IMPROVED TRAIL USABILITY AND INFORMATION ACCESSIBILITY FOR THE NATURE RESERVES OF TSHWANE – A GEOINFORMATION SCIENCE APPROACH

by

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DECLARATION

By submitting this thesis/dissertation, I, Melandrie Smit declare that the thesis/dissertation, which I hereby submit for the degree Master of Science in Geography at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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ABSTRACT

The usability of the nature reserves in the City of Tshwane, which is located in the province of Gauteng, South Africa, is a consequence of the information accessibility that the users of these areas have. Although maps have been produced for some of the nature reserves, these maps do not provide information on the level of difficulty of the trails. By incorporating information such as the difficulty level associated with each trail, users can better understand the physical requirements associated with the given trail, which in turn increases the usability of these areas. Importantly, this directly relates to SDG 11 which states that cities and communities must be, amongst other, more sustainable, and inclusive. This study aims to improve the information accessibility of the nature reserves in the City of Tshwane, by creating resources that better inform users of the relevant features of the reserves, more specifically the physical characteristics of the available trails.

Various known algorithms were used to model the physical parameters needed to grade the trails. These algorithms included The Modified Hiking Function, Pandolf's Metabolic Rate Function, as well as Epstein's Function. By using these algorithms, results were obtained that reflected each trails' distance, estimated travel time, and energy expenditure, which were then subsequently used to grade the trails. Fieldwork data, as well as Volunteered Geographic Information were used to verify the modelled results. Lastly, these results were disseminated through infographics, hardcopy maps, and an online resource. This study successfully modelled the various relevant physical parameters of each trail, which were subsequently used to assign a difficulty level to each trail. Infographics, hardcopy maps, and an online resource were then created that reflected the relevant information of each trail. These informational products are available to the public, either in hardcopy format available at the nature reserves or via a QR code (printed on the hardcopy maps and/or infographics) that directs them to the online resources. By providing the public with adequate information regarding each nature reserve's trails, as well as its added amenities, users can now be in a position where they can make more informed decisions, which improves the usability of these areas, as well as incorporates the intentions of SDG 11.

Keywords: Epstein's Function, FAIR data use principles, information accessibility, Modified Hiking Function, Pandolf's Metabolic Rate Functions, Target 11.7, Volunteered Geographic Information

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TABLE OF ABBREVIATIONS

Abbreviation	Definition
CoT	City of Tshwane
CTMM	City of Tshwane Metropolitan Municipality
DEM	Digital Elevation Model
GIS	Geographic Information Science
kCal	Kilocalories
kJ	Kilojoules
MIDE	Excursion Information Method
SDG	Sustainable Development Goals
UAV	Unmanned Aerial Vehicle
UN	United Nations
VGI	Volunteered Geographic Information
WHO	World Health Organization

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CHAPTER 1: INTRODUCTION

This chapter described the background (section 1.1) of this study, covering the research problem (section 1.2, pg. 12), research questions (section 1.3, pg. 12), research aim (section 1.4, pg. 13), and the research objectives (section 1.5, pg. 13). To conclude, a short discussion regarding the importance and significance of this research project is provided (section 1.6, pg. 13).

1.1 BACKGROUND

Urban green spaces can be defined as natural or partly natural areas found in urban areas, that are covered by vegetation and used by users for sporting and recreational activities (Vargas-Hernandez & Pallagst, 2018). Citizens utilise these spaces to participate in physical activities such as walking, hiking, running, and cycling (Schipperiin *et al.,* 2013), which decreases the risk of many diseases, some life-threatening, such as heart disease, breast and colon cancer, and type 2 diabetes, as well as increase the life expectancy of individuals (Lee *et al*., 2012). Also, many use these spaces for social interactions and stress-reducing activities (such as picnics, book clubs, or other social gatherings), which enhances the mental health of citizens (Enssle & Kabisch, 2020). Interestingly, it was found that outdoor recreational activity during the Covid-19 pandemic increased by 291% (Venter *et al*., 2020), which highlights the importance of green spaces in urban areas. From an environmental perspective, these spaces improve air quality, reduce noise pollution, and increase the biodiversity of various fauna and flora species (Maes, 2020).

Globally urbanisation is increasing. Currently more than 55% of the world's population lives in cities, with an approximate 6 billion urban dwellers by the year 2045 (World Bank, 2020); 68% by 2025 (Taisan & Mohammed, 2022). It is expected that Africa and Asia will be the main contributors of urbanisation, having 90% of the projected 2.5 billion new urban dwellers coming from these two continents (World Bank, 2020). Higher levels of urbanisation may result in the loss of green infrastructure, which subsequently impacts the health and quality of life of urban dwellers (Byomkesh *et al.*, 2012). Urban land expansion is one of the key drivers of habitat loss, with an expected reduction of between 36 to 74 million hectares of natural habitat by the year 2100 (Li *et al.,* 2022). However, budget constraints and funding for current and future green space projects are usually limited, which hinders the growth and further development of green spaces being erected in cities. As such, natural space being lost to expanding cities is not necessarily replaced within the city, meaning urban dwellers have less access to green space.

The United Nations recommends a series of objectives, known as Sustainable Development Goals (SDGs) that are used as a benchmark for countries to live sustainably and in cohesion with the natural world. One of these goals (SDG 11) is to create and construct cities and communities that are more "inclusive, safe, resilient and sustainable" (UN, n.d.). Of particular importance is Target 11.7, that focuses on the provision of "universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities" (UN, n.d.). Thus, it is important for green spaces to be inclusive by providing accessible and safe spaces for individuals with disabilities, as well as the elderly and young (Enssle & Kabisch, 2020), for these spaced to be extensively and appropriately utilised. More specifically, accessibility relates not only to the physical accessibility of these spaces, but also to the information accessibility where informational products regarding these spaces results in a more well-informed public, which leads to better usage of these spaces.

Many cities worldwide have implemented initiatives that increase the amount of green space in the city. One of the most successful and popular initiatives is that of PlaNYC in New York, USA. One of the problems that New York is currently facing is the combined sewer overflows (CSOs) that are directed to the harbour. CSOs are a combination of sewer water, storm water runoff and industrial wastewater which could lead to serious health risks, as well as have a negative impact on waterways. To combat these CSOs, the city is increasing its tree cover to 30% by 2030, as well as integrating several "gray infrastructures" (networks of water retention and purification structures) (Nicholas Institute for Environmental Policy Solutions, n.d) strategies (McPhearson *et al.,* 2013).

Within a South African context, few similar projects have achieved success. Most areas that can be used for green spaces are often rather used for housing and business zoning (Cilliers *et al.,* 2011). However, in Inanda in Kwa-Zulu Natal, Munien et al. (2015) found that residents used their green spaces regularly and derived various physical and emotional benefits thereof. Also, in Gauteng the management team of Faerie Glen Nature Reserve, amongst others, is actively involved in protecting the golden mole, which is an endangered species that flourishes around the Bronberg ridge (Kritzingern, 2023). However, Venter *et. al* (2020) highlighted that South Africa suffers from 'Green Apartheid', where urban green areas are unequally distributed across race and income geographies. With that being said, an estimated 80% of South African citizens are projected to live in cities by the year 2050 (UN, 2014), and thus the availability and accessibility of green spaces will become increasingly important, not only for its protection of fauna and flora, but also for the additional benefits they hold to the public.

For green spaces to be effectively used, not only must their location be planned properly, but so also the trails and other amenities contained within each, for these spaces to be successfully utilised (Harasimowics, 2018). Security is another consideration, but falls outside the scope of this study. Trails need to be accessible and sensible for citizens to make use of these areas, and adequate information should be provided for users to maximise the benefits that these areas can provide to the public. Another important facet that is of significance for good urban space usage is the proper mapping of trails. Previously, the main form of mapping was done on paper and distributed in hardcopy formats. Nowadays, with the evolution of technologies and techniques, computerized information services such as Geographical Information Services (GIS) and Remote Sensing (RS) can be used to map areas, trails, and features (see Xiang, 1996). Various authors have utilised GIS and RS in their mapping of trails and have further used these approached successfully to identify new trails if necessary (e.g., Olafsson & Skov-Petersen, 2013; and Xiang, 1996).

This project specifically looks at the City of Tshwane Metropolitan Municipality (CoT) nature reserves that contain trails that can be walked or run. There are currently 18 nature reserves in the City of Tshwane (herein after referred to as the CoT) available to the public that are being used for a variety of physical and social activities such as running, hiking, walking, cycling, bird watching, fishing, and sailing. It is important to note that ''access'' in the context of this study does not consider economic costs such as entrance fees, but is rather defined based on information access only. With the CoT being the third largest metropolitan area in the world (spanning an area of over 6300 km^2) and an estimated population of 4.0 million people (StatsSA, 2022), citizens use these areas to enjoy and interact with nature, while also taking part in social and physical activities. These reserves function as green spaces where many citizens partake in a variety of physical activities such as walking, hiking, running, and cycling. Here, the focus is on accessibility in terms of quality of the urban green space, where quality relates to the information available on trails within these areas. To achieve this, sufficient information needs to be available for each of the nature reserves, including aspects such as a reserve's facilities (including trails), distance of trails, and estimation on how long it will take someone to traverse the trail, points of interest in the reserve, and an estimation on how much energy an individual would expend when walking or running a trail. Such information can be determined using geoinformation science (GISc) and GIS (Geographic Information Systems), not only to obtain data but to do subsequent analyses.

Several functions exist to model travel time and the energy expenditure of an individual when traversing a trail. The Modified Hiking Function (Márquez-Pérez et al., 2017) models the walking speed of an individual, while Naismith-Langmuir's rule (Fritz, Carver & See, 2000) models the running speed. To obtain the metabolic cost associated with walking a trail, Pandolf's Metabolic Rate Function is used (Pandolf et al., 1977). Additionally, Epstein's function (Epstein et al., 1987) is used to model the metabolic cost while running the trails. Such results can then be applied to assign a grading level to trails, by adapting the already existing grading systems of Hugo (1999a), the Australian Walking Track Grading System (Victorian Government DSE, 2010), and Wildrunner Trail Grading System used in South Africa (Wildrunner, n.d.). The grading of trails has been successfully done in past studies and is especially important since trail activities usually cover a variety of terrain, which affects the difficulty and time of completion of the route (Elliot, 2012).

This project's aim is to increase the awareness and usability of the nature reserves in the City of Tshwane Metropolitan Municipality. It specifically looks at the trails available to the public within these nature reserves, which are all located within the Gauteng Province of South Africa, by providing users with maps that indicate trail length, estimated duration time, approximate energy expenditure, and the grading level associated with each trail. Various functions, like those mentioned above, are used to model parameters. The Volunteered Geographic Information (VGI) component is obtained via an online survey, which collects the experiences of trail users once they have finished walking or running the trails. Of note is that since not all of the 18 nature reserves are designed for walking or hiking, only a portion of these reserves (12 in total) are included in this study.

The results of this study are subsequently made available to the public via hardcopy and online interactive maps, as well as infographics. By creating information products that provide the public with more details regarding the trails of the nature reserves, this study aims to incorporate and utilise the fundamental goal of SDG 11. Providing these information products without restraint to the public, the concept of the open access paradigm (which refers to the sharing of, in this case, free geographical data) is also incorporated, which further contextualises and incorporates the recommendations of SDG 11 (European Union Commission, 2017). Hardcopy maps include the trails, the trail lengths, the points of interest, the travel time, the approximate energy expenditure for both male and female users when walking or running, as well as a difficulty grade per trail. The online interactive map includes the same features as the hardcopy maps but allow users to select/deselect certain information layers, as well as to zoom in or out if they wish to do so. The infographics are a visual representation of the data that incorporates graphics (such as photos, charts, and text) to convey the information that is associated with each nature reserve in the CoT.

1.2 RESEARCH PROBLEM

Currently the CoT has delineated trails for walking, hiking, and running for 12 of the nature reserves. However, these nature reserves do not provide maps that include adequate information on the level of physicality required for these trails. Furthermore, maps can be outdated, and trails drawn where none exist, or some trails not drawn at all. There is also no grading system available that informs citizens on the approximate time that it will take to complete the trail, the estimated energy expenditure associated with the trail, and how difficult the trail is. Having maps and infographics that include these types of information of these trails will better inform the citizens of what is to be expected of each trail, making it easier for them to make educated decisions while also enhancing the public understanding and usage of these nature reserves. Using aspects of geoinformation science (GISc), an improved grading system can be applied that indicates each trail's difficulty based on various parameters. Geographic Information Systems are further used to produce maps and infographics that are available to the public, leading to a better-informed public and (hopefully) improved usage of these nature reserves.

By making these information products available to the public, this study aims to enhance the understanding of individuals regarding the characteristics of the nature reserves and the difficulty (or ease) associated with each trail, which in turn will make it easier for them to choose the appropriate trails when visiting the nature reserves of the CoT. Subsequently, this leads to a better understanding of the functions that urban green spaces can provide to the public, by allowing users to be well-informed on each nature reserve's qualities and features. These open spaces can then be accessed and appropriately utilised, allowing users to access all the benefits that such areas can supply, supporting Target 11.7 of SDG 11.

1.3 RESEARCH QUESTIONS

The research questions of the study include:

1. Can a grading system be adapted for the CoT nature reserves by consolidating the existing grading systems of Hugo (1999a), the Australian Walking Track Grading System (Victorian Government DSE, 2010), and Wildrunner Trail Grading System (Wildrunner, n.d.)?
2. Can GISc be used to model various trail parameters of the trails of the CoT nature reserves?

3. Will the provision of enhanced information on trails, either online or in print maps and infographics, improve the information accessibility of the CoT's nature reserves?

1.4 AIM

The aim of this project is to improve the (information) accessibility of the CoT's nature reserves (i.e., urban public green spaces) by providing its citizens with enhanced information regarding the trails found in these nature reserves. Such information includes the distance, estimated time taken, expected energy expenditure while walking or running, and difficulty of trails, which are disseminated using a series of maps, infographics, and an interactive online platform (online mapping resource).

1.5 OBJECTIVES

The aim is achieved through the following key objectives:

1. Adapt Hugo's (1999a, b), the Australian Walking Track Grading System (Victorian Government DSE, 2010), and Wildrunner Trail Grading System (Wildrunner, n.d.) grading systems into a composite grading system.
2. Model various parameters (distance, time, gradient classes, and energy expenditure while walking or running) for existing trails in the CoT's nature reserves using relevant functions in a GIS.
3. Apply the composite grading system of Objective 1, together with the parameters calculated for Objective 2, to the CoT nature reserve trails.
4. Create resources that are accessible to the public that provide information regarding the trail difficulty, distance, estimated duration, as well as the energy consumption of the trail.

1.6 IMPORTANCE OF THIS STUDY

This study aids the information accessibility of nature reserves of the CoT, by creating information products that better inform citizens regarding the available trails of the nature reserves. Also, by providing citizens with the necessary information, especially the physical characteristics of the trails, they can be better informed and consequently more accurately gauge which nature reserve's trails are most suitable to their needs and preferences. This in turn promotes the usage of these nature reserves, as well as contributes to SDG, 9particularly when making these maps freely available to the public (incorporation of the open access paradigm). Through the collection, manipulation, and analyses of geospatial, quantitative, and qualitative data of the nature reserves, citizens are given access to enhanced information products in the form of maps and infographics. Integrating various known grading systems into one consolidated grading system, it allows for a wider range of characteristics to be included and assessed, which improves the overall accuracy of the assigned difficulty levels of the trails.

CHAPTER 2: LITERATURE REVIEW

This chapter provides an overview of the literature that is related to the research of this project, with further exploration of the concepts and theories that are utilised. In section 2.1 below the significance of urban green spaces is discussed, followed by the considerations, processes, and techniques utilized in the planning and grading of trails (section 2.2, pg. 18). In section 2.3 (pg. 22), the data requirements for trail planning and mapping are discussed, followed by the processes of modelling and grading trails in nature reserves is (section 2.4, pg. 28). The chapter concludes with a discussion on mapping as an information product (section 2.5, pg. 32).

2.1 URBAN GREEN SPACES

Globally, cities have developed into vibrant centres for the individuals who dwell there, as well as the many that migrate to these centres each year. An estimated third of the global population is projected to live in cities by 2045 (UN, 2019, The World Bank, 2020). According to the United Nations, Africa and Asia will have the biggest increase in its urban populations, with countries such as India, China and Nigeria expected to attain the highest urbanisations rate by the year 2050 (UN, 2018). Furthermore, by 2050 the United Nations estimates that approximately 80% of South Africans will live in cities (UN, 2014; Galal, 2023), which exceeds the projections forecast for the African continent, where it is projected that that the urban population will include approximately 60% of the total African populace (UN Habitat, 2012). Within South Africa, the cities with the fastest growing urbanisation rates include Polokwane, Rustenburg, Nelspruit, Ekurhuleni, and Vanderbijlpark, with Gauteng leading as the most populated and fastest expanding province in terms of its urbanisation percentage (Makhura, 2016). Urbanisation and the management of urban areas are thus important considerations. Green infrastructure, which encompasses all the natural landscapes of an area, are increasingly lost because of urbanisation. This is known to have a negative impact on the health and quality of life of citizens in these areas (Byomkesh *et al*., 2012). Thus, the correct management, development, and organization of both the cities and its citizens is becoming increasingly important.

Urban green spaces are open-spaced, public areas within cities that make use of natural landscape features such as trees, shrubs, grass, or water bodies to construct areas where citizens can participate in various social and physical activities (Cvejic *et al*., 2015). These spaces provide a free or lower-cost substitute for people to engage in physical activity such as walking, hiking, running, and cycling compared to that of the more mainstream methods such as gym memberships (Schipperijn *et al*., 2013). Physical activity decreases the risk of many illnesses, such as heart disease, breast- and colon cancer, and Type 2 diabetes, as well as increasing the life expectancy of individuals (Lee *et al*., 2012). Such areas further provide spaces for senior citizens to participate in physical activity that improves their cardiovascular health (Kabisch *et al*., 2021), and lowers the risk of heart-related illnesses (Burkart *et al*., 2016). Green spaces thus afford a low or no-cost alternative for physical activity. Yet the success of green spaces in the provision of spaces for physical activity is largely dependent on the facilities the green space offer. For example, the presence, accessibility, and maintenance of trails found within such areas are known to play an important role, since trails within green spaces can greatly improve the effective and equitable usage of such spaces. Running and hiking on trails that are unpaved also have benefits that road running does not exhibit. Trails are more porous which lessens the loads experienced on joints, decreasing the likelihood of overuse injuries from occurring (Drum *et al*., 2023). Additionally, because these trails often have variety in terrain, various stability and accessory muscles gets strengthened and an individual's balance and proprioception also get stimulated (Drum *et al*., 2023).

Several cities around the world take part in the Parkrun initiative that is essentially a running or walking event (depending on user's preference) held in a public area that covers a course of about 5 km. These events are free, timed, and organized by volunteers. People of all ages and fitness levels can participate, and individuals with disabilities are also encouraged to join these weekly events. Currently (August 2023), there are over 28 countries that regularly host parkrun events globally, with more than 2,000 cities participating (Parkrun, n.d.). Having such events in public green open spaces illustrates the integral part these spaces play in the healthy functioning of any city. Other trail running events are also held throughout the year throughout the world, with some of the most well-known trail running events held in areas of exceptional natural beauty. Some of these events include the Gran Trail Courmayeur (Courmayer, Italy), Audi Power of Four Trail Run (Aspen, Colorado), Hoka XTrail (Courcheval, France), Pyrénées Stage Run (Spain and Andorra), and South African examples such as Run the Karoo (Middelburg, Eastern Cape), and Table Mountain Beast (Cape Town, Western Cape) (Trail Running, 2023).

In addition to the health benefits associated with exercise, various other social and environmental benefits are derived from urban green spaces and the subsequent use thereof. Green environments further cognitive abilities of younger individuals including their attentiveness, memory, as well their ability to learn (Vujcic & Tomicevic-Dubljevic, 2018), and reducing stress. Senior citizens derive these same mental health benefits (Enssle & Kabisch, 2020). In addition, urban green spaces reduce noise pollution, improve air quality, and increase biodiversity (Maes, 2020), by providing spaces for trees and other vegetation to grow. Furthermore, green spaces help regulate temperatures in urban environments, especially during periods of intense heat, by providing shaded areas (because of tree cover) that exhibit much cooler temperatures than areas that are predominantly paved (Romanello *et al*., 2021). Such spaces also help in mitigating the impacts of extreme weather events (WHO, 2017), such as flooding and heavy rain (by reducing overland flow due to increased surface roughness compared to artificial surfaces), and heat waves (natural vegetation providing reprieve from heat through shading and ameliorated temperatures).

Cognisant of the importance of urban green spaces to the health and well-being of citizens, numerous cities are improving their access to such spaces, implementing various approaches that enhance the usage and accessibility of public green spaces. Accessibility, integral to the usage and potential benefits of urban green spaces, can be defined by their geospatial location, area, offerings, and safety (Maryanti *et al*., 2016, WHO, 2017). To ensure equitable access and sustainable use of urban green spaces trails found within them need to be correctly, efficiently, and sustainably planned and erected to maximise their value, as well as provide the necessary benefits and attractions to the public. New York City, one of the largest megacities in the world, established several initiatives that increases green infrastructure in the city, such as PlaNYC and the NYC Green Infrastructure Plan. The PlaNYC initiative inspires to reduce the combined sewer overflows (CSOs) that are currently being directed to the harbour by increasing its tree cover to 30% by the year 2030 along with other 'gray infrastructure' strategies

(McPhearson *et al*., 2013). PlaNYC also aims to equally distribute the green space of New York, to increase the accessibility and the usage of these spaces (PlaNYC, 2012). Additionally, the NYC Green Infrastructure Plan has actively ensured that green spaces are sufficiently provided for and that these spaces (such as Central Park and Prospect Park) are accessible and available to the public (McPhearson *et al*., 2013), to promote a healthier from of living within the city.

Improved access to green spaces is, further, not only dependant on geographical access, but can also depend on the demographic characteristics of the area. As such, several cities have initiatives that focus on including all socio-economic, political, and ethnic groups in the broader context of access to green spaces. This is evident in cities such as Berlin, Sheffield, and London where migrants and asylum seekers use public green spaces to connect with other residents (Rishbeth *et al*., 2019). Urban green spaces provide spaces where such individuals can interact and socialise with people from different ethnic, religious, and socio-economic backgrounds, in an environment that is accessible and available to all members of the public, without any prejudice. In Barcelona, the “Barcelona green infrastructure and biodiversity strategy” (Barcelona Field Studies, 2020) has introduced policies that increase the availability of green spaces to individuals of lower socio-economic status. Also, in Italy, as well as in Berlin, Germany, certain initiatives make use of green spaces to offer permaculture courses to asylum seekers, to allow opportunities for social integration for these individuals (Oscilowics *et al*., 2019).

Benefits can also be economical. Land values of properties close to, or near, urban green areas are often higher than those of properties that are situated further from such areas. McCord *et al*. (2014), for example, found that the sale price of terrace and apartment residential properties increased by 42% and 49% respectively, in the City of Belfast (Northern Ireland). Similarly, Trojanek (*2021*) found that apartment prices in Warsaw (Poland) increased when in closer proximity to green spaces, especially if the apartments are located within a 100 m radius of these green spaces (Trojanek, 2021). In contrast, Lategan *et al*. (2022) found a difference in the effect of urban green space proximity on the property valuations of different income areas within Potchefstroom (South Africa). Here, within lower- and higher-income neighbourhoods, property prices increased with closer proximity to green spaces, but this correlation was not true for properties in middle-income areas (Lategan *et al*., 2022). As such, while the impact of urban green spaces on property prices differs depending on the geographic location and unique demographics of an area, the fact that they impact property prices is acknowledged.

For urban green spaces to be successfully utilised, the organization and promotion of events that not only includes all social groups but also cover an array of activities is an important objective. Throughout, the accessibility of green spaces needs to be considered. Holding festivals, family days, sporting events, fitness classes, and similar small-scale group activities increases usage of these areas, which augments the overall success of such an urban green space (WHO, 2017). However, various other factors influence the usage and subsequent success of urban green spaces, such as the proximity of green spaces to residential areas (Giles-Corti *et al*., 2005); the inclusion of different facilities such as restrooms, seating, available water, as well as well-maintained and accessible paths (Lynch *et al*., 2020); the perceived safety of the area (Evenson *et al*., 2006); and the weather-related circumstances of the area (Wolff & Fitzhugh, 2011). Furthermore, the successful introduction of urban green spaces into existing and newly erected communities, as well as their suitability and efficiency as a public space, relies heavily on other aspects. Firstly, adequate research must be done before, during, and after the construction of urban green spaces. Having knowledge of the quantity and quality of current urban green spaces, as well as how it is presently being utilised indicated the success of such green spaces in specific communities, while also determining any gaps for improvement (WHO, 2017). Secondly, community participation in the planning and maintenance of these areas assists in acknowledging most needs of the community, and helps residents identify with these areas (WHO, 2017). Lastly, it is important to include multi-sector collaboration to help maximise the benefits of urban green spaces and to decrease the possible negative impacts thereof (WHO, 2017).By having a clear understanding of the needs of the community, as well as the limitations and possible areas of expansion and improvement, urban green spaces can become more accessible and desired in a community, leading to better utilization and integration of these spaces in existing and newly-built or future projects.

The accessibility and availability of green spaces within cities have and will continue to become more important as they provide citizens a space in which they can partake in various physical and social activities within the realms of nature (Weber & Anderson, 2010). The WHO recommends a minimum of 9 m^2, preferably 50 m^2 of urban green space per person (WHO, 2017). In addition, this green space needs to be accessible[1], safe, and functional (Maryanti *et al*., 2016). Accessibility not only refers to the physical access that individuals have to these areas, but also incorporates the provision of informational products regarding these green spaces. These informational products can provide users with detailed descriptions of the areas and its amenities, resulting in well-informed citizens. By providing citizens with information regarding the characteristics (for example the distance) of the trails available, as well as the added amenities of the green space, individuals will be able to make better-informed decisions, utilise the areas better, and improve its quality by increasing the standard and the attributes of the space.

Greater green space availability also makes a city more liveable (Jim, 2003). For example, the 2016 Mercer's Quality of Living Survey identified Vienna as the most liveable city, featuring 120 m^2 of green space available for everyone (Maryanti *et al*., 2016). Thus, the accessibility of sufficient green space in urban settings is necessary to achieve a more sustainable and liveable environment, a sentiment that is also recommended and advised in the Sustainable Development Goals (SDGs) of the United Nations. Within these SDGs, the aim to make cities and settlements more "inclusive, safe, resilient and sustainable" (UN, n.d.) includes the planning, accessibility, and usage of public green spaces. This is especially evident in SDG 11 Target 11.7 where the provision of "universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities" is targeted (UN, n.d.).

Within a South African context, the integration of urban green spaces in existing city structures has been met with some difficulties. Green space initiatives must typically compete against other land uses (Cilliers *et al*., 2011), where the priority of more residential blocks or business zoning often gets precedence over green spaces. Limited human resources and inadequate funding (Cilliers *et al*., 2011), the inequalities associated with green space availability, as well as the political history of South Africa (Cilliers et al., 2011) are all factors that negatively affect the construction and implementation of urban green spaces. Munien *et al*. (2015) investigated the public's relationship with green spaces in an area

[1] Here, accessibility with regards to urban green space revolves around five key concepts: 1) the location of the urban green space, 2) its distance from the users, 3) its overall quality, 4) the amount of urban green spaces available, and 5) how safe these areas are (WHO, 2017).

of Inanda (Kwa-Zulu Natal), also looking at the benefits that are derived from these areas. Results indicate that individuals that make use of these areas "display notable levels of environmental knowledge" (Munien *et al*., 2015, pg.163). The study further iterated the various utilizations of green spaces where the residents of Inanda not only regularly used these areas for "recreational, educational, cultural, religious and environmental protection purposes" (Munien *et al*., 2015, pg.164), but also generated income by selling of goods and produce. This indicates that urban green spaces have a large impact, and subsequent contribution, to the lives and livelihoods of the individuals who makes use of these areas, and that there is a need for such areas within the various communities of South Africa. Nevertheless, Venter *et. al* (2020) highlighted that South Africa suffers from 'Green Apartheid', where urban green areas are unequally distributed across race and income geographies. Thus, by improving the accessibility of these areas, individuals of all social backgrounds will be given the opportunity to partake and enjoy the various social, psychological and physical benefits that these areas have to offer.

2.2 TRAIL PLANNING AND GRADING

2.2.1 Trail planning

To properly delineate and outline trails in urban green areas, it is important to understand and appreciate the procedures involved in trail planning, as well as being able to identify the various aspects that need to be considered during the planning process. Having knowledge of the area and its characteristics assists in the mapping and grading phases of an area. Although the motives and objectives of each trail conception differ, most aim to provide areas for physical and social activities, while also striving toward creating longstanding relationships between nature and humans (American Trail Staff, 2021). Proper trail planning aims to construct sustainable trails, by reducing the environmental impact of the trail construction, as well as the effects that consistent and continual use of these trails cause. It also reduces the production and maintenance costs associated with trail construction. For example, by making use of the natural features available like ridge lines and cliffs, less construction is needed to create a pathway (American Trail Staff, 2021), reducing the amount of economical and physical input needed to create the trail.

The process of designing trails is complex and should be carefully thought out to ensure that all the necessary factors are considered. Most important is the stage of analysis, where the location, layout, and length of the trail are determined (Schwartz *et al.*, 1993). It also requires input from various contributing informational products, including data collection, modelling, analyses, and surveys that include the area's ecological, geographical, and land-use components to plan a trial that fulfils all the objectives and aims of the proposed development (Xiang, 1996). It is important to not only take into consideration the physical and ecological aspects and constraints of the park, but to also understand the needs and preferences of the users of these urban green spaces (Zhang *et al.*, 2020). This ensures that conflicts between users are limited, and that strategic and correct management of the urban green spaces' infrastructure and ecology occurs. Koemle & Morawetz (2016) further suggest that trail routes must be designed and mapped in such a way that they accommodate various trail user's needs and preferences, to maintain a balance between the different trail users. This also leads into the accessibility factor of an urban green space and how the characteristics of these spaces and its trails are being disseminated to the public. Including information such as the distance of the trail, the estimated time of completion, the average energy expenditure, and the difficulty level of the trail, users will be better informed and can choose the trail that best suits their preferences.

Another important consideration of trail planning is its aesthetic qualities, where scenic routes that incorporate sites of biological, historical, and cultural relevance were found to be the main motivation behind the reason why people will visit certain areas (Proshansky *et al*. (1983). It was also found that individuals will exhibit emotional, as well as cognitive responses because of the environment (Pronshonsky *et al*., 1983). Li (2000) studied the effect that geographical awareness has on an individual's experiences and found that such effects result from spatial and time-based links that are formed between places and people (Li, 2000). In 1989, Hull and Harvey studied the effect that a park's physical characteristics (i.e., tree density, understory, the presence, or absence of pathways) had on the emotions of individuals and found that there is an increase in pleasure when trees are bigger and denser (Hull & Harvey, 1989). This correlation between increased aesthetic qualities, as well as the presence of other amenities with the perceived increase in enjoyment in parks, has also been highlighted by Dinda & Ghosh (2021), Mundher *et al*. (2022), and Chhetri (2015). Thus, providing a trail that has a diverse ecology and well-planned and well-maintained walkways, in addition to suitable and beneficial amenities, enhances the overall satisfaction and attainment of the park.

Trail planning is not only needed to produce trails that are sensible, accessible, and traversable, it is also required to ensure that the environmental impact of such undertakings will not be damaging to the current and future natural systems of the area. It also assists in producing and maintaining economically sustainable projects that minimise the cost of construction, as well as the maintenance costs of these trails in the long run. It should also be seen as a tourism activity, and as such be developed and planned with the needs and demands of consumers in mind. Trail planning is thus not only a process of delineating a walkable trail, but also a way of participating as a sustainable tourism product, a notion also encouraged by Hugo (1999a). This fits directly into the importance of maps as an information product. Correctly and accurately delineated trails, points of interest, and amenities provide the end user with important information on the desired trail they wish to traverse. Intrinsic to this is the mapping of trails, which follows on from the planning process. By providing users with adequate information regarding the available trails, users can make well-informed decisions regarding which trail best suits their fitness goals and personal needs. Having information available for users to peruse beforehand can help them decide which trail they prefer to use, which in turn also ensures that the trails are adequately utilised and benefitted from the most. Information regarding the characteristics of the trail and the urban green spaces can be disseminated through maps and infographics to the public, allowing for better accessibility and utilization of these spaces, as the information needed by users to make decisions will be provided to them in the form of such informational products.

2.2.2 Trail grading

Certain trail characteristics are known to increase the difficulty of a trail, thus increasing the energy output needed to partake and complete the trail (Hugo, 1999a). Parameters such as trail slope, distance, the travelling speed of the user, load carried by the user, fitness level of the user, age and gender of the user, weather conditions, and the general condition of the trail are all important factors to consider when assigning a difficulty level to a trail. Trails that have steeper slopes and more rugged terrain are classified as "more difficult" than trails that have gentler slopes and more even terrain (Elliot, 2012). The distance of the trail also affects its difficulty level, as trails that are longer require more energy expenditure, and as such are given higher difficulty ratings (Lanza, 2022). Certain weather conditions, such as elevated levels of humidity and temperature also increase energy expenditure when individuals are partaking in forms of physical activity (Sawka *et al*., 1993). This is because high levels of heat and humidity increase core body temperature and potential dehydration, which decreases muscle endurance, lessens blood flow to the heart, and shifts energy production to anaerobic mechanisms (Healthcare, 2014).

Globally, several grading systems have been developed that are either based on formal evidence collected, or informal measurements done by experts that use various variables to produce the grading systems. Different systems of description are also used, with most putting the most emphasis on trail distance, elevation, and terrain (Coetzee, 2018). These descriptions are also subjective to an individual's own experience and preferences. However, some research-based grading systems do exist that not only study user's perceptions of the trails, but also models known functions to quantify several parameters to obtain a difficulty level for a trail. Quantifying all these parameters into a single formula is not an easy task.

Yamaki & Shoji (2004) used the Recreation Opportunity Spectrum method (this method specifically looks at the quality of a user's experience) to identify areas that can be improved by management in the Daisetsuzan National Park (Japan). Although this study did not aim to provide a grading system for the trails in the park, it successfully classified the areas according to user's preferences, allowing management to identify areas that can be used in future expansion projects, as well as improve the utilization of the park's accessible spaces (Yamaki & Shoji, 2004). Other grading systems that rely more on research-based facts and formulae have also been developed and utilised by numerous countries. One such grading system is the Australian Walking Track Grading System that was proposed to regulate the standard of grading systems used by Australian parks and reserves to indicate the difficulty level of a trail (Coetzee, 2018). This system takes note of a trail's distance, the quality of the path and markings, the gradient associated, the experienced required, and the number of stairs to climb on the path (Victorian Government DSE, 2010). The trails are then given a grade according to its difficulty to complete, with grade 1 trails being the easiest and grade 5 trails the hardest (Table **1**).

Table 1: The Australian Walking Track Grading System (Victorian Government DSE, 2010).

Grade	Bushwalking experience	Surface condition	Steps	Steep sections	Distance	Wheelchair friendly
1	Not required	Flat, even	None	None	< 5 km	Yes
2	Not required	Hardened, compacted	Occasional	Gentle hill sections	< 10 km	No
3	Some experience recommended	Rough	Many	Short steep sections	< 20 km	No
4	Recommended. Directional signage limited	Long, rough	Many	Very steep sections	> 20 km	No
5	Required, specialised skills needed (navigation, emergency first aid), unmarked trail	Rough	Many	Very steep sections	> 20 km	No

The Wildrunner Trail Grading System (South Africa) was established in 2009, and takes note of the terrain difficulty, how much track is on difficult terrain, and the route steepness to form a grading system that informs users of how challenging the terrains of the trail is (Wildrunner, n.d.). This grading system has been used by all the trail running events hosted by Wildrunner and has been successful in providing participants the necessary forewarning of a trail's difficulty. There are three parts to this grading system. Table **2** (pg. 21) details aspects of terrain difficulty,

Table 3 (pg. 21) the percentage of a track off-rad or single laned, and

Table 4 (pg. 21) route steepness.

Table 2: Wildrunner PART 1 grading parameters based on terrain difficulty.

Grade	Description
Yellow	Easy, non-technical terrain, all on established trails & tracks
Orange	Moderately easy terrain, short sections of 'technical' terrain but largely easy running, all on established trails tracks
Green	Moderate challenging terrain, with a mix of 'technical' and 'non-technical' terrain, mostly on established trails tracks but may or may not have extended sections regarded as being 'off-trail'
Brown	Moderately difficult terrain, more 'technical' terrain than 'non-technical' terrain, challenging but mostly established trails & tracks although may or may not have extended sections regarded as being 'off-trail'
Red	Difficult terrain, majority 'technical' terrain that is extremely demanding, may or may not have large sections on un-established trails & tracks

Table 3: Wildrunner PART 2 grading parameters based on percentage of the trail off-road or single track.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100

Table 4: Wildrunner PART 3 grading parameters based on route steepness.

Grade	Description
A	Mostly runnable gradient
B	Mostly runnable gradient, but has some steep ascent and descent that may require walking
C	Lots of steep ascent and descent that may require walking

The grading system developed by Hugo (1999a) attributes the difficulty of the trail to the amount of energy needed to complete the trail. This grading system only regards the time of completion, energy expenditure, and the distance of the trail in its calculation. Based on this grading system, a trail that requires more energy output to complete will be given a higher difficulty level, while a trail that requires less energy output to complete will be given a lower difficulty level (Hugo, 1999). Table **5** below indicates the difficulty grading assigned as per the energy output required for a certain trail length and travel time.

Table 5: Difficulty grading adapted from Hugo (1999a).

Distance	Walking time at 3 km/h	Energy needed (kJ)	Energy needed (kCal)	Difficulty grading
< 5km	1.7h	< 2500	< 597	Very easy
5 – 10km	1.7 – 3.3h	2500 – 5000	597 – 1195	Easy
10 – 15km	3.3 – 5h	5000 – 7500	1195 -1792	Fair
15 - 20km	5 – 6.7h	7500 – 10 000	1792 -2390	Moderate
20 – 25km	6.7 – 8.3h	10 000 – 12500	2390 -2987	Difficult
25 – 30km	8.3 -10h	12500 – 15000	2987 -3585	Severe
30km +	10h+	15000+	3585+	Extreme

The grading system proposed by Hugo (1999a, b) has successfully been adopted by organizations such as Green Flag Trails (South Africa) where trails that want to become accredited must first be investigated and audited based on several aspects (such as, amongst others, the difficulty level, energy output required, trail type, and environmental characteristics), which has led to an increased knowledge and better understanding of the physical characteristics and consequence of the trails (Green Flag Trails, 2015).

2.3 DATA REQUIREMENTS FOR TRAIL PLANNING AND MAPPING

Nowadays, various methods can be used to plan possible trails, especially computerized information services such as GIS. GIS are digital spatial systems that are used to create, analyse, manage, and map data by linking locations to various types of descriptive information to better analyse and communicate information (Merry *et al*., 2023). GIS further allow for the efficient creation and manipulation of geospatial data. Various data requirements exist for appropriate trail planning and mapping, including delineation of reserve boundaries, identification of points of interest, delineating existing trails, mapping land cover and other topographic information, which represent some of the data sets needed when wishing to create new trail.

One of the earliest studies using GIS in trail alignment planning was done by Xiang (1996) in a North Carolina (USA) park. Through the extensive analysis and survey of the area's ecological, physical, and land use characteristics (Xiang, 1996), a future trail's origin and destination were linked and purported by assessing the adjacent land parcel cells that have the greatest trail potential, thus allowing for the identification of new routes that adjoin existing routes. Similarly, Martinez & Ocana (2014) used a multi-criteria method to identify where the most suitable hiking routes are situated in the study rea of Sierra de las Nieves, which is a mountainous area of ecological importance in Spain. Here GIS not only enabled the researchers to pinpoint new trails quickly and economically (Martinez & Ocana, 2014), but also allowed for the rearrangement of trails to include new areas that hadn't been utilised in the past, as well as enabling the management of the park to reduce the utilization of certain routes as deemed necessary. In another study done by Petrosova *et al*. (2015), high-resolution data were used to identify routes that optimized travel time and the suitability of paths using geospatial modelling. Trails were designed using Tangible Landscape, where waypoints (i.e., trailheads or scenic spots) were manually placed on a physical model, after which the optimal network connects the waypoints on the physical model (Petrosova *et al*., 2015), delineating the most optimised trail.

Remote sensing is also beneficial in the mapping process, especially when using LiDAR (Light Detection and Ranging). High-resolution LiDAR penetrates canopy coverage, which enables users to observe the structures below the canopy (Hill, 2015). In a study done by Hill (2015), ground return LiDAR data were used to map recreational trails in the Umstead State Park, a densely forested area in North Carolina, USA. This study found that LiDAR mapped trails with an accuracy of 68.9% - 80.8% of their lengths (Hill, 2015). Mohamed and Al-Gilani (2005) used RS and GIS to pinpoint and map the historical trail of Jabal Kara in Saudi Arabia (Mohamed & Al-Gilani, 2005). This trail was constructed during the 10th Century and was primarily used by foot and camel travellers. Unfortunately, some parts of the trail have since been destroyed. The authors used an aerial photo and an IKONOS image that underwent geo-referencing to successfully identify the entire trail's length, width, and slope. A GIS database was subsequently built that assists in the rehabilitation of this trail (Mohamed & Al-Gilani, 2005), highlighting the importance of geospatial data and the mapping of such features for management purposes.

By having updated maps of an area, resources can be adequately directed to spaces and projects that most need it, and it can also highlight areas that can be utilised in future projects, as well as indicate where spaces and trails can be improved. Management can use the maps to indicate areas that might need more attention from an administrative point of view (i.e., some trails might become flooded and require restoration during rainy periods). Well-made maps can also be beneficial to users in that they provide detailed information regarding the mapped area, which allows the users to make informed decisions such as whether the space will meet all their physical and social requirements and goals.

Indicating the difficulty level of each trail enables users to choose a trail more suited to their purpose Individuals who want to use trails for exercise purposes might gravitate towards the more difficult trails, while families with small children might prefer shorter, gentler sloped trails. Also, providing a grading system for each trail via an informational product (such as a map), will allow all users the privilege of accessing this information. By providing such information to the public, individuals can then choose their more preferred trail, increasing the proper utilization of that urban green space and improving its quality by appropriate usage and improved accessibility.

2.3.1 Land cover mapping

Trail planning requires a thorough understanding of the environment of a region. Land cover plays an important role since the type of land cover affects where a trail can or should be. Not only is it important for tourism purposes, but it also has environmental protection and safety consequences. Trails that feature more natural and aesthetic scenery increase the likability of that trail (Chon & Schafer, 2009). Trails can thus be built in such a way to incorporate more aesthetic aspects to increase usage of the trails. However, in some instances natural areas should rather be avoided or protected, especially when these areas consist of protected fauna and flora species. Developing trails that will disrupt these protected species should be avoided, not only because of the consequences of continues foot traffic, but also because of the damage that trail creation can cause. By taking note of the land cover, trails can be created that take into consideration the characteristics of to the environment of that region, extracting the most benefits by, for example, excluding areas that are difficult to traverse or including areas that contain good shade coverage. It is thus important and beneficial to study an area's land cover before trail creation and amenity planning commences.

Land cover mapping makes use of various types of data from different disciplinary fields. Traditionally, data were collected through ground-based measurements and *in-situ* methods (Al-doski *et al*., 2020), but nowadays such methods are mainly used to validate other techniques, such as RS. Remote sensing uses platforms such as satellites or aircrafts to detect the physical features of an area at a distance by measuring both emitted and reflected radiation (Costa *et al*., 2018). Such images have spatial, spectral, radiometric, and temporal resolutions that all have an impact on the quality of product obtained; each different platform will have its own characteristics regarding these resolutions, and obtaining high-quality features for all resolutions by one platform is not always possible due to the costs associated and platform limitations (Liu *et al*., 2020). This technology is further less time-consuming, less expensive and can detect areas that might otherwise be hard to survey on foot (Lillesand *et al*., 2015). Such technologies include hyperspectral, multispectral, radar (radio detection and ranging) and LiDAR (Al-doski *et al*., 2020) techniques, and data collected from such platforms are primarily in a digital format. Land cover mapping derived from RS methods is extracted using either supervised or unsupervised classification methods and provides a suitable and efficient alternative to *in situ* determination of land cover.

One of the biggest challenges associated with land cover mapping is the inconsistencies and uncertainties between the definitions of the mapping classes (Congalton *et al*., 2014) Congalton *et al*. (2014) applied an error budget approach to analyse the level of inconsistencies between available land cover mapping projects and found that the classification and validation processes exhibited the greatest error contribution (Congalton *et al*., 2014). The authors concluded that better and clearer definitions for land cover classes needed to be created, and that accuracy assessments should be done more thoroughly and efficiently, subsequently reducing the number of inconsistencies and uncertainties within land cover mapping.

Similarly, Verberg *et al*. (2011) specified the different categories of inconsistencies associated with land cover data, which include temporal, spatial, and thematic consistency issues (Verberg *et al*., 2011). The problem of temporal inconsistencies derives from the fact that most data sets are created using different algorithms, classification classes, training sites, spatial resolutions, and map projections. The technology used, methods of data capture and storage, and the level of skill of the operators is also factors that influence the temporal characteristics of the data sets (Verberg *et al*., 2011). Spatial inconsistencies are mainly a result of positional errors produced when georeferencing remote sensing data or the simplification of a vector map (Castilla & Hay, 2007). Rasterization methods, as well as the extent of aggregation, can also affect the level of uncertainty (Verberg *et al*., 2011). Thematic differences mainly occur because of variations and dissimilar definitions but can also be produced by differences in observation techniques that lead to disparities amongst data sources (Verberg *et al*., 2011). As such, data integration, enhanced validation techniques, and synchronization of classification systems (Verberg *et al*., 2011) should be used to reduce these uncertainties to optimally extract the necessary information from any given dataset.

However, differences in the definitions of land cover classes are not the only reason for inaccuracies in maps. Schultz *et al*. (2015) found that accuracy estimates differ between 10-16% (the authors investigated five different global 1 km land cover maps), but that the homogeneity of the reference points greatly influences this accuracy. Furthermore, the overall accuracy varied by approximately 10% for the maps, depending on the correlation between the reference points and the map categories for a heterogeneous environment (Schultz *et al*., 2015). Thus, it is important to know and consider these issues and limitations from the onset of the study, as the outcome and success of the project will be influenced by these shortcomings and constraints.

Rujoiu-Mare & Mihai (2016) attempted to find an approach to accurately map the land cover of Prahova Subcarpathians (located in Romania), an area that is especially difficult to map due to its complex landforms and dynamic geomorphic processes. This study made use of remote sensing, GIS, and cartography techniques. Firstly, supervised classification using Landsat 8 OLI image data was used to obtain land cover classes after which land cover features were extracted from the GlobeLand30 and CORINE Land Cover models. Lastly, orthophotos and satellite images were used to generate ground truth points, which were used to validate the results obtained from the integrated classification dataset. This approach resulted in a high level of accuracy for the subsequent land cover map, which is indicative of its possible success as an alternative methodology, especially in areas with complex landscapes (Rujoiu-Mare & Mihai, 2016). Thus, although not all landscapes are complex, the methods and techniques used in this study argue for the accuracy and effectiveness that RS and GIS have in analysing and mapping land cover features.

A study done by Cihlar & Jansen (2001) further discusses the difficulty of land cover mapping: how to map larger landscape areas properly, accurately, and efficiently. The authors made use of land cover maps that were derived from remote sensing data and techniques, where the thematic and spatial information was used to recognize varying land cover- land use relationships, to produce land use maps. These relationships were categorized from direct (where each land use class has one corresponding land cover class) to multiple/complex (where a land cover class has multiple corresponding land use classes), with each ‘relationship category’ being assigned a different mapping strategy. This study successfully reached a compromise between the accuracy, cost, and detail (Cihlar & Jansen, 2001), which iterates the fact that land cover maps have a variety of uses, but also that integrated methodologies that comprise both remote sensing, as well as GIS techniques, can be beneficial for land cover mapping.

Science and technology have advanced in such a way that many additional methods and techniques of data capturing have emerged. One such method is that of unmanned aerial vehicle (UAV) remote sensing, as applied by Feng *et al*. (2015) who looked at the suitability of UAVs to capture ultra-high-resolution images, for land cover mapping. However, because UAVs generally make use of cameras with a low spectral resolution, part of this study was to propose a hybrid methodology where Random Forest, as well as texture analysis, was used to accurately distinguish between the land cover types of an urban vegetated area. The authors found that Random Forest was on par with the performance of object-based image analysis (OBIA) and that the classification accuracy significantly improved by including texture features (Feng *et al*., 2015). Further, UAVs are efficient and capable platforms for vegetation mapping, and this proposed form of hybrid methodology adequately differentiates between the land cover classes.

In 2015, the Sentinel-2A (S-2) satellite was launched. Amongst its many improved properties, the additional three bands in the red segment of the electromagnetic spectrum (EM) have been highlighted. Forkour *et al*. (2017) evaluated and compared the data from Sentinel-2 and Landsat-8 to determine which satellite produced more accurate results (in the context of land use and land cover mapping). The study found that the added red bands of S-2 “alone produced better and comparable results” (Forkour *et al*., 2017) to that of Landsat-8 and other Sentinel-2 bands. However, by combining Landsat-8 and Sentinel-2 red-edge bands, improved accuracy was noted over that of just Landsat-8. Notably, accuracy improvements of the land use and land cover classes were attributed to the red segment bands of S-2. Besides the observable improvements in accuracy because of the red-edge bands of S-

2, this study also iterates the usefulness of a multi-sensor approach when one is mapping land cover or land use.

Although satellite images provide high-resolution images that can adequately be utilised for mapping land cover, other platforms of imaging can also be used. Kaiser *et al.* (2004), assessed the performance of a helicopter-based platform where an Airborne Data Acquisition and Registration (ADAR) digital camera was mounted on the helicopter. The study aimed to map the various smuggler trails that connect Mexico with the United States. Using image enhancement methods and a programmed neural-network extraction technique (Kaiser *et al*., 2014), the authors were able to extract the necessary information from the very high spatial resolution imagery obtained from the helicopter platform. This platform proved to be efficient in capturing high-resolution imagery in the rapidly varying elevation, where several adjustments had to be made along the track altitude to maintain the image scale. Again, the use of a hybrid, as well as a multi-spectral analysis approach was highlighted, as such a methodology was exceptionally useful in this study and yielded a 73% increase in total mapped trails and an overall higher accuracy, as opposed to interpreting and digitizing the baseline CIR image (Kaiser *et al*., 2014).

With improved technology, data capturing systems, and computational power, questions regarding the analysis and processing of the captured data began to emerge. Already in 2001, Blaschke & Strobl doubted the effectiveness of "pixel-by-pixel image analysis" (Blaschke & Strobl, 2001). The use of OBIA was thoroughly investigated by Blaschke (2010) who found that it can successfully combine both the spectral and spatial information of objects, in contrast with just the spectral information given by a pixel-based approach (Blaschke, 2010). OBIA relies heavily on segmentation, where segments are generated by using either one or more homogenous measurement in one or more feature (Blaschke, 2010) Object-based analysis thus allows the simultaneous usage of images, as well as GIS processing techniques to integrate both the spectral and the spatial characteristics of an "object", which in turn supports the extraction of information and comprehensive analysis of an area. Thus, remote sensing methods and GIS techniques are indeed useful and efficient in mapping the land cover of an area.

As this study mainly focusses on the mapping of existing trails, and not creating and/or delineating new trails, land cover and land use mapping was not included herein. However, land cover mapping is indeed an important aspect that needs to be considered when one is planning a new trail, as such mapping will identify the terrain coefficient of the area which in turn has an impact on how difficult it will be to traverse the terrain of the trail. Therefore, it is necessary to appropriately understand the process of land cover and land use mapping. Additionally, such knowledge is also useful when disseminating the characteristics of the trails through infographics, since adding this information will enhance the public's understanding of the trail and also improve the functionality of the CoT's nature reserves.

2.3.2 Extraction of topographical data

GIS can further be used to extract topographic data, especially information such as the slope and relief of the area, required to grade the trails of the nature reserves. Topographic structure lines are important in a variety of analysis procedures, including that of terrain analysis (Tsai & Lin, 2019). Whereas traditional structure lines were manually construed from contours on hardcopy topographic maps, nowadays, these topographic maps have been digitised and converted into digital terrain models (DTM) that contain both elevation, and surface characteristics. Many different forms of DTM exist, each with a specific and distinctive approach to terrain surface modelling. The digital contour model (DCM) uses lines of corresponding elevation, the digital elevation model (DEM) is a 2D evenly spaced network of sampled elevations (Tsai & Lin, 2019), the digital surface model makes use of LiDAR to create a point dataset for elevation values, and the triangulated irregular network (TIN) is an irregular distribution of topographic features (Tsai & Lin, 2019).

An elevation profile is a useful tool when analysing the morphometric characteristics of a trail and its surrounding area, which enhances the spatial knowledge of that trail (Tirla *et al*., 2014). Mashimbye *et al*. (2013) found that image segmentation is an effective method to delineate terrain morphology from DEMs. The authors compared certain land components derived from five different DEMs, which include ASTER GDEM2, SRTM DEM, GEOEYE DEM, and SUDEM L1 and L2, and found that the GEOEYE DEM yielded the best results, closely followed by the SUDEM L2. These DEMs had the lowest SGSD values (indicates high internal homogeneity), and the boundaries of the land components often coincided with the morphological discontinuities (Mashimbye *et al*., 2013). In another study done by Nkeki & Asikhia (2013), the relevance of using GIS for topographical simulation was yet again highlighted. The authors used several GIS software and algorithms to manipulate and extract terrain features from DEM data. Topographical features were gradually extracted and generated, to build a GIS-supported topographical database (Nkeki & Asikhia, 2013) that consisted of physical features of the study area. In this study, the usefulness of GIS and DEMs were noted to enhance the understanding of the area's landscape, which in turn further aids in policymaking and planning (Nkeki & Asikhia, 2013).

In addition to this, digitisation of paths and point of interest are needed to extract other necessary information. The most common form of digitising these days is heads-up digitising that encompasses screen-to-screen digitisation (features will be traced from an online source directly from a computer screen), to create a digital copy of the feature (Longley et al., 2015). The process of digitisation differs depending on the software used, with coordinates being captured in a point, line, or polygon format that leads to the creation of vector data. Advantages of manual digitisation include lowered production costs, it is a relatively easily taught skill, and different types and sources of data can be digitized (Longley et al., 2015.). However, several errors including (but not limited to) dangling nodes, switchbacks, over/undershoots, or slivers during the digitisation process can reduce the accuracy of the data, which is especially problematic if these datasets will be used for analyses purposes. GIS allow users to manually digitise from any given basemap, after which the datasets can be used in calculations and other analyses processes.

Thus, making use of DEMs is beneficial when mapping and grading the trails of the nature reserves in the CoT, as DEMs are more cost-effective, objective, and less time-consuming (Minar & Evans, 2008) than field-based and visual analysis methods (Mashimbye *et al*., 2013). However, careful consideration should be given to the type of DEM that is being used, since not all are suitable for extracting land cover, or other feature data. DEMs with a higher resolution of approximately 5 m, such as GEOEYE and SUDEM, are, therefore, best suited to obtain such data. Also, incorporating digitisation methods to obtain data that does not yet exist is a necessary process, but should also be done with care to lessen errors that could result in inaccuracies in calculations which will also affect the results.

2.3.3 Fieldwork and Volunteered Geographic Information (VGI)

Data validation is an important facet of any research project, as it reduces the risk of errors and increases the accuracy and completeness of a dataset (Bastos *et al*., 2014). This is especially true for data that have been retrieved via calculations and formulae (as done in this study), as such modelled data needs to still be compared to known results. Only datasets that are known to be reliable and correct can be used in further analysis, as these datasets will allow for studies to be properly conducted with the results being more realistic, true, and usable. One way of validating data is through fieldwork assessments, which is the process of gathering in-field data that is subjected to the same characteristics as that which have been used in the modelling process. The data collected via fieldwork allows the reliability of the modelled data to be tested by comparing the modelled data to the fieldwork collected data (Bastos *et al*., 2014). Careful consideration should be given to the exact specifics of the modelled data to obtain ambiguity when doing the fieldwork. Since the modelled datasets will be directly compared to the fieldwork data, researchers must ensure that all testing parameters are the same for the validation process to be successfully done.

Another form of data validation that is useful is Volunteered Geographic Information (VGI). VGI data is submitted by citizen volunteers and is especially helpful when time constraints reduce the amount of data that can be collected through fieldwork studies, which is important since an adequate amount of data is necessary for the verification process (Sui *et al*., 2012). Crowd-sourced data is a form of VGI where data is collected through an online platform by means of, for example, a questionnaire or survey (Irtenkauf, 2014). This method allows for a vast amount of information to be collected, as these platforms are available by any individual that has access to the internet, social media, or smartphone. Thus, VGI can gather high volumes of data that can then be analysed and used for research purposes. However, the standards of the data can come into question since most individuals that submit their responses do not have knowledge of data standards, which is why such data must be carefully studied before being used (Sui *et al*., 2012).

2.4 MODELLING AND GRADING TRAILS IN NATURE RESERVES

As discussed in trail grading (pg. 19), trail mapping is an important facet of tourism information that not only provides the user with better understanding of the area and trails, but ensures that proper management and the ecological and economical sustainability of the area are considered (Peterson *et al*., 2018). This study analyses, among others, the estimated travel time per trail and energy expenditure of individuals while traversing the various trails of the CoT's nature reserves. Various factors can influence the amount of energy needed to complete a given trail, such as the slope/gradient, the terrain coefficient (human energy cost over different surface conditions), the load carried by the individual, the travel time, and the distance travelled. To accurately model and grade the trails, these factors must be considered.

Several functions exist that model travel time when walking, or energy expenditure when walking or running. For example, the Modified hiking function (Márquez-Pérez *et al*., 2017) models walking speeds of an individual, whereas Pandolf's metabolic rate function (based on walking speeds), models an individual's energy expenditure (in Watts), based on metabolic rate, subject weight, load, velocity, slope, and a terrain coefficient (Pandolf *et al*., 1977). These two functions, when used together, allow for the determination of energy expenditure for an individual across a particular terrain. Such terrain, in this context, would be the walking and hiking paths as delineated in the CoT open spaces. Epstein's function (Epstein *et al*., 1987) in turn allows for the modelling of energy expenditure while running. Other functions to consider are Tobler's hiking function (Tobler, 1993), or Naismith-Langmuir's rule (Fritz *et al*., 2000).

The usage of functions to model travel time has effectively been utilised in various engineering, planning and support sectors (see Fisk, 1991; Carteni & Punzo, 2007), with one of the biggest advantages of using functions to model parameters being its ability to estimate values without having to use extensive datasets (Fisk, 1991). Similarly, functions can be used to estimate the travel time associated with trails, both for walking, as well as running speeds. Travel time can be quantified as the ratio between the distance travelled and the average speed of the individual (Orsi & Genelitti, 2013). Although Naismith-Langmuir's rule (Fritz *et al*., 2000) is one of the earliest such functions modelling travel time when walking or running, commonly used functions are Tobler's Hiking Function (Tobler, 1993), and the modified Hiking Function (Márquez-Pérez *et al*., 2017).

Naismith-Langmuir's rule (Fritz *et al*., 2000; Equation 1) is used by runners and walkers to estimate travel times, especially when traversing more hilly terrain (Scarf, 2007). Additionally, this function is used for depicting cycling times in mountainous areas (Howes & Fainberg, 1991). Naismith-Langmuir's rule considers both the horizontal, as well as the vertical distances travelled when calculating the estimate travel time of the route. As mentioned above, routes with steeper gradients will result in decreased travel speeds, which in turn increase the travel time of the route.

T = [(a) * (Delta S)] + [(b) * (Delta H *Uphill*)] + [(c) * (Delta H *Moderate Downhill*)] + [(d) * (Delta H *Steep Downhill*)]

Equation 1: Naismith-Langmuir's rule (Fritz, Carver & See, 2000), where T is travel time in seconds, Delta S is the horizontal distance travelled and Delta H is the vertical distance travelled. Moderate Downhill is between negative 5 and 12 degrees and Steep Downhill is less than negative 12 degrees slope. The other parameters adjust travel speed based on these slope classes. Langmuir's proposed values are: a: 0.72; b: 6.0; c: 1.9998; d: -1.9998.

Tobler's Hiking Function (Tobler, 1993; Equation 2, pg. 29) allows for the determination of a person's walking speed while walking on variable terrain by converting a pre-calculated slope surface to a walking velocity surface. Travel time along a path can then be calculated by dividing the path distance by the walking velocity for the terrain, and is dependent on the chosen route or trail, as the geographic characteristics of the trail affect both the distance and speed at which one can travel along the set path. It must be noted that this function considers only the topography of the terrain, and not a terrain factor, which takes into consideration the slope as well as the surface roughness. As such, the input to the function is slope (gradient) only. On flat terrain (gradient of 0) this function yields 5 $km.hr^{-1}$ or 1.4 $m.s^{-1}$ (Tobler, 1993), i.e., the walking speed of a subject on flat terrain will be 5 $km.hr^{-1}$.

$$V = 6 * e^{(-3.5*|G+0.05|)}$$

Equation 2: Tobler's hiker function (Tobler, 1993), where G = $dh.dx^{-1}$ (slope in degrees), and where V is walking velocity. The walking velocity is in $km.h^{-1}$.

The most important parameter of this function is the slope of the trail. Various studies have reviewed the effect that slope has on the travel rate of individuals, especially when hiking and walking. Steeper uphill slopes require increased energy output while steeper downhill slopes demand more braking against gravity, both of which result in longer travel time and decreased speed (Minetti *et al*., 2002). Petersen *et al*. (2018), for example, found that trail difficulty, of which an uphill gradient was the biggest experiential element, negatively influenced the enjoyment of long-distance hikers to a particular trail (Petersen *et al*., 2018). This reiterates the findings of various authors, which indicate that hikers find trails with steeper gradients more challenging (Zealand, 2007), and that gradients have a noticeable effect on travel times and energy expenditure (Pandolf *et al*., 1977). Subsequently, hikers also experience increased feelings of distress when traversing more challenging terrain (Chhetri, 2015).

The Modified Hiking Function (Equation 3) is an improvement on Tobler's Function (Tobler, 1993) and the MIDE Rule (Paris Roche, 2002), which subsequently lessens the variation between the measured and calculated travel times (Márquez-Pérez *et al*., 2017). This function makes use of three variables to model a person's walking speed, namely the maximum speed reached, the slope gradient where this maximum speed was reached, and a modification parameter for the speed depending on the gradient of the slope (Márquez-Pérez *et* al., 2017). This function was successfully utilised by, e.g., Magyari-Saska & Dombay (2012), to delineate the possible area in which a lost person can be, by using DEM to determine the minimum hiking time. The MIDE Rule is used to estimate excursion complexity by taking into consideration the maximum speed, the projected length, and the slope of every trail section in its calculation of travel time (Paris Roche, 2002). By incorporating the above-mentioned factors, a difficulty scale is produced, which enables the classification of routes according to both its difficulty and the physical effort needed to complete the route (Paris Roche, 2002). It is used by the Spanish Mountain and Climbing Federation (FEDME) to calculate the average hiking time for an individual carrying a light load.

$$W = 4.8 * e^{(-5.3*|G*0.7+0.03|)}$$

Equation 3: Modified Hiking Function (Marques-Perez et al., 2017), where G = dh.dx^{-1} (slope in degrees).

Marques-Perez *et al*. (2017) used the Modified Hiking Function when estimating the travel times for walking trails in natural areas. The authors found that this function indeed produced more accurate results for the estimated travel times and suggested that this function be used by trail managers when planning and developing new trails.

Once travelling speed has been modelled, estimated energy expenditure of an individual across a surface can be calculated. Energy expenditure defines the energy that is required to partake in physical activities (Kramer, 2010). Factors such as body weight, the load carried, the travelling speed, and the terrain coefficient are all important contributing aspects that affect the total energy expenditure of an individual. The total body weight (Taylor *et al*, 1970), as well as the age of an individual (DeJaeger *et al*., 2001) influence the energy output of an individual during physical activity. Furthermore, running exhibits higher energy expenditures than walking (Farley & McHahon, 1992), and women tend to have lower energy output than men when travelling over the same distance and traversing at the same speed (Hall *et al*., 2004). Another contributing factor to increased energy output is steeper gradients (Marsh *et al*., 2006), with downhill slopes tending to produce less energy output than that walking on level ground (Minetti *et al*., 2002). The effect of carrying loads while walking or running has also been thoroughly investigated. Most, but not all individuals, exhibit increased energy expenditure with increased loads (Kramer, 2010). A study done by Bastien *et al*. (2005) found that energy cost followed a U-shaped curve as travel speed continuously increases and that at an optimal speed of 1.3 m.s^{-1} the appropriate load for long-distance walking would be quarter of the person's body mass (Bastien *et al*., 2005).

The last contributing factor that affects energy output is the terrain the person is traversing. Terrains such as paved paths or dirt roads are easier to traverse than terrains that have loose sand or bogs (De Gruchy *et al*., 2017). To assign a difficulty level to terrain types, terrain coefficients have been developed that indicate how difficult it will be to traverse that terrain (De Gruchy *et al*., 2017). De Gruchy et al. (2017) quantified the terrain coefficient of various terrain types based on metabolic output (as determined by Pandolf's Function), where the more difficult the terrain, the higher the coefficient and the higher the estimated energy expended across the terrain. Since these coefficients are based on the land cover, it is important to have thorough knowledge about an area's land cover features and characteristics. Table 5 indicates the subsequent terrain coefficients.

Table 5: Pre-determined terrain coefficients based on metabolic rate, adopted from de Gruchy et al. (2017)

Terrain	Coefficient
Asphalt/blacktop	1.0
Dirt road	1.1
Grass	1.1
Light brush	1.2
Heavy brush	1.5
Swampy bog	1.8
Loose sand	2.1
Hard-packed snow	1.6
Ploughed field	1.3

Pandolf's Metabolic Rate Function (Equation 4, pg. 31) quantifies the metabolic cost when travelling with loads while slowly walking or standing. It incorporates an individual's weight, the load carried, the travelling speed, the slope, and the terrain coefficient (Pandolf *et al*., 1977). It was designed to predict the metabolic cost associated with carrying loads at slow speeds, and thus is only applicable for speeds below 2.2 m.s^{-1}, i.e. walking speeds. Pandolf *et al*. (1977) further used this function to model the physical activity of individuals at higher altitudes and found that the function is also a suitable estimate of the energy expenditure of individuals at higher altitudes while carrying a load. This function is thus useful for quantifying the energy expenditure of individuals even at higher altitudes, as is the case of the trails in the CoT's nature reserves. Furthermore, while Hall et al. (2004) found that this function overestimates energy expenditure by 2.8%, the differences are deemed minimal and the function can thus successfully be used to model energy expenditures (Hall *et al*., 2004).

$$M = 1.5W + 2(W + L)\left(\frac{L}{W}\right)_2 + \eta(W + L)(1.5V_2 + 0.35VG)$$

Equation 4: Pandolf's Metabolic Rate Function (Pandolf et al., 1977)., Where W is the individual's weight, L is the load carried, η is the terrain coefficient, V is the travel speed, and G is the slope in %.

Epstein's Function (Equation 5) takes into consideration the load carried and the metabolic rate function, as calculated by Pandolf's Metabolic Rate Function, to quantify the metabolic cost of running for an individual across a range of speeds, grades, and external loads (Epstein *et al*., 1987).

$$M_r = M_w - 0.5(1 - 0.01L)(M_w - 15L - 850)$$

Equation 5: Epstein's Function (Epstein et al., 1987), where Mr is energy expended in Watts, Mw is Pandolf's Metabolic Rate Function, and L is the load carried in kilogram.

This function is similar to that of Pandolf's Metabolic Rate Function, but can be applied when modelling the metabolic cost of running, and is thus useful when travel speeds exceed 2.2 $m.s^{-1}$ (as is the limitation of Pandolf's Metabolic Rate Function). Epstein *et al*. (1987) found that this function expressed a high correlation between the predicted and reported values of their study, which speaks to the function's accuracy as a predictor of metabolic cost under a range of different conditions (Epstein *et al*., 1987). However, the authors did warn against possible inaccuracies when loads are carried in an individual's hands or on their ankles.

For this study, the Modified Hiking Function (Marques-Perez *et al*., 2017) is used to estimate the travel times for walking trails; this function also becomes in input into Pandolf's Metabolic Rate Function (Pandolf et al., 1977). Pandolf's Metabolic Rate Function (Pandolf et al, 1977) is used to model energy expenditure along a trail while walking, whereas Epstein's Function (Epstein et al., 1987) is used to model energy expenditure while running along a trail.

2.5 MAPPING AS AN INFORMATION PRODUCT

Once the process of trail planning and the subsequent construction of the routes are completed, it becomes necessary to map these routes accordingly. The mapping of these routes must be done with as much precision and accuracy as possible. In addition to the most exact delineation and distance of the route, other information such as the estimated travel time, the difficulty of the trail, points of interest (including those of ecological, historical, and cultural significance), where restrooms or benches are situated, and warnings of areas that have difficult or dangerous ground conditions, can be provided. This ensures that the user is adequately informed on all the important aspects and facets of the route.

Maps can be defined as a visual representation of certain characteristics of an area presented on a flat surface, focusing on a set of criteria and features depending on the purpose of the map. Not only are maps used to give information in a simpler way, but they are also functional (GPS and other location maps), educational (history maps, world maps, amongst others), useful in research, give context, and conceptualizes difficult data and phenomena (Tarman & Erkan, 2021). Importantly, visual data representations (such as maps) have shown to increase the cognitive recall of its associated text (Kulhavy & Stock, 1996), thus making such informational products appropriately useful. However, great care must be taken to accurately present the information on maps to limit error and reduce false and inaccurate accounts of events and phenomena, as this can have significant consequences if it is not adequately done. One of the oldest surviving maps of topographic importance, especially with regards to its planning purposes, is the Egyptian *Turin Papyrus* (Harrell & Brown, 1992), drawn approximately 1150 BC. Although the geometric processes of how the map was made are not known, what is especially interesting is the accuracy with which the map exhibits both topographical, as well as geological information. This map was made for Ramesses IV, who was conducting quarrying expeditions in Wadi Hammamat (a dry riverbed in the Eastern Desert of Egypt), an area well known as an excellent mining site (Harrell & Brown, 1992). This indicates the importance of accuracy not only today, but already displayed in the 12th century BC, through maps such as the Turin Papyrus.

Since then, much advancement in survey instruments and techniques has been documented, as indicated by historic records that depict Greek, Roman, and Italian influences throughout the ages. These processes and techniques used for land surveying and trail mapping have been greatly enhanced since the 17th and 18th Century, when an improvement in the science of mechanical engineering, metallurgy and optics occurred (Nelson *et al*., 2009). This enabled surveyors to make use of various new and improved instruments that were eventually used in the 19th Century as the primary methods of triangulations from which many nations were mapped. Some of these instruments and devices include the theodolite, level, plane table, and barometer. It was only in the 20th Century that digital electronics, such as GPS and handheld computers, logging electronically and laser distance measuring (Teeuw *et al*., 2005) were developed and became the main methods used in the field of modern land surveying.

Ever since the mid-1990's, the Internet has become the platform of web-based cartography and online mapping. From 1995, cartography, a discipline mostly distributed and studied in a physical medium, became more digital (Peterson, 2005). Pre-Internet (hardcopy) maps are increasingly digitised through scanning, and GIS utilised to study and produce digital static, as well as dynamic online maps. Some examples of online maps and atlases include the Global Solar Atlas[2] (which indicates the solar potential worldwide), the UN Environmental Programme[3] (which has a variety of environmental information in map format), and T-Drive[4] (an initiative where taxi drivers' route histories are used to map the fastest routes). Online maps and atlases can also act as data repositories, which in essence are spaces for researchers to store the datasets that are linked to their research, such as the Global Biodiversity Information Facility[5] (holds biodiversity data), Cancer Imaging Archive[6] (holds medical cancer images) and the ArrayExpress[7] (holds genomics data), amongst others. The power of the digital medium has further improved data collection and verification methods (Petersen, 2005). And as the Internet has shifted to also become a medium of communication due to the advancements in computer literacy and the increase in digital content, other technologies and programs have similarly been developed to expand the methods of information delivery, such as that of infographics.

Presently, infographics have become a major form of information communication and presentation (Naparin & Saad, 2017). They effectively integrate data and graphics by making use of elements such as photos, maps, or charts to convey information. They represent a visual communication of data and information with the aim of conveying a message, knowledge, or story quickly and effectively in a format that is simplified, concise, and easier understood (see Lankow *et al*., 2013; Slocum *et al*., 2022). This

[2] Available at https://globalsolaratlas.info/map
[3] Available at https://wesr.unep.org/
[4]Available at https://www.microsoft.com/en-us/research/publication/drive-smartly-as-a-taxi-driver/?from=https://research.microsoft.com/apps/pubs/default.aspx?id=138985&type=exact
[5] Available at https://www.gbif.org/
[6] Available at https://www.cancerimagingarchive.net/
[7] Available at https://www.ebi.ac.uk/biostudies/arrayexpress

is one of the greatest assets of this form of information display, although the quality and the organization of the infographic greatly influence its attainment as an information product (Naparin & Saad, 2017). In comparison to original research communication forms like journal articles, infographics receive a higher consumer interest rate and subsequently also attract more social media attention (Kunze *et al*., 2021). Using infographics also increases the retention capacity of learners when comparing learners who only used graphic text with those that made use of other data visualization modes (Lyra *et al*., 2016). Infographics are thus an effective communication medium. While traditional cartographic maps are designed to accurately represent the geospatial layout of an area, they are not always intuitive to the public. In comparison, infographics present information in a visually engaging manner, enhancing understanding of critical elements the author wishes to convey.

One of the objectives of this study is to provide the public with resources (i.e., printed, and online maps and infographics) that give them more information regarding the delineated trails of the nature reserves in the CoT. To achieve this objective, various methods used to capture, extract, manipulate, and analyse the geospatial characteristics, including type of terrain and slope (Feng *et al*., 2015) of these areas. By using the various geospatial techniques available, mapping and modelling of the area is done to subsequently enhance the informational products distributed to the public. Geospatial methods are thus utilised to not only create and extract data, but to model trail aspects and to assign a grading to trails of the nature reserves (as discussed in section 2.4).

For this project, GISc and specifically GIS are used to map and grade the existing delineated trails of the CoT's nature reserves. GIS allow for a multi-criteria approach, which is necessary to grade existing trails accurately and comprehensively. GIS also enhance the mapping of the trails, as the various functions available allow for a thorough and detailed product to be achieved. While RS is highly suited to determine land cover, this is not a requirement for the current study and not done here.

CHAPTER 3: MATERIALS AND METHODS

This chapter discusses the type of research that was conducted in this study (section 3.1), as well as including more detail regarding its planning and execution. Details regarding the study area (section 3.2) and the methodologies (section 3.3, pg. 37) follow thereafter. The chapter concludes with a discussion surrounding the limitations and assumptions (section 3.4, pg. 47), as well as the ethical considerations that needed to be respected and adhered to (section 3.5, pg. 48).

3.1 TYPE OF RESEARCH

The type of research conducted in this study is classed as empirical quantitative, since it is based on direct observations made from the spatial data collected, where focus is put on quantifying the collected and analysed data, as well as the research being established by the observations and measurements made. Some of the trails in the nature reserves are physically tested, with smart watches recording the total distance travelled, the time it took to complete the trial, and the approximate energy expenditure of the trail. Measurements and observations taken through fieldwork analysis are supplementary to the spatial metrics modelled using GIS, and aid in data verification.

3.2 STUDY AREA

This research project was conducted in the nature reserves of the City of Tshwane Metropolitan Municipality (CoT), of the Gauteng Province of South Africa. Currently there are 18 reserves that are accessible to the public within this area. These reserves function as green urban spaces where many citizens partake in a variety of physical activities such as walking, hiking, running, and cycling. The following nature reserves are included in this study as they had existing delineated paths: Austin Roberts Memorial Bird Sanctuary, Bishop Bird Nature Area, Boardwalk Bird Sanctuary, Faerie Glen Nature Reserve, Fort Klapperkop Nature Reserve, Groenkloof Nature Reserve, Luton Valley Bird Sanctuary, Moreleta Kloof Nature Reserve, Pierre van Ryneveld Nature Area, Struben Dam Bird Sanctury, Tswaing Meteorite Crater and Wonderboom Nature Reserve. This represents 12 of all nature reserves, with 33 trails evaluated. The remaining nature reserves' conditions are not suited to hiking and/or running and mainly consists of caravan parks, game drives and dams for boating activities.

The CoT spans a total of 6 345 km^2, resulting in it being the 3rd largest city in the world with only New York and Tokyo covering a larger land mass area (City of Tshwane, n.d). It is also the administrative capital of South Africa, housing various embassies and government officials, including the President of South Africa (City of Tshwane, 2015). Several research institutes, such as the Council for Scientific and Industrial Research and the Medical Research Council can be found here, as well as the educational-based institutions Tshwane University of Technology, University of Pretoria, and the University of South Africa.

With a population of more than 2.9 million people, it is classified as one of the "youngest" cities, with 37% of its population between 14-35 years of age (Statistics South Africa, 2011). There was a 3.1%

population growth between 2001 to 2011 (Statistics South Africa, 2011). The 2011 census data also indicate that the female to male gender ratio is almost the same, with 50.2% of the population female and the remaining 49.8% of the population male (Statistics South Africa, 2011). Citizens of different ages and demographics thus potentially make use of the designated nature reserves.

This area is characterized by a continental-type climate since it is moderately elevated at an altitude of between 1,000 and 1,500 m a.s.l. (Kruger & Mbatha, 2021). Summer temperatures are relatively high, easily being between 30 and 40 degrees Celsius, with lower winter temperatures that can go below freezing (Kruger & Mbatha, 2021), and the area receives predominantly summer rainfall, with some rain showers occurring during late spring, autumn, and winter. The two biomes that extend throughout the CoT are savannah and grassland with several areas consisting of ridges that offer a habitat for many species of fauna and flora, as well as various important freshwater features (Holness & Skowno, 2016). Thus, the CoT is classified as being a Bankenveld area, where vegetation ranges from grassland to bushveld, with interspersed "rocky hills, ridges, plateaux and plains" (Bredenkamp & Brown, 2003, pg.7).

The varied terrain with pleasant climate lends itself to an outdoor lifestyle. The CoT's citizenry can partake in such by visiting and using the facilities offered by the 18 nature reserves of the city.

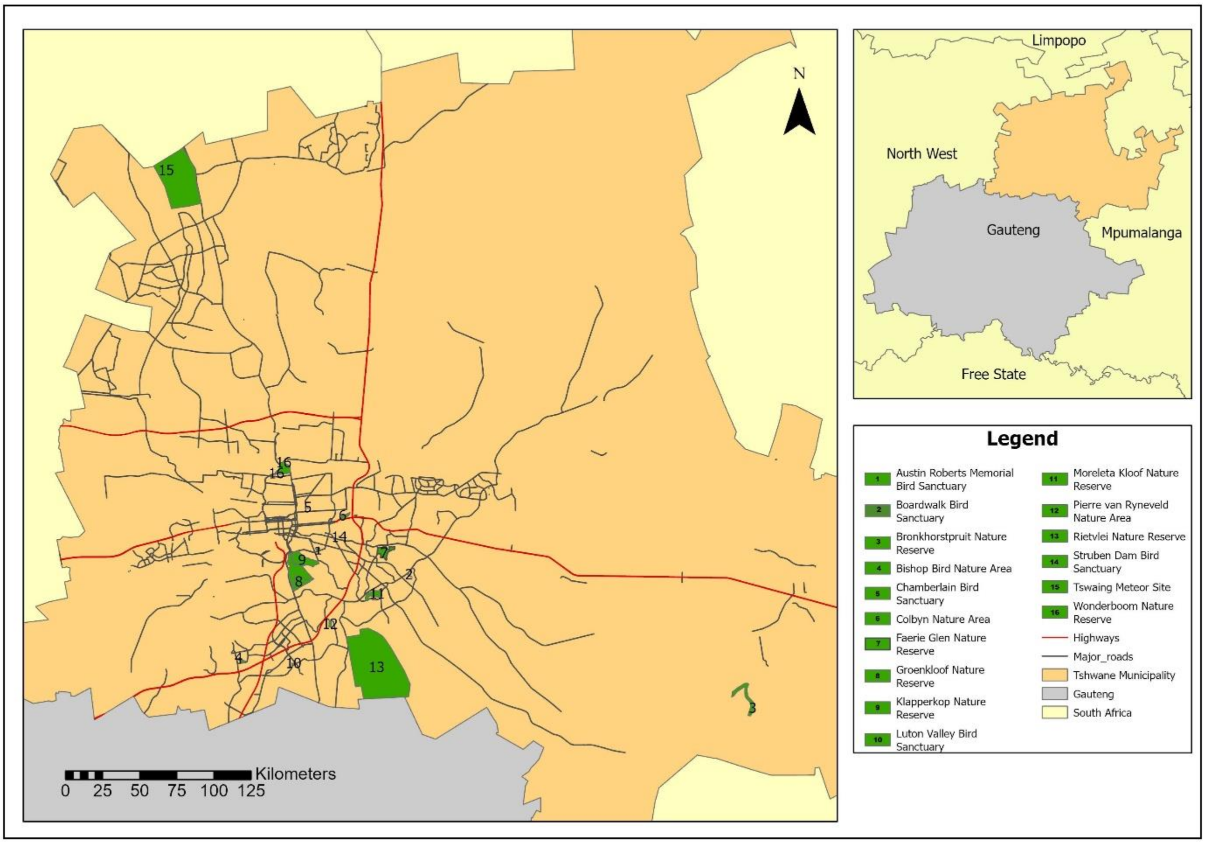

Figure 1: The nature reserves of the City of Tshwane

3.3 METHODS

To achieve the study's objectives, a thorough, systematic, and comprehensive literature review was conducted. By evaluating, reviewing, and assessing different source material and research methods, a good knowledge of current literature's processes, shortcomings, and limitations were established. It also allowed for identifying possible areas for improvement, as well as the areas where gaps could potentially be addressed and resolved through this study. Methods are outlined under their relevant objectives in the subsequent sections. An overview flow chart depicting the steps taken for this project is shown in Figure 2. A consolidated detailed flowchart of steps is given in APPENDIX A: CONSOLIDATED DETAILED STEPS (pg. 91).

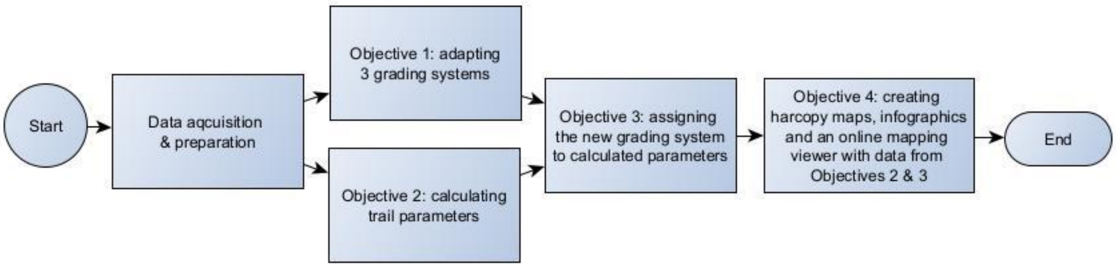

Figure 2: Flowchart of the methods used in this study.

3.3.1 Data Acquisition and Preparation

Steps followed to acquire and prepare data are illustrated in Figure 3.

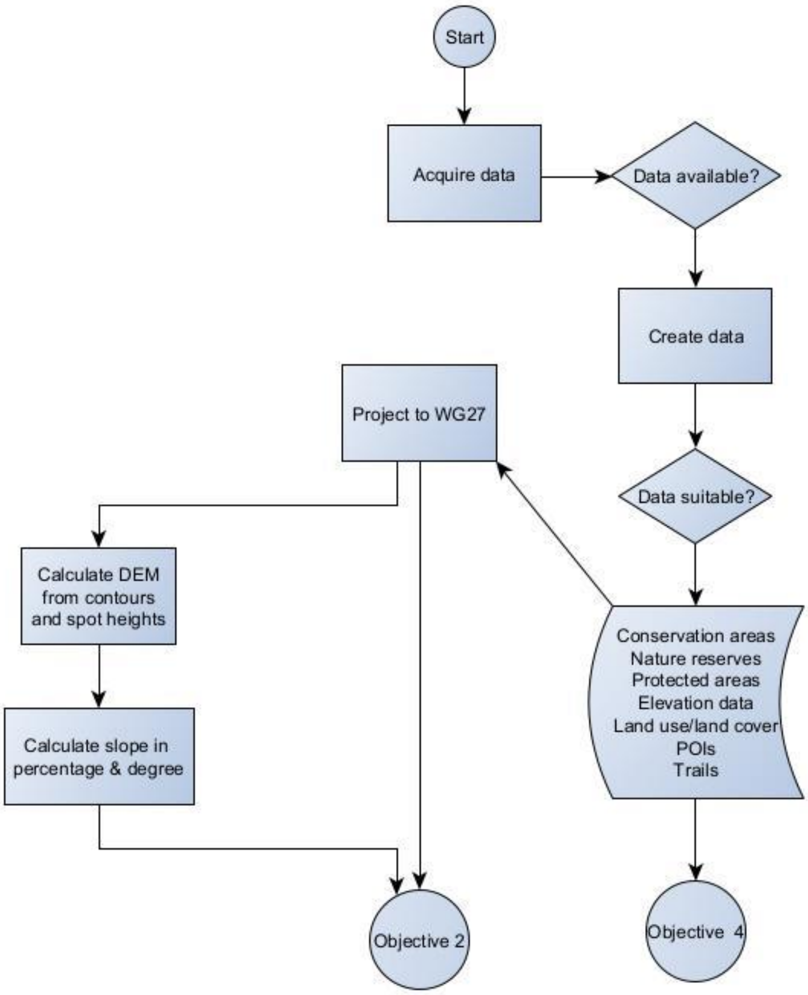

Figure 3: Steps followed to acquire and prepare data.

3.3.1.1 Geospatial data acquisition

The spatial data used in this project and listed in Table 6 were obtained from numerous sources, including the CoT and the University of Pretoria. Data not available were created in a GIS.

Table 6: The datasets used in this study.

Dataset	Data Type	Source
Conservation areas	Vector	CoT
Contours	Vector	CoT
DEM	Raster (interpolated from vector)	Vector: CoT Raster: own data
Nature reserves	Vector	University of Pretoria
Points of Interest	Vector	Digitised from CoT maps
Protected areas	Vector	CoT
Trails	Vector	Digitised from CoT maps

3.3.1.2 Data creation

A Digital Elevation Model DEM) is created by interpolating to a surface (raster) using the 5 m contour layer, as well as available spot heights. This was done by using the Topo to Raster Tool in ArcGIS Pro

3.x. The trails (a total of 33) of nature reserves were digitsed from existing maps. These were subsequently verified and amended as needed using high resolution imagery available as a basemap in ArcGIS Pro (South Africa 50 cm Colour Imagery[8]). Since this layer is from 2012, trails were subsequently verified using the World Imagery[9] basemap available in ArcGIS Pro, or Google Earth Pro as needed. The Modified Hiking Function, as well as Pandolf's Metabolic Rate Function require the slope of the trail in its calculation. The slope of the trails is created using the "Slope" function on the 5 m DEM layer. This function gives the slope in both degrees (as needed for the Modified Hiking Function) and percentage rise (as needed for Pandolf's Metabolic Rate Function).

3.3.1.3 Data projection

ArcGIS Pro 3.x was used to conduct all geographical analyses. All data were converted to the same planar projection (WG27). This projection was chosen due to the minimal distortion evident for data projected along the latitude of origin for the CoT, centred on 27 degrees East. Raster data were resampled to the same spatial resolution where appropriate.

3.3.2 Objective 1: Consolidated trail grading system

The proposed systems of Hugo (1999a), the Australian Walking Track Grading System (Victorian Government DSE, 2010), and Wildrunner Trail Grading System (Wildrunner, n.d.) were adapted to this study. Hugo (1999a, b) uses the average energy expenditure of a trail and it's walking time to grade its difficulty level (which ranges from easy to extreme). The Australian Walking Track Grading System considers a trail's distance, the quality of the path and markings, the gradient associated, the experienced required, and the number of stairs to climb on the path (Victorian Government DSE, 2010). Finally, the Wildrunner Trail Grading System incorporates terrain difficulty, how much track is on difficult terrain, and route steepness (Wildrunner, n.d.).

By using the inverse of the Modified Hiker Function, and the energy expenditure values calculated using Pandolf's Metabolic Rate Function (for walking), and Epstein's Function (for running), using factors such as the individual's weight, the load carried, the travel speed, the slope, and the terrain coefficient, the appropriate difficulty grading can be assigned to each trail (see Table 5, pg. 21). Although Pandolf's Metabolic Rate Function includes certain topographic factors, these factors become generalised once the functions are run and occurrences of extreme instances of topography, such as sections that exhibit steeper slopes, are not evident in the system of Hugo (1999a, b), although present for the Australian Walking Track Grading System (Victorian Government DSE, 2010), and the Wildrunner Trail Grading (Wildrunner, n.d.).

The additional parameter of sections of steep slopes to derive a steepness index is a geomorphological aspect, investigated separately and integrated into the grading systems where appropriate. Steps followed to achieve Objective 1 are illustrated in Figure 4.

[8] Currency: 2012; available at https://www.arcgis.com/home/item.html?id=9d01fa9041264cb283c353a5a613c81e
[9] Currency: 3-5 years; available at https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

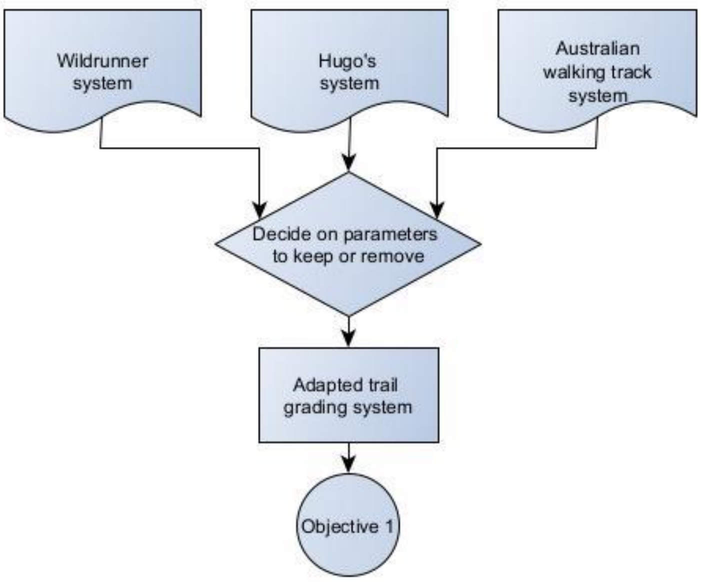

Figure 4: Steps followed to achieve Objective 1.

3.3.3 Objective 2: Existing trail modelling

Once input data are obtained, verified, and projected, various manipulations and calculations are made. Calculations are subsequently verified. Steps to achieve Objective 2 are detailed on Figure 4 (pg. 40).

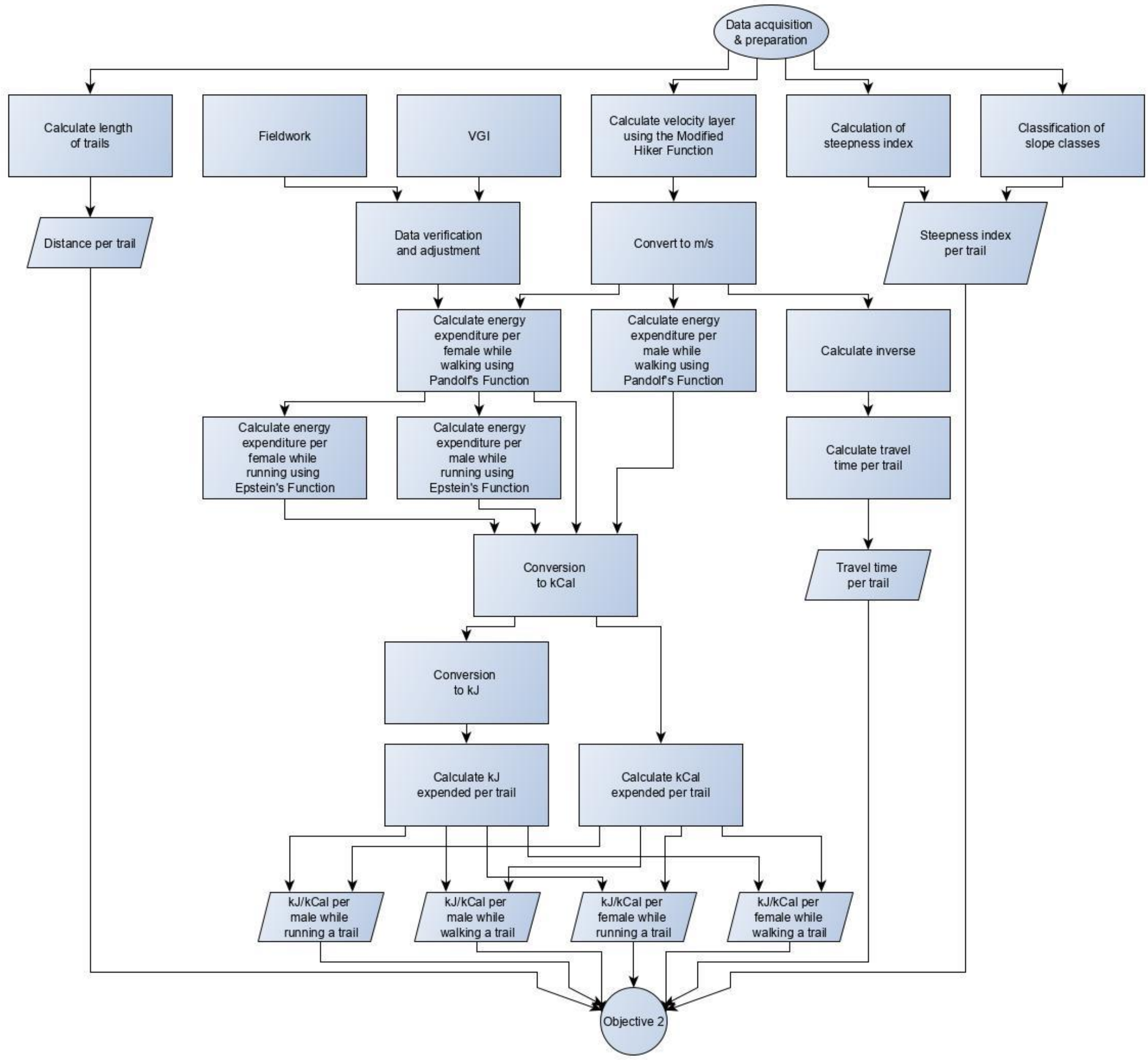

Figure 5: Steps required to achieve Objective 2.

3.3.3.1 Data manipulation

3.3.3.1.1 Distance

The distance of each trail was calculated by using the attribute length function automatically created in any GIS, which gives information regarding the length of a linear feature in the attribute table of that feature. Total length per path is a function of summing all path segments on the length attribute, where the path feature is projected into a planar projection. To be able to use this information in raster calculations for the travel time, the length attributes of the linear features were converted to a raster.

3.3.3.1.2 Steepness index

The steepness index, as generated by the Barcelona Field Studies Centre (2020) (refer to Table 7, pg. 42), and modified using slope gradient descriptions from Agriculture and Agri-Food Canada (Soil Landscapes of Canada Working Group, 2010) was used to assign a description (ranging from level to very steep slope) to each trail. More specifically, the slope description is not merely based on the average of the trail's slope but depicts the range of the trail's slope. For example, a route with a slope percentage ranging from 0.7 to 3.0 will be given a slope description of nearly level to gentle slope. Where a slope has a range of steepness values, the highest steepness grade is ultimately assigned to the trail. For example, if a trails has a steepness class ranging from 'Nearly level to a strong' slope, the trails is assigned the grade of 'Strong'.

Table 7: Slope steepness index as adapted from the Barcelona Field Studies Centre (2020).

Slope (%)	Approximate Degrees	Terminology	Equivalent to grading systems
0 – 0.5	0	Level	No steep sections
0.5 – 2	0.3 – 1.1	Nearly level	
2 – 5	1.1 – 3	Very gentle slope	Gentle hill sections
5 – 9	3 – 5	Gentle slope	
9 – 15	5 – 8.5	Moderate slope	Varying gentle and short steep sections
15 – 30	8.5 – 16.5	Strong slope	Short steep sections
30 – 45	16.5 – 24	Very strong slope	Very steep sections
45 – 70	24 – 35	Extreme slope	
70 – 100	35 – 45	Steep slope	
> 100	> 45	Very steep slope	

3.3.3.1.3 Walking speed/ velocity

To determine a person's walking speed, the Modified Hiking Function (Equation 3, pg. 30) is determined by means of the raster calculator available in any GIS. The slope layer is first converted from degrees to radians to calculate the velocity. This ensures that the average walking speed of each trail can be calculated. Because Pandolf's Metabolic Rate Function requires the speed layer to be in $m.s^{-1}$, the Modified Hiking Function also needs to be converted from $km\ h^{-1}$ to $m\ s^{-1}$. This is achieved by dividing Equation 3 by 3.6, as illustrated in Equation 6.

$$W = \frac{4.8 * e^{(-5.3*|G*0.7+0.03|)}}{3.6}$$

Equation 6: The Modified Hiker Function (Márquez-Pérez et al., 2017), converted to $m.s^{-1}$. G = $dh.dx^{-1}$ (slope in degrees), and W = walking velocity in $km.h^{-1}$.

3.3.3.1.4 Estimated travel time

The simplest method to estimate time spent on a path, is to convert the Modified Hiker Function output of $km.h^{-1}$ to $m.s^{-1}$, to take its inverse, and to sum along the length of the path (Equation 7).

$$\boldsymbol{T} = \frac{\mathbf{1}}{\boldsymbol{Modified\ Hiker\ Function}}$$

Equation 7: Inverse of the Modified Hiker Function, converted to minutes, where T = time in seconds.

3.3.3.1.5 Energy expenditure/ metabolic cost

One of the required parameters for Pandolf's Metabolic Rate Function (Equation 4, pg. 31) is the terrain coefficient. All the hiking trails in the nature reserves consist of compacted ground, which resulted in the terrain coefficient being presupposed as a coefficient of 1 as was pre-determined by de Gruchy et al. (2012) for an asphalt/blacktop terrain. This terrain coefficient is used to calculate the average energy expenditure for each trail by making use of Pandolf's Metabolic Rate Function. Another important parameter is the load carried, which is assumed to be approximately 1 kg when running and 3.5 kg when walking. Also, the average weight of males and females in South Africa differ. According to World Data (2020), the average weight of a South African male is 71.9 kg, and the average weight of a South African female is 74.1 kg. Thus, the calculation must be done separately for each gender group. The average energy expenditure is subsequently used when applying a grading system to the trails. Similarly, Epstein's Function (Equation 5, pg. 32) is used to model the energy expenditure associated when running, using the results obtained from Pandolf's Metabolic Rate Function and the load carried.

Both Pandolf's Metabolic Rate Function and Epstein's Function give the metabolic cost in Watts. As such, the values are converted from Watts to kilocalories per second (kCal.s^{-1}); a multiplication of the velocity layer to kilocalories (Equation 8 and Equation 9 respectively).

$$MkCal = \frac{1.5\,W + 2(W+L)\left(\frac{L}{W}\right)^2 + (W+L)(1.5V^2 + 0.35VG)}{4176} * velocity$$

Equation 8: Pandolf's metabolic rate function with a terrain coefficient of 1 and converted to Kilocalories (Pandolf et al., 1977), where MkCal – metabolic rate, kCal; W – subject weight; L – load; V – velocity (m.s-1); G – slope (%).

$$MrkCal = \frac{\left(\mathrm{Mw} - 0.5\,(1 - 0.01\mathrm{L})(\mathrm{Mw} - 15\mathrm{L} - 850)\right)}{4176} * velocity$$

Equation 9: Epstein's Function (Epstein et al., 1987), where M_rkCal = running speed in kCal, L = load carried in kilogram, and M_w = Pandolf's metabolic rate function.

Kilocalories (kCal) are converted to Kilojoules (kJ) using Equation 10.

$$kJ = kCal * 4.184$$

Equation 10: Conversion of Kilocalories to Kilojoules.

3.3.3.2 Data verification

Data verification takes the form of two steps, 1) fieldwork, and 2) data obtained through Volunteered Geographic Information (VGI).

3.3.3.2.1 Fieldwork

To verify the results obtained through modelling of the trails, fieldwork was conducted in Groenkloof Nature Reserve, Moreleta (Marekele) Nature Reserve, Wonderboom Nature Reserve, and Faerie Glen Nature Reserve. Groenkloof Nature Reserve was chosen because of variable terrain. Moreleta Nature Reserve was chosen, however, because of its relative "flat" surface gradient and easy terrain. Furthermore, these reserves have the highest visitor numbers after Rietvlei Nature Reserve (CoT, unpublished data), increasing the likelihood that VGI would be successful. Rietvlei Nature Reserve was not considered as a study site, since it is mostly used for citizens embarking on game drives or sailing on the Rietvlei Dam. Visitor records provided by the CoT indicate that these chosen reserves receive approximately 6,685 visitors per year, which is almost half of the entirety of visitors for all the nature reserves in a year.

Three participants of mixed ages, weight and height biometrics, and gender groups who are moderately fit willingly volunteered to partake in this research project. Since personal information was collected from these volunteers, the project adhered to the Protection of Personal Information Act 4 of 2013 (POPI) of South Africa (Republic of South Africa, 2013). For a further discussion on this please refer to section3.5 (page 48). Each volunteer received two different smart watches that were trained to their specific biometrics (i.e., weight, height, age, and gender group). The two types of smart watches that were used are: Samsung Galaxy Watch Active2 BT Smartwatch 40mm and the Garmin Forerunner 55. The Samsung smart watch has a built-in accelerometer, barometer, light sensor, gyro sensor and optical heart rate sensor, and only weighs 26g (Samsung, n.d.). The Garmin Forerunner 55 weighs 37g and has an accelerometer, heart rate sensor, as well as various other tracking features that are specifically inclined for walking, running, and cycling (Garmin, n.d.).

These smart watches recorded the distance of the trail, the time it took to complete the trail, the number of steps taken while traversing on the path, the elevation gain or descent, and the approximate energy expenditure of the trail. Participants were tasked to walk the trails of the designated nature reserves trails at least five times each (n=75 per trail), to receive sufficient sampling points to accurately assess and verify the data received from the modelling section. After completion of each trail, the information collected was downloaded and stored on an Excel sheet for easy reference and calculations.

3.3.3.2.2 Volunteered Geographic Information (VGI)

In addition to the fieldwork component, Volunteered Geographic Information (VGI), which involves and incorporates data that are submitted by citizen volunteers (Sui *et al*., 2012), was obtained from the citizens of the CoT. At the start of each route a sign was erected that contained a QR code and a link to an online survey, which was built using ArcGIS Survey123. The survey questions are available in APPENDIX B: SURVEY OUTLINE, pg. 91; the link to the survey is https://arcg.is/D1L950. These data constitute VGI crowd sourced data (Irtenkauf, 2014), which can be used effectively to verify modelled values if precautions are taken. Such an approach is especially valuable when data are lacking, or in the case of this study, where time constraints make it difficult to gather adequate quantities of data for verification purposes. However, since such data are usually collected by individuals who do not necessarily have knowledge of data standards, the quality of such collected data can be below standard and should thus be used with caution (Sui *et al*., 2012). This can be controlled by carefully worded and appropriate survey questions.

When someone accesses the survey, they are taken to a landing screen that details 1) the details of the study, 2) requirements of the study, 3) the ethics application number (received from the University of Pretoria Faculty of Natural and Agricultural Sciences (NAS) Ethics Committee), 4) a participant's right to access their contributed data, 5) the capture of personal information, 6) the duration of retaining such information, and 7) a participant's right to withdraw from the study at any point. If that is not done, the survey cannot be completed. This survey was available to the public to answer, and users could participate multiple times. These questions were used to obtain more information regarding their overall experience on the trail, including if they took breaks while walking the paths. After answering all the questions and submitting the forms, the information that was captured was analysed, and used to further verify the information obtained from modelling the data. A total of 286 entries were received by the time this dissertation was submitted, however, only 127 entries were deemed usable, with the remaining entries either having incomplete or erroneous data.

3.3.4 Objective 3: Assigning grades to existing trails

The adapted grading system of Objective 1 is assigned to the parameters calculated for each trail from Objective 2. These parameters include trail distance, estimated minimum time of completion (without rest periods), expected energy expenditure in Kilojoules and Kilocalories for men and women while walking or running, as well as the slope grade. A final grade is assigned based on the highest difficulty level per trail for any of its evaluated parameters. For example, if a trail was overall scored as 'Easy' for all parameters, but one parameter was scored as 'Fair', then the trail would score as 'Fair'. This final output – the trail final difficulty grade – becomes an important geospatial layer in the hardcopy maps, infographics, and the online map viewer that are the outputs of Objective 4. The methods for Objective 3 are given in Figure 6.

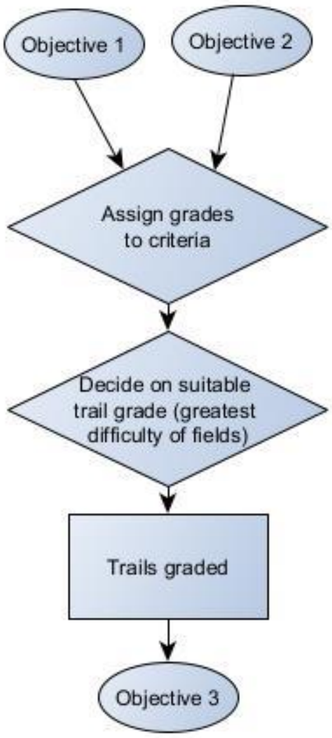

Figure 6: Steps followed to achieve Objective 3.

3.3.5 Objective 4: Trail mapping

Dissemination of the results takes the form of three outputs: 1) maps, 2) an online resource (web map), and 3) infographics (see Figure 7, pg. 46).

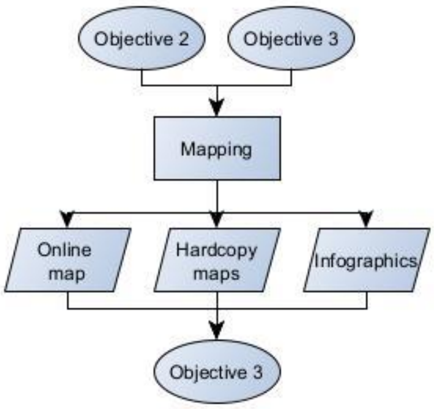

Figure 7: Steps followed to achieve Objective 4.

Hardcopy and digital maps conform to cartographic standards. Hardcopy maps indicate the nature reserves delineated trails, the distance of the trails, the estimated time it will take to complete the trails, the expected energy expenditure of the trails (for both male and female gender groups), as well as the difficulty level assigned to the trail (the trail grading system). By providing the abovementioned information for each nature reserve, the public will be better informed and will be able to use these information products to their advantage.

Alternatively, an online interactive web map is also made available with, as the hardcopy maps, information regarding the distance of the trail, the length of the trail, the time needed to complete the trail, and approximate metabolic output of the trail. However, it also allows the public a more interactive approach to study the trails and areas of the nature reserves. Users can then zoom in or out, activate or deactivate certain layers, and focus on specific requirements and/or features that they want to include in their route. Online maps also enable users to make use of these products anywhere and at any time, either by using a phone, computer, or any other device that can connect to the Internet (Lee, 2021).

Several platforms exist that enable online maps to be made accessible and available for use to the public. One such platform is Mapbox, which allows for the development and distribution of maps for a variety of purposes such as, amongst others, travel, retail, and real estate (Mapbox, n.d). Mapbox gives developers a range of styles that can be used to create and edit a map and allows the creation of both static and interactive maps. Once the map is completed and 'published' (which refers to the production version of your map), a URL for that specific map is given that, together with an access token, will allow public users (individuals who are not the developer of the map) to access the maps. It also allows interoperability between Mapbox and Esri where maps created using Esri software can be edited in Mapbox and re-uploaded onto Esri without losing the edits done in Mapbox (Mapbox, n.d). Similarly, ArcGIS Online is an online platform that allows maps that have been created using ArcGIS to be made available for public use. As with Mapbox, each map is given a unique URL that is shared via a webpage (if applicable) and will thereafter be available to anyone that accesses the website. Both Mapbox and ArcGIS Pro require payment for its licensing to be able to use the software, however, both can freely be viewed once the map is created and published. Since the maps are made using ArcGIS Pro, it was decided to only make use of ArcGIS Online to minimise costs and provide a more efficient mapping environment. Furthermore, the City of Tshwane uses the Esri platform for its eGIS viewer[10]. Providing the online map on an Esri platform thus ensures greater familiarity to citizens.

Another aspect of this study is to provide the public with infographics. The infographics are used to graphically portray the information by using graphs, photos, charts, maps, and texts to give more of a visual representation of the data collected and modelled. Studies have shown that displaying information visually not only enhances readability and comprehension, but also improves decision making by increasing the rate at which the portrayed information is processed (Murray *et al*., 2017). Infographics use striking colours and data-appropriate visuals that highlight and emphasise certain aspects of the information that is important and significant.

Maps, the online mapping platform, as well as the infographics are used in this project to enhance information access and user experience by providing citizens with informational products that enhances their understanding and knowledge of the benefits and uses that these nature reserves have. This directly relates to the implementation of SDG 11 which strives to make cities and communities more inclusive and provide universal access to public spaces for all citizens. By providing informational products of the nature reserves, citizens will be able to use these spaces more extensively and appropriately.

3.4 LIMITATIONS AND ASSUMPTIONS

Limitations can be defined as restrictions or restraints that could inhibit the quality, precision, and accuracy of a study. Some of the spatial data that were used in this study were created by means of digitization, since not all of data needed in this study existed or were up to date. This could possibly result in some complications and inaccuracies when analysing and processing the data. However, great care was taken to minimise such discrepancies and errors through various verification and validation processes of the data. Furthermore, when data were digitised, this was done at a consistent scale (a scale of 1:500 was continuously used when digitising the routes, reserve outlines, dams, and other amenities). Another hindrance in the success of the outcomes of this research project is the little research done on how energy expenditure can be used to establish grading levels for hiking trails. Due to this lack in literature, previous methodologies that were examined and reviewed could not be utilised as a verification tool in this study.

Other important user characteristics that ultimately affect the energy output needed to complete a trail, and subsequently also alter the difficulty grade of the trail, are the age, gender, and fitness level of the user. Such personalization to specific user features is not included in the functions that are used in this study. However, this study does address the differences in gender energy output by quantifying energy expenditure for both the male and the female gender groups. This is based on published average weights per male and female in South Africa. Differences in energy expenditure relating to user age and fitness level are not addressed.

Due to time constraints, not all the reserves could be included in the fieldwork portion of this study. The fieldwork section was particularly of importance as it was used to verify the data collected through

[10] https://e-gis002.tshwane.gov.za/E_GIS_Web/

modelling of the various functions. As such, most of the nature reserve's modelled results were assumed to be correct, since the verification was inferred from the results obtained of the fieldwork for the Groenkloof Nature Reserve, Moreleta Nature Reserve, Wonderboom Nature Reserve, and Faerie Glen Nature Reserve. This serves both as a limitation, and as an assumption in this study.

The use of VGI can be extremely helpful, but it can also be a limitation as not all such data collected are within the data quality standards. Also, such data indicate the perceptions of individuals, and may not necessarily be the facts of the situation. Assumptions are the attributes and elements that are presumed to be correct, accurate, and acceptable in a study. Data obtained from the survey are assumed to be correct and accurate, but as this is volunteered information given by individuals who do not necessarily have the background knowledge of data accuracy and acceptable data capturing, the survey data can obtain inaccuracies.

The load carried while running were assumed to be 1 kg (the approximate weight of a phone and car keys), with the load carried while walking assumed to be 3.5kg (the approximate weight of a phone, car keys, 500 ml water bottle, backpack, and a small number of snacks). The average weight of a South African were retrieved from statistical data for both the male and female gender group and was assumed to be true and applicable to all demographic groups. Similarly, the walking speed was also assumed to be correct and appropriate for all demographic groups and genders. These parameters and considerations were believed to be from reliable and accurate sources.

3.5 ETHICAL CONSIDERATIONS

The Protection of Personal Information Act No. 4 of 2013 (Republic of South Africa, 2013) has strict stipulations that need to be adhered to regarding the collection, processing and the storage of all personal information that is being captured or used for research purposes. This study makes use of voluntary participation by citizens, as well as data retrieved from World Data. No potentially harmful information, such as names, surnames, and email addresses of the volunteers were collected to execute the objectives of the study. All voluntary participants' information was kept anonymous and/or confidential. By agreeing to participate in this project, citizens were giving consent for any such personal information that is needed for the execution and completion of this project to be used in the manner stated, as clearly and ambiguously communicated to them. They were also able to opt out of this research project at any given time. The data retrieved from World Data did not contain any sensitive information pertaining to the sensitivity of certain answers.

Furthermore, research was conducted in such a manner to ensure that the results were accurately represented and portrayed, with no bias or prejudice. No personal information was published and once the research was done, all personal information that was collected was deleted.

Finally, the project was approved by the Ethics Committee of the Faculty of Natural and Agricultural Sciences of the University of Pretoria (ethics number NAS160/2021).

CHAPTER 4: RESULTS

This chapter discusses the results that were obtained for each nature reserve in the CoT, focussing on each objective of the study separately. Firstly, are the findings of the grading system as adapted from the system proposed by Hugo (1999a), the Australian Walking Track Grading System (Victorian Government DSE, 2010), and the Wildrunner Trail Grading System (Wildrunner, n.d.). Subsequently, modelling of the existing trails is discussed (page 49) which includes the results of the physical requirements, cost surface calculations, as well as the data received through the verification steps (both the fieldwork and VGI data collected). Following the previous mentioned, the adapted grading system is assigned to the trails of the nature reserves based on the calculated parameters of Objective 2 (page 57). Lastly, the outcomes of the generated maps, online resources, and infographics are given (page 62).

4.1 CONSOLIDATED TRAIL GRADING SYSTEM

A new proposed grading system combining the parameters of Hugo (1999a), the Australian Walking Track Grading System (Victorian Government DSE, 2010) and Wildrunner Trail Grading System (Wildrunner, n.d.) was created (Table 8, pg. 50), to comprehensively study the characteristics of the trails and consequently assign a difficulty grade. Bushwalking experience needed and surface condition were excluded, since all trails are found within an urban setting and regularly maintained by either the CoT or the various Friends of the nature reserves.

Table 8: New proposed grading system based on Hugo (1999a), the Australian Walking Track Grading System (Victorian Government DSE, 2010) and Wildrunner Trail Grading System (Wildrunner, n.d.)

Grade	Difficulty grading	Walking time at 3 km.h^{-1}	Energy needed (kJ)	Energy needed (kCal)	Distance (km)	Steep sections
Very easy	Easy, non-technical terrain, all on established trails & tracks	< 1.7h	< 2500	< 597	< 5	None
Easy	Moderately easy terrain, short sections of 'technical' terrain but largely easy running, all on established trails tracks	1.7-3.3h	2500 – 5000	597 – 1195	5 -10	Gentle hill sections
Fair	Slightly more challenging terrain, with some technical terrain mostly on established trail tracks, but may or may not have extended sections regarded as off-trail	3.3-5h	5000 – 7500	1195 – 1792	10 – 15	Varying gentle and short steep sections
Moderate	Moderate challenging terrain, with a mix of 'technical' and 'non-technical' terrain, mostly on established trails tracks but may or may not have extended sections regarded as being 'off-trail'	5-6.7h	7500 – 10 000	1792 – 2390	15 – 20	Short steep sections
Difficult	Moderately difficult terrain, more 'technical' terrain than 'non-technical' terrain, challenging but mostly established trails & tracks although may or may not have extended sections regarded as being 'off-trail'	6.7-8.3h	10 000 – 12 500	2390 - 2987	20 -25	Very steep sections
Severe	Moderately difficult to difficult terrain, technical terrain that is demanding that may or may not have extended sections on unestablished tracks	8.3-10h	12 500 – 15 000	2987 - 3585	25 – 30	Very steep sections
Extreme	Difficult terrain, majority 'technical' terrain that is extremely demanding, may or may not have large sections on un-established trails & tracks	10h+	15 000+	3585+	30+	Very steep sections

4.2 EXISTING TRAIL MODELLING

4.2.1 Data manipulation

The results of the modelled data are shown in Table 9 to Table 20 (pgs. 52 to 56) for each of the delineated trails in the nature reserves. Some of the trails have assigned names, which have been used as its unique identifier (Name), or where no trail name is available, a unique identifier was given to differentiate the trails' results separately. Each respective trail's distance in m (Distance), steepness index as a percentage (Slope %), slope description as determined by the Barcelona Field Studies Centre (2020) (Slope description), estimated travel time in minutes for walking (Travel time), and energy expenditure for walking (Energy walking) and running (Energy running) in Kilojoules and Kilocalories, for both male and females respectively, are indicated. The maximum walking speed (as determined by using the Modified Hiking Function) was found to be 1.4 $m.s^{-1}$.

The length of the trails varied, with the shortest route being 259 m (located within Boardwalk Bird Sanctuary) and the longest route being 9.9 km (Groenkloof Nature Reserve's Yellow route). Boardwalk Bird Sanctuary's 259 m route only requires two minutes to complete, whilst the Yellow Route of Groenkloof Nature Reserve requires 117 minutes to complete. Also, the 259 m route of the Boardwalk Bird Sanctuary had the lowest energy expenditure with regards to walking and running activities for both genders, with the Yellow Route of Groenkloof Nature Reserve had the highest energy expenditure. Thus, the shortest route took the least time to complete and required the least amount of energy output, and the longest route took the most time to complete and required the most amount of energy output. The slope description for most reserves ranged from level to moderate, however, two trails had higher slope descriptions. The slope of Groenkloof Nature Reserve's Yellow Route was described as being level to strong, and that of Tswaing Meteorite Crater was described as being level to extreme.

Table 9: Physical parameters of Austin Roberts Memorial Bird Sanctuary

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
1	641.0	3.0-5.0	Very gentle	9	29.0	30.0	121.0	125.0	51.0	52.0	215.0	216.0
2	549.0	1.1-3.0	Nearly level to very gentle	7	25.0	26.0	106.0	109.0	46.0	47.0	194.0	196.0

Table 10: Physical parameters of Bishop Bird Nature Area

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
3	1,980.0	0.1-4.9	Level to very gentle	24	88.0	91.0	369.0	379.0	163.0	164.0	681.0	687.0
4	1,475.0	0.9-2.4	Nearly level to very gentle	16	66.0	68.0	277.0	285.0	123.0	124.0	513.0	517.0
5	383.0	1.2-2.5	Nearly level to Very gentle	5	16.0	17.0	67.0	69.0	29.0	30.0	123.0	123.0

Table 11: Physical parameters of Boardwalk Bird Sanctuary

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
6	259.0	1.0-3.0	Nearly level to very gentle	2	9.0	9.0	38.0	39.0	17.0	17.0	69.0	70.0
7	700.0	1.0-3.0	Nearly level to very gentle	10	30.0	31.0	125.0	129.0	53.0	54.0	223.0	225.0

Table 12: Physical parameters of Faerie Glen Nature Reserve

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
Hadeda	2,203.0	2.0-7.0	Very gentle to gentle	28	77.0	79.0	322.0	331.0	123.0	124.0	515.0	519.0
Kiepersol	2,270.0	2.0-8.0	Very gentle to gentle	28	83.0	86.0	348.0	358.0	140.0	141.0	586.0	590.0
Acacia	2,275.0	1.0-6.0	Nearly level to gentle	28	80.0	82.0	333.0	344.0	125.0	127.0	524.0	524.0

Table 13: Physical parameters of Fort Klapperkop Nature Reserve

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
Brollocks & Bittergal	4,134.0	2.0-16.0	Very gentle to strong	49	173.0	178.0	722.0	743.0	296.0	299.0	1240.0	1252.0
Road	4,680.0	1.0-20.0	Nearly level to strong	54	194.0	196.0	811.0	821.0	313.0	317.0	1308.0	1324.0
Red	2,595.0	2.0-17.0	Very gentle to strong	30	88.0	90.0	368.0	376.0	147.0	148.0	615.0	620.0
Van Hunks se Pyp	1,241.0	3.0-5.0	Very gentle	15	21.0	23.0	89.0	96.0	31.0	33.0	131.0	139.0

Table 14: Physical parameters of Groenkloof Nature Reserve

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
Red	4,455.0	0.5-2.1	Nearly level	55	190.0	195.0	796.0	818.0	310.0	312.0	1295.0	1307.0
White	3,739.0	0.8-12	Nearly level to moderate	45	142.0	147.0	596.0	613.0	225.0	227.0	940.0	948.0
Yellow	9,905.0	0.1-20	Level to strong	117	335.0	345.0	1403.0	1444.0	535.0	540.0	2240.0	2260.0

Table 15: Physical parameters of Luton Valley Bird Sanctuary

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
8	1004.0	1.0-3.0	Nearly level to very gentle	12	46.0	47.0	193.0	198.0	83.0	84.0	349.0	351.0
9	366.0	1.0-3.0	Nearly level to very gentle	5	18.0	19.0	76.0	78.0	33.0	33.0	138.0	139.0
10	615.0	2.0-4.0	Very gentle	8	25.0	26.0	105.0	108.0	45.0	45.0	189.0	190.0

Table 16: Physical parameters of Moreleta Kloof Nature Reserve

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
Duiker	1,597.0	4.0-6.0	Very gentle to gentle	16	61.0	63.0	255.0	263.0	98.0	99.0	409.0	413.0
Suikerbos	2,787.0	1.0-12.0	Nearly level to moderate	33	93.0	95.0	387.0	398.0	142.0	143.0	594.0	600.0
Rademeyer	1,454.0	4.0-13.0	Very gentle to moderate	18	65.0	67.0	271.0	278.0	108.0	109.0	451.0	455.0

Table 17: Physical parameters of Pierre van Ryneveld Nature Area

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
11	783.0	1.0-2.0	Nearly level	9	33.0	34.0	140.0	144.0	58.0	59.0	243.0	245.0
12	1,177.0	1.0-2.0	Nearly level	13	50.0	51.0	209.0	215.0	84.0	85.0	352.0	355.0

Table 18: Physical parameters of Struben Dam Bird Sanctuary

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
13	510.0	1.0-3.0	Nearly level to very gentle	6	21.0	21.0	87.0	89.0	36.0	36.0	150.0	152.0
14	818.0	1.0-3.0	Nearly level to very gentle	9	33.0	34.0	139.0	143.0	57.0	58.0	240.0	242.0

Table 19: Physical parameters of Tswaing Meteorite Crater

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
15	6,217.0	0.1-51.63	Level to extreme	92	245.0	251.00	1025.00	1054.00	412.0	416.0	1723.0	1738.0

Table 20: Physical parameters of Wonderboom Nature Reserve

Name (ID)	Distance (m)	Slope (%)	Slope Description	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running
Alternate waterfall & cave	326.0	3.0-4.0	Very gentle	4	15.0	16.0	64.0	66.0	27.0	27.0	111.0	112.0
Waterfall & cave	477.0	3.0-5.0	Very gentle	6	19.0	20.0	81.0	84.0	31.0	31.0	130.0	132.0
Fort towards waterfall & cave	1,179.0	2.0-11.0	Very gentle to moderate	13	21.0	22.0	88.0	91.0	33.0	33.0	137.0	138.0
Fort	1,208.0	2.0-15.0	Very gentle to moderate	14	18.0	18.0	74.0	76.0	28.0	28.0	117.0	118.0
Joos Becker	2,464.0	0.7-12.0	Nearly level to moderate	29	80.0	82.0	333.0	342.0	121.0	122.0	507.0	511.0

4.2.2 Data verification

4.2.2.1 Fieldwork

The distance of the trails (in metres), its subsequent travel time (in min), and the total energy expended (in kCal), as well as the weight and gender of the individuals and the load carried, are listed in Table 20 below. Also indicated is the type of smartwatch used (either the Samsung Galaxy Watch Active2 BT Smartwatch or the Garmin Forerunner 55), showing the differences (or lack thereof) between the two different devices.

The longest route recorded was 4, 380 m, which route also had a travel time of 64 minutes and an energy output of 236 kCal. This was recorded by a female volunteer weighing 75 kg. The shortest route recorded 3,000 m and had a travel time of 78 minutes. This route was also recorded by a female volunteer who weighed 64 kg and which had an energy output of 467 kCal.

Table 21: Fieldwork data collected from various volunteers

Route name	Gender	Smartwatch	Weight (kg)	Load (kg)	Distance (m)	Travel Time (min)	Energy (kCal)	Energy (kJ)
Faerie Glen – all trails[11]	Female	Garmin	75.0	1.0	Not given	45	358.51	1500.00
Faerie Glen – combination of trails	Female	Samsung Galaxy Watch Active2 BT	75.0	1.0	4,380	64	236.00	987.00
Wonderboom – combination of trails	Female	Garmin Forerunner 55	64.0	1.0	3,000	78	342.00	1431.00
Wonderboom – combination of trails	Female	Samsung Galaxy Watch Active2 BT	64.0	1.0	3,580	78	467.00	1954.00
Wonderboom – combination of trails	Male	Garmin Forerunner 55	105.0	5.0	3,007	79	351.00	1469.00
Wonderboom – combination of trails	Male	Samsung Galaxy Watch Active2 BT	105.0	5.0	3,550	79	480.00	2008.00

4.2.2.2 Volunteered Geographic Information (VGI)

Posters and flyers with the link to the survey were put up and distributed at Faerie Glen Nature Reserve, Groenkloof Nature Reserve, Moreleta Kloof Nature Reserve, and Wonderboom Nature Reserve. A total of 286 entries were received by the time this dissertation was submitted, with Faerie Glen Nature Reserve receiving 131 entries, Groenkloof Nature Reserve receiving 39 entries, Moreleta Kloof Nature Reserve receiving 97 entries, and Wonderboom Nature Reserve receiving 12 entries. However, only 127 entries were deemed usable, with the entries that could not be used having incomplete or erroneous data. For example, an entry indicating that it took four minutes to walk Groenkloof's Yellow Route and the rest time as 15 minutes were discarded since we can only use the data as it is provided and cannot make assumptions or infer that the participant in fact meant four hours and not four minutes as was indicated in the survey. Also, many entries did not properly indicate which route was taken, and as such

[11] This entry was provided by a survey participant who consented to providing their actual data for the relevant routes walked/run.

these entries were noted but not used to verify and improve the modelled data. The results of the usable entries are indicated in

For Faerie Glen Nature Reserve, results were received for all three routes namely, Kiepersol Route, Acacia Route, and Hadeda Route. For the Kiepersol Route the travel time ranged from 60 to 190 minutes and rest times ranged from zero to 30 minutes. The route description ranged from easy to difficult, and the load carried ranged from one to four kilograms. The average energy expenditure for females ranged between 291 and 460 kCal, and 440 to 606 kCal for males. The Acacia Route had a travel time which ranged between 60 and 70 minutes, with zero rest times indicated. The route description was given as being easy and fair. The average load ranged between zero and three kilograms, and no energy expenditure was provided. The Hadeda Trail's travel time ranged from 53 minutes to 150 minutes, with rest times ranging between five to 30 minutes. The route description ranged from very easy to moderate and the load carried ranged from zero to 10 kilograms. For females, the energy expenditure ranged from 328 and 512 kCal, and for males it ranged between 80 and 278 kCal.

Within the Moreleta Kloof Nature Reserve all the trails received meaningful results, which includes the Duiker Route, Suikerbos Route and Rademeyer Route. The Duiker Route's travel time ranged between 40 and 150 minutes, with rest times for this trail ranging between zero and 45 minutes. The route was described as being very easy to difficult, with the load carried ranging between zero and five kilograms. For females, energy expenditure ranged between 223 and 360 kCal, and for males it ranged between 207 and 574 kCal. For the Suikerbos route, it was found that the time travelled ranged between 60 to 120 minutes with the rest times ranging between zero and 20 minutes. The route was found to be easy to moderate. There were not enough data given to calculate the average energy expenditures for males and females. The Rademeyer Route had travel times that ranged between 45 and 130 minutes and rest times ranging between zero and 15 minutes. The route was described as being easy to moderate, with the load carried ranging between zero and two kilograms. Yet again there was not enough data provided to calculate the average energy expenditures for males and females.

With regards to Groenkloof Nature Reserve, only the Red and Yellow routes received usable data. The travel time for the Red Route ranged between 60 and 160 minutes, with rest times ranging between two and 30 minutes. The route was described as easy to moderate. The load carried ranged between one and three kilograms. For the Yellow Route, the travel time ranged between 90 and 250 minutes, with rest times ranging between zero and 40 minutes. The route was described as very easy to difficult, with the load carried ranging between zero to six kilograms. For females, the energy expenditure ranged between 400 and 1255 kCal, and for males it ranged between 523 and 1978 kCal.

Table 22 to Table 29 (pg. 58 to 62).

For Faerie Glen Nature Reserve, results were received for all three routes namely, Kiepersol Route, Acacia Route, and Hadeda Route. For the Kiepersol Route the travel time ranged from 60 to 190 minutes and rest times ranged from zero to 30 minutes. The route description ranged from easy to difficult, and the load carried ranged from one to four kilograms. The average energy expenditure for females ranged between 291 and 460 kCal, and 440 to 606 kCal for males. The Acacia Route had a

travel time which ranged between 60 and 70 minutes, with zero rest times indicated. The route description was given as being easy and fair. The average load ranged between zero and three kilograms, and no energy expenditure was provided. The Hadeda Trail's travel time ranged from 53 minutes to 150 minutes, with rest times ranging between five to 30 minutes. The route description ranged from very easy to moderate and the load carried ranged from zero to 10 kilograms. For females, the energy expenditure ranged from 328 and 512 kCal, and for males it ranged between 80 and 278 kCal.

Within the Moreleta Kloof Nature Reserve all the trails received meaningful results, which includes the Duiker Route, Suikerbos Route and Rademeyer Route. The Duiker Route's travel time ranged between 40 and 150 minutes, with rest times for this trail ranging between zero and 45 minutes. The route was described as being very easy to difficult, with the load carried ranging between zero and five kilograms. For females, energy expenditure ranged between 223 and 360 kCal, and for males it ranged between 207 and 574 kCal. For the Suikerbos route, it was found that the time travelled ranged between 60 to 120 minutes with the rest times ranging between zero and 20 minutes. The route was found to be easy to moderate. There were not enough data given to calculate the average energy expenditures for males and females. The Rademeyer Route had travel times that ranged between 45 and 130 minutes and rest times ranging between zero and 15 minutes. The route was described as being easy to moderate, with the load carried ranging between zero and two kilograms. Yet again there was not enough data provided to calculate the average energy expenditures for males and females.

With regards to Groenkloof Nature Reserve, only the Red and Yellow routes received usable data. The travel time for the Red Route ranged between 60 and 160 minutes, with rest times ranging between two and 30 minutes. The route was described as easy to moderate. The load carried ranged between one and three kilograms. For the Yellow Route, the travel time ranged between 90 and 250 minutes, with rest times ranging between zero and 40 minutes. The route was described as very easy to difficult, with the load carried ranging between zero to six kilograms. For females, the energy expenditure ranged between 400 and 1255 kCal, and for males it ranged between 523 and 1978 kCal.

Table 22: Data collected for the Kiepersol Route in Faerie Glen Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Agender	167	55	3	120	20	Fair	291
Female	175	85	4	120	30	Moderate	287
Female	192	95	4	120	25	Fair	450
Female	181	95	1	65	0	Fair	460
Female	183	62	5	150	5	Difficult	None provided
Female	178	50	2	80	5	Moderate	None provided
Female	175	115	2	132	5	Fair	None provided
Female	190	193	3	120	20	Fair	None provided
Female	176	122	0	67	0	Moderate	360
Male	178	66	2	90	5	Fair	440
Male	163	67	0	60	5	Easy	None provided

Male	168	53	0	180	30	Moderate	None provided
Male	167	71	2	80	5	Moderate	566
Male	169	75	2	120	5	Moderate	None provided
Male	167	95	3	190	30	Difficult	606
Male	173	75	1	60	20	Easy	600

Table 23: Data collected for the Acacia Route in the Faerie Glen Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Female	182	75	0	70	0	Fair	None provided
Female	186	74	3	60	0	Easy	None provided

Table 24: Data collected for the Hadeda Route in the Faerie Glen Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Female	180	80	3	90	10	Easy	None provided
Female	186	100	1	45	1	Easy	512
Female	185	70	0	100	30	Easy	None provided
Female	186	94	2	40	10	Easy	328
Female	186	96	8	120	30	Fair	None provided
Male	160	56	2	75	30	Very easy	None provided
Male	167	83	10	90	10	Fair	None provided
Male	168	60	6	63	0	Very easy	None provided
Male	153	61	2	90	10	Moderate	114
Male	178	80	1	60	10	Moderate	278
Male	169	73	0	53	20	Moderate	223
Male	170	60	2	90	15	Easy	80
Male	172	95	0	75	5	Fair	None provided
Male	172	82	2	150	30	Fair	None provided

Table 25: Data collected for the Duiker Route in the Moreleta Kloof Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Female	179	98	2	40	0	Easy	223
Female	178	75	0	90	0	Fair	None provided
Female	170	66	5	150	20	Difficult	358
Female	192	74	2	100	5	Very easy	360
Female	167	83	1	120	0	Moderate	229
Female	178	80	0	40	0	Easy	None provided
Female	178	62	0	50	0	Easy	None provided
Female	180	80	1	90	30	Very easy	None provided
Female	180	104	0	75	5	Fair	None provided
Male	177	77	1	90	5	Fair	574

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Male	156	65	1	40	2	Fair	None provided
Male	168	53	1	50	20	Easy	None provided
Male	164	65	3	120	45	Easy	300
Male	155	87	1	75	20	Fair	None provided
Male	167	88	1	90	15	Fair	198
Male	160	87	1	54	0	Easy	275
Male	159	53	1	78	0	Easy	207

Table 26: Data collected for the Suikerbos Route in the Moreleta Kloof Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Female	178	130	2	90	10	Fair	None provided
Female	183	130	0	90	0	Moderate	358
Female	182	82	21	120	5	Moderate	None provided
Male	163	65	0	70	0	Easy	None provided
Male	158	80	1	60	5	Moderate	None provided
Male	173	76	2	75	0	Fair	None provided
Male	180	100	0	75	0	Fair	None provided
Male	161	56	0	90	10	Moderate	None provided
Male	154	68	1	76	5	Moderate	None provided
Male	167	63	3	100	20	Moderate	334
Male	170	86	0	93	10	Fair	None provided
Male	None provided	55	2	90	5	Fair	None provided

Table 27: Data collected for the Rademeyer Route in the Moreleta Kloof Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Female	190	84	1	130	15	Moderate	None provided
Female	190	85	1	75	10	Fair	None provided
Female	165	80	1	60	0	Easy	None provided
Female	180	77	2	75	15	Easy	None provided
Male	140	70	0	130	15	Easy	None provided
Male	156	50	0	45	0	Easy	None provided
Male	163	79	0	125	15	Moderate	167
Male	170	57	0	65	0	Easy	None provided

Table 28: Data collected for the Red Route in the Groenkloof Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Female	183	93	1	160	30	Moderate	296
Female	168	86	2	60	2	Moderate	275
Female	179	56	5	120	30	Moderate	None provided
Female	162	100	3	90	10	Moderate	None provided
Female	178	62	1	120	3	Fair	None provided
Female	192	101	3	120	5	Easy	193
Male	None provided	50	1	120	15	Fair	None provided

Table 29: Data collected for the Yellow Route in the Groenkloof Nature Reserve through VGI

Gender	Height (cm)	Weight (kg)	Load (kg)	Travel time (min)	Rest time (min)	Route description	Energy (kCal)
Female	176	84	0	100	10	Difficult	400
Female	174	85	2	155	5	Fair	None provided
Female	175	100	3	150	0	Moderate	755
Female	183	105	1	200	10	Difficult	None provided
Female	163	62	2	155	0	Moderate	698
Female	162	71	0	201	10	Fair	922
Female	173	100	3	205	30	Fair	1255
Female	177	77	1	120	5	Easy	None provided
Female	180	69	4	150	0	Fair	None provided
Female	None provided	171	2	143	0	Moderate	652
Female	169	85	0	205	10	Moderate	1400
Female	185	85	1	180	40	Fair	306
Female	189	78	2	240	5	Moderate	None provided
Male	None provided	65	3	250	0	Moderate	None provided
Male	153	63	2	138	0	Very easy	523
Male	174	55	1	240	10	Moderate	763
Male	168	70	2	135	2	Moderate	800
Male	160	75	0	120	5	Difficult	866
Male	176	70	6	240	5	Fair	1978
Male	165	103	2	90	5	Fair	592
Male	190	86	2	240	10	Moderate	1600
Male	160	69	0	240	30	Moderate	1318

4.3 ASSIGNING GRADES TO EXISTING TRAILS

The new proposed grading system of Objective 1 (see Table 8, pg. 50), was assigned to parameters from Objective 2. These include trail distance, minimum time per trail, slope class, and energy needed calculated using Pandolf's Metabolic Rate Function (for walking) and Epstein's Function (for running), which included user weight, load carried, travel speed, slope, and terrain coefficient in the calculations. This was calculated for both male and female genders. A consolidated overview of all parameters calculated for the evaluated trails in the CoT is given in Table 30 (pg. 64). An assigned difficulty grade based on Table 8 (pg. 50), is given in as well as a final grade (Grade), is provided in Table 31 (pg. 65).

Seven trails are graded as 'Very easy', reflecting trails in Fort Klapperkop (1 out of 4), Groenkloof (2 out of 3), Moreleta (1 out of 3), Pierre van Ryneveld (all trails), and Wonderboom (1 out of 5). Nineteen are classed as 'Easy', reflecting trails from Austin Roberts (all trails), Bishop Bird (all trails), Boardwalk (all trails), Faerie Glen (all trails), Fort Klapperkop (1 out of 4), Luton Valley (all trails), Moreleta (1 out of 3), Struben Dam (all trails), and Wonderboom (2 out of 5). Three trails are seen as 'Fair' one from Moreleta, and two from Wonderboom. Three are classed as 'Moderate', two from Fort Klapperkop, and one from Groenkloof (Yellow Trail). Only the Tswaing trail is seen as 'Difficult'.

Table 30: Consolidated parameters of all evaluated trails, including the final assigned grade

Name (ID)	Reserve	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running	Distance (m)	Slope (%)	Slope Description
1	Austin Roberts	9	29	30	121	124	51	52	215	216	641	3.0-5.0	Very gentle
2	Austin Roberts	7	25	26	106	109	46	47	194	196	549	1.1-3.0	Nearly level to very gentle
3	Bishop Bird	24	88	91	369	379	163	164	681	687	1,980	0.1-4.9	Level to very gentle
4	Bishop Bird	16	66	68	277	285	123	124	513	517	1,475	0.9-2.4	Nearly level to very gentle
5	Bishop Bird	5	16	17	67	69	29	30	122	123	383	1.2-2.5	Nearly level to Very gentle
6	Boardwalk	2	9	9	38	39	17	17	69	70	259	1.0-3.0	Nearly level to very gentle
7	Boardwalk	10	30	31	125	129	53	54	223	225	701	1.0-3.0	Nearly level to very gentle
Hadeda	Faerie Glen	28	77	79	322	331	123	124	515	519	2,203	2.0-7.0	Very gentle to gentle
Kiepersol	Faerie Glen	28	83	86	348	358	140	141	586	591	2,270	2.0-8.0	Very gentle to gentle
Acacia	Faerie Glen	28	80	82	333	344	125	127	523	524	2,275	1.0-6.0	Nearly level to gentle
Brollocks & Bittergal	Fort Klapperkop	49	173	178	722	743	296	299	1,240	1,251	4,134	2.0-16.0	Very gentle to strong
Road	Fort Klapperkop	54	194	196	811	821	313	317	1,308	1,324	4,680	1.0-20.0	Nearly level to strong
Red	Fort Klapperkop	30	88	90	368	376	147	148	615	620	2,595	2.0-17.0	Very gentle to strong
Van Hunks se Pyp	Fort Klapperkop	15	21	23	88	96	31	33	131	139	1,241	3.0-5.0	Very gentle
Red	Groenkloof	55	190	195	796	818	310	312	1,295	1,307	4,455	0.5-2.1	Nearly level
White	Groenkloof	45	142	147	596	613	225	227	940	948	3,739	0.8-12	Nearly level to moderate
Yellow	Groenkloof	117	335	345	1,403	1,444	535	540	2,240	2,260	9,905	0.1-20	Level to strong
8	Luton Valley	12	46	47	193	198	83	84	349	351	1,004	1.0-3.0	Nearly level to very gentle
9	Luton Valley	5	18	19	76	78	33	33	138	139	366	1.0-3.0	Nearly level to very gentle
10	Luton Valley	8	25	26	105	108	45	45	189	190	616	2.0-4.0	Very gentle
Duiker	Moreleta	16	61	63	255	263	98	99	409	413	1,597	4.0-6.0	Very gentle to gentle

Name (ID)	Reserve	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running	Distance (m)	Slope (%)	Slope Description
Suikerbos	Moreleta	33	93	95	387	398	142	143	594	600	2,787	1.0-12.0	Nearly level to moderate
Rademeyer	Moreleta	18	65	67	271	278	108	109	451	455	1,454	4.0-13.0	Very gentle to moderate
11	Pierre van Ryneveld	9	33	34	140	144	58	59	243	245	783	1.0-2.0	Nearly level
12	Pierre van Ryneveld	13	50	51	209	215	84	85	352	355	1,177	1.0-2.0	Nearly level
13	Struben Dam	6	21	21	87	89	36	36	150	152	510	1.0-3.0	Nearly level to very gentle
14	Struben Dam	9	33	34	139	143	57	58	240	242	818	1.0-3.0	Nearly level to very gentle
15	Tswaing	92	245	251	1,025	1,054	412	415	1,723	1,738	6,217	0.1-51.63	Level to extreme
Alternate waterfall & cave	Wonderboom	4	15	16	64	66	27	27	111	112	326	3.0-4.0	Very gentle
Waterfall & cave	Wonderboom	6	19	20	81	84	31	31	130	131	477	3.0-5.0	Very gentle
Fort towards waterfall & cave	Wonderboom	13	21	22	88	91	33	33	137	138	1,179	2.0-11.0	Very gentle to moderate
Fort	Wonderboom	14	18	18	74	76	28	28	117	118	1,208	2.0-15.0	Very gentle to moderate
Joos Becker	Wonderboom	29	80	82	333	342	121	122	507	511	2,464	0.7-12.0	Nearly level to moderate

Table 31: Assigned difficulty level for all computed parameters, as well as an overall grade per trail

Name (ID)	Reserve	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running	Distance (m)	Slope Description	Grade
1	Austin Roberts	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
2	Austin Roberts	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
3	Bishop Bird	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
4	Bishop Bird	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
5	Bishop Bird	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy

Name (ID)	Reserve	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running	Distance (m)	Slope Description	Grade
6	Boardwalk	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
7	Boardwalk	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Hadeda	Faerie Glen	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Kiepersol	Faerie Glen	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Acacia	Faerie Glen	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Brollocks & Bittergal	Fort Klapperkop	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Moderate	Moderate
Road	Fort Klapperkop	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy
Red	Fort Klapperkop	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Moderate	Moderate
Van Hunks se Pyp	Fort Klapperkop	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Red	Groenkloof	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy
White	Groenkloof	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy
Yellow	Groenkloof	Easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Moderate	Moderate
8	Luton Valley	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
9	Luton Valley	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
10	Luton Valley	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Duiker	Moreleta	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Suikerbos	Moreleta	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy
Rademeyer	Moreleta	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Fair	Fair
11	Pierre van Ryneveld	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy
12	Pierre van Ryneveld	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy
13	Struben Dam	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
14	Struben Dam	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy

Name (ID)	Reserve	Travel Time (min)	Energy Male (kCal) - walking	Energy Female (kCal) - walking	Energy Male (kJ) - walking	Energy Female (kJ) - walking	Energy Male (kCal) - running	Energy Female (kCal) - running	Energy Male (kJ) - running	Energy Female (kJ) - running	Distance (m)	Slope Description	Grade
15	Tswaing	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Difficult	Difficult
Alternate waterfall & cave	Wonderboom	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Waterfall & cave	Wonderboom	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Easy	Easy
Fort towards waterfall & cave	Wonderboom	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Fair	Fair
Fort	Wonderboom	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Fair	Fair
Joos Becker	Wonderboom	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy	Very easy

4.4 TRAIL MAPPING

The results of the study are indicated and communicated through maps, an online resource, as well as infographics that were created. The hardcopy and/or online maps includes information such as the delineated trails and points of interest in the reserve, as well as information regarding the length of the trail, the difficulty grade, the estimated travel time, and the expected energy expenditure for both males and females.

Maps of the four most visited reserves that also have trails that can be used for walking and hiking are provided in APPENDIX C: MAPS (pg. 100). An online resource was created using ArcGIS Online, which can be accessed at this link https://bit.ly/46CIp6E. It can also be accessed by scanning the QR code as given in Figure 8 below.

Figure 8: QR code to access the online web resource.

This platform is interactive and indicates all the accessible nature reserves, points of interest, as well as the available routes of every reserve. *Please note that this resource is an output of the larger project that this dissertation forms a part of. As such, this dissertation provided the data layers to the online resource, but the design and additional information falls under the purview of the larger project.* Additionally, infographics were also created that provides the trail length, difficulty grade and expected energy expenditure in a more fun and informal way. These infographics are provided in the APPENDIX D: INFOGRAPHICS, page 102 onwards.

CHAPTER 5: DISCUSSION

In this chapter the results are discussed more in depth. Firstly, the proposed grading system is discussed, followed by a discussion on the results obtained from the various modelled formulas (section 5.1.1, pg. 69), and the data received from the volunteers and the survey (section 5.1.2, pg. 71). Subsequently, the application of this grading system to the trails of the nature reserve is discussed (section 5.2, pg. 74). Lastly, the process and application of the informational resources is expanded on (section 5.3, pg. 76).

5.1 CONSOLIDATED TRAIL GRADING SYSTEM

The grading system comprised of several difficulty levels ranging from "very easy" to "extreme", which is based on Hugo's proposed grading system (1999a), the Australian Walking Track Grading System (Victorian Government DSE, 2010) and Wildrunner Trail Grading System (Wildrunner, n.d.). By combining these grading systems, a wide variety of factors are considered and as such the difficulty level that is assigned is more accurate and comprehensive in its description. The new proposed grading system takes into consideration the walking time, the energy needed, the route distance, the amount of bushwalking experience needed, the surface conditions of the route, and the route's slope characteristics. A trail which is classified as "very easy" is less than 5 km in length, has an estimated walking time of 1.7 hours, estimated energy needed less than 2500 kJ (597 kCal), and has no steep slope sections. A trail that is classified as "extreme" is more than 30 km in length, takes more than 10 hours to complete, has an energy expenditure of more 15 000 kJ (3585 kCal), and has terrain with steep sections.

5.2 EXISTING TRAIL MODELLING

5.1.1 <u>Data manipulation</u>

The modelled data as calculated by the various functions are indicated in Table 9 to Table 20 (pg. 52-56). Only 12 of the nature reserves of the CoT have walkable trails that are available to the public, yielding 33 trails. These reserves cater for a diverse range of individuals with some reserves providing various amenities (i.e., picnic areas, bird hides, lookout areas), as well as other activities such as horseback riding, 4x4 driving and cycling. It is thus important to highlight that the CoT have reserves that cater for all members of the public with routes that can be used and enjoyed not only by more fit individuals, but also by individuals who embrace the positive attributes that nature and outdoor activities subsequently provide.

Various routes are specifically delineated to include certain points of interest. For example, the routes of Struben Dam Bird Sanctuary have been created to provide as many opportunities for bird watching next to Struben Dam as possible, with the routes of Pierre van Ryneveld Nature Reserve incorporating several geological features. Wonderboom Nature Reserve and Fort Klapperkop Nature Reserve have specifically included the historical fort sites in their routes. As was highlighted by Chon & Schafer (2009), Chhetri (2015, and Dinda & Gosh (2021, among others, incorporating aesthetic qualities such as points of interest on trails significantly increases the likability and enjoyment of the trails, and as such it is an important factor to keep in mind.

Each trail was assigned a slope description range that is based on the descriptions as determined by the Barcelona Field Studies Centre (2020), as adapted by slope gradient descriptions from Agriculture and Agri-Food Canada (Soil Landscapes of Canada Working Group, 2010). This range is not calculated based on the slope percentage average of a trail, but indicates the corresponding description associated with the lowest, as well as the highest slope percentage for any given trail. Most of the trails were assigned slope descriptions that are either "level", "nearly level" and "very gentle", which again highlights the user-friendliness of these trails. Some trails, however, did include "moderate", "strong", and "extreme" slope descriptions. Examples thereof are the trails in Wonderboom Nature Reserve which included "moderate" in their slope descriptions, as well as the trails of Moreleta Kloof Nature Reserve. Most of Fort Klapperkop Nature Reserve's trails included "strong" in its slope description, while Tswaing Meteorite Crater Site's route ranged from "level" to "extreme" in its description of the slope. These routes can be seen as being more challenging, and as such will not necessarily be suitable for all users.

Routes that are shorter in distance required less time to traverse, while longer routes required more time to complete. Subsequently, the shortest route had the shortest travel time, which was a route in Boardwalk Bird Sanctuary measuring 259 m with a predicted travel time of two minutes. The longest route also had the longest estimated travel time, which was the Yellow route of Groenkloof Nature Reserve. This route is 9.9 km long and has an estimated travel time of 117 minutes. However, these estimated travel times do not include rest times and is based on the maximum walking speed of an individual (which is 1.4 $m.s^{-1}$), which is not always the actuality of events as some people do take breaks when on a route and are not necessarily walking at precisely 1.4 $m.s^{-1}$. It is important to remember that these estimated travel times are not comprehensive in its method to modelling the reality of the trails, and as such, the data received from the data verification section of this study must be used to enhance and improve these modelled results.

With regards to the energy expenditure calculated, some clear trends came forth through the results. Firstly, as was found when calculating the travel time of the routes, a longer route required more energy output. This reiterates the findings of Lanza (2022) who found that longer trails are associated with increased energy expenditure. The Yellow Route of Groenkloof Nature Reserve (which is the longest route at 9.9 km) had an estimated energy expenditure when walking of between 1,403 (male) and 1,444 (female) kJ, while the route of Boardwalk Bird Sanctuary (which is the shortest route at 259 m) only had an estimated energy expenditure of between 125 (male) and 129 (female) kJ. When looking at the energy expenditure associated with running the trails, it was found that the metabolic output required was much higher than that of walking for all trails for both gender categories, as is also evident in the study done by Farley & McHahon (1992). For example, when looking at Faerie Glen Nature Reserve Hadeda Trail's results for men, the modelled walking energy output was found to be 322 kJ, with the energy output associated with running the trail being 515 kJ. Secondly, it was noted that females have a higher estimated energy expenditure than males on all routes of the nature reserves. Interestingly, this contrasts with the study done by Hall *et al*. (2004), which indicated that women had lower energy outputs compared to men when traversing the same distance at the same speed. However, this discrepancy can be attributed to the fact that the average weight of a female in South Africa is higher than that of a male, which directly increases the energy output needed when traversing a path (DeJaeger *et al*., 2001).

As mentioned before, within the nature reserves of the CoT there are routes that suit a variety of different physical needs and goals. There are longer and more challenging routes that can be used by users that have certain fitness goals, while the elderly and the young can also enjoy outdoor activity on routes that are less physical and more user friendly. This allows more individuals to use these areas as there is something for everyone to partake in. Also, by providing routes that cater to a variety of needs, these areas become more usable which directly relates to the aim of SDG 11, as was also highlighted by Enssle & Kabisch (2020).

5.1.2 Data verification

5.1.2.1 Fieldwork

The data collected through the fieldwork portion of this study proved invaluable in verifying the modelled results. By also incorporating different smart watches, the results could be further analysed and verified.

For the Faerie Glen Nature Reserve, the data that was collected includes multiple routes, and as such cannot be directly analysed with the modelled data. However, certain parameters could be successfully analysed. The trails were walked by female volunteers and were tracked using the Samsung Galaxy Watch Active2 BT. With regards to the time travelled, it was found that the modelled data and the fieldwork data compares well. The modelled data predicted that a 2,2 km trail can be completed in 28 minutes, with the fieldwork data indicating that a 4,4 km trail took 64 minutes to complete, which also included a rest period of five minutes. When one averages the amount of time walked per kilometre for the fieldwork data, it equals to 14.55 minutes per kilometre, compared to the 14 minutes per kilometre for the modelled data. It can thus be argued, that in this instance, the modelled data did indeed provide an accurate estimate of the actual travel time. When comparing the energy expenditure for these trails, the modelled data indicated that a 2,2 km trail will on average require 345 kJ, while the fieldwork data indicate that a 2,2km trail expended 493 kJ. The load carried at one kilogram is less than the modelled assumption of 3.5 kilograms, and the average weight is also less for the fieldwork data than the modelled data, being 75 kilograms instead of the average of 77.6 kilogram used in the modelled results.

Within Wonderboom Nature Reserve the following routes were physically walked, namely Fort to Waterfall and Cave Trail, Waterfall and Cave Trail, and the Fort Trail. The combined modelled length of these trails was calculated to be 2,8 km long. However, the smartwatches tracked the routes to be 3,0 and 3,5 km. The reason for this discrepancy in the measured distance of these routes can be attributed to the fact that the trails are not properly marked, as was stated by the volunteers. This resulted in them walking on trails that are not necessarily part of the Fort to Waterfall and Cave Trail, Waterfall and Cave Trail, and the Fort Trail, and subsequently the distance is more than what was initially modelled. This also has an impact on the energy output indicated, as one of the factors that determine the metabolic cost is the distance of the trail (Lanza, 2022). The modelled results of the energy expenditure of these trails are 243 kJ for the male and 250 kJ for the female, which is significantly less than the energy expended tracked by the smart watches. Also, this yet again in contrast to the findings of Hall *et al*. (2004), which indicated that females have lower energy outputs than men when traversing the same path. The values received from the Garmin Forerunner 55 indicated that the female expended 1430 kJ, while the Samsung Galaxy Watch Active2 BT measured 1954 kJ. For the male, the Garmin Forerunner 55 indicated that 1470 kJ were expended, with the Samsung Galaxy Active2 BT measuring a value of 2008 kJ. Additionally, another reason why the energy output measured by the smart watches is much higher than that of the modelled values can be the travel time associated with these trails. The smart watches tracked that these trails took 78 minutes to complete, while the modelled results indicate that these trails can be completed within 33 minutes (the modelled results do not take into consideration rest times). Also, the load carried by the male is 1.5 kilogram heavier than the load used in the calculations, and the weight of the male is 105 kilograms, which is 33.1 kilograms heavier than the average weight of a male. A higher body weight (Taylor *et al.,* 1970), as well as a heavier load carried (Kramer, 2010) both increases the total amount of energy expended over a trail. These factors, as well as the longer travel time and extra 200 m walked led to a significant increase in the energy expended when walking these trails.

5.1.2.2 Volunteered Geographic Information (VGI)

It is important to highlight that although VGI data does have its positives and can be successfully used to verify and enhance modelled data, such data do contain inconsistencies and, in some instances, inaccurate results that cannot be used and as such should be carefully analysed and thoughtfully incorporated in a study. Also, it must be considered, especially when including qualitative aspects (as was done in this study when asking users to provide a description of the routes), that users provide answers based on their own personal perceptions and experiences, which can be usable, but can also not be indicative of the actual reality.

For Faerie Glen Nature Reserve, results were received for all three routes namely, Kiepersol Route, Acacia Route, and Hadeda Route. For the Kiepersol Route the travel time ranged from 60 minutes to 190 minutes, with the average being 109 minutes. This is comparably longer than the 28 minutes modelled. However, rest times ranged from zero minutes to 30 minutes with an overall average of 13 minutes. The route description ranged from easy to difficult, with the mean indicating that the trail is mostly perceived to be fair to moderate, while the modelled results assign this trail to be easy. The average load carried was two kilograms, which is 1.5 kilograms less than the assumed 3.5 kilograms used in the modelled results. The average energy expenditure for females was 387 kCal, compared to the modelled 86 kCal. For males, the average energy expenditure was 553 kCal, compared to the modelled 83 kCal. Interestingly, this now correlates to the findings of Hall *et al*. (2004). The time travelled ranged from 60 to 70 minutes and averaged 65 minutes. The Acacia Route had a travel time which ranged between 60 and 70 minutes, with the average being 65 minutes. Compared to the 28 minutes modelled, this is significantly longer. The entries indicated that zero minutes were spent to rest. The route description was given as being easy and fair, compared to the easy description assigned by the modelled data. The average load was found to be 1.5 kilogram, and no energy expenditure was provided. The Hadeda Trail's travel time ranged from 53 minutes to 150 minutes, with the average time spent on the route being 82 minutes. The modelled data indicate that the route can be completed in 28 minutes, which is 54 minutes less than the average of the VGI data. The VGI data indicate that rest times range between five to 30 minutes, with the average being 15 minutes. The route description ranged from very easy to moderate, with the mean being easy, corroborating the assigned grade for the trail. The average load carried was found to be 2.8 kilogram, compared to the 3.5 kilogram used in the modelled data. The average energy expenditure for females was found to be 420 kCal, compared to the 79 kCal modelled. The average energy expenditure for males was indicated to be 174 kCal, with the modelled data being 77 kCal. Yet again, this contrasts with the findings of Hall *et al*. (2004). Overall, the grade assigned to the Faerie Glen Nature Reserve trails is in close agreement by the perception provided by volunteers in the study.

Within the Moreleta Kloof Nature Reserve all the trails received usable data, which includes the Duiker Route, Suikerbos Route and Rademeyer Route. The Duiker Route's travel time ranged between 40 and 150 minutes, with the average 79 minutes. This is significantly longer than the modelled travel time which is 16 minutes. Rest times for this trail ranged between zero and 45 minutes, with the average being 10 minutes. The VGI data indicated that the trail is very easy to difficult, with a mean of easy, which compares with the grading level of easy assigned by the modelled data. The average load carried was found to 1.3 kilogram. For females, the average energy expenditure was 293 kCal, compared to the modelled results of 62 kCal. For males, the average energy expenditure was 311 kCal which is more than the 61 kCal of the modelled data. This correlates with the findings of Hall *et al*. (2004). For the Suikerbos route, it was found that the time travelled ranged between 60 to 120 minutes, with the average time travelled being 86 minutes. Again, this is significantly higher than the 33 minutes that was modelled. The rest times ranged between zero and 20 minutes, with the average load carried being 2.6 kilogram. The route was easy to moderate, with the mean being moderate. This contrasts with the grade of very easy assigned through the modelled data. There were not enough data given to calculate the average energy expenditures for males and females. The Rademeyer Route had travel times that ranged between 45 and 130 minutes, with the average being 88 minutes. This, again, is higher than the 18 minutes travel time that was modelled. Rest times were indicated to range between zero and 15 minutes, with an average of 9 minutes. The route description ranged from easy to moderate, with the mean being easy which is graded slightly less difficult than the modelled data of fair. The average load carried was found to be 0.6 kilogram. Yet again there was not enough data provided to calculate the average energy expenditures for males and females.

With regards to Groenkloof Nature Reserve, only the Red and Yellow routes received usable data. The travel time for the Red Route ranged between 60 and 160 minutes, with the average being 113 minutes, which is longer than the modelled travel time of 55 minutes. The rest times ranged between two and 30 minutes, with an average of 14 minutes. The route was described as easy to moderate, with the mean being moderate. Compared to the grading level of very easy as depicted by the modelled results, the VGI data indicates that the trail was perceived as being more challenging than what is indicated by the modelled data. The average load was 2.3 kilogram. For the Yellow Route, the travel time ranged between 90 and 250 minutes, with the average being 177 minutes. This is again much longer than the modelled travel time of 117 minutes. The rest times ranged between zero and 40 minutes, with an average of 9 minutes. The route was described as very easy to difficult, with the mean being moderate. His compares well to the modelled data, which assigns a value of moderate. The average load carried was found to be 1.8 kilogram. For females, the average energy expenditure was found to be 798 kCal, and for males is 1055 kCal. This is also significantly higher than the energy modelled which was calculated to be 345 kCal for females and 335 kCal for males. Again, this correlates with the findings of Hall *et a*l. (2004).

Some interesting discrepancies were highlighted by the VGI data. Overall, it was found that the time travelled for the routes are significantly longer than the time that was modelled. This could be attributed to the fact that individuals do not walk at the assumed speed of 1.4 $m.s^{-1}$. Also, most of these nature reserves have game and several points of interests along the routes, which increases the amount of time spent on the route when users then stop and enjoy these amenities. Moreleta Kloof Nature Reserve in particular has a number of game and people will stop along the trails to view these. This significantly increases the amount of time of citizens spent on such trails. The modelled data also do not indicate rest times, which were included in the VGI data. The average energy expenditure was also significantly higher than that of the modelled results. Regardless, in most cases the final difficulty grade assigned to trails aligns with the perceptions of trails provided by volunteers.

However, many entries indicated that routes were not walked in its entirety because of poor markers, which needs to be considered as it can have an impact on the data received. For example, a user can think that they have walked the Acacia Route in Faerie Glen Nature Reserve, because that is the signage that they followed in the beginning. But due to lack and/or inconsistent signage along the route, they accidentally incorporated some of the Hadeda Route. When filling in the survey, however, they were still under the impression that they only walked Acacia Trail and as such only indicated that they walked the Acacia Trail. Consequently, we process the entry as an entry for the Acacia Trail, when in fact it also incorporated the Hadeda Trail, which makes it inaccurate and unusable when comparing the modelled data, which is trail specific, to the VGI data. Also, some of the entries received contained numerous errors and inaccuracies, which is important to note and a limitation in this study. It also reiterates the caution given by Sui *et al*. (2012), which stated that data standards of VGI collected data can come into question, and therefore such data should be carefully studied before being used.

5.2 ASSIGNING GRADES TO EXISTING TRAILS

Most routes in this study (58%) were assigned a difficulty level of “easy”. This was followed by “very easy” (21%), “moderate” and “fair” (both 9%), and “difficult” (3%) (see Figure 9, pg. 75), The Tswaing trail is seen as “Difficult”, with the Yellow route of Groenkloof and the Brollocks & Bittergal, and Red routes of Fort Klapperkop as “Moderate”. As indicated previoulsy, an “easy” route has moderately easy terrain, takes roughly 1.7-3.3 h to complete, and has gentle hill sections. Because most of the routes in the nature reserves of the CoT are not long in distance and are over well-established tracks with minimum steep sections, these trails are classified as being “easy” and can be utilised and enjoyed by most individuals including children and the elderly. Similarly, those trails classed as “very easy” are more easily traversed by children, the elderly, and those requiring additional assistance. Groenkloof Nature Reserve’s Yellow Trail is 9,9 km and has an estimated travel time of almost two hours, but sections of moderate slope, which is why it was classified as being "Fair". Tswaing Meteorite Crater Site's route is 6,2 km in length and has areas with extremely steep sections, which resulted in this route being classified as "difficult". This reiterates the findings of Elliot (2012), Marsh *et al*. (2006), and Zealand (2007) who all indicated that hikers perceived trails with steeper gradients to be more difficult.

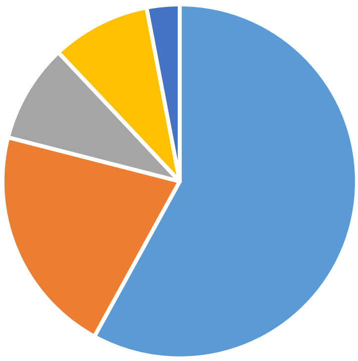

Figure 9: Quantity of each difficulty level (in percentage)

The biggest discrepancies found between the modelled and fieldwork data was that of the energy expenditure and the travel time. With regards to the energy expenditure, it was found that the modelled values were much less than the data collected through the fieldwork portion. For example, Wonderboom Nature Reserve's Fort to Waterfall and Cave Trail, Waterfall and Cave Trail, and the Fort Trail was modelled to be 2,8 km (when the values were added together), with an estimated energy expenditure of 243 kJ for a male and 250 kJ for a female. However, the fieldwork data indicated that the routes are three kilometre or more, and the energy expended ranged between 1431 and 1954 kJ for females, and 1469 kJ for males. The slight discrepancy in the trail distance can, however, be attributed to poor trail marking as the volunteers indicated that they did not just traverse one specific trail, because of poor and/or the lack of proper route markers. What is most notable is the difference between the modelled energy expenditure and the energy expenditure collected through the fieldwork data. One of the reasons why the male's fieldwork data indicated higher energy values could be attributed to the fact that the male volunteer's weight is 105 kilograms, which is 33.1 kilograms heavier than the average weight of 71.9 kilogram used in the modelled calculations. Something that was also interesting to note was the fact that the different smart watches weren't cohesive in their results. The Garmin Forerunner detected 500 m less than the distance detected by the Samsung Galaxy Watch Active2 BT. The increased distance also increased the energy expenditure with the Garmin Forerunner indicating 1431 kJ expended compared to the Samsung Galaxy Watch Active2 which indicated 1954 kJ (for the female volunteer). For the male volunteer the Garmin Forerunner indicated an energy expenditure of 1469 kJ, with the Samsung Galaxy Watch Active2 indicating 2008 kJ.

When incorporating the data collected through the survey, an argument can be made that grading systems should not only include quantitative approaches but should also incorporate qualitative factors to assign a grading level more accurately to a trial, as was also iterated by Coetzee *et al*. (2021). This was particularly evident when comparing the modelled data with the fieldwork data which indicated inconsistencies, especially with regards to the time travelled and the energy expenditure. Also, careful consideration should be given to the input parameters which, in this study, were assumed to be correct. In this study it was assumed that the walking speed is 1.4 $m.s^{-1}$, the load carried is 1 kg and 3.5 kg for running and walking respectively, and the weight used for a female 77.6 kg is and for a male 75.4 kg is. As highlighted by the VGI data, these averages are not entirely accurate and can thus lead to the modelled results being erroneous. Furthermore, the VGI data indicates an average load of 2 kg. However, when trails are evaluated individually, these values change. The level of detail (scale of investigation) is thus important when modelling parameters. Furthermore, it is important to note that VGI data inherently is not always correct and precise, and as such it is recommended that such data not be used on its own, but rather be supplemented with more qualitative results. This is because VGI data are based on the perceptions of individuals that all come from different backgrounds and as such each person's reference framework of what is considered an "easy" trail and what is considered a "hard" trail will differ. Most individuals also make use of smart watches or other activity-tracking technology, which is also not as accurate because of the limited modelling capabilities that these software programs and applications have.

With this being said, the new proposed grading system was found to be an improvement for measure of route difficulty by taking into consideration the route length, travel time, energy expenditure, and slope characteristics when assigning a difficulty level to a trail. The more difficult a trail, the longer it will take the user to complete the trail and the more energy output will be required for the activity, which corroborates the findings of Lanza (2022). Thus, knowing the characteristics of each trail will allow users to make well-informed decisions, as well as enhance their understanding of each trail and how these characteristics align with their current fitness levels and health status. This in turn, as also highlighted by Slabbert & du Preez (2017), allows users to properly utilise these urban green spaces that are available to them.

5.3 TRAIL MAPPING

As was highlighted by Hugo (1999a), trail hiking and/or running should be seen as tourism activities, as such activities increases the visitation and usage of their respective green areas, which in turn increases these areas' revenue and their ability to sustainably continue in an ever-increasing urbanised world. When associating trails as tourism products, the specific demands and needs of the target consumer must be viewed as important and subsequently reflected in the planning, usage, and marketing of these areas. It is thus imperative to provide adequate information regarding these green areas, enabling users to make better and more well-informed decisions. Correctly and accurately portraying the trail characteristics and points of interest will provide users with the necessary information to make these decisions, which will lead to better and more proper usage of these areas. This directly relates to the importance of maps as information products, as well as the importance of the accessibility of these areas to the public.

Hardcopy and/or online maps, an online resource, and infographics have been produced that indicate the trail distance, the difficulty grade of the trail, the estimated travel time, and the energy expenditure for both walking and hiking activities for males and females in each nature reserve. Additionally, the points of interest and relevant amenities are also indicated. Copies of the hardcopy maps are available at the info desk of the nature reserves, and occasionally also on the trails. The online maps and online resources are both accessible by scanning respective QR codes that have been printed on posters and flyers and distributed at the nature reserves. The infographics are also available in hardcopy format at each nature reserve. Benefits derived from access to urban green spaces (see Lee *et al*., 2012, Schipperijn *et al*., 2013, Cvejic *et al*., 2015, Burkart *et al*., 2016, Oscilowics *et al*., 2019, Rishbeth *et al*., 2019, Kabisch *et al*., 2021), cannot be realised if access (in this case based on information) is restricted. By calculating parameters of interest, and making these available in various formats, information access is improved.

By calculating and providing the physical parameters of each reserve's associated trails, users will be able to choose the routes that are most suited to their needs. Families with small children, for example, might prefer routes that are shorter and less strenuous, whilst individuals wanting to use the trails for exercise purposes might desire a more challenging and longer route. By also providing the estimated energy expenditure and grading system of each route, users can get an idea of the physicality required to complete the route and they will then be able to decide whether a route falls within or outside of their physical limitations. This adequately provides sufficient means for users to access the necessary information which directly ties back to the aim of SDG 11, which is to make cities more liveable, inclusive, and accessible.

As was mentioned previously, these nature reserves should be seen and appreciated as tourism destinations and as such the ability of these areas to sustainably exist is important. By providing information products in the form of hardcopy and/or online maps, an online resource, as well as infographics, information regarding the physical characteristics and features of the nature reserves are more accessible to the public. This allows users to choose more accurately which trail, and more specifically which nature reserve, is most suited to their current needs and physical limitations, leading to better usage of these areas. This also enhances public health and well-being, as individuals will be more inclined to partake in the activities that these areas have to offer when they are more adequately informed on its various services. Also, with regards to SDG 11, usage of these areas is promoted through the provision of these information products as it improves the accessibility and sustainability of these urban green areas.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

The aim of this study was to improve the information accessibility of the City of Tshwane's nature reserves by providing its residents with the necessary information products, to make these urban green spaces more accessible and usable to the public. These informational products including each nature reserve's relevant details such as the trail length, estimated travel time, expected energy expenditure, as well as the points of interest and the difficulty grade.

This study successfully used various relevant functions to model the estimated travel time and the energy expenditure for the existing delineated trails of the nature reserves, both for walking and running. This was effectively done by using The Modified Hiking Function, Pandolf's Metabolic Rate Function and Epstein's Function. These functions modelled the travel time and metabolic cost, which was further substantiated by the data collected through the fieldwork analysis, as well as the input received from the survey entries. The successful modelling of the energy expenditure allowed for a difficulty grade to be assigned to each trail. By adapting and merging the proposed grading systems of Hugo (1999a, 1999b), the Australian Walking Track Grading System (Victorian Government DSE, 2010), and Wildrunner Trail Grading System (Wildrunner, n.d.), the subsequent study of each trail's relevant characteristics enabled the allocation of a more comprehensive grading level.

Informational resources were created and disseminated in the form of hardcopy and/or online maps, an online resource, and infographics. These resources provide information to the public that enable users of these areas to make well-informed decisions and use these areas more appropriately. This allows citizens to be able to access the information of each nature reserve in whichever format they want, which in turn enhances their spatial awareness, and subsequently also their usage of these urban areas.

Benefits ascribed to urban green spaces cannot be effectively used if information accessibility is poor. This project provides a measure of improving the information accessibility on the nature reserves of the CoT. Not only do the findings of this study enhance the public's spatial awareness through improved informational accessibility, but it also promotes the usage of these green spaces which directly links to the aim of SDG 11. By providing informational products to the public regarding the characteristics of the nature reserves, these areas can be appropriately and more extensively utilised and enjoyed. This aids in promoting cities that are more liveable and sustainable and encourages healthier living by endorsing outdoor recreational activities and the many health benefits that can be derived from a more active society.

6.1 Recommendations

A recommendation is to use Naismith-Langmuir's Rule when determining parameters for existing trails, which offers the opportunity to estimate the travel time of trails more accurately. By considering both the horizontal, as well as the vertical distances travelled, it models a more accurate travel time, as not all trails have a set gradient that is applicable to the entirety of the route. *Moderate Downhill* is between negative 5 and 12 degrees and *Steep Downhill* is less than negative 12 degrees slope (Fritz, Carver & See, 2000). The other parameters adjust travel speed based on these slope classes. Langmuir's proposed values are a: 0.72; b: 6.0; c: 1.9998; d: -1.9998 and these can be applied to data in future studies.

Survey data offer the opportunity to improve the grading systems by Hugo (1999a, b), the Australian Walking Track Grading System (Victorian Government DSE, 2010), and Wildrunner Trail Grading System (Wildrunner, n.d.). By incorporating the perceptions of users into the grading system, a more accurate grading system can be created that does not only focus on quantitative measurements alone, but which also allows for qualitative insights to be integrated therein. Additional parameters to include in this new grading system are rest times for walks in time modelled per path, and environmental parameters such as temperature and humidity (both based on VGI). Such information is compared to the perceived difficulty of a trail as provided by the public using VGI. By integrating the above-mentioned factors into existing grading systems one can more accurately gauge the difficulty of the trail, which will have a significant impact on the energy expenditure associated with the trail (DeVoe *et al.,* 1997).

A further recommendation is to create trails for the nature reserves that do not currently have designated trails available, as well as suggesting alternative routes for the reserves that already have delineated trails. Reserves that currently do not have delineated routes can designate trails to include certain points of interest, as well as incorporate least-cost path analysis (LCPA) which finds the most suitable route while taking into consideration the restrictions and limitations of any cost surface, including those considering the surrounding topography. Similarly, nature reserves with existing trails can improve these routes by incorporating points of interest along the routes, or by analysing where these paths can be expanded, reduced and/or redirected to make these paths less “expensive” based on a specific cost layer. Future studies should also consider the inclusion of land cover in modelling new trails. This requires high resolution land use and land cover extraction, something doable using machine learning such as Random Forest and Support Vector Machine, using platforms such as Google Earth Engine.

Due to time constraints, not all the nature reserves were included in the fieldwork portion of this study. Instead, the focus was on the 4 most visited reserves that also have demarcated walking hand hiking trails. As the fieldwork data were used to verify the modelled results, including more, if not all the reserves, will significantly improve the verification process and will thus lead to more accurate results and a more accurate assignment of the grading levels to the paths. Also, due to the lack of proper signage on the trails, it is difficult to follow only one specific trail, especially in nature reserves that provide several routes that cross one another, which affects the effectiveness of such data collected in the verification process.

Similarly, also due to time limitations, environmental parameters such as temperature and humidity were not considered but is considered a recommendation for further studies as such parameters have been found to influence the energy expenditure of a trial (see section 2.4, page 28). Also including demographic data such as age, as well as other physical characteristics such as disabilities, prior injuries and other health-related ailments can also be used to improve the grading system. By producing a grading system that incorporates specific user preferences and needs, users will have a better understanding of the trail characteristics, which allows them to make better decisions as well as use the trails more competently. Future research should also look at incorporating security and crime in the delineation and analyses of hiking trails within this context.

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APPENDIX A: CONSOLIDATED DETAILED STEPS

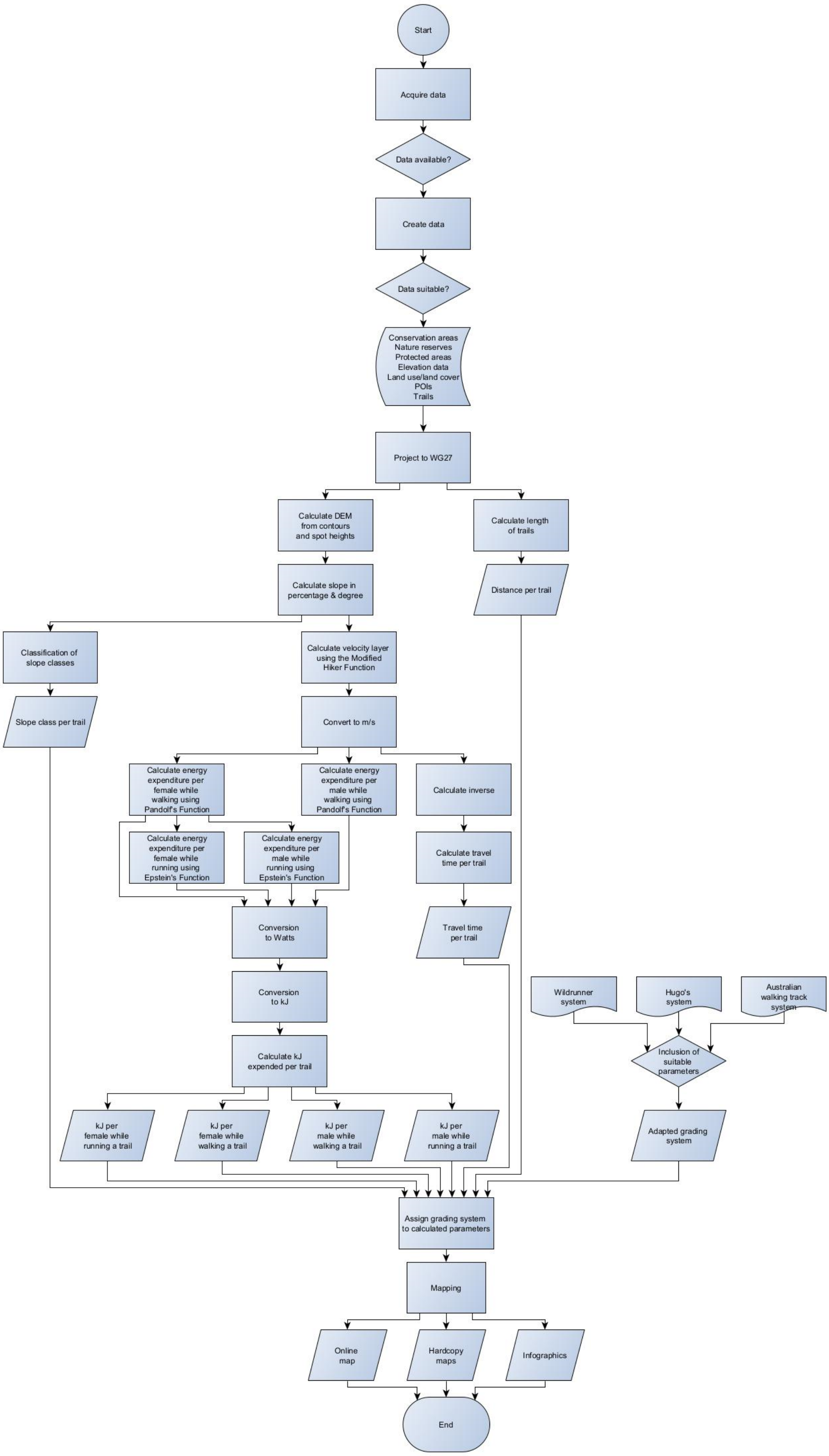
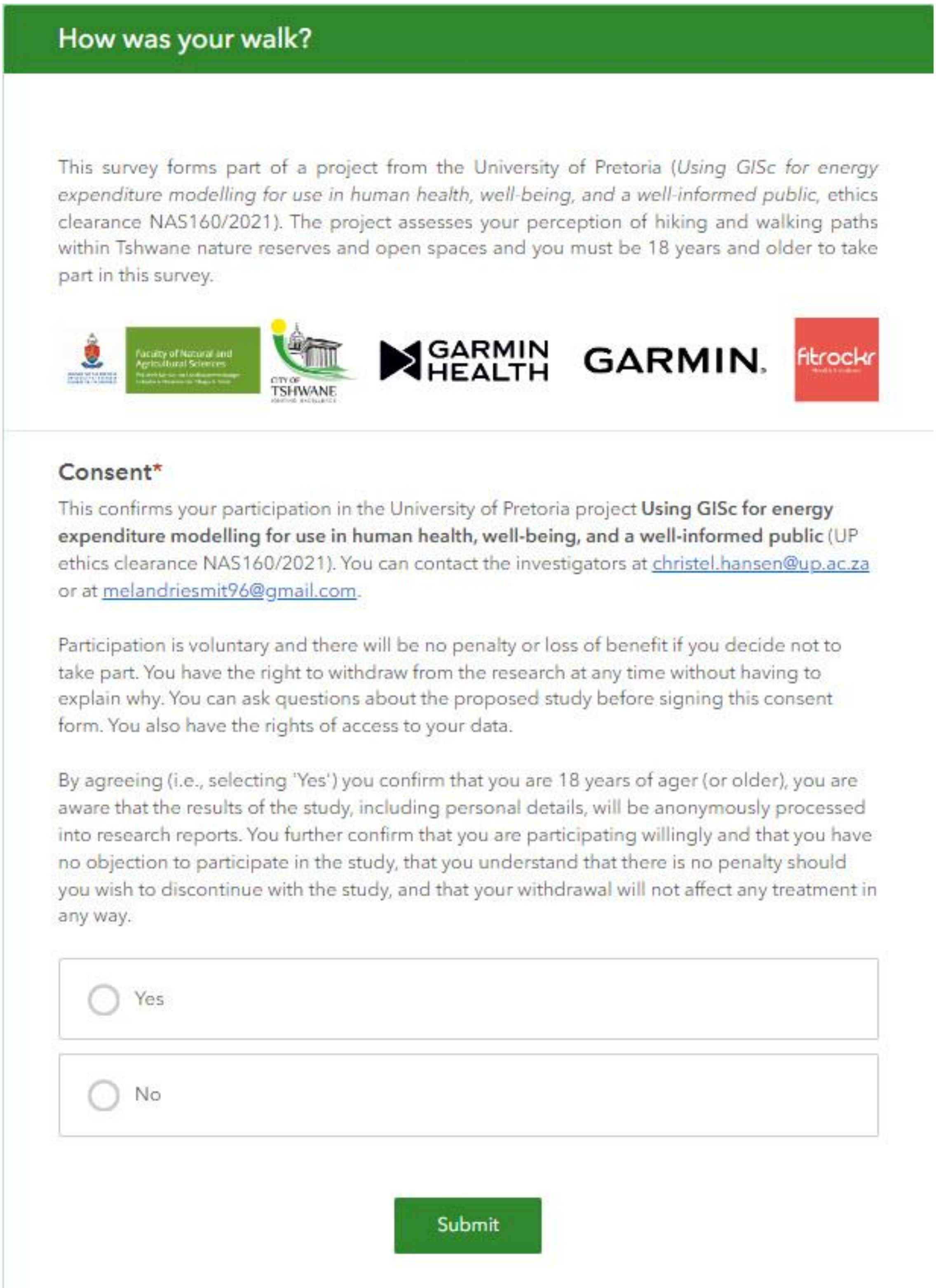


Figure 10: Consolidated and detailed steps of the methodology employed.

APPENDIX B: SURVEY OUTLINE

Figure 11 illustrates what the participant sees when starting the survey. Participants are given text to read, after which they are required to indicate their willingness to partake in the survey (by selecting ‘Yes’). Only if a participant indicates ‘Yes’, can they continue with the survey.



How was your walk?

This survey forms part of a project from the University of Pretoria (*Using GISc for energy expenditure modelling for use in human health, well-being, and a well-informed public*, ethics clearance NAS160/2021). The project assesses your perception of hiking and walking paths within Tshwane nature reserves and open spaces and you must be 18 years and older to take part in this survey.

Consent*

This confirms your participation in the University of Pretoria project **Using GISc for energy expenditure modelling for use in human health, well-being, and a well-informed public** (UP ethics clearance NAS160/2021). You can contact the investigators at christel.hansen@up.ac.za or at melandriesmit96@gmail.com.

Participation is voluntary and there will be no penalty or loss of benefit if you decide not to take part. You have the right to withdraw from the research at any time without having to explain why. You can ask questions about the proposed study before signing this consent form. You also have the rights of access to your data.

By agreeing (i.e., selecting 'Yes') you confirm that you are 18 years of ager (or older), you are aware that the results of the study, including personal details, will be anonymously processed into research reports. You further confirm that you are participating willingly and that you have no objection to participate in the study, that you understand that there is no penalty should you wish to discontinue with the study, and that your withdrawal will not affect any treatment in any way.

Yes

No

Submit

Figure 11: Participation consent.

Figure 12 details the survey questions related to the personal information of survey participants. This includes information on the participant's age, gender, population group, height, and weight. Compulsory questions are indicated by the red asterix (*).

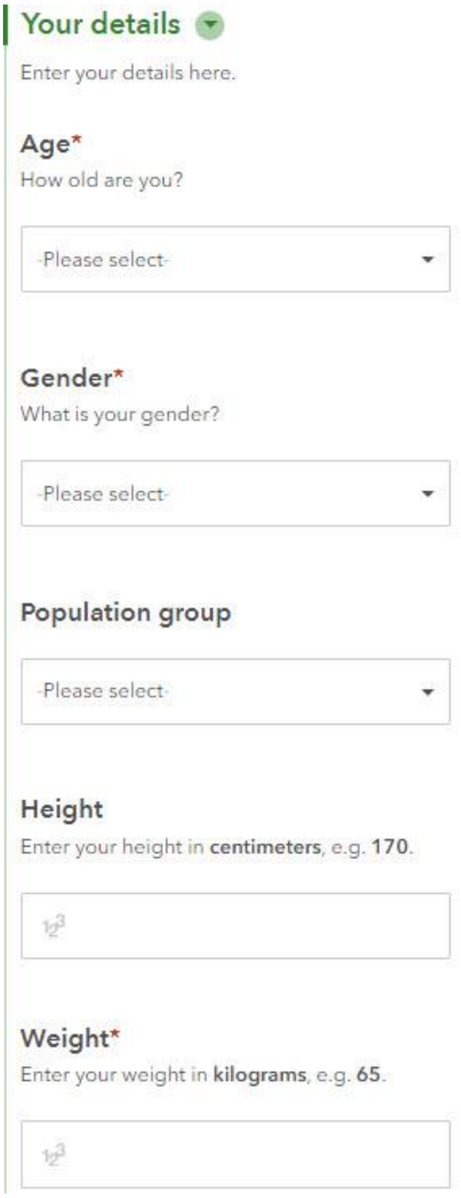


Figure 12: Survey section recording information on the personal particulars of volunteers.

Age brackets are:

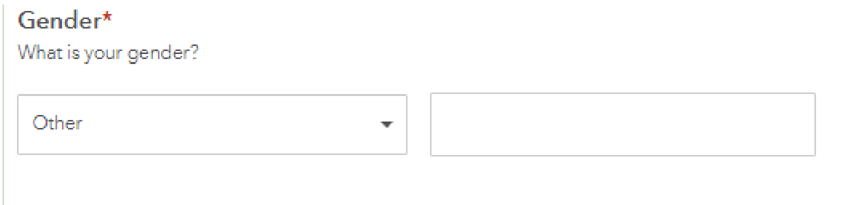
- 18-29
- 30-39
- 40-49
- 50-59
- 60-69
- 70-79
- 80-89
- 90-99
- 100-109
- 110-119

No age group for under 18 years of age is provided, since anyone under that age may not complete the survey.

Gender options include:

- Female
- Male
- Other
- Prefer not to say

Participants also have the option to add a gender not listed, by selecting Other. Once this option is selected, an additional text box becomes visible. This is illustrated by the image below. In this image, the Other option has been selected.



Population group information is recorded to gauge insight into the various physical parameters (average male or female weight) for the different population groups. For consistency, population groups are based on the official groups of the South African Census 2022, and include:

- Black African
- Coloured
- Indian
- White
- Prefer not to say

The next section of the survey records particulars of the trails. This section asks questions on which trails was walked, and if children were in the party (Figure 13, pg. 95).

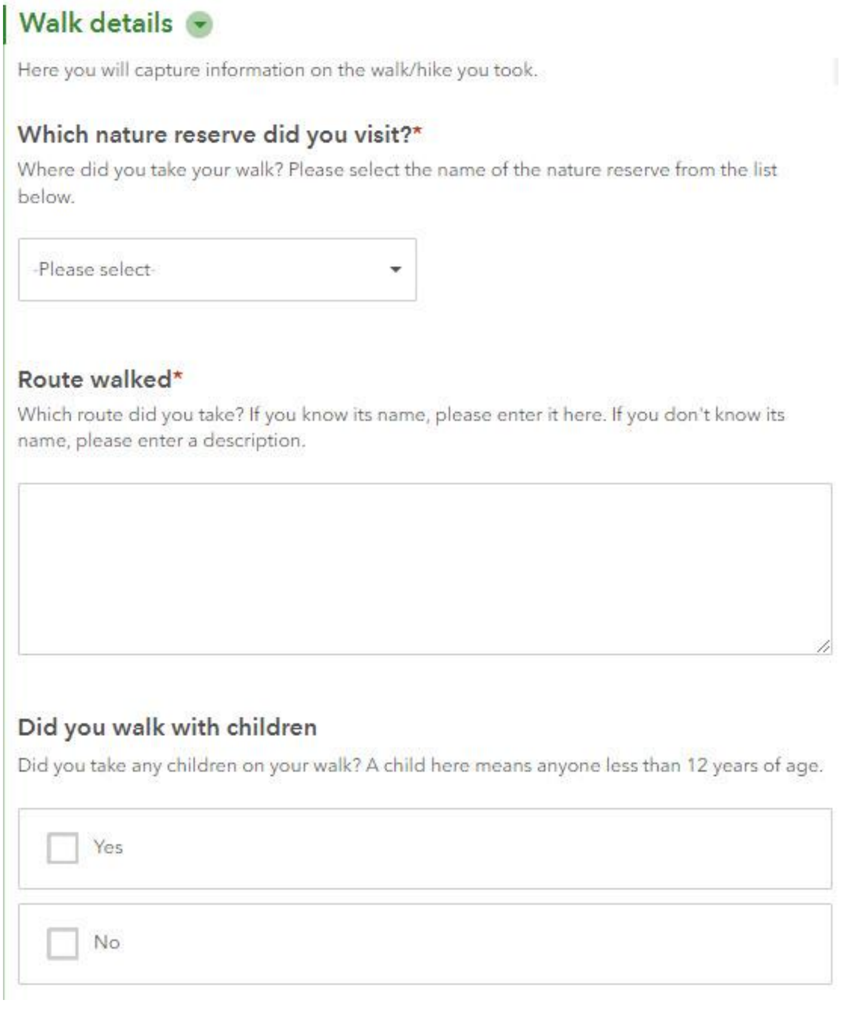


Figure 13: Survey questions on which nature reserve was visited, the option to describe a route taken, and if children took part in the excursion.

Options for nature reserves include those of listed CTMM nature reserves:

- Austin Roberts Memorial Bird
- Bishop Bird Nature Area
- Boardwalk Bird Sanctuary
- Bronkhorstspruit Angling Area
- Bronkhorstspruit Nature Reserve
- Chamberlain Bird Sanctuary
- Colbyn Nature Area
- Faerie Glen Nature Reserve
- Groenkloof Nature Reserve
- Klapperkop Nature Reserve
- Kwaggaspruit Nature Area
- Luton Valley Bird Sanctuary
- Moreleta Kloof Nature Area
- Pierre van Ryneveld Nature Area
- Rietvlei Nature Reserve
- Struben Dam Bird Sanctuary
- Tswaing Meteorite Crater
- Wonderboom Nature Reserve

However, if participants did not walk only one designated route, they have the option to provide a description of the route walked.

Participants also have the option to indicate if they walked with children.

The section continues by asking what the environmental conditions were like, how long the walk took, and if a load was carried (Figure 14).

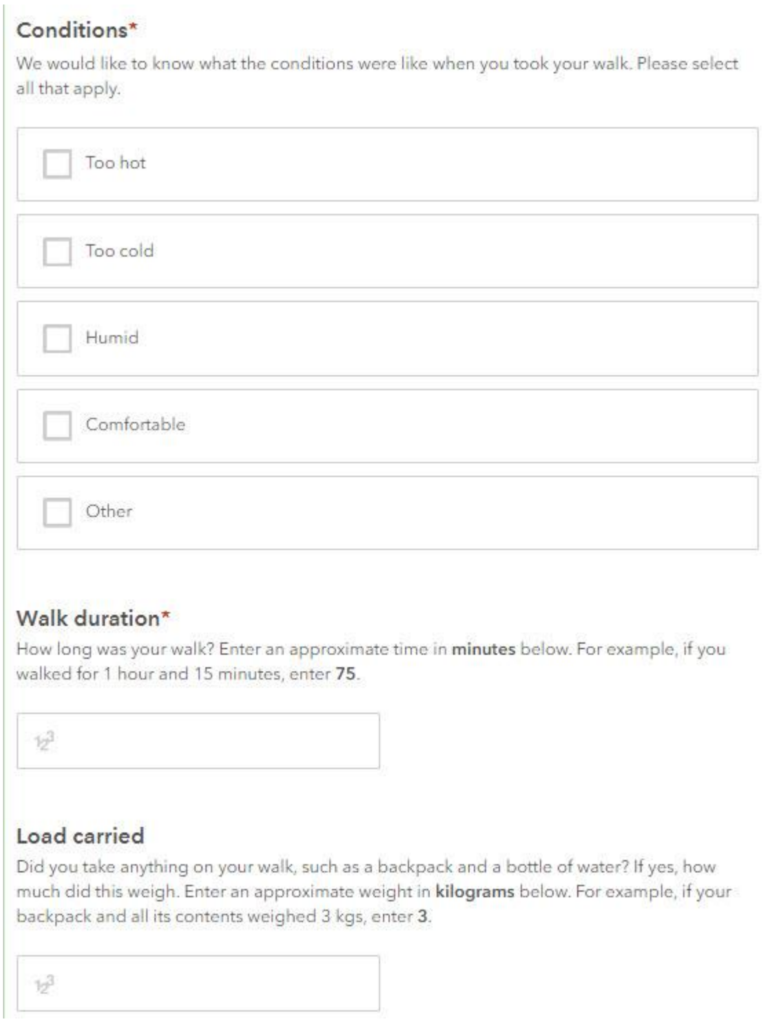


Figure 14: Survey questions on environmental conditions prevalent during the walk, the walk duration in minutes, and the load carried while walking.

Environmental conditions include an ‘Other’ option (Figure 15). Once this option is selected, an additional text box becomes visible. This is illustrated by the image below. In this image, the Other option has been selected.

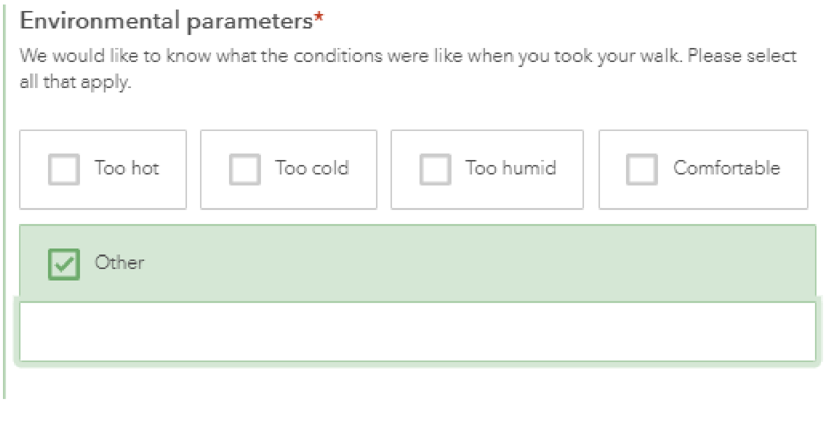
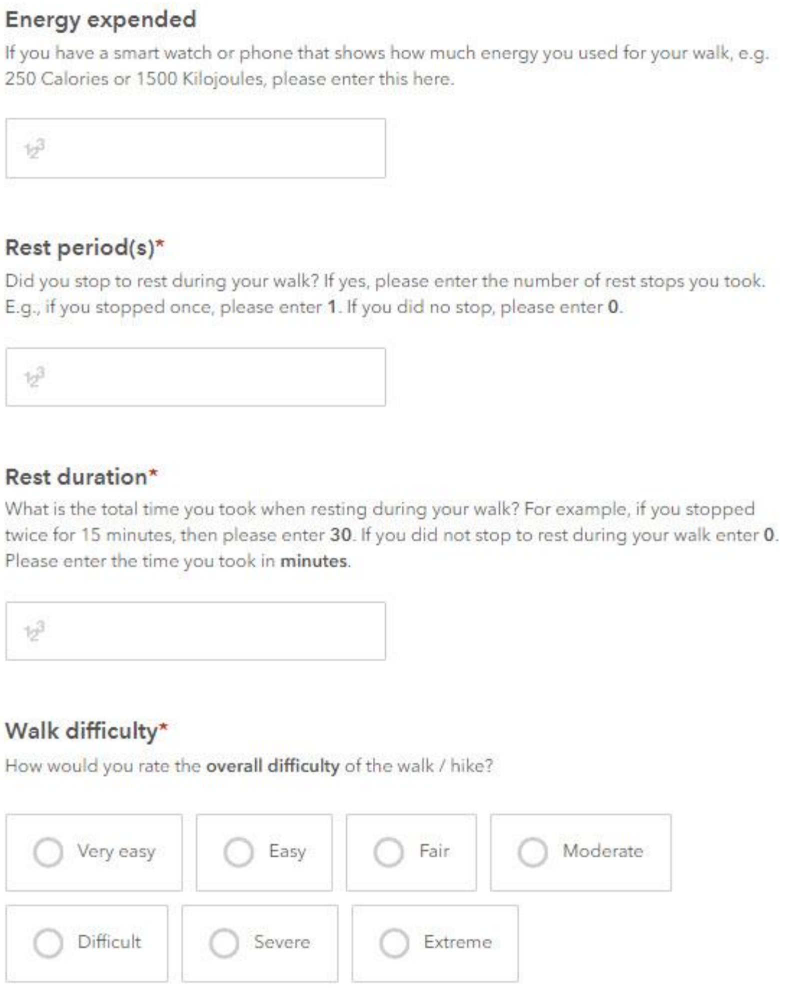


Figure 15: Selecting 'Other' among the options of environmental parameters.

Finally, this section of the survey asks the participant to indicate how much energy was expended traversing a trail, how many times a volunteer stopped to take a break, overall, how long those breaks were, and how difficult the walk or hike was (Figure 16).



Energy expended

If you have a smart watch or phone that shows how much energy you used for your walk, e.g. 250 Calories or 1500 Kilojoules, please enter this here.

Rest period(s)*

Did you stop to rest during your walk? If yes, please enter the number of rest stops you took. E.g., if you stopped once, please enter **1**. If you did no stop, please enter **0**.

Rest duration*

What is the total time you took when resting during your walk? For example, if you stopped twice for 15 minutes, then please enter **30**. If you did not stop to rest during your walk enter **0**. Please enter the time you took in **minutes**.

Walk difficulty*

How would you rate the **overall difficulty** of the walk / hike?

Very easy | Easy | Fair | Moderate | Difficult | Severe | Extreme

Figure 16: Survey questions on the energy expended while walking, the number of rests (breaks) taken, how long those were altogether, and the perceived difficulty of the walk.

The next section focuses on participant's fitness level and health status (Figure 17, pg. 98).

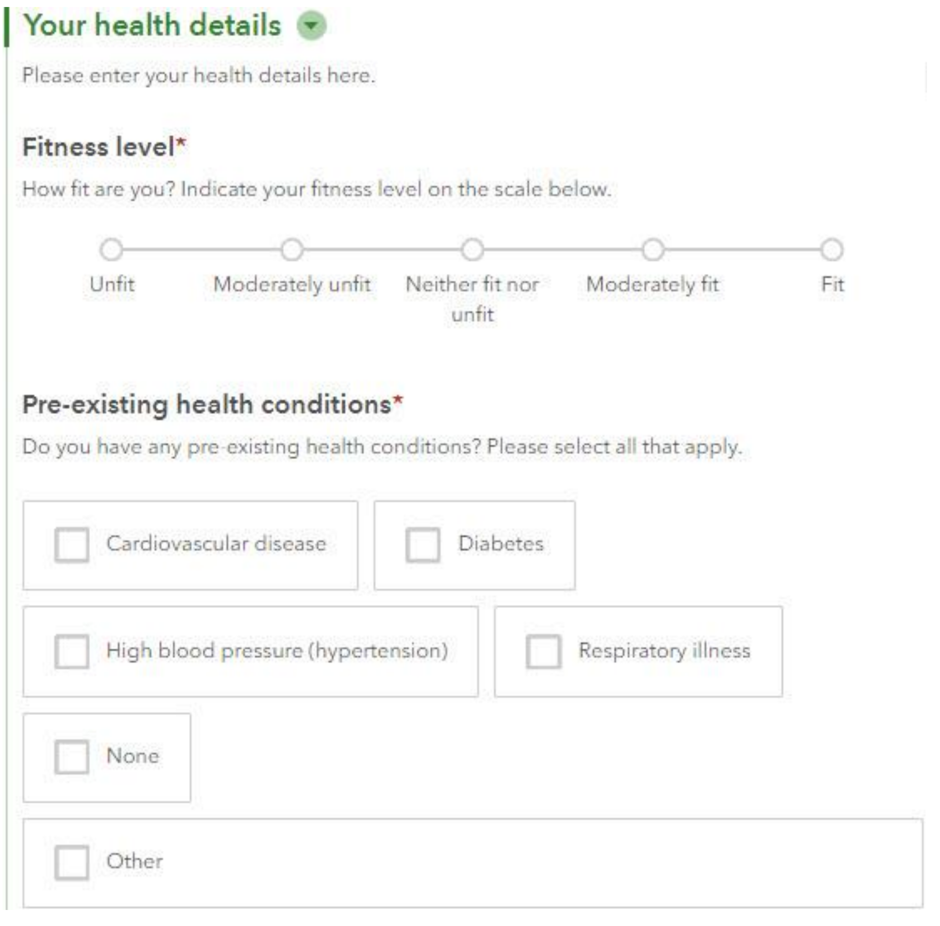


Figure 17: Survey questions on the participant's fitness level, and any pre-existing heath conditions.

The first question in the final section requires the participant to select their (perceived) fitness level.

The second question in this section requires the participant to select from a selection of health conditions (or None, if applicable). Participants also have the option to add other conditions not listed, by selecting Other. Once this option is selected, an additional text box becomes visible. This is illustrated by Figure 18. In this image, the Other option has been selected.

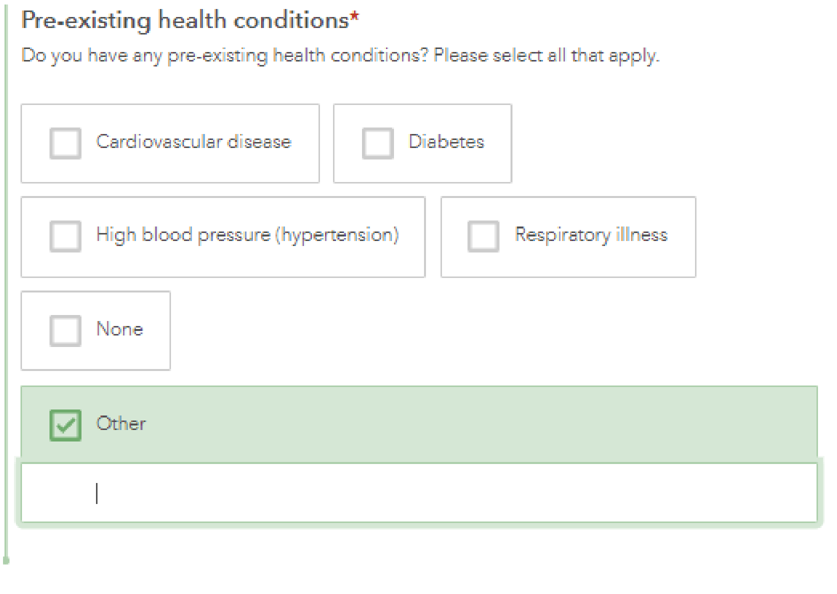


Figure 18: Selecting 'Other' among the options of health parameters.

The survey concludes with the splash screen illustrated in Figure 19.

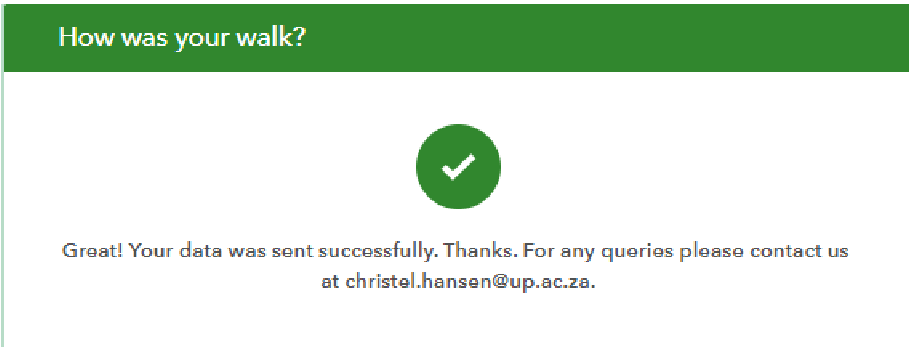


Figure 19: Survey splash screen (conclusion of survey).

APPENDIX C: MAPS

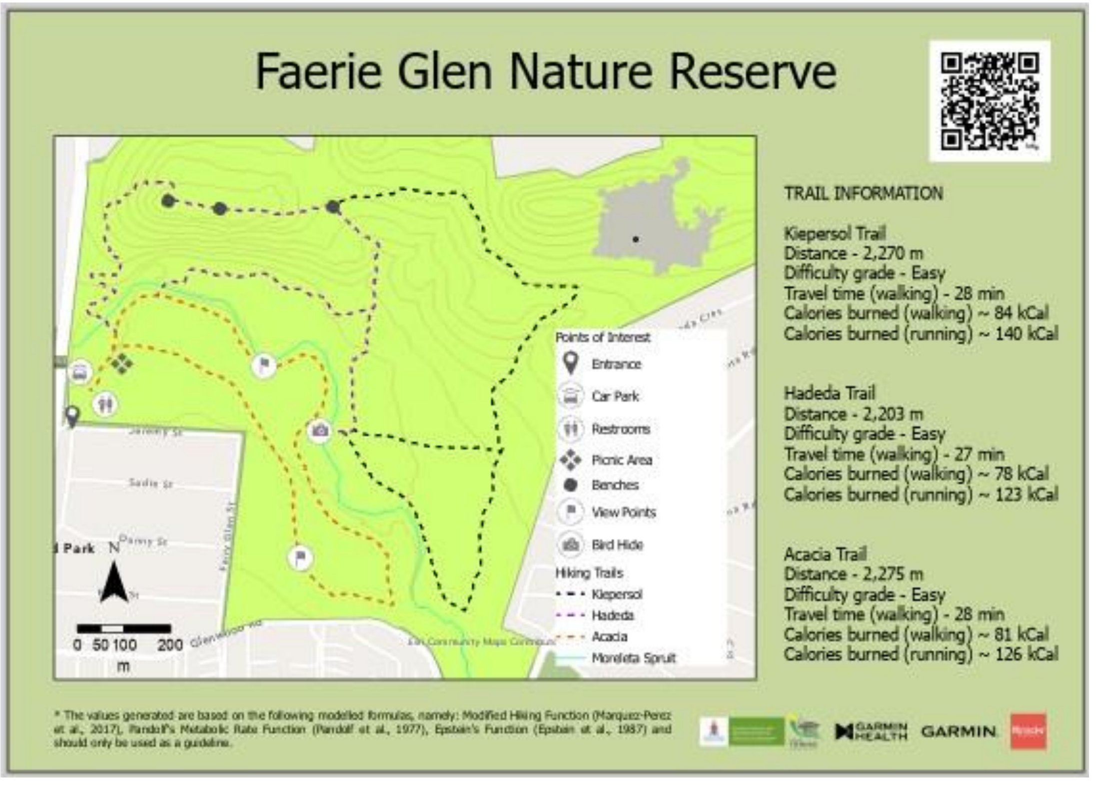


Figure 20: Map for Faerie Glen Nature Reserve

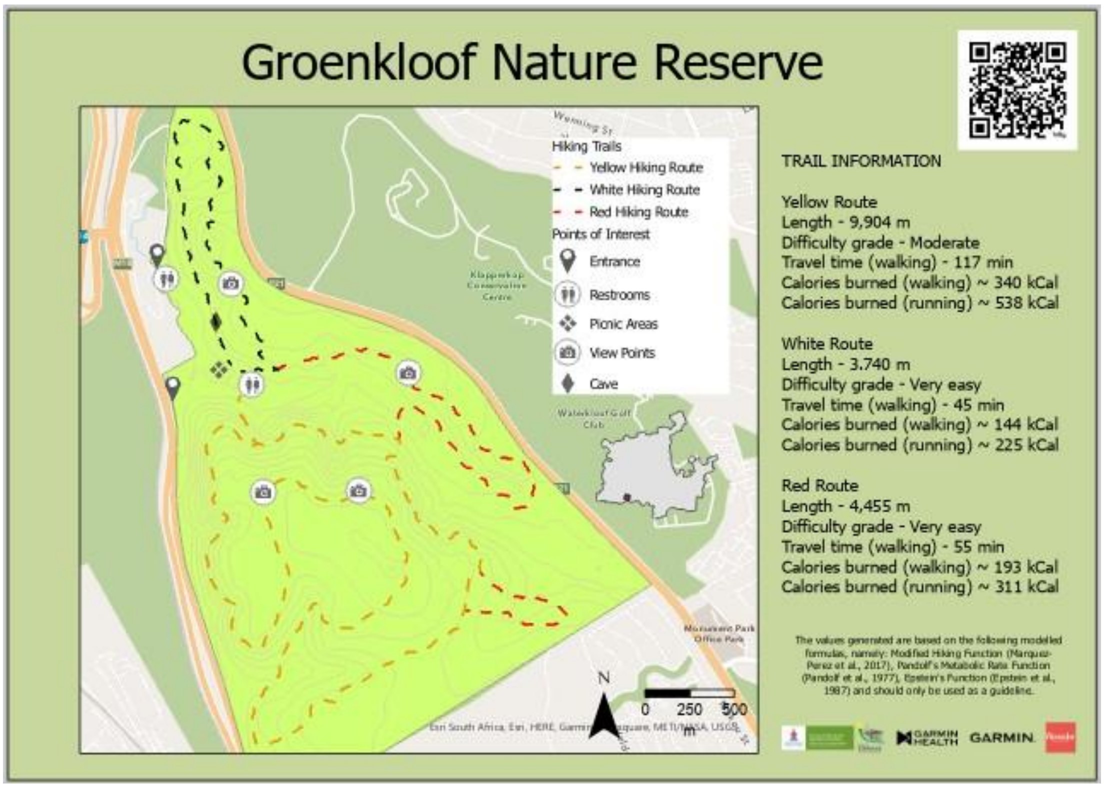


Figure 21: Map for Groenkloof Nature Reserve

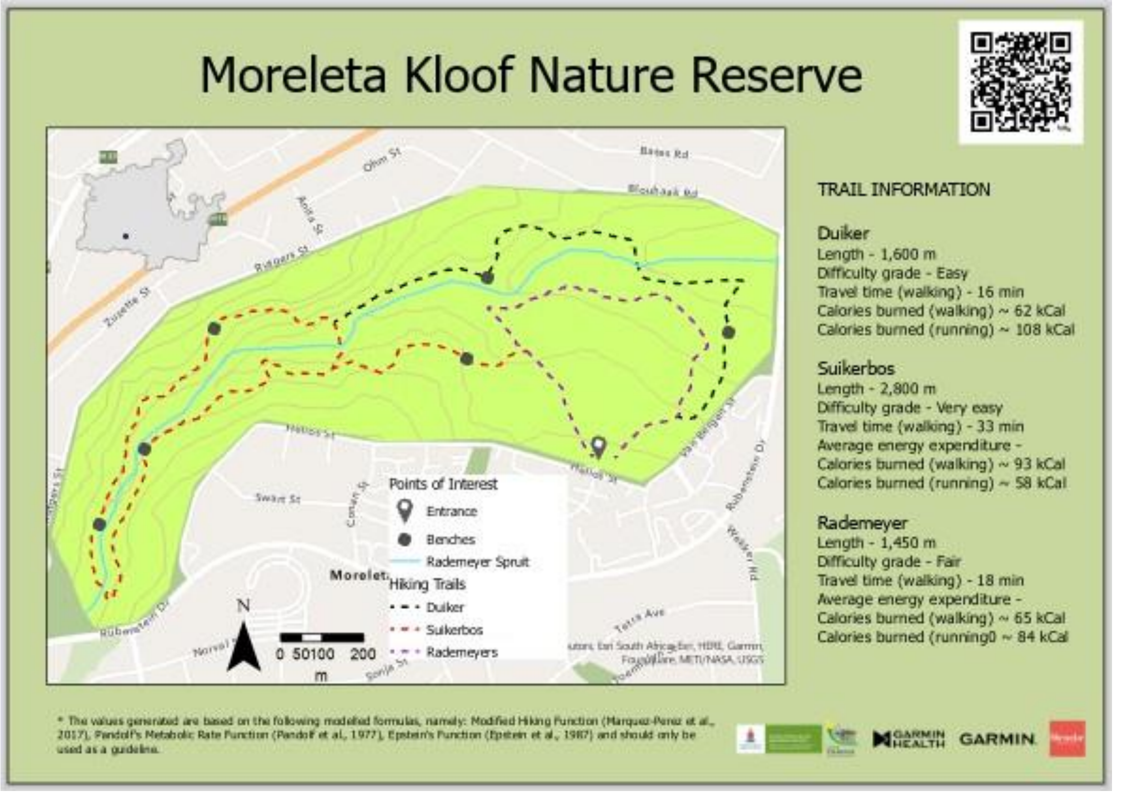


Figure 22: Map for Moreleta Kloof Nature Reserve

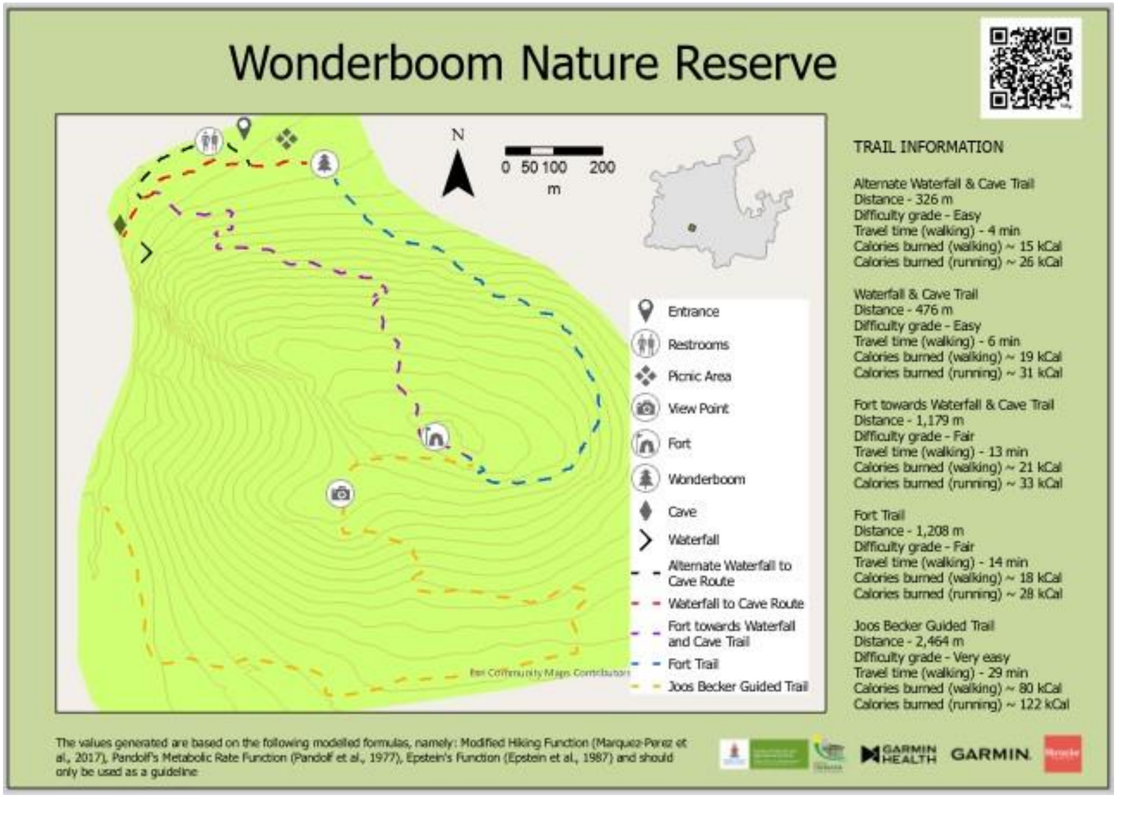


Figure 23: Map for Wonderboom Nature Reserve

APPENDIX D: INFOGRAPHICS

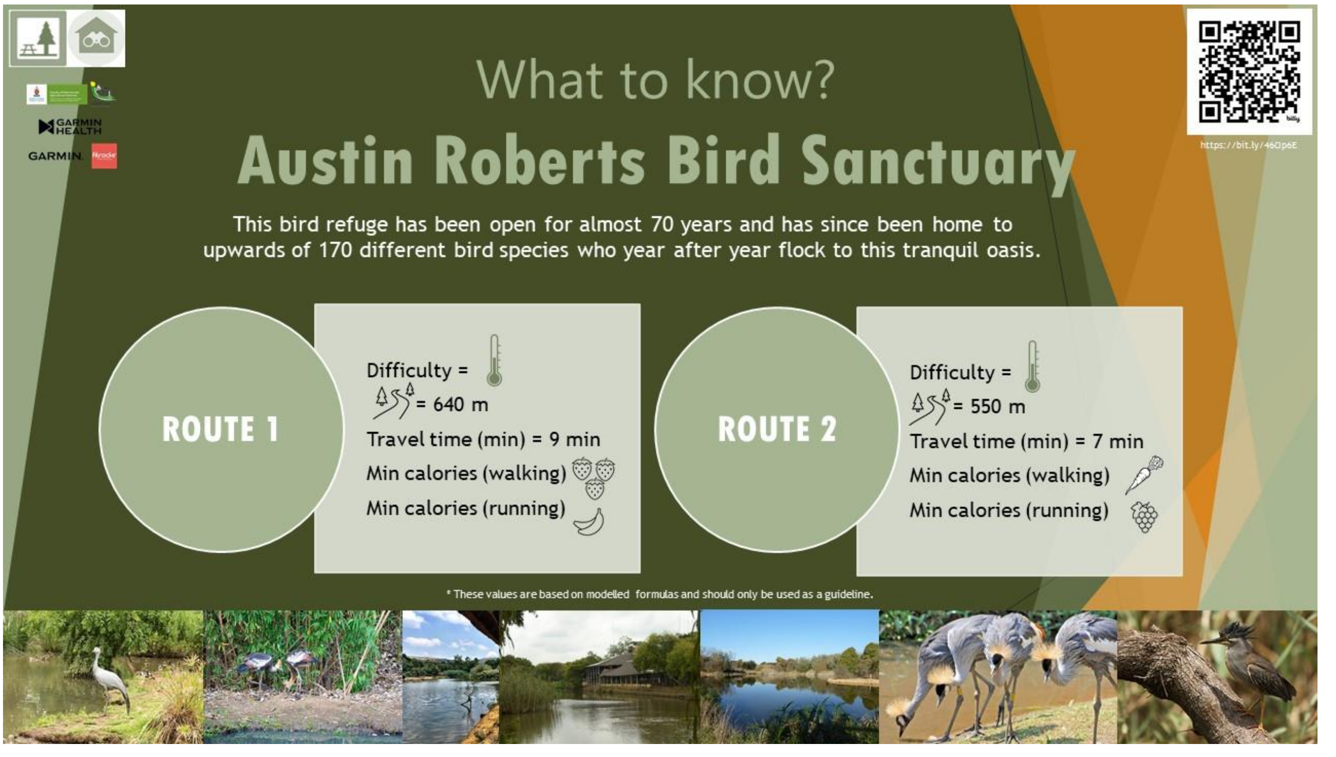


Figure 24: Infographic of Austin Roberts Bird Sanctuary.

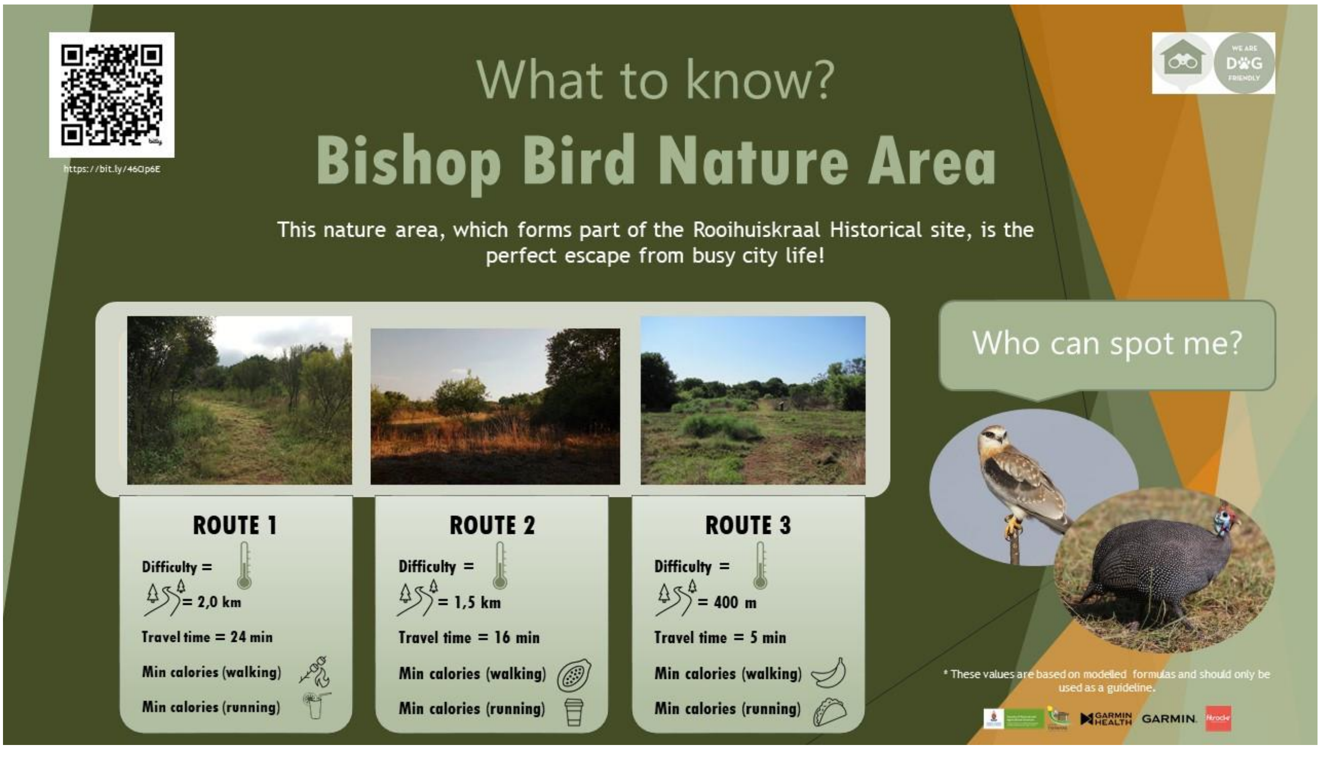


Figure 25: Infographic of Bishops Bird Nature Area.

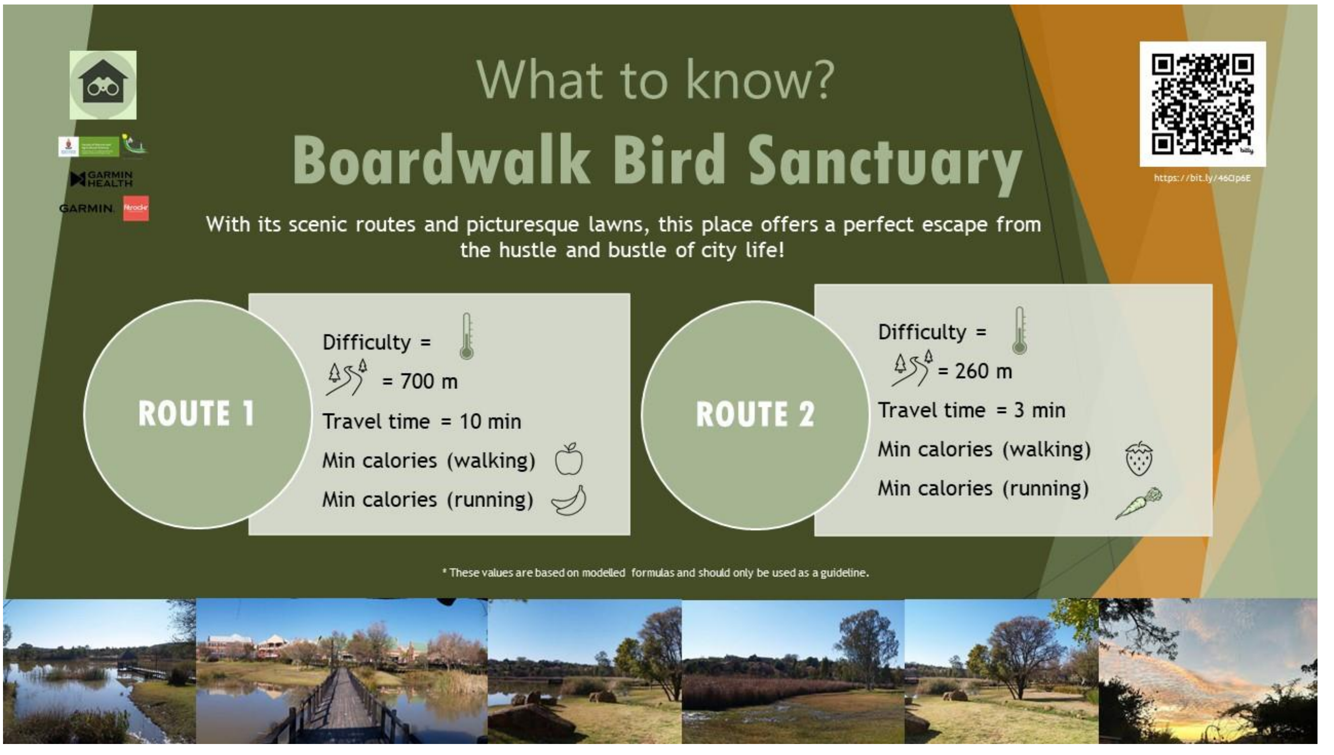


Figure 26: Infographic of the Boardwalk Bird Sanctuary.

Figure 27: Infographic of Faerie Glen Nature Reserve.

Figure 28: Infographic of Fort Klapperkop Nature Reserve.

Figure 29: Infographic of Groenkloof Nature Reserve.

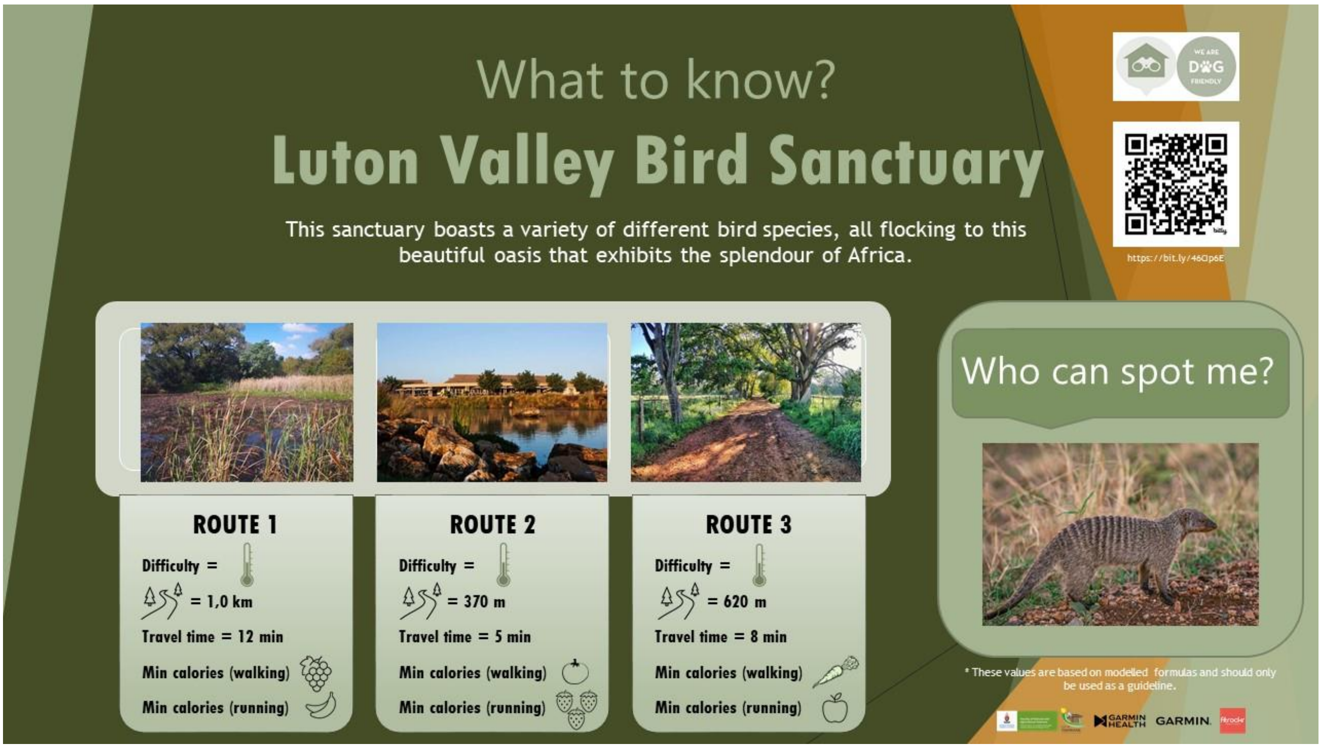


Figure 30:Infographic of Luton Valley Bird Sanctuary.

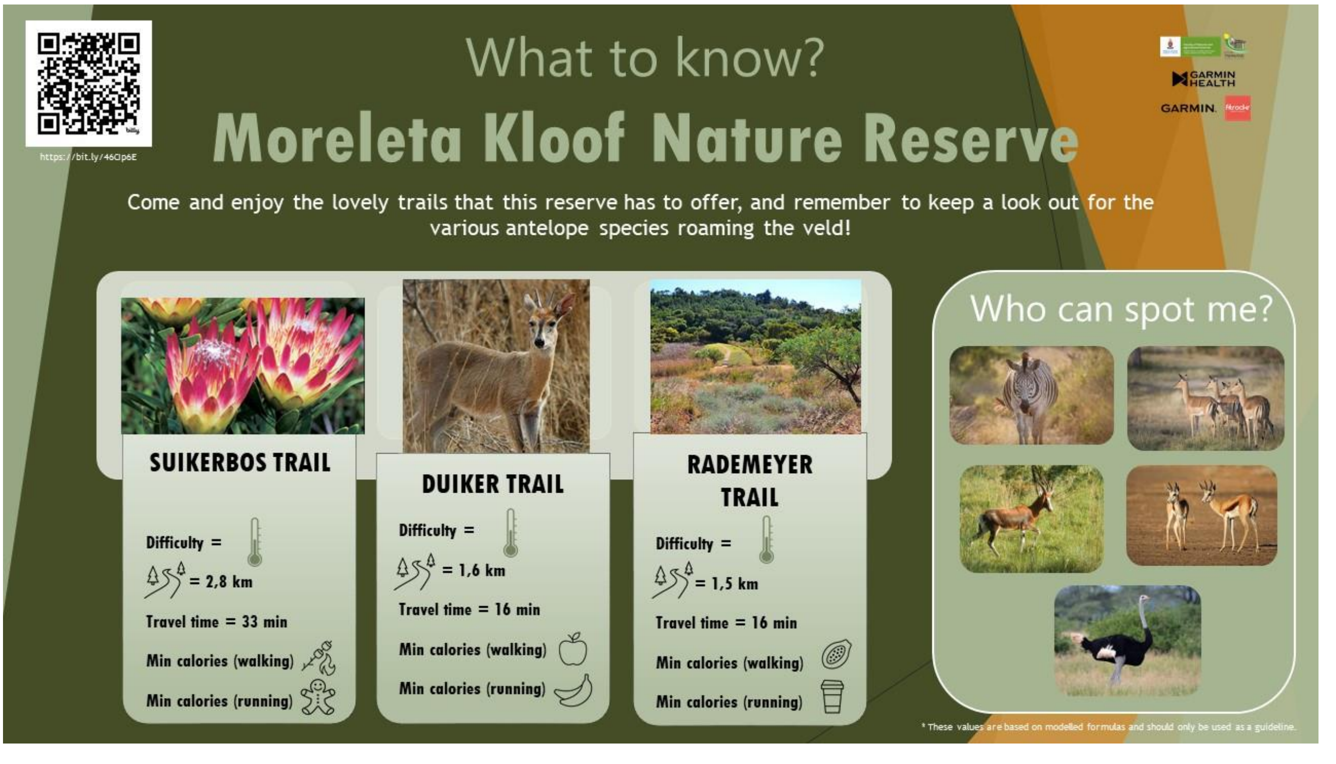


Figure 31: Infographic of Moreleta Kloof Nature Reserve.

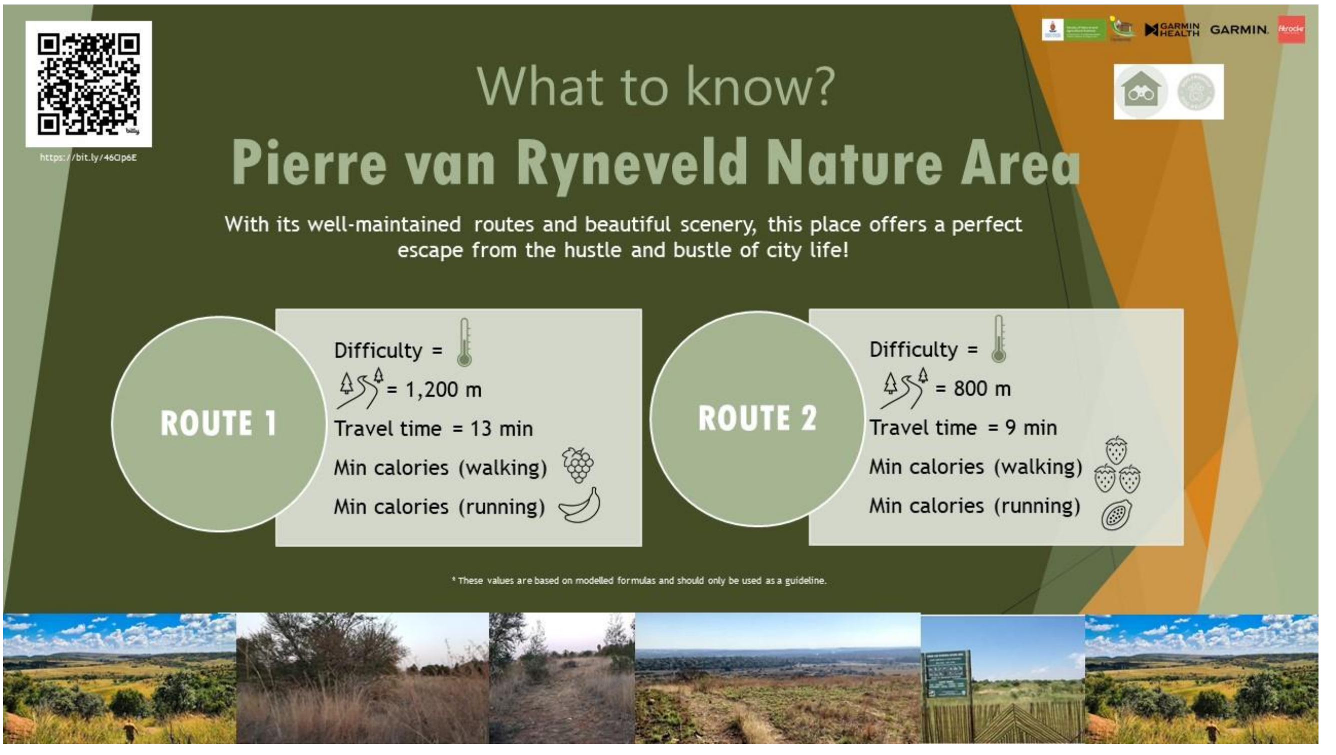


Figure 32: Infographic of the Pierre van Ryneveld Nature Area.

Figure 33: Infographic of the Struben Dam Bird Sanctuary.

Figure 34: Infographic of Wonderboom Nature Reserve.