the lack of experts familiar with the study area.

As most of the inventoried geosites are currently not being visited by tourists, it was difficult to find actual visitors able to assess the scenic beauty. One possible option was to show photos of geosites to potential visitors. It is not unacceptable to use photos for rating scenic beauty as they are used for promoting attractions to visitors. Daniel (2001) reviewed various studies and concluded that the photo-based visual esthetic quality of landscapes usually closely matches assessments based on direct experience. Hence, photos of geosites were shown to 64 potential visitors selected from Ethiopia and other countries. Sixty respondents were students at various levels: 20 Bachelor's, 16 Master's, and 24 PhD students. In addition, 28 respondents were from Ethiopia, 26 from Belgium, and the remaining 10 from other parts of the world. As to their interest in different types of attractions, 21, 14, and 12 of the respondents mentioned that their first choices are geology and landscape, culture and history, and biodiversity, respectively. In addition, 16, 13, and 12 respondents indicated that their second choices are geology and landscape, biodiversity, and culture and history, respectively. The photos were shown to the respondents using two techniques: sending the photos via email or projecting them in a classroom. Respondents rated the scenic beauty of the geosites (including viewpoints) on a five-point Likert scale (ranging from 1 = "not at all interesting" to 5 = "extremely interesting", see Table S2 and Table S3 in the Online Supplement), and the mean value was taken for the final assessment of scenic beauty. The rating made using the five-point Likert scale was later converted to that of 0 to 1, to make it uniform with the assessment results of other indicators used to evaluate geosites. Note that the scenic beauty score of a geosite with viewpoint represented either the scenic beauty score of the geosite itself or its viewpoint, whichever is higher. Respondents were also asked to list feature/s of geosites they like (Table S2 and Table S3 in the Online Supplement), and the most frequent words they mentioned were analyzed using Word cloud.

Accessibility of geosites

The accessibility map was prepared based on the time it takes to travel (one-way) from Bahir Dar City to the geosite by car/boat and on foot. The distance of each geosite from the city was taken from Google Earth and validated with distances from the internet and data from drivers. In addition, for calculating the one-way travel time from Bahir Dar to a geosite, the nature of the road and the means of transport were considered. The average driving speed for each type of road (asphalt, gravel, and dirt) with a four-wheel-drive was received from drivers. Besides, for geosites accessible by boat, the lowest speed of 17 km/h was taken based on information from boat captains (note that the speed depends on the type of boat: some metal boats have a speed of 17 km/h, others 23 km/h while fiber boats can travel at 27 km/h). Furthermore, an average walking speed of 5 km/h was taken for geosites accessible only on foot, while still allowing flexibility for certain footpaths depending on the topography (for example, in some steep slope footpaths such as Aba Gurez cave and viewpoint, the walking speed taken was 1 km/h).

Results

Inventory of geosites in the eastern and southeastern Lake Tana region

As mentioned above, the 120 geosites on the initial list were further screened and clustered, and resulted in 61 geosites (Table 2, Fig. 3).

Table 2 Inventory of geosites in the eastern and southeastern Lake Tana region (see Fig. 3 for their location)

Code	Name of the geosite	Code	Name of the geosite	Code	Name of the geosite	Code	Name of the geosite
1	Arefamie/Reti Falls	17	Nachabet cave	33	Bahireshesh wetland	49	Menta Debir viewpoint
2	Blue Nile Falls and Canyons	18	Kess cave and viewpoint	34	Wukiro Medihanealem rock-hewn Church	50	Dewol Amidemariam viewpoint
3	Aba Gurez cave and viewpoint	19	Gedame Eyesus cave	35	Bira volcanic dome and viewpoint	51	Dewol viewpoint
4	Dingay Debalo Mariam rock-hewn church	20	Wanzaye hot springs	36	Shamo volcanic plug and viewpoint	52	Kibebe Dasira hill viewpoint
5	Gudo Bahir wetland	21	Duriba Falls	37	Astamariam volcanic column and viewpoint	53	Zarina Jegina viewpoint
6	Dibankie volcanic cone and viewpoint	22	Sositu Dilmo hot water wetland	38	Zena Mariam rock-hewn Church	54	Alemsaga viewpoint
7	Gicha Kokeb volcanic cone	23	Fogera flood plain	39	Wohiny Amba volcanic plug	55	Debre Tabor Eyesus viewpoint
8	Makisegnit volcanic cone and viewpoint	24	Woji baked contact	40	Worq Amba volcanic plug	56	Semerinaha viewpoint
9	Barud volcanic cone and viewpoint	25	Mintura volcanic plug and viewpoint	41	Asiva volcanic plug	57	Mohitro viewpoint
10	Siwan volcanic cone and viewpoint	26	Gawudy volcanic dome and viewpoint	42	Endiriyas cave church	58	Mt Guna peak viewpoint
11	Yiganda Wetland	27	Zengaba volcanic dome and viewpoint	43	Teklehayimanot cave church	59	Angot Agela viewpoint
12	Zegie peninsula and viewpoint	28	Amora Gedel volcanic plug and viewpoint	44	Qualit volcanic plug	60	Astamariam viewpoint 1
13	Lake Tana	29	Alemsaga dike	45	Bezawit viewpoint	61	Washa Endiriyas viewpoint
14	Gugubie volcanic dome and viewpoint	30	Alemsaga landslide	46	Mulilit viewpoint		
15	Lalibela dike	31	Wiza Falls	47	Kachura viewpoint		
16	Lalibela cave	32	Mt Guna	48	Lalibela viewpoint		

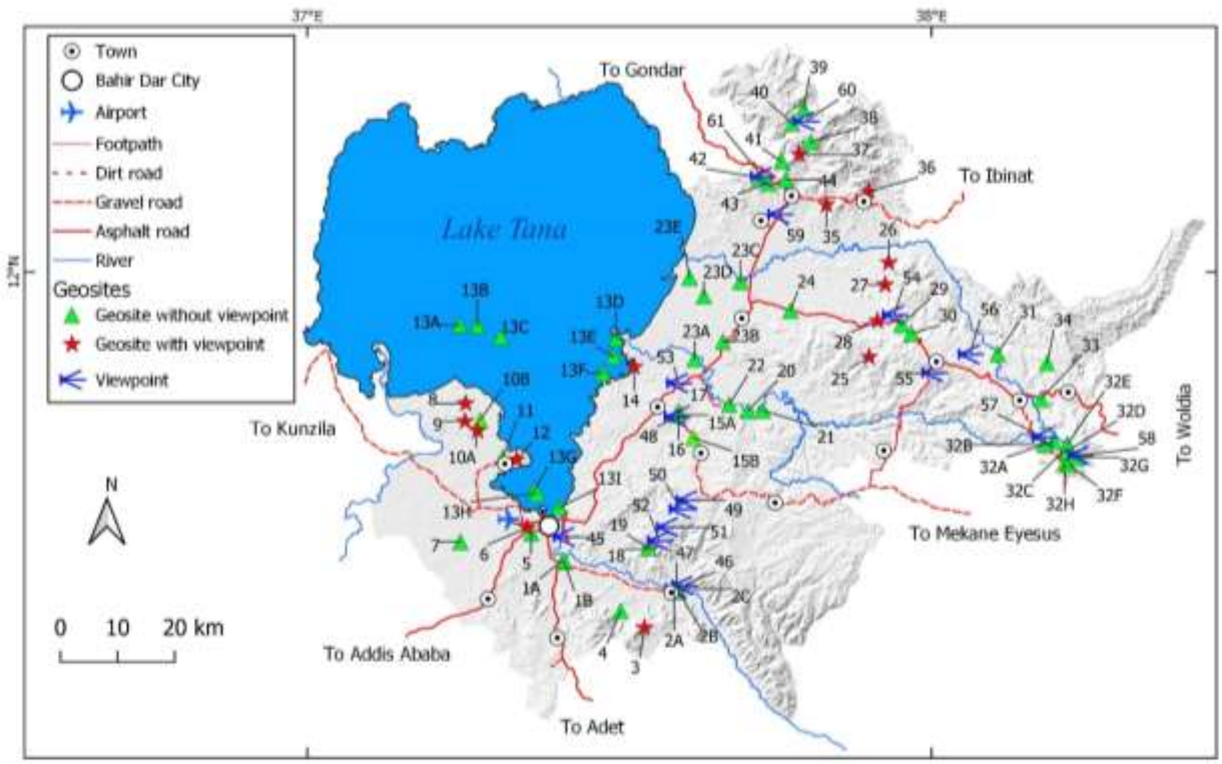

Fig. 3 The 61 selected geosites in the eastern and southeastern Lake Tana region. Note that codes 2, 10, 13, 15, 23 and 32 are clustered geosites (i.e. they have individual geosites that were coded alphanumerically). Geosites with codes 1 to 44 are geosites with and without viewpoints while codes 45 to 61 represent viewpoints. All the geosites with their numerical codes and full names are listed in Table 2. See the classification of geosites in the section "Geosite Inventory and Selection". All geosites on Lake Tana are islands with monasteries or churches. Islands located in the northern Lake Tana part were not included in this map/study.

Description of selected geosites in the study area

In all, 61 geosites were inventoried and assessed in the study area. Among these are waterfalls, a large lake with island monasteries, a shield volcano, caves and cave churches, lava tubes, volcanic cones, volcanic plugs, volcanic domes, volcanic columns, block streams, hot springs, rock-hewn churches, a peninsula, wetlands, and viewpoints. Some of these geosites are briefly described below.

Blue Nile Falls (geosite 2A): this is the largest waterfall in Ethiopia (Fig. 4a). It is formed over a barrier of hard Quaternary basalt layer that resisted headwater erosion of the Blue Nile River (Williams 2016, 2020). The Blue Nile Falls is located ca. 30 km southeast of the Lake Tana outlet. Bruce (1804) visited the Blue Nile Falls in the eighteenth century, and described his impression as follows:

> *The river … fell in one sheet of water, without any interval, above half an English mile in breadth, with a force and noise that was truly terrible, and which stunned and made me, for a time, perfectly dizzy. … the stream, in a noise like the loudest thunder, to make the solid rock (at least as to sense) shake to its very foundation, and threaten to tear every nerve to pieces, and to deprive one of other*

senses besides that of hearing. It was a most magnificent sight, that ages, added to the greatest length of human life, would not deface or eradicate from my memory.

Lake Tana and its island monasteries (geosite 13): The formation of Lake Tana is still not well understood. One argument is that the lake was formed as a result of subsidence and the convergence of grabens (Chorowicz et al. 1998; Williams 2016), and lava damming (Skovitina et al. 2012; Poppe et al. 2013; Williams 2016; Asrat 2018). Chorowicz et al. (1998) stated that the lake lies at the junction of three grabens: the Dengel Ber, Gondar and Debre Tabor. However, the lava-damming theory has received critics. The equidimensional form of Lake Tana and the absence of an aggraded surface in the Gilgel Abay valley imply that the lava-damming theory does not work (Chorowicz et al. 1998). In addition, the lake's formation and the lava south of the lake did not occur in the same period. Prave et al (2016) found that the lava is only 33,000 years old, whereas the lake, from the dating of its oldest bottom sediments, is at least 150,000 years old (Lamb et al. 2018). The other argument is that Lake Tana is "a caldera ringed by fault blocks formed by caldera collapse" (Prave et al. 2016). Williams (2016) indicated that, based on evidence from ancient shorelines ca. 15,000 years ago, "the lake was twice as large, in area, as it is today, and its surface level was ca. 75 m higher". Lake Tana has ca. 35 islands hosting ca. 20 monasteries and churches. Some monasteries date back to the thirteenth and fourteenth centuries, and monasteries such as Tana Kirkos date back to the pre-Christian period (Phillips and Carillet 2006). According to Williams (2016), the majority of the Lake Tana islands are formed of blocky lava fragments or are cinder cones. The lake and its islands are part of the UNESCO registered Lake Tana Biosphere Reserve.

Zegie peninsula and viewpoint (geosite 12): this peninsula is located south of Lake Tana, and is the largest peninsula in the study area. It provides a spectacular view of Lake Tana and some of its islands, Bahir Dar City and the surrounding landscapes (Fig. 4b). It also has six monasteries and biodiversity (Fig. S1b in the Online Supplement), and is part of the UNESCO registered Lake Tana Biosphere Reserve. The peninsula is one of the most visited sites in the study area mainly due to its monasteries with their sixteenth- to twentieth-century heritage (Phillips and Carillet 2006).

Jib Washa lava tube (geosite 10B): This lava tube (Fig. 4c) is located ca. 15 km north of the Zegie peninsula. It is associated to eruptions in the nearby Siwan volcanic cone as lava tubes are "formed at the same time as the surrounding rock" (Garofano 2018).

Makisegnit volcanic cone (geosite 8): this volcano, located ca. 20 km north of the Zegie peninsula (Fig. 4d), has very steep slopes on its western side. Its central part is cropland. Another crescent-shaped volcanic cone can be seen ca. 200 m west of Makisegnit volcano.

Kess cave and viewpoint (geosite 18): This geosite is located ca. 25 km south of Anbesamie town. It has an area of ca. 5,500 m^2 and is the largest single chamber in Ethiopia (Weare et al. 2016). The cave has speleothems. It also hosts a large colony of bats. The area provides a spectacular view of the Blue Nile River valley and the surrounding landscape.

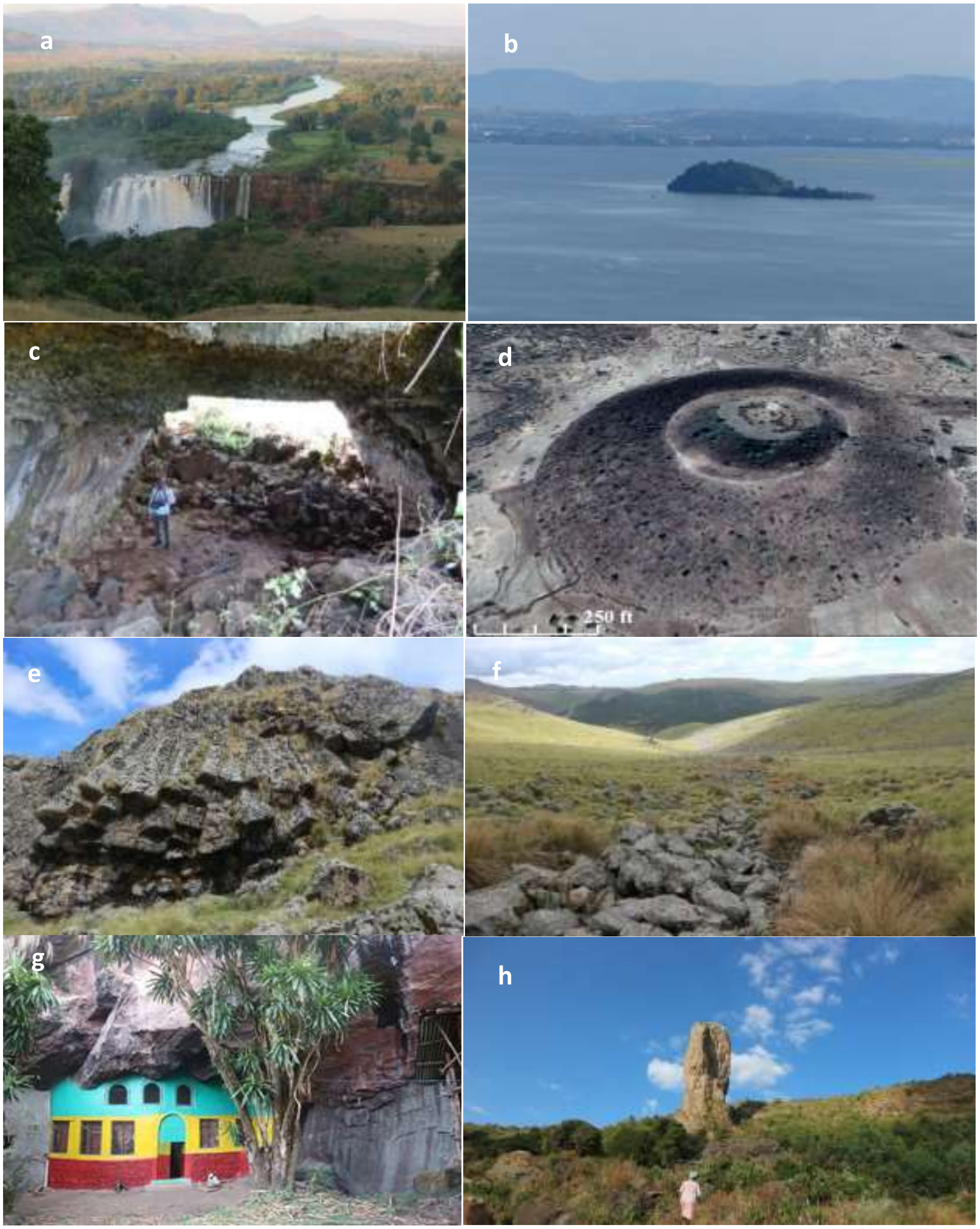

Fig. 4 Illustration of some selected geosites in the eastern and southeastern Lake Tana region. **a** The Blue Nile Falls (geosite 2A) as seen from the Kachura viewpoint (geosite 47), ca. 45 m high (photo GA Tessema 2018). **b** Lake Tana (geosite 13) as seen from the Zegie peninsula viewpoint (geosite 12), with the Kibran Gebriel island monastery (geosite 13G) on the lake and Bahir Dar City in the background (photo Jean Poesen 2019). **c** The Jib Washa lava tube (geosite 10B), ca. 3.75 m high, ca. 15 km north of the Zegie peninsula (photo Jean Poesen 2019). **d** The Makisegnit

volcanic cone and viewpoint (geosite 8), ca.20 km north of the Zegie peninsula (photo Google Earth Image August 31 2020). **e** Volcanic columns (geosite 32H), probably phonolite, Mt Guna (photo GA Tessema 2019). **f** Block Stream (geosite 32F), up to 1.2 km long, Mt Guna (photo GA Tessema 2018). **g** Teklehayimanot cave church (geosite 43), ignimbrite, ca. 90 m long, ca. 10 km north of Addis Zemen town (photo GA Tessema 2018). **h** Qualit volcanic plug (geosite 44), also called "God's Finger" ("*Ye'ab Idj*"), trachyte, ca. 75 m high, ca. 5 km north of Addis Zemen town (photo GA Tessema 2018). For the location of these geosites, see Fig. 3; and for their values, see Fig. 5.

Fogera flood plain (geosite 23): it is located east of Lake Tana. This flood plain, which was a former lake bottom of Lake Tana (Nilsson 1940), is characterized by Quaternary lacustrine and alluvial deposits (Nigate et al. 2017). Shesher and Welala are the two major wetlands in the Fogera plain which are home to many birds. For example, Atnafu et al. (2011) identified 62 species of birds in the two wetlands, and Aynalem et al. (2011) recorded 91,000 wetland birds in the Shesher wetland alone. Moreover, due to periodic flooding during summer, the human–environment interactions in the Fogera flood plain are interesting (Fig. S2 in the Online Supplement).

Mt Guna (geosite 32): It is found ca. 30 km southeast of Debre Tabor town. With an elevation of 4113 m a.s.l., Mt Guna is the highest mountain in the study area, and one of the highest in Ethiopia. It is the source of ca. 40 rivers and several streams that flow to either the Blue Nile or the Tekeze basins (Fetene et al. 2012). Mt Guna serves as a water divide in the southeastern margin of the Lake Tana basin (Poppe et al. 2013). It is a community conservation area with core, buffer, and development zones already demarcated. Having erupted 10.7 million years ago (Kieffer et al. 2004; Williams 2016), Mt Guna appears to be the youngest of the northwestern Ethiopian highland shield volcanoes (Williams 2016). Geologically, it mainly consists of rhyolite lava flow, pyroclastic flow deposit, and phonolite lava flow, from bottom to top (Mekonnen 2006). Mt Guna has volcanic columns (probably phonolite, Fig. 4e), volcanic plugs, block streams (Fig. 4f), caves, wetlands, andosols, and viewpoints. The mountain also shelters endemic plants (e.g., giant lobelia) and animals (e.g., gelada baboon).

Teklehayimanot cave church (geosite 43): this cave church is located ca. 500 m west of the Bahir Dar–Gondar road near Tara Gedam, and is the most accessible cave church in the study area. According to information from the zonal tourism office, its origin dates back to the fourteenth century (Fig. 4g). It is one of the three cave churches in the study area.

Qualit volcanic plug (geosite 44): this plug is located ca. 500 m east of the Bahir Dar–Gondar road near Tara Gedam, and is one of the most accessible plugs in the study area. It consists of trachyte (Desta 2018, Fig. 4h). Several large rockfall deposits can be observed along the main road.

The potential of geosites for geotourism development in the eastern and southeastern Lake Tana region

To understand and compare the potential of geosites, a bar graph with five main value indicators (scientific, educational, scenic, recreational, and protection) and two additional value indicators (i.e., added and functional) is presented (Fig. 5). Most geosites received a score higher than 0 in each of the seven indicators. The values of the geosites assessed based on the seven indicators are briefly discussed below under two sub-headings: main and additional.

Main value of the geosites

It can be observed in Fig. 5 that clustered/complex area geosites have received relatively higher scores in terms of scientific, scenic, and recreational values (see the full assessment result in Table S4 in the Online Supplement). For example, the top four geosites in terms of scientific values are Lake Tana, the Blue Nile Falls and Canyons, Mt Guna, and the Fogera flood plain. They received higher scientific value mainly because of their rarity and/or the availability of scientific knowledge about these geosites. Only four geosites have educational values below 0.75. Caves, waterfalls, and wetlands are among the top-ranking geosites in terms of educational value. The Blue Nile Falls and Canyons and Mt Guna were rated as the two most scenic geosites in the study area. The Blue Nile Falls and Canyons, Mt Guna, the Mintura volcanic plug, Lake Tana, the Zegie peninsula and viewpoint, and the Fogera flood plain are in the top rank for recreational value. As most geosites are volcanic features that can withstand natural and anthropogenic forces, they have a higher protection value (which is good for geotourism development). The Woji baked contact, the Dibankie volcanic cone (Fig. S3b in the Online Supplement), and the Gudo Bahir wetland received the lowest protection scores due to disturbance by anthropogenic processes: the first two are (old) gravel quarry sites while the last one is shrinking due to urbanization and farming. Mt Guna and Lake Tana, which received high scores in other main value indicators, are affected by anthropogenic and natural processes. The former is affected by community encroachment for grazing and agriculture while the latter mainly suffers from pollution, sedimentation (Goshu et al. 2017; Lemma et al. 2018), and invasive water hyacinth (Van Oijstaeijen et al. 2020).

Additional values of the geosites

Lake Tana and the Zegie peninsula and viewpoint have the highest additional value scores, followed by Mt Guna (Fig. 5). The former two are home to monasteries and churches as well as biodiversity. Because of their ecological values, Lake Tana (e.g. Fig. 6a) and the Zegie peninsula have become part of the UNESCO registered Lake Tana Biosphere Reserve. For example, Lake Tana is known for its hippos and birds. The Lake Tana islands host ca. 20 monasteries and churches, of which ca. 10 are endowed with important religious, cultural and historical treasures worth a visit. Mt Guna is a community conservation area and has important mountain fauna and flora. It is home to ca. 30 mammal species, some of which such as the gelada baboon (Fig. 6b), the Ethiopian highland hare and the Abyssinian grass rat are endemic (Fetene et al. 2012). In addition, the Mt Guna conservation area has more than 139 bird species, of which five are endemic, and 96 plant species, including five endemic plants. On the other hand, dikes, volcanic plugs, volcanic domes and volcanic cones are among the geosites that received the lowest additional value scores.

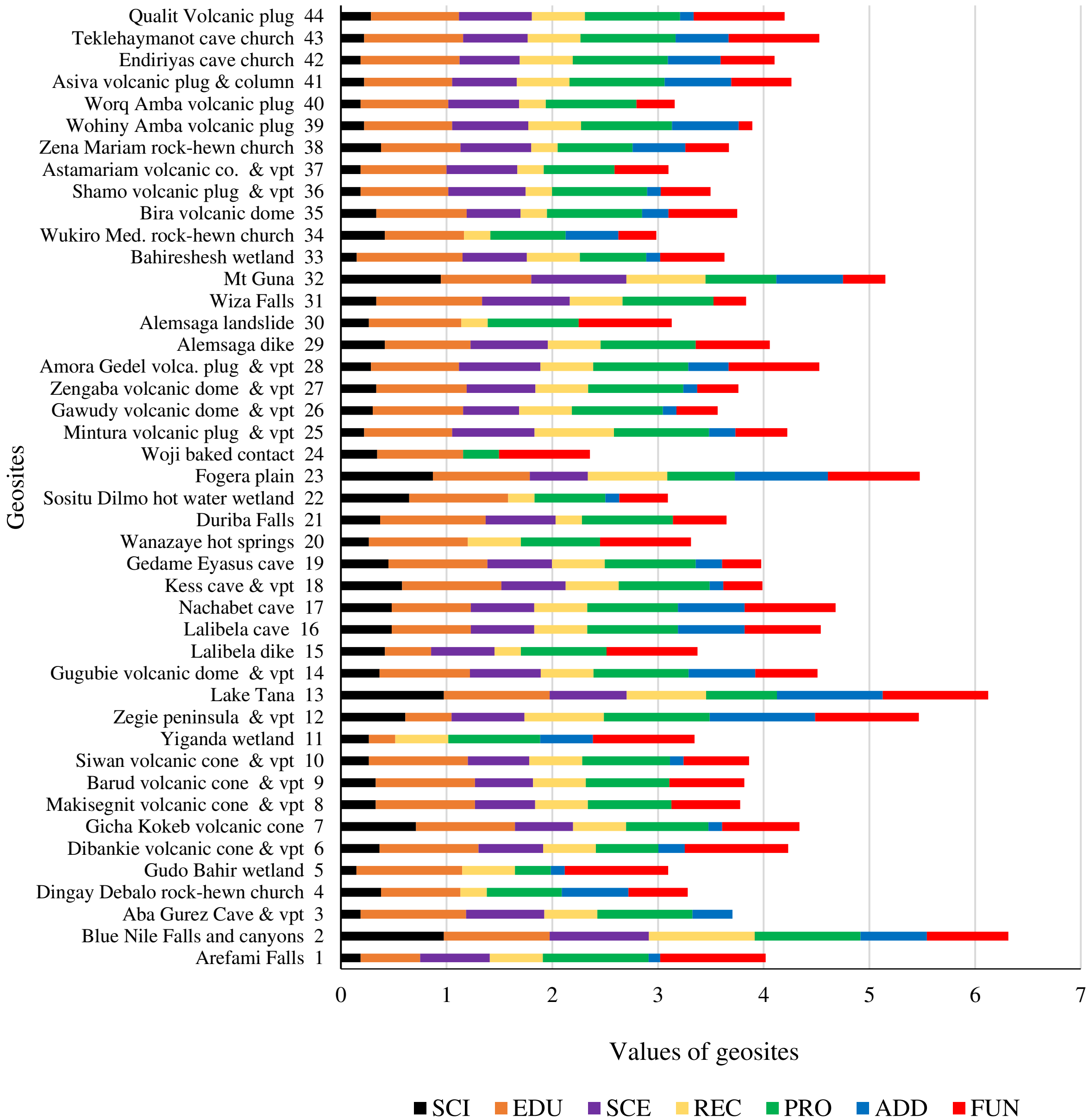

Fig. 5 Main and additional values of geosites (with and without viewpoints) in the eastern and southeastern Lake Tana region. (SCI = scientific value, EDU = educational value, SCE = scenic value, REC = recreational value, PRO = protection value, ADD = added value, FUN = functional value, vpt = viewpoint, co. = cone). For the calculations, see the section on "quantifying the potential of geosites", and for the location of the 44 geosites, see Fig. 3.

A close look at the detailed data about the added value (sum of cultural and ecological values) revealed that of the 44 geosites, 32 have cultural and/or ecological values. For example, seven islands in Lake Tana are volcanic cones (Williams 2016) and home to monasteries, three of which date back to the thirteenth and fourteenth centuries. Some caves in the area are also important cultural and archeological sites. For example, excavations in Lalibela and Nachabet caves at the end of the 1960s yielded finds from 500 BC up to the present (Dombrowski 1970). Furthermore, some geosites in the study area are part of the UNESCO registered Lake Tana Biosphere Reserve, which justifies their ecological importance.

In relation to functional value, those geosites which are located close to Bahir Dar, close to the main road and/or nearby other attractions (geosites or other types of attractions) received the highest scores. Hence, 15 geosites scored 0.86 and above. By contrast, 13 geosites received a mean score of less than 0.5. Aba Gurez cave and viewpoint is the lowest in terms of functional value rating, receiving a zero score. This geosite is located southwest of the Blue Nile Falls, with no other attraction nearby, and the only means of accessing the site is by motorcycle (during the dry season) or on foot. It should be noted that, due to the nature of the roads, some geosites are accessible only during the dry season. Geosites such as the Shesher and Welala wetlands are not even accessible in the period from June to January.

Fig. 6 Biodiversity in the eastern and southeastern Lake Tana region. **a** Pelicans on Lake Tana (photo GA Tessema 2018). **b** Gelada baboons at Mt Guna (photo GA Tessema 2018).

Comparison of main and additional values of the geosites

Of the 44 geosites, 37 and 26 received above-average (more than 0.5) scores in their main and additional values, respectively (Fig. 7; for the detail, see Table S4 in the Online Supplement). The top five geosites in terms of main value are the Blue Nile Falls and Canyons, Lake Tana, Mt Guna, the Fogera flood plain and the Wiza Falls (represented by codes 2, 13, 32, 23 and 31, respectively), in descending order. Lake Tana, the Zegie peninsula and viewpoint and the Fogera flood plain are the top three geosites in terms of additional value. This is mainly due to their cultural and ecological values, and easy access from Bahir Dar City.

Many geosites have a relatively lower additional value than main value (the geosites to the right of the 1:1 line). Good examples of this are the Aba Gurez cave and viewpoint, and the Wohiny Amba volcanic plug (Fig. S4 in the Online Supplement). The lower additional value is mainly due to accessibility issues: means of transport to reach the geosite, direct access to the geosite and travel time to the geosite.

The geosite scores in both main and additional values could be classified as very low (scores 0–0.19), low (0.2–0.39), moderate (0.4–0.59), high (0.6–0.79), and very high (0.8–1.0). The matrix of main and additional values based on this categorization resulted in 25 cells (Fig. 7). Such classification helps to prioritize the geosites for development.

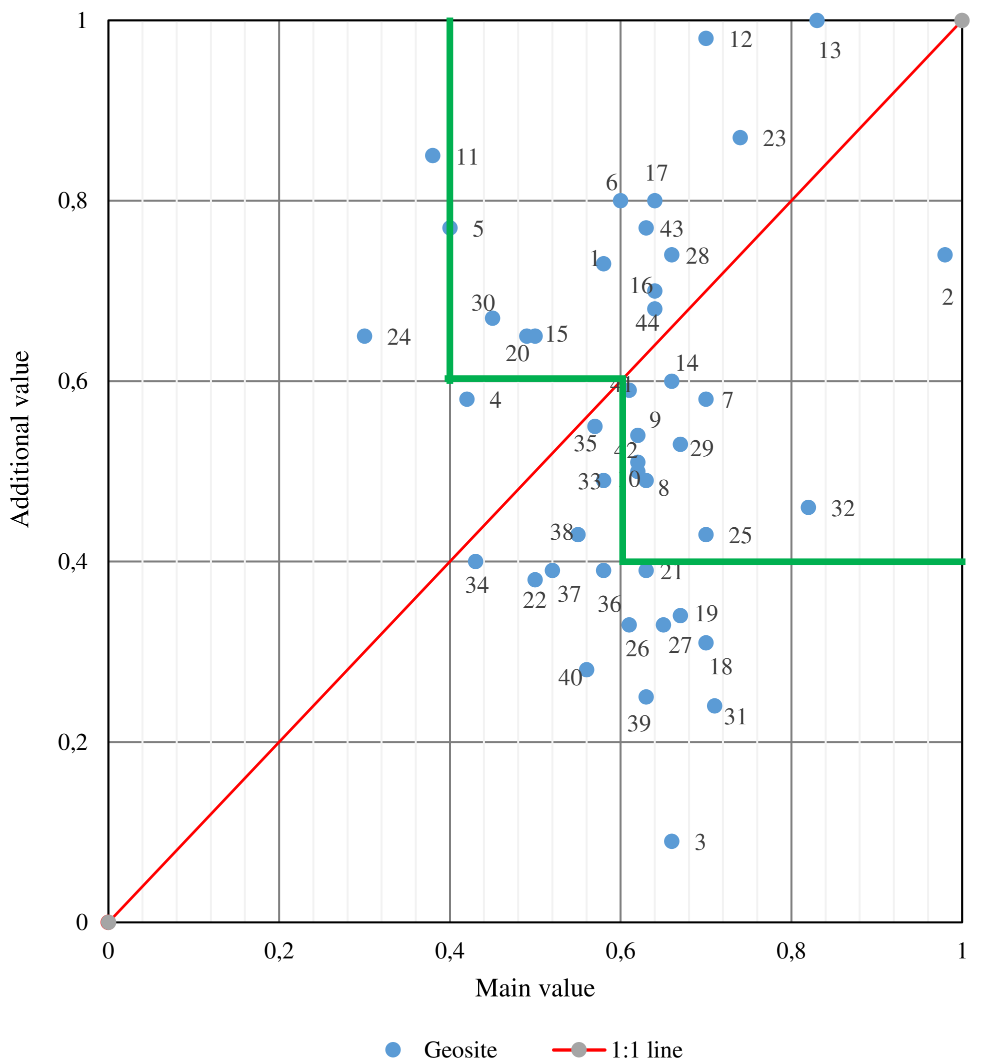

Fig. 7 Main versus additional values of geosites (with and without viewpoints) in the eastern and southeastern Lake Tana region. Numbers refer to geosite codes (see Table 2 for their names). The geosites to the right and above the green line are those with a matrix of high/very high main and additional values as well as a high/very high main value and moderate additional value.

Mapping accessibility of the geosites

Accessibility is a critical factor for geotourism development in the eastern and southeastern Lake Tana region. Bahir Dar City has tourist standard accommodation facilities and is taken as a reference visitor facility center for calculating travel time. As shown in Fig. 8, of the 84 geosites (61 when clustered) in the study area, 43 are accessible (by car/boat and on foot) within less than 2 h from Bahir Dar. Only ten geosites have a travel time of less than 1 h (by car/boat). It should be noted that most geosites require walking from the parking areas.

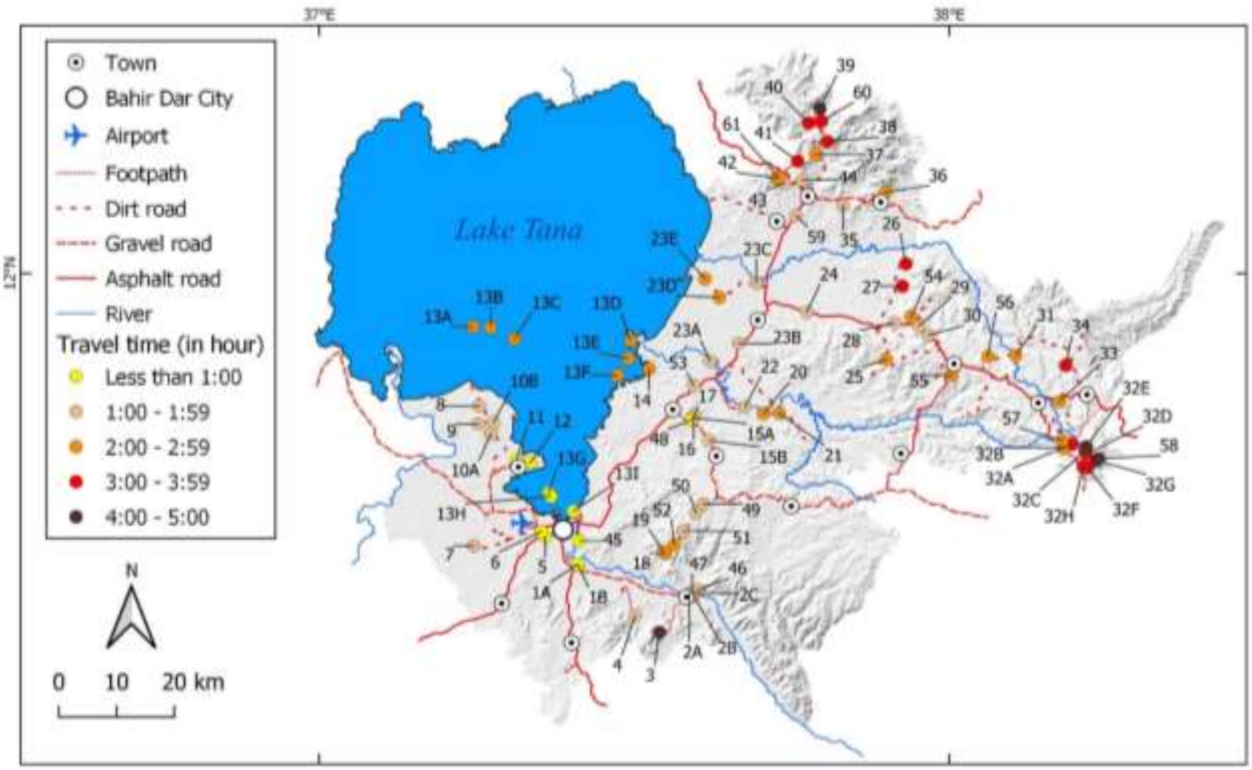

Fig. 8 Travel time from Bahir Dar City to each geosite (by car/boat and on foot). All the geosites with their numerical codes and their full names are listed in Table 2.

The longest travel time is to geosites 3, 32E, 32G, 39, and 58, which represent the Aba Gurez cave and viewpoint, the Ergib Medihanealem cave church on Mt Guna, a wetland near the peak of Mt Guna, the Wohiny Amba volcanic plug, and the Mt Guna peak viewpoint (Fig. S5 in the Online Supplement). This is mainly due to the lack of a road (for the first two geosites) and the nature of the topography around all these geosites. After driving a certain distance, access to these geosites is only on foot over very steep terrain.

Familiarity, promotion and interpretation of the geosites

In the absence of (organized) data about which geosites in the area are known, one option is to use web-based information sources such as tour operators' itineraries, TripAdvisor reviews, and photos from Google Images and Instagram. This is based on the idea that geosites that frequently appear in tour operators' itineraries, and those with a higher number of TripAdvisor reviews and photos (in Google Images and Instagram) are the ones that are popular (and probably those most frequently visited).

The frequency a geosite is mentioned in the itineraries of 30 randomly selected tour operators based in Addis Ababa and offering tours to Bahir Dar were counted (Table S6 in the Online Supplement). The Blue Nile Falls and Lake Tana monasteries (the latter mentioned as "Lake Tana monasteries" or with specific places such as Ura Kidanemihiret, Azwa Mariam, Kibran Gebriel or Debre Mariam) are found in all the itineraries. All the tours arranged are within a ca. 40 km radius from Bahir Dar City.

The number of TripAdvisor reviews made so far were also counted on March 07/2020 (Table S7 in the Online Supplement). Lake Tana and the Blue Nile Falls received the highest number of reviews, with 560 and 450, respectively. The Azwa Mariam and Ura Kidanemihiret monasteries (on the Zegie peninsula) had 134 and 44 reviews, respectively. The Lake Tana island monasteries of Debre Mariam and Narga Selassie received 89 and 8 reviews, respectively.

Furthermore, photos of geosites in the study area were counted in May/2019 using keywords in the Google Images and Instagram search engines. The Blue Nile Falls and Lake Tana had the highest number of photos in these two web-sources. There were ca. 335 and ca. 630 photos of the Blue Nile Falls in Google Images and Instagram, respectively. Lake Tana had ca. 190 and ca. 600 photos in Google Images and Instagram, respectively. With ca. 200 photos in Google Images, Ura Kidanemihiret (Fig. S6 in the Online Supplement) is probably the most photographed monastery in the study area. Three volcanic plugs (Qualit, Amora Gedel, and Asiva) have 53, 23, and 2 photos in Google Images, respectively. The Qualit volcanic plug is the most photographed of the three mainly because of its roadside location, along the Bahir Dar–Gondar route.

As most of the geosites inventoried are "new" and not visited regularly by tourists, it is premature to make a quantitative assessment of these geosites using sub-indicators such as the number of visitors and organized visits, interpretative panels, promotions, and tour guiding services. These sub-indicators can only be applied to geosites that are already being visited frequently. However, in our case, most geosites inventoried are new and very few tourists visit these sites. The only exceptions are the Blue Nile Falls and Lake Tana and its monasteries. Currently, tourists who travel to Bahir Dar visit any one or more of these geosites: Lake Tana and its island monasteries, the Zegie peninsula and its monasteries, the Blue Nile Falls, and the Bezawit viewpoint. Both organized visits and independent travels are made to these sites. In the years between 2007/8 and 2018/19, an average of over 28,000 international tourists per year visited some or all of these geosites (Bahir Dar City Culture and Tourism Office 2020). Local tour guides have organized themselves into associations and provide services for visitors to Bahir Dar and its vicinity. Three associations have been established at three sites: in Tis Abay, Bahir Dar, and the Zegie peninsula, which have 24, 28, and 25 members, respectively.

Efforts to promote the geosites in the study area are limited. The Blue Nile Falls and Lake Tana and its monasteries are promoted in tour operator websites, guidebooks, and tourism trade fairs (including international ones). Except for signposts showing distances and directions, no other information panels are currently available around these geotouristic attractions.

The scenic beauty of viewpoints

Viewpoints with relatively higher scenic beauty scores are those located close to Lake Tana, the Blue Nile River/Falls, and Mt Guna. For example, the viewpoint with the highest scenic value score is Mohitro, which is located on Mt Guna. The Kachura and Mulilit viewpoints are located near the Blue Nile Falls/River and are among those that received relatively higher scores. The Bezawit viewpoint provides a spectacular view toward the Blue Nile River, Lake Tana, and Bahir Dar City, and is one of the most beautiful viewpoints in the study area. The average score for the 17 viewpoint geosites is 0.64, the minimum and maximum being 0.5 and 0.9, respectively. It should be noted that Mt

Guna has several viewpoints because of its higher elevation. However, only two sample viewpoints were selected as showcases.

Interesting features about the scenic beauty of geosites

Scenic beauty is one of the main reasons for geotourists to travel to geosites. Hence, it is important to identify features of geosites that are interesting to visitors. This helps with inventorying, developing, and marketing geosites. Figure 9 shows the most frequent words respondents mentioned about interesting features related to the scenic beauty of geosites. Six of the most frequent words expressing their appreciation were formation (shape), feature, mix, color, nice, and size, each with a frequency of 180, 147, 122, 103, 103, and 84, respectively. The minimum word frequency in Fig. 9**a** is 11. On the other hand, Fig. 9**b** shows the most frequent words respondents mentioned in relation to the scenic beauty of landscapes as seen from a viewpoint. Six of the most frequent words along with their frequency were: landscape = 147, formation = 109, mix (such as mix of elements in the landscape) = 104, color = 97, green = 92, and view = 89. The minimum word frequency in Fig. 9**b** is 15. Among the interesting features that appear at a higher frequency in both Fig. 9**a** and Fig. 9**b** are formation, feature, landscape, color, contrast, size, and rock.

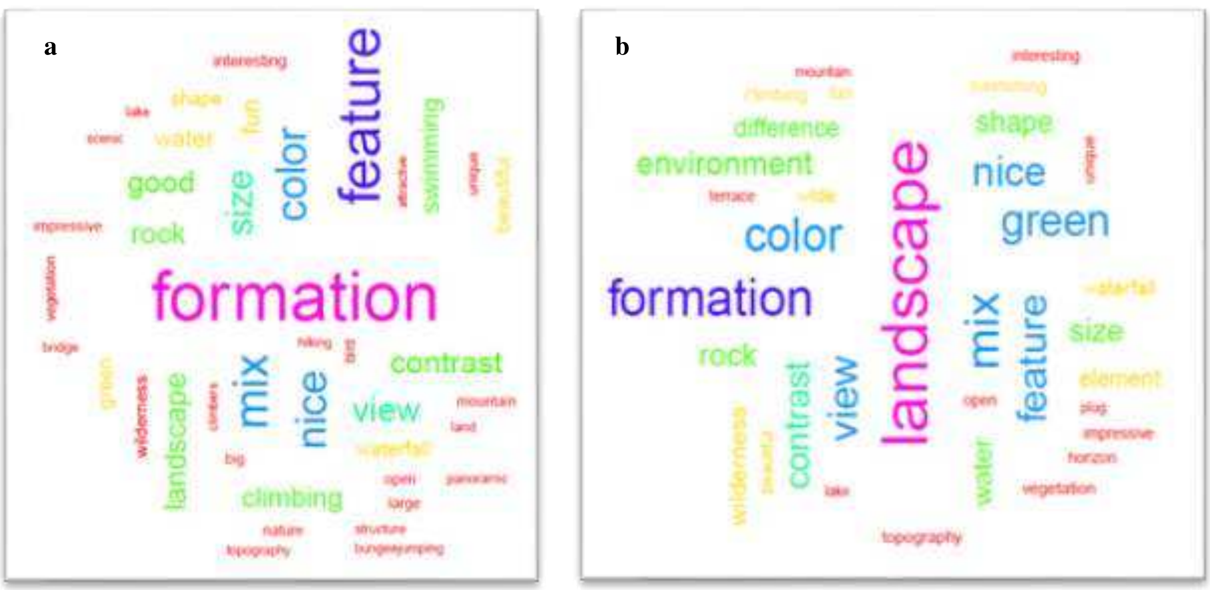

Fig. 9 Word cloud analysis of interesting features related to the scenic beauty of geosites (as expressed by 64 respondents). **a** Geosites with and without viewpoints. **b** Viewpoints.

Based on the interesting features of geosites illustrated in Fig. 9, respondents' judgment of scenic beauty can be classified into five themes, each consisting of several elements. These are size/scale (big, mountain, large, open, panoramic, view, horizon), color (contrast, vegetation, water, mix, green), shape (structure, formation, open, difference, wide, topography, contrast), activity (hiking, swimming, fun, climbing), and diversity/presence of different features (lake/water, vegetation, wilderness, bird, waterfall, terrace, element, rock). Kirillova et al. (2014) conducted a qualitative study to identify the dimensions of tourist aesthetic judgments for both nature-based and urban tourist destinations. They identified 21 esthetic dimensions and categorized them into nine themes: “scale, time, condition, sound, balance, diversity, novelty, shape, and uniqueness”.

Discussion

Methodology for inventory and assessment of geosites for geotourism development

Inventory and assessment of geosites is a crucial requirement for geotourism development. Pereira et al. (2007) and Suzuki and Takagi (2018) pointed out that doing so has important implications for the effective development, management and protection of geosites.

A methodology that takes into account the definition, nature, and principles of geotourism was developed. The criteria, indicators, and sub-indicators were taken based on a review of literature on geotourism, scenic beauty assessment, and geosite inventory and assessment. The development of methodologies based on a review of relevant literature is a common method in many geotourism studies (e.g., Pereira et al. 2007; Kubalíková 2013; Suzuki and Takagi 2018; Mucivuna et al. 2019).

Mucivuna et al. (2019) identified several of the procedures researchers use to inventory geosites. The four most commonly used procedures (review of the literature; field work; interpretation of maps; and interpretation of satellite images, digital elevation models or aerial photographs) were also applied in our study. In addition, other procedures the authors mentioned such as interviews with experts and tourism publications were also conducted to inventory geosites in the study area. The use of a number of procedures can help to inventory the most important geosites in an area.

While developing a methodology for assessing geosites for geotourism development, certain important considerations were addressed in this study. The first is that, in addition to intrinsic values, indicators related to culture and biodiversity were included. This has important implications for a comprehensive understanding of the environment and for sustainable (geotourism) development. Schrodt et al. 2019, p.3) also support this, arguing that “a holistic approach that recognizes and tracks the integrity of the abiotic and biotic components of geosystems and ecosystems is the most effective means to address global environmental challenges”.

The second consideration is setting weights for the sub-indicators and indicators used in assessing geosites. Experts set weights for sub-indicators of scientific, educational, protection, added, and functional values (Table 1) as well as indicators of additional values. However, equal weights were assigned for all indicators of the main value. This is because some geotourists might be more interested in the scientific/educational value of geosites, while others will simply be attracted by the scenic beauty and/or the recreational benefit a geosite provides. For example, according to Suzuki and Takagi (2018), geosites with a high scientific value may be more interesting to the scientific and student community, whereas (general) tourists may be more interested in geosites with esthetic and cultural attributes. Hence, the interest of geotourists toward indicators such as scientific/educational value, scenic value, and recreational value might be different, and so setting different weights for them to calculate the main value of geosites will be misleading.

The third is allowing (potential) visitors to judge the scenic beauty and identify the interesting features of geosites. Allowing visitors to rate the scenic beauty helps to understand their preferences, and also helps to identify the key features that contribute to landscape quality and their relative importance (Lothian 1999). Identifying the interesting features of geosites contributes theoretically to the body of knowledge related to scenic beauty, and practically for destination planning, marketing, and management (Kirillova et al. 2014).

The fourth consideration is the use of a five-point scale, instead of three or four as used in some studies (e.g., Vujičić et al. 2011; Kubalíková 2013; Suzuki and Takagi 2018), which gives room to better discriminate geosites based on their potential for geotourism development.

The final consideration is the use of web-based data sources such as a review of tour operator itineraries, TripAdvisor reviews, and counting photos of geosites in Google Images and Instagram to understand the familiarity of geosites. This is especially important where official tourist numbers visiting geosites are not available.

Certain points must be kept in mind when interpreting the geosite inventory and assessment results in this study. One of these is that although the quantitative methodology helps reduce subjectivity, it was difficult to be totally objective. Bruschi and Cendrero (2005) and Pereira et al. (2007) also indicated that subjectivity is unavoidable in such quantitative methods. Subjectivity is expected when inventorying and selecting geosites, setting weights for each sub-indicator and when assessing each geosite. The other point is that some indicators/sub-indicators used to assess the potential of geosites (such as rarity) mainly apply to a particular study area. Hence, understanding their values at a regional, national or international level and making comparisons in such levels requires further study with such a framework. The final point is that the pictures used to assess the scenic beauty of the geosites were taken between October and January, during the data collection time. This is a peak season for the international tourist flow in Ethiopia in general, including the study area. Some geosites might have a different scenic beauty score, probably lower, if the pictures had been taken in a different season. A good example of this is the Blue Nile Falls, whose water discharge significantly reduces during the dry season (mainly due to diversion of the water to the Tana Beles hydropower plant on the western side of Lake Tana, and to the Tis Abay hydropower plant just behind the Blue Nile Falls at Tis Abay town).

The methodology used in this study could be applied in other parts of the world, with little or no modification. It could be especially important in areas where new geosites are to be inventoried and assessed (for which there is little or no literature available and little or no organized tours to the geosite). In such conditions, emphasis should be on consulting experts and interviewing people working/living in the study area. The latter needs to be shown sample photos of geosites (which can be gathered from literature) so they can easily understand and identify them. It could also help in regions where geosite inventory and assessment is to be conducted in a relatively large area with no clear administrative boundary (such as a protected area, basin or valley), and with several individual geosites. In complex geosite areas that have more than one individual geosite, clustering is advised for the convenience of assessment.

The indicators and sub-indicators used to assess geosites cover topics not only concerning the earth sciences but also culture, biodiversity, accessibility, and tourist facilities. As a result, as indicated by Fassoulas et al. (2012), in order to get a reliable result, a multidisciplinary group of experts must produce the quantitative geosite assessment.

Inventory and assessment of geosites for geotourism development

An inventory and quantitative assessment of the values for the 44 geosites (with and without viewpoints) and the scenic values of 17 viewpoint geosites demonstrated that the Lake Tana area has several geosites with a significant potential for geotourism development. The area is home to three very important geosites: Lake Tana, the Blue Nile Falls, and Mt Guna.

As mentioned in the definition of geotourism, visitors traveling to geosites appreciate not only geological and geomorphological features but also the associated biodiversity and culture. Thirty-two of the 44 geosites (with and without viewpoints) have ecological and/or cultural values, providing an additional incentive for tourists to visit these sites. In addition, the presence of diverse features (scientific, educational, scenic, cultural, and ecological) could help to accommodate tourists with different interests.

The results of this study have important policy implications for the destination under study. One of the goals of geotourism is fostering tourism development opportunities (Dowling 2009). The inventory of new geosites and their proper development in the near future can contribute to extending visitors' length of stay in the area. In addition, the development of geotourism can help find alternative means of income for the communities living near these attractions. Geotourism has the potential to change new areas into tourism destinations, and can significantly contribute to poverty alleviation in many parts of the developing world (Newsome and Dowling 2006).

An assessment of the values of the geosites could help create awareness and justify the need for conservation of these sites (Brilha and Reynard2018). The development of geotourism can also support conservation efforts (Williams 2020) as one of its goals is the protection of geosites (Dowling 2009). Identification and promotion of the values of geosites enhance visitors' awareness not only of their importance and attractiveness but also the need to conserve them (Vujičić et al. 2011). The promotion of geosites in Ethiopia helps not only enhance the government's and communities' awareness of the values of geoheritage but also provides an extra dimension to the visitors' experience (Williams 2020).

Sustainable geotourism development and geoconservation

The geotourism potential of the area is partly reflected in the number of activities available to visitors. A closer look at the recreational values of the geosites revealed a number of activities visitors can practice, including cave exploration, hiking/trekking, rock climbing, paragliding, kayaking and canoeing, motor boating, and biking (including mountain biking). Along with these (pure) geotouristic excursions, tourists can also make cultural tours, such as village tours and tours to visit monasteries on islands, as well as ecotours such as to watch birds, hippos, and gelada baboons.

We propose two alternatives for geotourism development in the area. The first is to prioritize geotourism development based on the main and additional value scores of geosites. It is clear that presentation of the assessment results of the main and additional values using a scatter plot (see Fig. 7) could help understand the status of the geosites with respect to these values, and prioritize them for sustainable geotourism development. Vujičić et al. (2011) also stated that such a presentation of results could be linked to appropriate overall tourism development, market appeal, and management policy that enhance sustainable development. As a result, all geosites with a high/very high score for main and additional values, as well as a high/very high score for main value and a moderate score for additional value (those geosites to the right of and above the green line in Fig. 7) could be given first priority in geotourism development. Priority in the promotion and development of required facilities and infrastructure could be given to these sites. A second priority could be given to geosites with a high score for main value and a low score for additional value (geosites 18, 19, 21, 26, 27, 31, and 39), and a moderate score for the main and additional values (geosites 4, 33, 35, and 38).

The second alternative is to cluster geosites based on access routes (to visit them in one go), and proximity to a nearby town (which could provide basic catering facilities and services for visitors). Six geotourist routes were proposed (Fig. 10).

The Blue Nile route links four of the 44 geosites. The main attraction of this route is the Blue Nile Falls. In addition to the geosites, tourists can also enjoy bird watching. Although this route is currently included in tour itineraries, only the Blue Nile Falls and Canyons are being visited.

The Zegie route covers ten of the 44 geosites. This route is dominated by volcanic cones and islands with monasteries. Geotourists can also visit church forests, practice bird watching and see hippos. The Zegie peninsula and the Lake Tana island monasteries are currently being visited by tourists.

The Anbesamie route connects five of the 44 geosites. This route is mainly for cave explorers. Four of the five caves (excluding cave churches) of the study area are located near this route, including the Kess cave, which is the largest single chamber in Ethiopia. No tourists are currently visiting these caves.

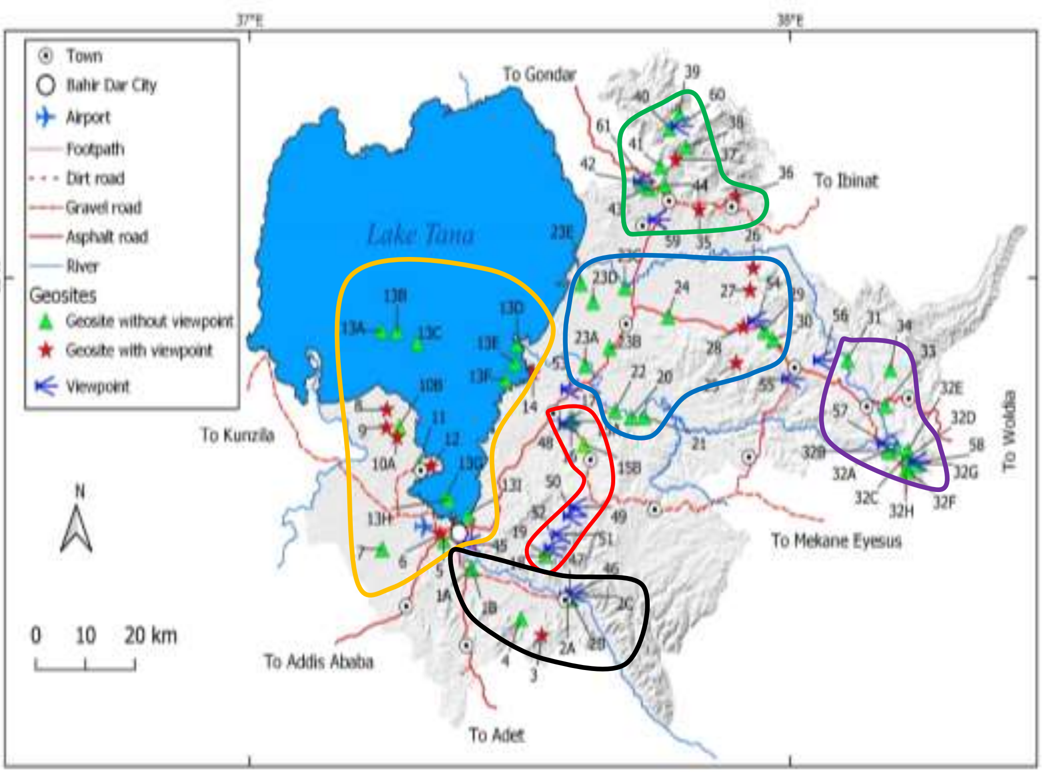

Fig. 10 Proposed clustered geotouristic routes (when developing the routes, viewpoints were considered as optional geosites to be visited, and hence were not necessarily included in the clusters).

Routes: Blue Nile Zegie Anbesamie Woreta Addis Zemen Mt Guna

The Woreta route passes near eleven of the 44 geosites. Wetlands, old river channels, volcanic domes and plugs are the major geosites in this cluster. Visitors can also enjoy bird-watching and visit local villages to experience human-environment interaction. Tourists do not currently visit this route except those taking pictures of rice fields and/or its birds on the Fogera flood plain (through their car windows or from the roadside).

The Addis Zemen route passes ten of the 44 geosites. It is dominated by volcanic plugs and cave churches. The route also has the Tara Gedam conservation area and a monastery. Tourists do not yet travel along this route, except to the Qualit volcanic plug, where many tourists make a quick stop near the road to take pictures.

The Mt Guna route brings tourists to four of the 44 geosites, including Mt Guna. There are eight individual geosites on Mt Guna, the major ones being volcanic columns, caves and block streams. The largest rock-hewn church in the study area, Wukiro Medihanealem (see Fig. S7 in the Online Supplement), is located on this route. In addition, the most spectacular volcanic columns in the study area, which are estimated to be ca. 100 m high, are found on Mt Guna (see Fig. S8 in the Online Supplement). Tourists do not yet travel along this route.

The mean score of main and additional values of the geosites in each cluster (Fig. 10) was calculated (Fig. S11 in the Online Supplement). In terms of mean additional values, the Blue Nile and Mt Guna routes received the highest scores. It should be noted that as some clusters consist of geosites with relatively lower main and/or additional values, their mean scores are also lower (for example, the mean main value score of the Woreta route and the mean additional value score of the Mt Guna route).

Developing and managing geotourism can be a complex task (Newsome and Dowling 2018). Certain issues must be considered for sustainable geotourism development. One of these is preparing geo-interpretation facilities and services at the geosites, including those currently being visited. Thomas and Asrat (2018) well noted that, in general, in Africa, geology is “neglected in guidebooks and by tour operators, and most tourists receive very little, if any, information about the geology and geomorphology of the areas they visit”. As a result, future geotourism development should consider providing adequate information (such as scientific, educational, and relevance) about the geosites for visitors. The other one is creating awareness among the local communities about geotourism, geotourists and the importance of geosites. Devising a mechanism on how the communities could best benefit from geotourism is also important. This makes it possible to get the cooperation of the community in conserving geosites, creating smooth host–guest relationships and developing sustainable geotourism. Furthermore, some of the geosites such as caves are so fragile that they can easily be destroyed when transformed into a geotouristic site (Cigna and Forti 2013). This, therefore, requires careful planning and development.

Many geosites in the study area are affected by natural and anthropogenic processes. These include pollution, excessive sedimentation, invasive water hyacinth growth, and overfishing (Lake Tana); gravel quarrying (the volcanic cones and baked contact); urbanization (the Gudo Bahir wetland); lake and river water diversion for hydropower (the Blue Nile Falls) and (over)grazing, soil erosion, and intensive farming (for many geosites such as the Gudo Bahir wetland, the Makisegnit and Gicha Kokeb volcanic cones, the Jib Washa lava tube, the Sositu Dilmo hot water wetland, and Mt Guna). Asrat (2018) also identified a number of challenges for geosites in Ethiopia, including damages due to infrastructural development and community encroachment, and the country’s economic model of “direct resource extraction”, rather than the more sustainable model of “resource utilization by conservation”.

Many of these geosite conservation problems are in one way or another related to conflicts of interest over the use of these geosites (between government and local communities, and between geosite conservation/geotourism and other developments such as hydropower generation, urbanization, and road construction). In other words, there are many stakeholders who claim ownership and/or use of the geosites. For example, many of the geosites are located on private/communal/church lands.

Part of the solution in tackling these problems and in ensuring geosite conservation and sustainable geotourism development is the formulation and enforcement of a legislative framework and management plan for the geosites. At the moment, there is no policy or legal framework in the country that recognizes a site as geoheritage nor a government body officially mandated to deal with geoheritage and geoconservation (Asrat 2018). A legislative framework that recognizes the values of the geosites and their protection is required. Currently, unless the geosites have cultural and/or ecological value/s worth protecting, the geosites are not valued and protected. In addition, the formulation of a geosite management plan that could guide the sustainable use of these resources is needed. For example, there is a conflict of interest on the use of the Blue Nile water: i.e., whether to use the water for tourism or for hydropower. A management plan could help optimize use of the water. There are management plans for some of the geosites, such as Lake Tana and Mt Guna, but these mainly focus on their biodiversity.

Conclusions

Inventory and assessment of geosites is an important prerequisite for the geotourism development of a given region. A clear and detailed methodology is required to inventory and assess geosites for geotourism development. An inventory and assessment methodology was developed in this study based on a literature review. A geosite inventory and assessment methodology with a holistic perspective that includes scientific, educational, scenic, recreational, protection, cultural, ecological, and functional values provides results important for understanding their potential for geotourism development. The methodology proved to be practical when applied to the eastern and southeastern Lake Tana region. The proposed methodology is a useful tool for the management and protection of geosites as it reveals priorities for sustainable geotourism development and geoconservation. It could be applied on a larger scale such as in national inventories as well as in other parts of the world with appropriate adjustments to the area.

The results of the inventory show that the eastern and southeastern Lake Tana region is endowed with 44 geosites (with and without viewpoints) and seventeen viewpoint geosites that have significant potential for geotourism development. The geosites differ in size, ranging from single points such as hot springs to complex areas such as Lake Tana and Mt Guna. Complex area geosites received relatively higher scientific, scenic, and recreational value scores. Most geosites have a higher main value score than additional value. The main reason for this is that these geosites have problems with access to transport and tourist facilities.

Lake Tana and its island monasteries, the Blue Nile Falls and Canyons, the Fogera flood plain and the Zegie peninsula and viewpoint are among the geosites with the highest geotourism potential. Although Mt Guna has one of the highest main value scores, it has relatively lower additional value due to accessibility problems and lack of visitor facilities in its vicinity.

Priority in geotourism development should be given to those geosites with high/very high scores for the main and additional values, as well as those with high/very high scores for the main values and moderate scores for additional values. On the other hand, clustering those geosites that are located along the same route could be very helpful for sustainable geotourism development in the area. It is necessary to promote and develop the geosites for geotourism in a way that will not degrade their conservation values, including their cultural and ecological values.

Many geosites are affected by anthropogenic and/or natural processes. This requires the formulation of a legislative framework and management plans that can guide geosite development and management in the area. Implementation and enforcement of such frameworks and plans requires close collaboration of all concerned stakeholders, including the government, local communities, tourism businesses, and visitors.

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