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Developing a Hydropower Atlas for South Africa

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Submitted in fulfilment of the requirements for the degree

MSc Geoinformatics

in the Faculty of Natural & Agricultural Sciences, University of Pretoria

Pretoria

29 July 2022

DECLARATION

By submitting this dissertation, I, NOLUTHANDO NICOLE MAHAMBA declare that the dissertation /dissertation, which I hereby submit for the degree Master of Science in Geoinformatics 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.

SIGNATURE: ____________________

DATE: Friday, 29 July 2022

ETHICS STATEMENT

The author, whose name appears on the title page of this dissertation, has obtained the required research ethics approval/exemption for the research described in this work. The author declares that he/she has observed the ethical standards required in terms of the University of Pretoria Code of ethics for scholarly activities.

ABSTRACT

Over the last two decades, the South African energy situation has seen a significant change on account of a growing population, urbanisation, and economic growth. With an increasing population and the governmental drive to connect all South African households to electricity (76.7% of households connected in 2002; 90% in 2020), electricity demand is likely to see an upward trend. Currently, the main source of energy for electricity generation is coal, which has manifested in increased harmful gaseous emissions including carbon dioxide and sulphur dioxide. The rapid increase in the demand for electricity and interrupted power generation capacity in the country have also emphasized the importance of energy conservation and more efficient energy production. The country has thus looked to renewable energy sources through its Renewable Energy Independent Power Producer Procurement Program (REIPPPF) to reduce its high dependency on coal, and to provide a stable electricity supply. One such renewable energy option is hydropower, an energy source that could potentially lessen South Africa's overdependence on fossil fuel and the threat of power outages, yet currently makes up an insignificant contribution to the energy mix.

South African information products in the form of web-based applications are available for renewable energy sources such as wind, hydropower, solar, and bio-fuel energy. However, no web-based application is available for hydropower, meaning insufficient information concerning existing and potential hydropower schemes (conventional and unconventional) is currently available for the country. Nevertheless, key to many of the hindrances to renewable energy products is access to information and making such information available contributes to discussions regarding the future of the South African energy system. Accordingly, this dissertation undertook the development of an interactive web-based South African Hydropower Atlas (SAHA), which entailed 1) assessing existing atlases for common and preferred functionality, 2) identifying a suitable platform for hosting SAHA, 3) creating a centralised database for existing hydropower-related geospatial and attribute data for South Africa, and 4) modelling South African dam hydropower potential using current flow data records. Once a prototype of SAHA was developed, surveys assessing the usability and functionality of SAHA were sent to the relevant stakeholders. Feedback received was subsequently used to improve SAHA.

The findings suggest that modelled dam hydropower potential within South African dams is estimated at 162.37 MW; the Free State province holds the greatest potential (112.43 MW) while the Gauteng holds the least (0.15 MW). In addition, provinces with the least access to electricity are also identified to hold potential for small-scale hydropower developments. Furthermore, the development of SAHA as a decision-making tool contributes to the realisation of SDG Goal 7, which aims at ensuring universal access to clean, affordable, reliable, and modern energy services by 2030. The gradual shift away from fossil fuel-based energy sources by incorporating and supplementing conventional electricity generation with renewable energy such as hydropower and the development of small-scale hydropower for rural and remote electrification in South Africa is thus proposed, partially achievable through a freely available and accessible information portal as that of SAHA.

ACKNOWLEDGEMENTS

The completion of this project would not have been possible without my supervisor, Dr Christel Hansen, who continuously offered her guidance through all the stages of the project. Thank you for your time, patience, enthusiasm and for sharing your knowledge with me. Together, we have created a masterpiece.

A debt of gratitude is also owed to my family and friends for their continuous support.

Finally, I extend my gratitude to Mr Marco van Dijk, the Department of Civil Engineering of the University of Pretoria, and the Water Research Commission (WRC) for giving me the opportunity to contribute to the development of SAHA - the South African Hydropower Atlas, as well as providing the financial support to complete my studies.

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CHAPTER 1: INTRODUCTION

Energy, either non-renewable or renewable, is integral to the social, economic, and sustainable development of a country (Shaikh et al., 2017). Non-renewable energy is generated from non-renewable sources such as coal, gas and oil. In comparison, renewable energy is generated from renewable sources including solar, hydropower, biomass and wind energy (Guney, 2019). Without an adequate energy supply, transportation, industrial, commercial, and residential activities become impracticable. Furthermore, a nation that does not have an adequate energy supply is considered underdeveloped (Bridge, Özkaynak, and Turhan, 2018).

The growth and development of South Africa have necessitated the expansion of the electricity generating capacity of the country. A community survey conducted by Statistics South Africa (2021), shows that since 2002 South Africa has seen a significant increase in the number of households that have access to electricity, enabling 90% of households to access electricity. The introduction of electricity has also reduced the inhalation of smoke from indoor fires in most South African households (Barnes et al., 2009). However, while most South African households have access to electricity, South African electricity supply is fraught with problems such as load-shedding (du Venage, 2020). Load-shedding (scheduled blackouts) is implemented in response to unplanned events to prevent the national power grid from collapsing due to high electricity demand. Load shedding was reintroduced by Eskom in 2014 when the electricity demand significantly increased (Matona, 2015). Load-shedding is not unique to South Africa, also having been implemented in, e.g., Nepal and Pakistan (see Shrestha, 2010; Kazmi et al. 2019). Regardless of its implementation, load-shedding has resulted in considerable far-reaching impacts. For example, Ndaguba (2018) examined the effect of load-shedding on South African communities, with a focus on community health centres. The author revealed that load-shedding has resulted in the loss of lives in hospitals, poor sanitation, and interrupted water supply. Its effect on the economy is also detrimental (Goldberg, 2015).

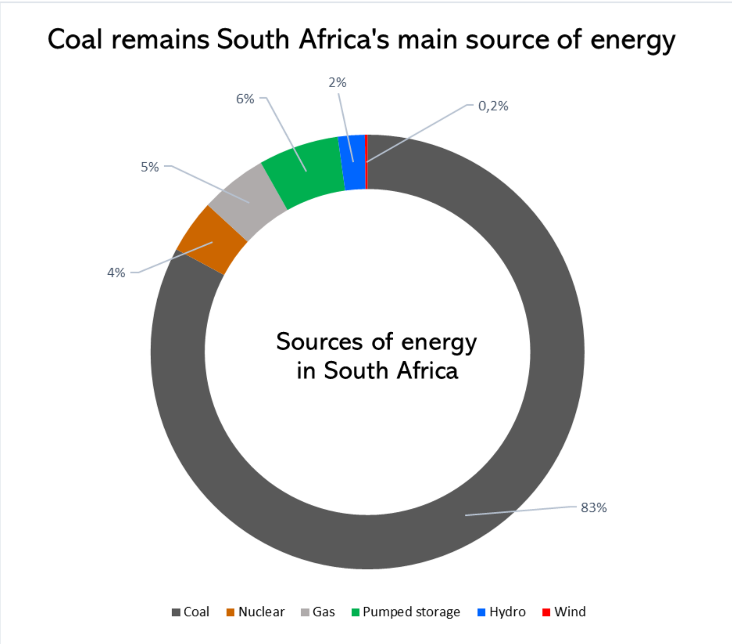


Figure 1: Sources of Energy in South Africa (Eskom Integrated Report, 2018).

As the electricity demand continues to increase, questions regarding potential alternative energy sources and the diversification of the energy mix of the nation have risen. In 2018, South African energy sources, as provided by Eskom, comprised coal (83%), hydropower (pumped storage) (6%), natural gas (5%), nuclear (4%), hydropower (2%), wind (0,2%), and solar (Department of Energy, 2019; Eskom, 2018; **Figure 1**; **Table 1**, pg. 2). **Table 1** lists power stations that are operated by Eskom in South Africa.

ELECTRICITY GENERATION IN SOUTH AFRICA

Table 1: Eskom operated power stations in South Africa.

Power Station	Type	Installed Capacity (MW)	Nominal Capacity (MW)
Acacia	Gas turbine	171	171
Ankerlig	Gas turbine	1338	1337
Arnot	Coal-fired	2352	2232
Camden	Coal-fired	1561	1481
Colley Wobbies	Hydroelectric	42	-
Drakensberg	Pumped storage	1000	1000
Duvha	Coal-fired	3000	2875
First Falls	Hydroelectric	6	-
Gariep	Hydroelectric	360	360
Gourikwa	Gas turbine	746	740
Grootvlei	Coal-fired	1180	1120
Hendrina	Coal-fired	1738	1638
Ingula	Pumped storage	1332	1334
Kendal	Coal-fired	4116	3840
Koeberg	Nuclear	1940	1860
Komati	Coal-fired	990	904
Kriel	Coal-fired	3000	2850
Kusile	Coal-fired	799	720
Lethabo	Coal-fired	3708	3558
Majuba	Coal-fired	4110	3843
Matimba	Coal-fired	3990	3690
Matla	Coal-fired	3600	3450
Medupi	Coal-fired	2382	2157
Ncora	Hydroelectric	2	-
Palmiet	Pumped storage	100	400
Port Rex	Gas turbine	171	171
Second falls	Hydroelectric	11	-
Sere	Wind	100	100
Tukuta	Coal-fired	3654	3510
Vanderkloof	Hydroelectric	240	240

The South African government continues with its attempts to provide universal access to electricity; however, these attempts are accompanied by several repercussions since the country is highly dependent on coal for electricity generation (Statistics South Africa, 2018). The combustion of coal during the electricity generation process produces a wide range of gaseous and solid waste including carbon dioxide (CO_2) (Pegels, 2010). CO_2 emissions in South Africa primarily stem from the production of electricity and account for 80% of the greenhouse gas (GHG) emissions in the country (Hook and Tang, 2013). This dependency on coal has increased the CO_2 emissions from the generation of electricity by 64 % since 1990, making South Africa the biggest African, and the world's 13th largest CO_2 emitter in the year 2017 (Beidari, Lin and Lewis, 2017). Furthermore, a recent article by Sguazzin (2021) indicates that South Africa's power utility, Eskom, is currently the biggest sulphur dioxide (SO_2) emitter in the world. This is of concern since The Centre for Research on Energy and Clean Air states that SO_2 is associated with asthma and heart attacks (Sguazzin, 2021).

Compounding this issue is that to increase generating capacity, Eskom undertook the construction of two additional mega coal-fired power plants, Medupi and Kusile, in 2007 and 2008 respectively, despite concerns and international pressure to not do so (Blignaut, 2012; Riekert and Koch, 2012). Consequently, the construction and operations of the power plants have introduced several environmental and socio-economic costs in the areas they are located; namely, eMalahleni and Lephalale (Blignaut et al., 2013). Although Kusile power station uses an innovative technology known as dry cooling, it is estimated that the station uses 71 million litres of water per day to turn its turbines with steam and cool its towers, which is 173 times more water than wind power would use (Groenewald, 2012). Groenewald (2012) further estimated that the power station's water usage would peak in the year 2021, while a 17 % gap between water supply and demand is expected by the year 2030. It is also important to note that the mines supplying the power stations with coal also contribute significantly to the degradation of the environment. As a result, the nearby mines and power stations in eMalahleni have left the community members discontented with the quality of water and the air pollution in the area (Olufemi, Mji and Mukhola, 2019). Furthermore, a study conducted by the Council for Scientific and Industrial Research (CSIR) revealed the damage of the coal mining and related industries to the water resources of Mpumalanga (Groenewald, 2012).

Similarly, the construction of the Medupi power station raised dissatisfaction among the workers and community of Lephalale where the power station is located (Nyembe, 2018). According to Nyembe (2018), the development and construction of Medupi proved to be more expensive than anticipated, exceeding the original budget, and thus impacting consumers, particularly low-income earners who are dependent on access to affordable electricity. Medupi has also been linked to pollution of the environment through environmental discharges, water diversions and irresponsible water use, failing to create jobs, and lack of meaningful community engagement and participation (Nyembe. 2018; Marcatelli, 2020). To further demonstrate the impact of coal-fired power stations, Sahu and QEP (2018) examined the data of 14 of Eskom's 15 coal-fired power stations, over a 21-month study period. The study showed that the examined power stations reported 3 200 exceedances of Atmospheric Emissions Licenses (AEL) limit values for particulate matter (PM), SO_2, and oxides of nitrogen (NO_x) (Sahu and QEP, 2018). Moreover, recent studies (e.g., Rahman, 2016; Tripathi et al., 2019) indicate that the world's population will have significantly increased by the year 2050, and most of this growth will be observed in developing countries, including South Africa, subsequently increasing energy consumption in these countries. The United Nations have also identified Africa as the most vulnerable continent to the effects of climate change (Aliyu, Modu and Tan, 2018).

It has become evident that coal-fired power stations are one of the biggest contributors to environmental degradation and climate change, and while South Africa has large coal reserves, the attached costs are too great for the country to ignore alternative means of power generation. Having access to clean and affordable energy is a requisite to poverty alleviation. According to a 2020 General Household Survey conducted by Statistics South Africa (2020), 90% percent of South Africans were connected to the mains electricity supply. The 10% of South African households that do not have access to electricity constitutes mainly of households in rural and remote areas. The findings of the survey further revealed that South African consumers were dissatisfied with electricity services and often found themselves compelled to use multiple energy sources due to load-shedding and increasing costs. Households in rural areas opted for use of wood and paraffin as energy sources since these alternatives are cheaper than the electricity supplied (Statistics South Africa, 2020). The increased access to electricity also has unfortunate concomitant effects, such as the use of environmentally degrading energy sources (as discussed previously). Furthermore, in South Africa continuously increasing electricity tariffs and load-shedding remains an issue (van der Merwe, 2019). This, therefore, highlights the need for increased electricity generation, and increased access to clean and affordable electricity. This can be achieved by increasing the contribution of renewable energy sources to the South African energy mix such as hydropower, which has previously proven to be suitable for supplying electricity in rural and remote areas (Klunne, 2009; Kusakana, 2014; Uamusse, 2019).

RENEWABLE ENERGY SOURCES IN SOUTH AFRICA

Previous research by Aliyu, Modu and Tan (2018) indicates that renewable energy sources such as solar, wind, and hydropower play a significant role in sustaining developed nations, thus the researchers believe that generating electricity from these renewable energy sources can contribute greatly to electricity generation in developing countries. One renewable energy source that has shown potential in South Africa, among others, is hydropower. Hydropower is a robust renewable energy technology that is efficient in energy conversion processes, with modern hydropower technologies converting up to 95% of the energy from moving water into electricity (Barta, van Dijk and van Vuuren, 2011). This may be water flowing from higher to lower elevations, in a river through a dam or in the ocean, as well as in man-made infrastructures such as wastewater treatment plants, pipelines, and irrigation systems. Hydropower is considered a relatively cleaner and cheaper alternative to traditional energy generation, such as those based on coal, which is accompanied by fewer environmental costs since it is fuelled by water and does not directly pollute the air and surrounding environment (Kim et al., 2017).

Rycroft (2014) argues that South Africa dominates the Southern African region regarding both available hydropower potential and installed small hydropower capacity. There also exists potential for further development of installed hydropower capacity under 10 Megawatts (MW) in rural areas located in the Eastern Cape, Free State, KwaZulu Natal, and Mpumalanga (Rycroft, 2014). Further potential for hydropower, specifically low-head hydropower in urban systems, irrigation schemes, and rivers in South Africa, including small dams and weirs, has been identified by van Vuuren et al. (2013). This manifests as evidence that there is indeed potential for hydropower and that hydropower schemes have been previously successfully developed in South Africa. Equally important, by including alternative forms of energy production in South Africa's energy mix, the reliance on coal-produced energy will be reduced, enhancing sustainability in the short and long term. This will alleviate the energy crisis South Africa currently faces, while simultaneously reducing environmental pollution due to coal-powered energy generation. However, there is insufficient information concerning existing hydropower schemes and potential hydropower (conventional and unconventional) for South Africa (van Dijk, 2016). Such information, in the form of an easily accessible online resource (atlas), could aid in identifying locations where more hydropower schemes could be installed, thus providing opportunities for the implementation of hydropower projects. Atlases such as the Wind Atlas for South Africa (WASA) and the Bioenergy Atlas for South Africa were developed to promote the development of large grid-connected wind farms and to identify potential wind and bio energy to be exploited (National Research Foundation, 2017; WASA, 2018). A hydropower atlas for South Africa will play a similar role by providing decision-makers, such as the government, investors, and the public with information related to available hydropower potential, existing hydropower schemes, and potential locations for both unconventional and conventional hydropower schemes in South Africa. This will in turn encourage the exploitation of existing hydropower potential in the country.

1.1. RESEARCH PROBLEM

The South African electricity sector is undoubtedly vital to the economy of the country while simultaneously being the country's biggest contributor to GHG emissions (Pegels, 2010). This has made the use of fossil fuel in generating electricity unfavourable. However, South Africa's public electric utility, Eskom, is also facing an energy crisis, with more power generation capacity required (Muller, 2017). This has left the country with a dilemma: a reliance on environmentally unfriendly sourced power generation (predominantly coal-based), and an ailing electricity infrastructure and electricity generation capacity. As a result, power outages have become the norm, with damaging effects on the economy of the country (e.g., Inglesi and Pouris, 2010). Fortunately, South Africa has access to several renewable energy sources. One of these, hydropower, can potentially help relieve South Africa's strained electricity grid while also providing electricity in isolated rural areas (van Dijk, Bhagwan and Dedekind, 2016; Ebhota and Inambao, 2017). Unfortunately, at present no easily accessible resource such as an online atlas, exists that collates and disseminates information resources regarding existing hydropower and the hydropower potential in South Africa.

1.2. RATIONALE

Coyle and Simmons (2014) believe that a global energy crisis is looming owing to the significant increase in global energy demand, over-dependence on fossil fuels for energy generation and transportation, and the steadily growing global population. The South African energy situation has seen a significant change on account of the growing population, urbanisation, and economic growth (Lucas et al., 2015). Lucas et al. (2015) project that the African continent will see its share in global energy-related carbon dioxide emissions increase by 23%, by 2100. These emissions will become apparent at a global scale only after the year 2050.

The rapid increase in the demand for electricity and limited power generation capacity in South Africa have emphasized the importance of energy conservation and more efficient energy production. In South Africa, the main electricity supplier, Eskom, which is predominantly dependent on coal for electricity generation, is failing to meet the electricity demand of the country since the electricity demand surpasses the available capacity during peak times (Capitanescu, 2015). This has resulted in Eskom implementing measures such as load-shedding (scheduled blackouts), which have led to numerous impacts including direct and indirect economic impacts, as well as social impacts (Goldberg, 2016). Furthermore, being highly dependent on one energy resource has proven to pose several risks such as price increases and supply disruptions (Odeku, 2019). Therefore, the solution to this is greater diversification of energy resources for electricity generation (Owusu and Asumadu-Sarkodie, 2016). Exploiting alternative energy sources is also important for enhancing the electricity supply in South Africa, job creation, mitigating the effects of climate change, and conserving our environment. In support of this, the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) was launched in 2011 to procure alternative sustainable energy and to encourage private sector investment into grid-connected renewable energy generation (Eberhard, Kolker and Leigland, 2014). By July 2020, 112 Independent Power Producers (IPP) projects had been procured (Nomjana, 2020). These projects are often established in rural areas, positively impacting the communities through job creation, social upliftment, and economic development (Jain and Jain, 2017).

Recently, the South African government raised the licensing threshold for distributed electricity generation from 1 MW to 100 MW, without the need for a license (Bellini, 2021). In other words, private electricity generation projects do not have to apply for a license but are obligated to register with the National Energy Regulator of South Africa (NERSA). According to the government, these amendments are aimed at encouraging investment in new generation capacity and reducing the ramifications of load-shedding. In addition, energy-intensive sectors such as the mining sector can now produce their own electricity. This will consequently reduce South Africa’s high dependency on one electricity utility, Eskom. It is anticipated that the majority of the embedded generation projects will be green energy projects - in other words, renewable energy projects, as a result reducing the South African carbon footprint (Stoddard, 2021). However, according to Ginindza (2021), there are currently only 34 companies in South Africa that can generate that amount of energy. Developing more information products regarding the different renewable energy sources in South Africa would provide room for this number to grow as project developers would become more knowledgeable on the type(s) of renewable energy that they want to invest in, as a result encouraging further development of renewable energy projects. This would subsequently increase national access to cleaner and affordable electricity and potentially reduce the unemployment rate through the establishment of new renewable energy projects.

Information products in the form of web-based applications are available for renewable energy sources that are currently operational in South Africa; namely, wind, hydropower, solar, and bio-fuel energy (Department of Energy, n.d.). However, no web-based application has been previously developed for hydropower, although hydropower is a currently operational energy source. This research study fills this gap by developing an interactive web-based hydropower atlas regarding existing hydropower in South Africa. Both conventional and unconventional hydropower potential, where such information is available, is modelled. This aids in identifying where hydropower schemes are located, as well as where potential locations for new hydropower schemes could be developed. Making such information available to the government, investors, and the public ultimately presents opportunities for hydropower to be considered a reliable energy source. Furthermore, this allows all interested stakeholders to make informed decisions concerning hydropower projects.

1.3. RESEARCH AIM AND OBJECTIVES

This research aims to develop a South African Hydropower Atlas (SAHA). To achieve this aim, the following key objectives have been identified:

1. Assess existing atlases for common and preferred functionalities for the hydropower atlas and identify a suitable platform for hosting the atlas.
2. Create a centralised database for existing hydropower-related geospatial and attribute data for South Africa.
3. Asses and model dam hydropower potential for South Africa using current flow data records.
4. Develop a web-based hydropower application that serves as an information product.

1.4. THESIS OUTLINE

This report comprises the introduction, literature review, materials and methods, results, discussion, and conclusion and recommendations chapters. The introductory chapter (**CHAPTER 1: INTRODUCTION**, pg. 1 onward) provides a background on the research topic, research problem, the main aim and objectives of the research, and the rationale behind the research. The literature review (**CHAPTER 2: LITERATURE REVIEW**, pg. 7 onward), on the other hand, provides a review of The Energy Situation in Africa, Hydropower, Hydropower Potential in South Africa and Assessing Existing Atlases. The materials and methods chapter provides an overview of the research plan, the datasets ideally included in the hydropower atlas, and methods that are followed to achieve each research objective (**CHAPTER 3: MATERIALS AND METHODS,** pg. 23 onwards). The results of the dam hydropower potential assessment, the developed SAHA and feedback from the stakeholder survey are presented in the results chapter (**CHAPTER 4: RESULTS,** pg. 40 onward). The findings are discussed in the discussion chapter (**CHAPTER 5: DISCUSSION**, pg. 69 onward). Lastly, the dissertation is concluded, and recommendations are provided (**CHAPTER 6: CONCLUSION AND RECOMMENDATIONS**, pg. 77).

CHAPTER 2: LITERATURE REVIEW

2.1. THE ENERGY SITUATION IN AFRICA

Expanding the African energy system by increasing access to a variety of energy sources will reduce poverty through job creation and catalyse economic growth. However, depending on the source(s) of energy chosen, environmental impacts at the local, regional and global scale could be escalated (Calvin et al., 2013; Liousse et al., 2014).

The United Nations (2018) regard Africa as the most vulnerable continent to the repercussions of climate change due to its high dependence on subsistence agriculture, low tolerance for change, and imminent water crises. Aliyu, Modu, and Tan (2018) also regard the African energy sector to be faced with sustainable development issues, despite its abundance of natural resources. The authors reviewed the future of four renewable energy sources; namely, hydropower, solar, wind, and biomass, for three African powerhouses; namely, South Africa, Egypt, and Nigeria. They found that all three countries advocate (with varying success) for energy efficiency to varying extents (Aliyu, Modu and Tan, 2018). The authors maintain that the advantages of energy efficiency include improved health due to reduced GHG emissions, reduced energy crises, reduced environmental pollution, improved industrial competitiveness as energy efficiency measures are applied, reduction in imported energy sources, and creation of jobs.

In South Africa, the main energy suppliers are Sasol (fuel) and Eskom, which produces most of the electricity and supplies most of the energy needs of the country, with independent power producers being in the minority (Krupa and Burch, 2011). The two main energy providers are also largely responsible for employing university graduates in the relevant fields, and energy research and development in the country (Pegels, 2010). Pegels (2010) considers the dominance of these two providers to be the reason why the country is lagging in the renewable energy sector. Projections by the Department of Energy (2013) indicate that the annual electricity demand in South Africa will increase from 345 terawatts-hour (TWh) to 416 TWh by 2030. This indicates that South Africa needs to increase electricity production and explore options to promote renewable energy on a larger scale to assist in power generation. For example, the South African government has introduced the REIPPP as part of its attempt to deal with anticipated peaks in energy demand (Pollet, Staffell, and Adamson, 2015).

South Africa experienced its first energy crisis in 2007-2008. According to Pretorius et al. (2015) an energy crisis occurs when electricity demand continues to increase while the electricity reserve remains limited. The electricity reserve is needed to respond to unplanned power outages, maintenance, and extreme weather conditions. This reserve can, therefore, be used to measure how much pressure an electricity generation system is experiencing (Pretorius et al., 2015). An investigation conducted by Inglesi and Pouris (2010) revealed that the main reason for the energy crisis was a lack of proportion between electricity supply and demand, a delayed decision by the South African government in 2004 to fund the construction of a new power station, a significant 50% increase in the electricity demand between 1994 and 2007, and the lack of energy research in the South African context at that time.

The 2019 and 2020 General Household surveys conducted by Statistics South Africa indicate that the percentage of South African households that have access to electricity increased from 76.7% in 2002 to 85% in 2019, to 90% in 2020. This signifies a 13.3% increase over 18 years. According to the survey, the provinces that had the highest percentage of households with access to electricity were Limpopo (93.4%), Northern Cape (91.2%), and Free State (91.6%). Those with the least percentage of households with access to electricity are Gauteng (76,6%) and North West (81.6%). Notable increases between the 2002 and 2019 period were observed in Eastern Cape (+34.0%), and Limpopo (+20%), while a decrease in the percentage of households with access to electricity was observed in Gauteng (-10.6%) and Western Cape (-0.1%) (Statistics South Africa, 2020). The decrease in access to electricity in these provinces is attributed to immigration and the associated increase in the number of households. Moreover, the sources of energy for cooking in South Africa, in 2019, were electricity (75.1%), gas (4.2%), paraffin (3,9 %), wood (7.8%), coal (0.4%), and other sources (8.7%) (Statistics South Africa, 2020). The Free State province (86.3%) and Northern Cape (84.2 %) recorded the highest use of electricity as the main source of energy for cooking, while the Northern Cape (84.2%) and Limpopo (62.2%) provinces recorded the lowest use. The use of paraffin was highest in Gauteng (7.3%) and lowest in Western Cape (0.7%). The use of wood was more common in Limpopo (32.1%), Mpumalanga (16.7%), Eastern Cape (10.5 %), and KwaZulu-Natal (8.4%), while gas was more common in households in the Western Cape (13.2%), Northern Cape (7.1%), Free State (3.5%) and Eastern Cape (4.8%) (Statistics South Africa, 2020). Thus, while varying energy sources for both lighting and cooking are evident, electricity remains the main and preferred source. With an increasing population and the governmental drive to connect all South African households to electricity, electricity demand is, therefore, likely to increase.

The annual statistics on utility-scale power generation released by The Council for Scientific and Industrial Research (CSIR) indicate that system demand increased by 5% during the first half of the year 2021, which is 2% lower than the first half of 2019. These statistics should be taken in the context of the COVID-19 pandemic and its effect on the South African economy. The statistics also indicate that coal continued to dominate the South African energy mix, during the first half of the year, contributing 81.8% with the addition of a coal unit at Kusile power station which entered commercial operation earlier in the year 2021 (Calitz and Wright, 2021). Calitz and Wright (2021) report that renewable energy sources including solar photovoltaics, wind, hydropower, Concentrating Solar Power (CSP) and other sources contributed 11% to the energy mix, while zero-carbon energy sources such as nuclear contributed 7.2%. In addition, the statistics show that South Africa experienced load-shedding for a total of 650 hours in the first half of the year 2021, whereby 963 GWh of electricity was shed (Calitz and Wright, 2021). Another compilation of data by the CSIR indicates that the year 2021 was also the worst year on record regarding load-shedding in the country (Steyn, 2021). The data demonstrates that South Africa experienced a total of 1136 hours of load-shedding in the year 2021, which is a 24% increase from the 859 hours recorded in the year 2020. This is equivalent to 2455 GWh of electricity shed in the year 2021, compared to the 1798 GWh of electricity shed in 2020 (Steyn, 2021). Furthermore, it is anticipated that acute power outages will persist in the year 2022.

While there is a need to put an end to the high dependency on coal in South Africa, the country relies on electricity generated from coal. According to the Centre for Research on Energy and Clean Air, South Africa is the biggest sulphur dioxide (SO_2) emitter in the world (Mkhize, 2021). Most of this SO_2 stems from eMalahleni in the Mpumalanga province, which hosts 12 power stations. During the COP26 climate conference in Glasgow, it was announced that the United States of America and several European countries, including Germany, have pledged $8.5 billion to assist South Africa – Africa's biggest carbon emitter – in transitioning from coal-fired power stations to renewable sources of energy (Boyle, 2021). It is said that the funding will be presented in the form of grants and loans over the next five years. Before the initiative was announced at the COP26 climate conference, the South African government had already planned to reduce the contribution of coal to the energy mix by a considerable 20%, by the year 2030 (van der Merwe, 2021). Coal was expected to contribute 60%, while wind and solar contribute 25%. The South African government believes that these funds will help achieve its goal to reduce emissions by 2030. This implies the country can decommission most of its coal-powered stations before the initial 2050 deadline. However, an estimate of 100,000 jobs in mining and the associated industries could be at stake (Mkhize, 2021).

Fashina et al. (2019) reviewed the barriers and challenges of renewable energy development in developing African countries with a focus on Uganda. The authors elucidate the barriers and challenges that may hinder renewable energy development in developing nations to include, first, lack of knowledge and public awareness regarding the socio-economic and environmental benefits of renewable energy, the importance of renewable energy and its technologies, and uncertainty regarding the feasibility of renewable energy projects (Mustapa, Peng, and Hashim, 2010; Peidong et al., 2009). Second, costs related to the development of renewable energy, including operational and maintenance costs, make its development unattractive to financially stressed nations (Murphy, Twaha, and Murphy, 2014). Third, the lack of skilled personnel to undertake the implementation and management of such projects remains of concern (Steffen et al., 2020). Fourth, the lack of support for research and renewable energy programs in the form of funding remains a barrier (Fashina et al., 2019). Fifth, the lack of electricity demand, unstable electricity grids, and the lack of electricity infrastructure is a hindrance to renewable energy development since extending electricity supply to such areas would not be cost-effective (Szabo et al., 2011; Zomers, 2014). Additionally, key to many of the hindrances to renewable energy products is access to information. Therefore, to successfully promote the inclusion of renewable energy in the energy mix of developing nations, these barriers, and challenges must be addressed. Duku and Hagan (2011) argue that investment in renewable energy sources will increase energy security in developing nations. To address the challenges to renewable energy development in South Africa, Pegels (2010) further recommends the support of independent power producers, being transparent, encouraging public participation in drafting policies and in decisions about long-term investments in renewable energy.

2.2. HYDROPOWER

The twenty-first century faces global challenges that are related to climate change, food security, population growth, and sustainable economic growth (Thatcher, Nayak and Waterson, 2020). When considering the status of national electricity shortages, the emphasis to reduce the emissions of GHG, and the growing electricity demand, it is evident that how energy is generated and consumed needs to change. Fossil fuels contribute a considerable proportion of the electricity that is generated globally; however, when fossil fuels such as coal are burned, airborne toxins and pollutants are released (Färe, Grosskopf and Pasurka, 2010; Cui et al., 2019). These toxins include lead (Pd), SO_2, carbon dioxide (CO_2), mercury (Hg), and nitrogen oxides (NO_2), which lead to anthropogenic climate change by increasing the greenhouse effect, and health issues such as asthma, heart diseases, brain damage, and neurological disorders. Shikwambana, Mhangara and Mbatha (2020) examined the trends of NO_2 and SO_2 produced by South Africa's coal-fired power stations, for a period of 39 years (1980–2019). An increase in SO_2 was observed in the Mpumalanga, Limpopo, and Gauteng regions. The authors believe the increase in SO_2 and NO_2 over the period investigated is attributable to the emissions from coal-fired power stations within these regions, aging power stations, increasing electricity demand, and the usage of low-quality coal. Furthermore, NO_2 and SO_2 were more concentrated in the regions during summer months, and less concentrated during winter months. The authors argue that the increasing number of power stations in South Africa will lead to a further increase in these toxic pollutants, and that cleaner sources of energy such as solar and hydropower need to be exploited.

To expedite sustainable development, the United Nations set out Sustainable Development Goals (SDGs), which were adopted by all members of the United Nations, in the year 2015 (Goodall and Moore, 2019). The SDGs aim to end poverty, protect the planet, and ensure that there is prosperity and peace among all human beings by the year 2030. One SDG that promotes the development of renewable energy sources is Goal 7, which aims at ensuring "universal access to clean, affordable, reliable and modern energy services by 2030" (United Nations, 2018). With the demonstrated drive toward the use of renewable energy sources, global and local communities are making efforts to explore renewable energy sources that are not only clean but also have reduced social and environmental impacts (Aliyu, Modu and Tan, 2018; Marcetelli, 2020). Although hydropower is the largest renewable source of energy with 71% of global production of renewable energy, it is estimated that only 22% of hydropower potential has been exploited globally (Moran et al., 2018).

CLIMATE CHANGE PROJECTIONS FOR AFRICA

The vulnerability of African countries to climate change is highlighted in the 6th assessment report of the Intergovernmental Panel on Climate Change (IPCC). This report provides an updated understanding of climate change at a regional level, with a focus on risk assessment, adaptation, decision-making, and a tool that assists in translating the latest advances in research of the climate such as heat, cold, precipitation, drought, snow, wind, and coastal flooding (IPCC, 2021). From the report, it is evident that CO_2 is the main driver of climate change, alongside other GHGs and air pollutants. The report suggests that anthropogenic activities still have the potential to influence the progression of climate change. The report also indicates that global average precipitation inland has increased since 1950, and at a faster rate since the 1980s (IPCC, 2021). According to the report, every region in the world is affected by human-induced climate change. To illustrate, the poleward shift in mid-latitude storm tracks in both hemispheres since the 1980s is said to be most likely influenced by anthropogenic activities. This is evident in the heatwaves, heavy precipitation, droughts, and tropical cyclones, which have strengthened since the release of the 5th IPCC report in 2014 (IPCC, 2021). See **Table 2** for a regional syndissertation provided by the IPCC Interactive Atlas[1] for the Southern African region. These projections indicate that precipitation will likely decrease and temperature increase, implying the installation of hydropower will be complex. This justifies the need for a South African Hydropower Atlas that collates hydropower-related data and makes it accessible to the public.

Table 2: Climate change projections of the IPCC Interactive Atlas for the Southern African region (IPCC, 2021).

West Southern Africa	East Southern Africa
High confidence of increase in extreme heat	High confidence of increase in extreme heat
High confidence of decrease in mean precipitation	Medium confidence of decrease in mean precipitation
Low confidence in direction of change in heavy precipitation and pluvial flood	High confidence of increase in heavy precipitation and pluvial flood
High confidence of increase in aridity	High confidence of increase in aridity
Medium confidence of increase in hydrological drought	Medium confidence of increase in hydrological drought
High confidence of increase in agricultural and ecological drought	Medium confidence of increase in agricultural and ecological drought
High confidence of increase in fire weather	High confidence of increase in fire weather

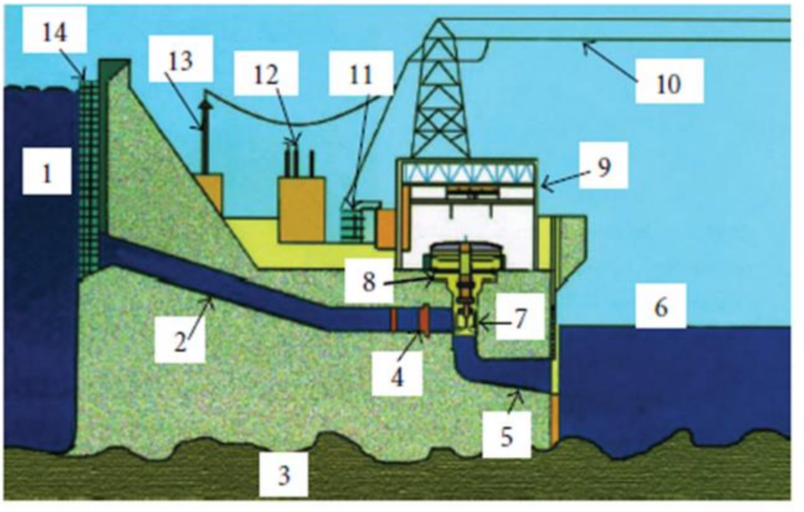
THE DEVELOPMENT OF HYDROPOWER

Hydropower is derived from the energy of water that is in motion, generating electricity in similar ways to coal-fired power stations (USGS, 2019). According to the USGS (2019), coal-fired power stations utilise steam to turn a propeller-like blade called a turbine; whereas hydropower stations utilise water that is in motion to turn the turbine. Typically, a dam is built on a river that has a decline in elevation (see **Figure 2**, pg. 11). The water is stored in the reservoir, behind the dam [1]. There is a water intake at the bottom of the dam wall, where water falls through the penstock [2], and rotates the turbine [7] (USGS, 2019). To generate electricity, the turbine output shaft is connected to the generator [8]. The generator consists of an electromagnetic rotor, which contains electric wires, which turn and generate electricity (Kaunda, Kimambo and Nielsen, 2012). Transmission of the generated electricity takes place through transmission lines [10] that transfer the electricity to different load points. Finally, the water continues into the river past the dam [5; 6].

Many countries have begun to prioritise the development of hydropower as a renewable energy source, considering its economic, environmental, and technical benefits (Huang and Yan, 2009). These countries include Brazil, where almost 75 % of grid electricity is obtained from hydropower (Yuksel, 2010), and many other African countries. According to the International Hydropower Association (2015), the DRC has the largest hydropower potential in Africa and if developed, possesses the potential to electrify a huge portion of Africa, reaching as far as South Africa through long-distance transmission. The technically feasible potential is estimated to be 100 000 MW, and only two-and-a-half percent of this potential had been developed as of 2015. The Congo River, which is the main source of this hydropower potential, holds the second-largest flow and second-largest watershed in the world and is thus the largest and most powerful river in Africa. Plans are being made for additional hydropower capacity as part of the Grand Inga III project. It is reported that if fully developed, Grand Inga will hold the capacity to generate 40 gigawatts (GW), and double the hydropower generated by the Three Gorges Dam in China, making it the largest hydropower project in the world (International Hydropower Association, 2015). Moreover, its generation costs are approximated to be USD 0.03 per kilowatt-hour (kWh), meaning it would be one of the most affordable sources of electricity and could theoretically meet 40 percent of Africa's electricity demands. However, a hindrance to the development of the Grand

[1] IPCC WGI Interactive Atlas: Regional syndissertation: https://bit.ly/3ymcIkn

Inga III project is the lack of a steady market for the electricity to be generated as the DRC does not have a demand that matches such a large-scale project. A South African example of hydroelectric implementation is the Drakensburg pumped storage scheme. The pumped storage scheme is the result of water transfer, over the Drakensburg, from the Tugela River catchment into the Vaal River catchment. The upper reservoir for the scheme is located in the Driekloof while the lower reservoir is located in Kilburn dam. The storage scheme has an installed capacity of 1000 MW.



(1) Reservoir (6) Tailrace water (11) Transformer
(2) Penstock (7) Turbine (12) Insulators
(3) Bed rock (8) Generator (13) Transmission tower
(4) Valve (9) Power house (14) Trash rack
(5) Draft tube (10) Transmission lines

Figure 2: Hydropower station and its basic components (Hydropower, 2000).

Hydropower is classed as either conventional or unconventional. The use of dams or impounds to store water in a reservoir, which is later used for hydropower generation refers to conventional hydropower. Different types of conventional hydropower include storage schemes (dams), run-of-river – also known as diversion, and pumped storage schemes. A storage scheme makes use of a dam to store water in a reservoir; this water is released from the reservoir for electricity generation (Water Power Technologies Office, 2020). Run-of-river schemes make use of little to no water storage; instead, these types of schemes channel a portion of a river through a canal or penstock (Rycroft, 2015; Water Power Technologies Office, 2020). Pumped storage schemes consist of lower and upper reservoirs. During periods of low electricity demand, the upper reservoir is pumped with water from the lower reservoir, using reversible pumps/turbines that make use of electricity from the national grid (Eskom, 2010). This water is then discharged back into the lower reservoir for electricity generation during periods of high electricity demand (Eskom, 2010).

Unconventional hydropower, on the other hand, entails harnessing the power of tides, waves, wastewater treatment plants, and man-made water supply infrastructure, without constructing a dam for the sole purpose of generating hydropower. Small water infrastructure, including extremely small water infrastructure such as those that supply water to our homes, have the potential to generate hydropower. Moreover, small hydropower turbines can be integrated into municipal and agricultural water systems, which supply drinking water, treated wastewater, stormwater, and irrigation water. This suggests that there is a substantial amount of hydropower potential that can be exploited in our water systems. Other examples of unconventional hydropower schemes include flow gauging systems, weirs, desalination plants, bulk transfer schemes, mines, and irrigation systems such as chutes, diversion, bridges, and canals.

Hydropower schemes are further generally classified according to size or head. The classification by head is related to the contrast in level between the inlet and outlet of a hydropower scheme (Kaunda, Kimambo and Nielsen, 2012). Head is an important parameter to consider as it determines the water pressure on the turbine and, thus, the power output. However, researchers have not reached common ground on classifying hydropower schemes according to head. The classification of hydropower schemes according to size has resulted in schemes being classified as either small-scale or large-scale, based on the power output. It is important to note that different countries categorise hydropower schemes differently. In South Africa, small-scale hydropower schemes have an electricity generation capacity that is up to 10 MW, whereas large-scale hydropower schemes have an electricity generation capacity that is greater than 10 MW as shown in **Table 3** (van Vuuren et al., 2014).

Table 3: Classification of hydropower schemes (van Vuuren et al., 2014).

Type	Category	Power output
Small-scale	Pico	< 5 kilowatts (kW)
	Micro	5 – 100 kW
	Mini	100 kW – 1 MW
	Small	1 MW – 10 MW
Large-scale	Large /Macro	> 10 MW

An example of small-scale hydropower in South Africa is the Ncora hydropower scheme, which produces 1,6 MW (Rycroft, 2014). Examples of large-scale hydropower stations include the Gariep, Ingula and Vanderkloof hydropower schemes, which produce 360 MW, 1332 MW and 240 MW respectively. A list of Eskom-operated hydropower power stations is given in **Table 4.**

Table 4: Eskom-operated hydropower stations in South Africa.

Power Station	Type	Installed Capacity (MW)	Nominal Capacity (MW)
Colley Wobbies	Hydroelectric	42	-
Drakensberg	Pumped storage	1000	1000
First Falls	Hydroelectric	6	-
Gariep	Hydroelectric	360	360
Ingula	Pumped storage	1332	1334
Ncora	Hydroelectric	2	-
Palmiet	Pumped storage	100	400
Second falls	Hydroelectric	11	-
Vanderkloof	Hydroelectric	240	240

Hydropower is said to be one of the most affordable energy sources in terms of electricity generation costs since water is readily available with reduced environmental and social cost implications (Hydropower, 2000). Von Sperling (2012) also believes that hydropower is a sustainable form of energy since water that is in motion is utilised to generate electricity, without consuming the water itself. Power utility companies recommend hydropower as a baseload (Kaunda, Kimambo and Nielsen, 2012). The Gariep and Vanderkloof large-scale hydropower schemes can supply South Africa with power in the case of a countrywide blackout. In addition, hydropower stations respond more efficiently to power demand fluctuations relative to other power generation systems such as thermal electric power stations. Thus, hydropower is a renewable energy source that could potentially lessen South Africa's overdependence on fossil fuel and the threat of load-shedding, yet currently makes up an insignificant contribution to the energy mix (Statistics South Arica, 2018).

Although hydropower is a renewable energy source, its reliability in water-scarce Southern African countries, including South Africa, has been questioned under projected impacts of climate change such as increased average temperatures, changes in precipitation, and run-off, which will increase competition for water (Mukheibir, 2013; Moran et al, 2018; IPCC, 2021). Southern Africa faces acute water scarcity caused by drought recurrence, degradation of surface water resources, and increased demand for water from the agriculture sectors, indicating that the impacts of climate change are already felt (Matchaya et al., 2019). South Africa receives an estimated average of 450 mm of rain per year, which is below the 860 mm global average, and is listed among the 30 driest countries in the world

(Sancold, 2019). While the country is not yet confronted with an absolute water shortage problem, Donnenfeld, Crookes and Hedden (2018) warn that South Africa is overexploiting its already scarce renewable water resources. Dam levels are persistently low, and more than 60% of the country's rivers are overexploited, while only 33% of the country's main rivers are in good condition (Donnenfeld, Crookes and Hedden, 2018). Areas that are more susceptible to physical water scarcity are those with high population densities and low availability of freshwater, such as the Gauteng and Eastern Cape Provinces (Statistics South Africa, 2018; Mnisi, 2020). Moreover, apartheid spatial planning has resulted in many rural areas in South Africa not having access to basic water supplies (Masindi and Duncker, 2016). Only eight percent of the rainfall that South Africa receives runs into rivers and is available to be used or stored in dams. Furthermore, South Africa often experiences (dry) El Niño rainfall phases (Muller, 2019), and droughts are not uncommon. This implies that the water resources of the country are at risk of being further reduced in the short term and possibly the long term, having implications for any hydropower developments.

Hydropower projects generally have long investment return periods and are designed based on the average historical and predicted climate (considering rainfall and water fluctuations) of the region of interest (Mukheibir, 2013). Therefore, South Africa needs to explore ways in which hydropower can be developed and exploited within the context of the scarce water resources of the country, and future impacts of climate change since a hydropower scheme's operation can be affected under undesired climatic conditions. Nevertheless, although South Africa is a semi-arid country, Aliyu, Modu and Tan (2018) ascertain that there is potential for all forms of hydropower development throughout the country, especially in the Eastern Cape and KwaZulu Natal provinces. The authors estimate that the total hydropower potential in the country amounts to 11 000 GWh/year; however, only 1 400 GWh/year has been exploited in the past. This stands in stark contrast to the potential for small-scale hydropower in the country, which is projected at 880 GWh/year (Aliyu, Modu and Tan, 2018).

According to van Vuuren, Blersch and van Dijk (2011) the positive environmental impacts of hydropower include the reduced release of toxic gases or chemicals during the hydropower generation process compared to traditional electricity generation processes, such as burning fossil fuels. This means that CO_2 is not directly produced, waste generation is reduced, and environmental and health effects related to coal mining are also reduced. Yuksel (2010), further states that the socio-economic benefits of hydropower include employment generation in areas where the schemes are constructed, the construction of roads; furthermore, the costs of operating and maintaining a hydropower scheme are less likely to be subject to any increases as opposed to coal, oil and natural gas stations, since fewer workers are required on-site during normal operation, and since hydropower schemes generally have long lifespans of 50 to 100 years. Therefore, investing in hydropower can benefit multiple generations. In some areas, hydropower schemes have become recreational, and tourist attraction sites. Examples of hydropower schemes that are tourist attraction sites include the Gariep Dam and Loskop Dam in South Africa, Enguri Dam on the Enguri River in Georgia, and the Karahnjukar Dam in Iceland.

Although there are several benefits associated with the development of hydropower projects, von Sperling (2012) states that the costs (economic, social and environmental) of hydropower also need to be considered. Negative environmental impacts of hydropower include changes in water quality, loss of flora and fauna, emission of GHG by bacteria and sediments that have accumulated in the water, and gases released during the construction of the hydropower scheme (von Sperling, 2012). Studies have shown that the construction of dams for hydropower generation can affect fish populations; for example, the number of fish was reduced by 25 % after the construction of dams on the Tocantins River, Amazon (Moran et al., 2018). The reduced quality of the water due to factors such as algal blooms and excessive vegetation growth can affect recreational use and aesthetics, lead to the overpopulation of insects, which in turn leads to disease outbreaks, such as malaria and schistosomiasis (bilharzia) (de Sousa and Reid, 2010). In addition, water in a dam tends to be warmer in winter and cooler in summer, than it would be if there were no dam (von Sperling, 2012). As this water flows downstream, the altered temperature of the water affects the temperature of the river, impacting plant and animal life in both the dam and river. In-stream flow is defined as the water that is retained in a river. In-stream flow requirements, on the other hand, refers to the amount of flows or releases required to protect and maintain estuarine ecosystems (MacKay and Moloi, 2002). In-stream flow requirements include the quantity and quality of water within a river, and the frequency and concentrations of water quality variables that are required to maintain a healthy river ecosystem (MacKay and Moloi, 2002). By diverting water for hydroelectric generation, dams reduce river levels thus reducing the amount of water that is required for healthy in-stream ecosystems. Dams can also alter the timing of flows by irregularly holding and releasing water.

Social impacts of hydropower include the high costs related to the construction of dams implying that the hydropower scheme must operate for years before the project becomes profitable, the relocation of community members who live in areas where hydropower schemes are planned, as well as dam failures. Moran et al. (2018) identify the aging of construction materials and accumulation of sediment behind the dam impoundment as the main sources of dam failures. In the past, dam failures have resulted in the loss of property and fatalities. For example, in 1994, a tropical storm in Georgia resulted in 230 dam failures. Similarly, the Oroville Dam Spillway in California failed in 2016 after heavy rains, resulting in the evacuation of 190 000 people (Moran et al., 2018). The Tucuruí project in Brazil resulted in the loss of 13.4 million m^3 of timber, several animal and plant species were lost to flooding, archaeological sites damaged and GHG emissions (de Sousa and Reid, 2010).

The construction of dams can also result in substantial geological damage. The construction of Hoover Dam in the United States of America triggered earthquakes and depressed the earth’s surface at its location (Bagher et al., 2015). The construction of the Aswan Dam in Egypt, on the other hand, led to the damage of several ancient monuments owing to destructive minerals and salts deposited on these structures, due to the altered water table level (Bagher et al., 2015). One example that is particularly close to home is the Lesotho Highlands Water Project which is a project between Lesotho and South Africa that comprises the construction of water tunnels and dams to divert water from Lesotho to the Vaal River system in South Africa. The project has resulted in the relocation of three villages, the drowning of villagers and livestock, loss of traditional assets, triggering of earth tremors, and the cracking and collapsing of houses (Manwa, 2014). As such, environmental and societal impacts can be profound. The resettlement of communities ultimately affects agriculture (loss of farming plots), lifestyles, businesses, and the economy of the affected area.

These events demonstrate that the construction of dams for hydropower projects may not necessarily be a favourable option. For this reason, van Vuuren, Blersch and van Dijk (2011) investigated unconventional applications of hydropower, such as retrofitting existing dams and reservoirs with hydropower plants. This entails fitting hydropower plants to already existing reservoirs to meet base or peak electricity demands, instead of constructing dams for the sole purpose of hydropower (van Vuuren, Blersch and van Dijk, 2011). Many countries have begun retrofitting hydropower onto their existing water infrastructure these include Japan, Sudan and Spain (Loots et al., 2015). This form of hydropower application does, however, present a few drawbacks since there are only a predetermined number of water infrastructure and sytems in existence. Nonetheless, impacts on the environment are minimised, there is energy to be exploited, and this form of hydropower is suitable for small-scale hydropower schemes where the construction of a large dam would be impractical.

Notwithstanding the risks and costs of hydropower, it is believed that further development of hydropower in South Africa will play a significant role in contributing to the energy mix, and rural and remote electrification since centrally generated power does not reach some remote areas in the country. This is due to; for example, lack of infrastructure, inadequate electricity generation and theft (van Dijk et al., 2014; Bonthuys, van Dijk and Bhagwan, 2016). To make the further development of South African hydropower attractive, the benefits of hydropower need to exceed the costs, thus environmental impact and social impacts assessments need to be optimally performed before hydropower projects are undertaken. Moreover, innovative hydropower technologies with minimal environmental impact need to be implemented, and transparency with society regarding the true benefits and costs of hydropower schemes also needs to be achieved (Moran et al., 2018).

2.3. POTENTIAL AND OPERATIONAL HYDROPOWER IN SOUTH AFRICA

Hydropower has been tested and proven to be a reliable and cost-effective energy source. However, Rycroft (2014), argues that only 24% of the hydropower potential in Africa has been developed relative to 86,8% in Europe, as of 2014. In South Africa, due to the scarcity of surface water, some researchers perceive the potential for hydropower development to be relatively low (Donnenfeld, Crookes and Hedden, 2018).

According to the Department of Water and Sanitation (2018), South Africa has 21 drainage regions. These drainage regions are given in **Table 5**. The largest region is that of Orange (D), while the smallest is that of Swartkops (M) (see **Figure 3**, pg. 16).

Table 5: South African drainage regions.

<table>
<tr><th>Drainage name</th><th>Code</th><th>Area (km²)</th><th>Brief description</th></tr>
<tr><td>Limpopo</td><td>A</td><td>62,541</td><td>Drains to the Indian Ocean.</td></tr>
<tr><td>Olifants</td><td>B</td><td>54,570</td><td>Drains to the Limpopo River.</td></tr>
<tr><td>Vaal</td><td>C</td><td>196,438</td><td>Drains to the Orange River.</td></tr>
<tr><td>Orange</td><td>D</td><td>973,000</td><td rowspan="2">Drains to the South Atlantic Ocean.</td></tr>
<tr><td>Olifants/Doorn</td><td>E</td><td>46,220</td></tr>
<tr><td>Buffels</td><td>F</td><td>9,249</td><td>Drains to the Atlantic Ocean.</td></tr>
<tr><td>Berg</td><td>G</td><td>7,715</td><td>Drains to the South Atlantic Ocean.</td></tr>
<tr><td>Breede</td><td>H</td><td>12,384</td><td rowspan="14">Drains to the Indian Ocean.</td></tr>
<tr><td>Gouritz</td><td>J</td><td>45,715</td></tr>
<tr><td>Coastal Rivers</td><td>K</td><td>-</td></tr>
<tr><td>Gamtoos</td><td>L</td><td>34,635</td></tr>
<tr><td>Swartkops</td><td>M</td><td>0.59</td></tr>
<tr><td>Sondags</td><td>N</td><td>-</td></tr>
<tr><td>Boesmans</td><td>P</td><td>2,670</td></tr>
<tr><td>Fish</td><td>Q</td><td>30,800</td></tr>
<tr><td>Nahoon/Keiskamma</td><td>R</td><td>1,287</td></tr>
<tr><td>Great-Kei</td><td>S</td><td>20 611</td></tr>
<tr><td>Mzimvubu/Umbashe</td><td>T</td><td>19,853</td></tr>
<tr><td>Mvoti/Mgeni/Mkomazi</td><td>U</td><td>2,829</td></tr>
<tr><td>Tugela</td><td>V</td><td>29,100</td></tr>
<tr><td>Usutu/Phongolo/Mfolozi</td><td>W</td><td>11,068</td></tr>
<tr><td>Sabie/Krokodil/Mfolozi</td><td>X</td><td>6,320</td><td>Drains to the Komati River.</td></tr>
</table>

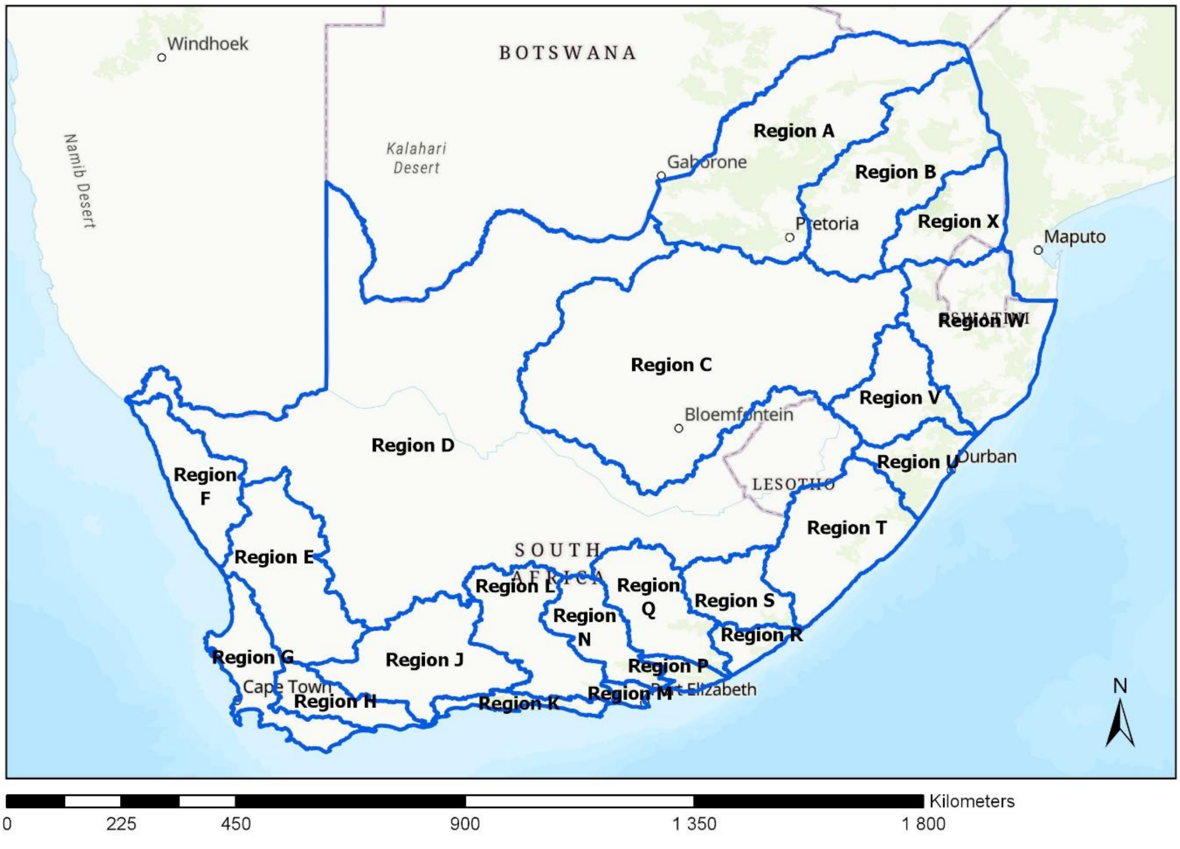


Figure 3: Drainage regions in South Africa.

Within these drainage regions lie over 4 000 South African dams (Water Research Commission, 2018). Dams are constructed for various purposes including irrigation, urban or rural water supply, recreation and hydropower generation. According to the Water Resource Strategy 2 (NWRS 2) of the Department of Water Affairs and Sanitation (DWS), only two percent of the water that is stored in the country's dams is utilised for power generation, while the remaining water is made available to various sectors including agricultural, domestic, and industrial (van Dijk, Bhagwan and Dedekind, 2016). When the national electricity grid was expanded, many of the hydropower schemes were decommissioned, these included the Sabie Gorge hydropower schemes in Mpumalanga, which was decommissioned in 1964, following the connection of the area to the national grid (Rycroft, 2014). The first new small-scale hydropower scheme was constructed in the Sol Plaatjie Municipality in 2009, after nearly 30 years of disregarding the hydropower potential of the country (Rycroft, 2014). This paved the way for the development of many more hydropower projects (see **Figure 4; Table 6**; pg. 17). South Africa has since dominated the Southern African region in terms of both installed small-scale hydropower capacity and available hydropower potential. According to Rycroft (2014), small scale hydropower schemes that have since been developed include the First Falls small hydropower scheme, which consists of two 3 MW units, the Ncora small hydropower scheme, which consists of a single 1,6 MW unit, and the Lydenburg small hydropower scheme with an electricity output of 2,6 MW. A further 75 MW has been allocated for small hydropower by the REIPPP. The REIPPP has encouraged more hydropower development, including the Neusberg hydropower scheme and the Stortemelk hydropower scheme (4,47 MW). There is also a considerable number of small hydropower schemes that have been decommissioned but could be reconstituted back to working order. These include the Belvedere (2,2 MW) and Hartbeespoort (37 kW) small-scale hydropower schemes.

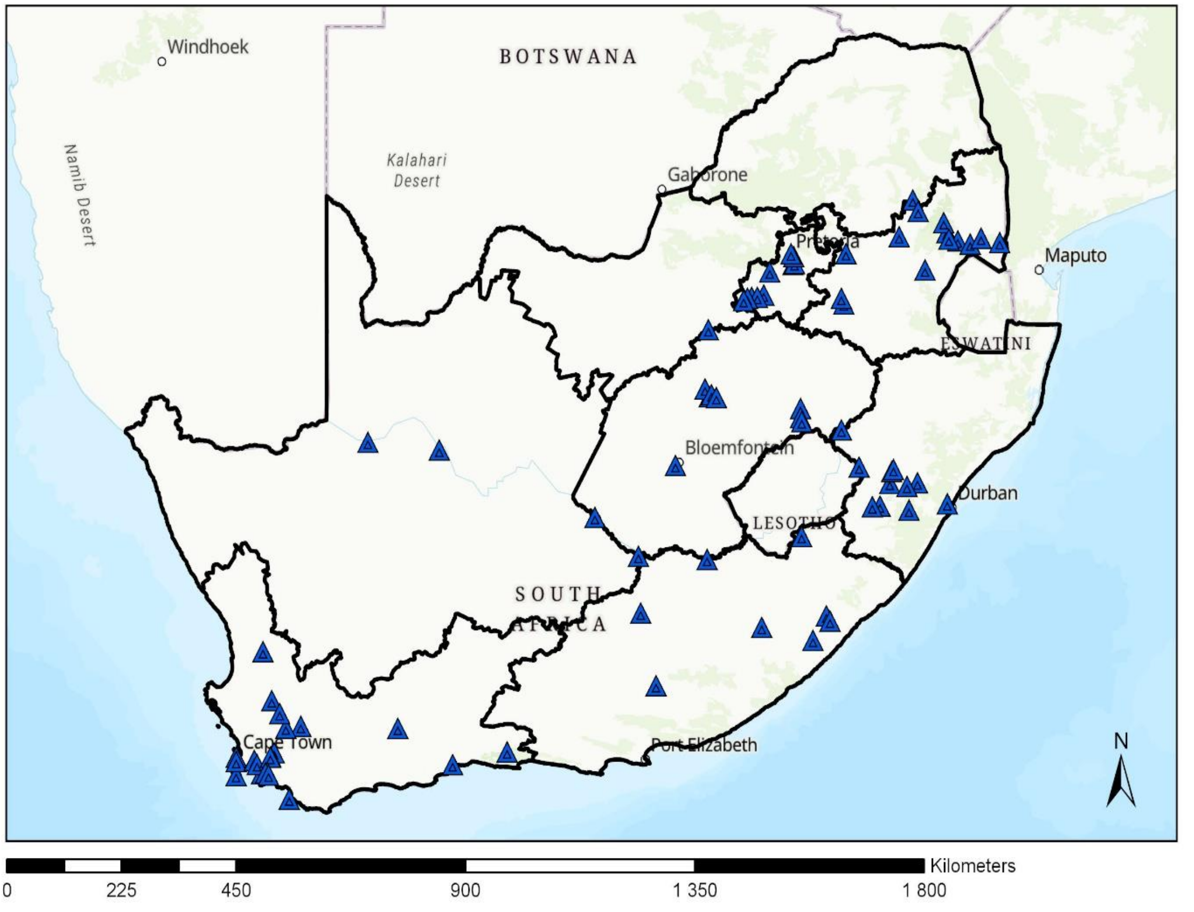


Figure 4: Existing hydropower schemes in South Africa.

Table 6: South African examples of hydropower schemes and the different categories they fall under (Sanitation, 2015).

Type	Category	South African example
Small-scale	Pico	Zeekoegat WWTW (0.0069 MW)
		Blackheath WWTW (0.712 MW)
	Mini	Steenbras WWTW (0.340 MW)
		Wemmershoek WTW (0.208 MW)
		Boston (4.2 MW)
		First Falls (6 MW)
		Merino (3.6 MW)
	Small	Ncora (2 MW)
		Sol Plaatjie (2.5 MW)
		Lydenburg (2.6 MW)
		Stortemelk (4.5 MW)
		Colley Wobbles/Mbashe (42 MW)
		Drakensberg (1 000 MW)
		Gariep (360 MW)
		Hazelmere (10 MW)
Large-scale	Large	Ingula (1332 MW)
		Neusberg (12.57 MW)
		Palmiet (400 MW)
		Second Falls (11 MW)
		Steenbras (180 MW)
		Vanderkloof (240 MW)

More recent small-scale hydropower developments include the 96 kW micro conduit hydropower plant at Bloemwater in Bloemfontein, and the 15 kW pico plant at the Pierre van Ryneveld Reservoir in Pretoria, which were implemented by the Hydro Research Group in the Department of Civil Engineering at the University of Pretoria, and the 150 kW hydropower plant at the Annlin reservoir in Pretoria North (van Dijk, Bhagwan and Dedekind, 2016). It is anticipated that soon, small hydropower projects in South Africa will be used for private use, as well as rural electrification. Micro hydropower stations have also shown great potential (see **Figure 5**, pg. 18). However, worthy of note is that some of the areas with micro hydropower potential that have been identified by Rycroft (2014) are located in a transfrontier park. A transfrontier park is an area with a primary purpose of wildlife and environmental conservation. Therefore, the development of hydropower within these areas would not be ideal. There is a considerable number of micro hydropower stations that have been developed in the country and are currently operating, mainly in the Eastern Cape and KwaZulu Natal. According to Rycroft (2014) these micro hydropower stations primarily supply electricity to individual farmers.

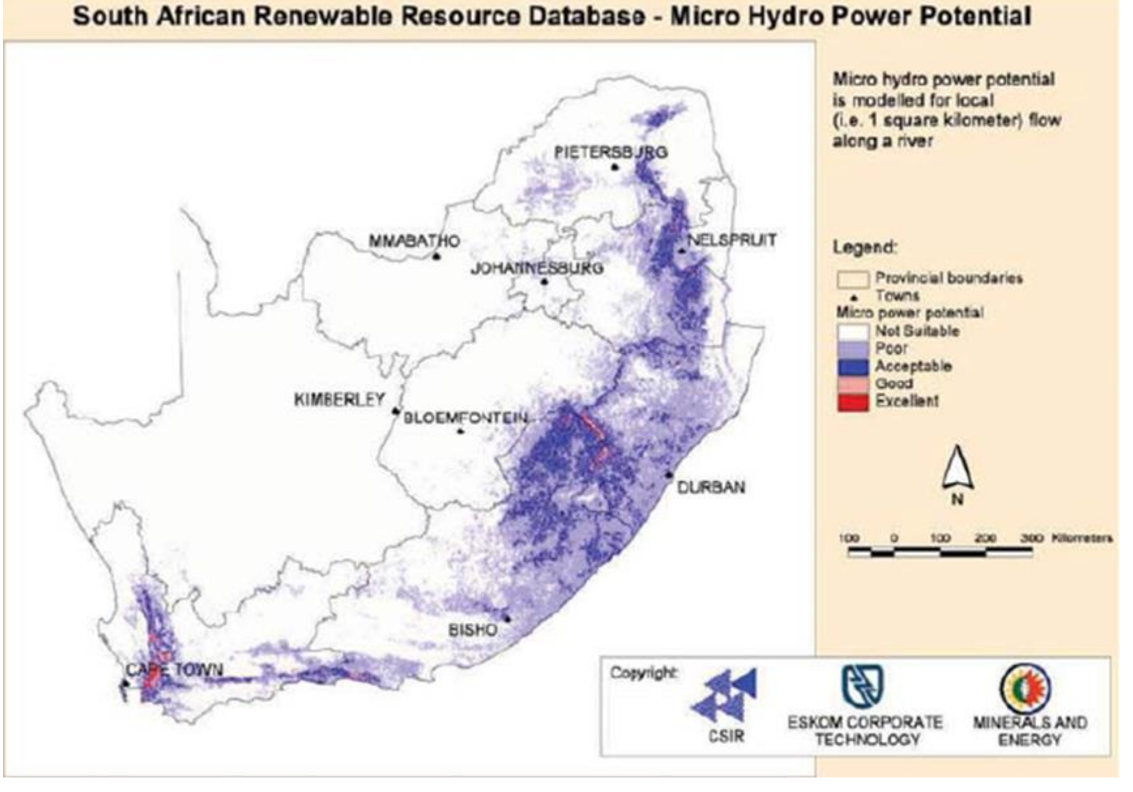


Figure 5: Micro hydropower potential in South Africa (Rycroft, 2014).

Van Vuuren, Blersch and van Dijk (2011) explain the hydropower generation process as one that entails the conversion of water pressure by hydro turbines, into mechanical shaft rotation, which is subsequently used to power an electric generator. The mathematical relationship, that the potential hydropower is directly proportional to the flow through the turbine and the pressure head (van Vuuren, Blersch and van Dijk, 2011), is given by the **Equation 1**:

Equation 1: Hydropower potential equation,

Where: P = mechanical power output [W], η = hydraulic efficiency of the turbine [%], ρ = density of water [1 000 kg/m^3], g = gravitational acceleration = 9.81 [m/s^2], Q = flow rate through the turbine [m^3/s], and H = head [m].

$$P = \eta \rho g Q H$$

A study by van Vuuren et al. (2013) indicates that owners and administrators of urban systems such as irrigation systems, water distribution networks, and wastewater treatment plants do not have the knowledge necessary to harness the hydropower that might be concealed in the plants that they are operating. From the study, it is gathered that the benefits of small-scale and conduit hydropower include their high efficiencies, long life span (average minimum of 20 years), they can be integrated into existing man-made infrastructure (i.e., environmental impacts are reduced), there is no need to build a dam or reservoir, and they have low maintenance and operational costs (van Vuuren et al., 2013). For this reason, this dissertation also investigated potential unconventional hydropower sites, as well as cataloguing conventional schemes, for inclusion in the atlas ultimately accessible to the public.

2.4. ASSESSING AND MODELLING HYDROPOWER POTENTIAL

Aman and Malik (2017) emphasize that streamflow discharge and head are important considerations when selecting a site for a hydropower project. Furthermore, the authors argue that the selection of a turbine for a hydropower site is dependent on the available data for the site such as head, flow discharge, efficiency, costs, *etc. (*Aman and Malik, 2017). The authors investigated the Bamyan River in Bamyan, Afghanistan for the assessment of hydropower potential. The Pelton turbine (see **Table 7**) was selected for the proposed site and the hydraulic efficiency (η) was assumed to be 80%. The probability of occurrence for a given mean monthly flow discharge (m^3/s) was then estimated. Similar to the study conducted by van Vuuren, Blersch and van Dijk (2011), **Equation 1** (pg. 18) was applied to assess the available power (P) in watts (W) from their proposed hydropower site. The hydropower potential at the site was then estimated to be 1090.20 kW.

Table 7: Hydropower turbines and their efficiency ranges (Aman and Malik, 2017).

Turbine	Efficiency range
	Impulse turbine
Pelton	80-90%
Turgo	80-95%
Cross flow	65-85%
	Reaction turbine
Francis	80-90%
Pump as turbine	60-90%
Propeller	80-90%
Kalpan	80%

A study conducted by Kotei et al. (2017) examined streamflow at Mampong-Ashanti in Ghana for the 1985-2009 (25 years) period. The authors analysed the mean daily discharge records to characterise the variability of the streamflow at 5 %, 50% and 95 % of the time during the 1985-2009 period. The authors observed the available streamflow to be 0.14 m^3/s at 95 % of the time, 45 m^3/s at 50% of the time, and 5.53 m^3/s at 5% of the time. The authors report that the changes in streamflow observed during the 25 years were driven by increases in temperature and variations in precipitation patterns.

Remote potential sites for hydropower have in some instances become a barrier to hydropower development. However, the increasing convenience of analysing and processing data using Geographic Information System (GIS), remote sensing software, and hydrological modelling have allowed researchers to apply various methods to determine potential sites for hydropower development and hydropower potential at specific sites. Hydrological modelling entails the characterisation of real hydrologic features, and systems using small-scale physical models, mathematical analogues, and computer simulations (Allaby and Allaby, 1999). Hydrological models that are frequently used include the Spatial Processes in Hydrology (SPHY), Soil & Water Assessment Tool (SWAT), Soil Water Atmospheric Plant (SWAP), Water Evaluation and Planning (WEAP), and AquaCrop. SWAT modelling has been applied in numerous studies to simulate the hydrological processes and provide estimations of river flow in ungauged basins (Stehr et al., 2008; Sammartano, Liuzzo and Freni, 2019). For example, Rospriandana and Fujii (2017) assessed hydropower potential in Ciwidey, Indonesia, using a combination of GIS methods and SWAT hydrological modelling. The SWAT hydrological model requires various inputs such as topological data or Digital Elevation Model (DEM), soil type, land use/ land cover data, and data that are related to the weather such as temperature and precipitation (Rospriandana and Fujii, 2017). The authors identified hydropower potential at nine different sites according to head, stream order, and the distance between each potential site. The results of their Flow Duration Curve analysis at 60%, 75% and 90% dependability thresholds suggested that Ciwidey has a total hydropower potential of 1.72 MW. While Larentis et al. (2010) made use of a GIS-based program named Hydrospot to identify hydropower potential sites. The authors automated remote sensing and regional streamflow data within the GIS program, which allowed them to extract terrain characteristics from a DEM to identify potential sites on the drainage network. Ballance et al. (2000), on the other hand, assessed hydropower potential in South Africa by calculating the energy potential from slope and runoff maps. This method allowed the authors to measure micro and macro hydropower potential. Micro hydropower potential was calculated from local and run-of-river flow data; whereas, macro hydropower potential was calculated from cumulative river flows since macro hydropower generation requires storage (Ballance et al., 2000).

Potential for both micro and macro hydropower was observed on steeper and humid slopes that are on the Southern escarpment near Cape Town and the Eastern Escarpment. Sammartano, Liuzzo and Freni (2019) applied GIS and SWAT hydrological modelling to identify potential locations for run-of-river hydropower stations, in the Taw at Umberleigh catchment, England. Kusre et al. (2010) assessed the hydropower potential of Kopili River basin in Assam, India, to identify suitable sites for hydropower generation. To achieve this, the authors similarly applied GIS tools and SWAT. A recent study by Thin et al. (2020) estimated run-of-river hydropower potential for the Myitnge River Basin in Asia, by integrating a GIS-based tool developed using Python and SWAT modelling. The authors identified potential locations for hydropower stations; furthermore, flow duration curves were developed at the identified locations and the design discharge for hydropower was also estimated. A total of 44 run-of-river potential hydropower sites were identified. Prajapati (2015) followed a different approach to assess the run-of-river hydropower potential of the Karnali Basin, by using GIS and Continuous Semi-distributed Hydrological Modelling (HMS) and estimated a total hydropower potential of 14 150,80 MW.

The example studies given above thus illustrate the use of GIS in modelling potential hydropower in various settings and using various methods and approaches. Some studies have been applied to the South African context, like the one of Ballance et al. (2000), yet few provide hydropower potential for the whole of South Africa. Yet such information needs to be included in any hydropower atlas, to provide suitable information to potential users.

2.5. ASSESSING EXISTING RENEWABLE ENERGY RESOURCES

South Africa has numerous renewable energy resources available to the public (Department of Energy, n.d.). Nonetheless, the main source of energy is derived from coal, which poses several health and environmental costs (Ewald, 2018). If South Africa is going to attempt to reduce the implications of depending on coal-fired powered stations for electricity generation, information regarding renewable energy resources of the country needs to be made accessible to the public. The Department of Energy has in part managed to achieve this by making information regarding the renewable energy resources of South Africa available. The available information for renewable energy sources in South Africa has been summarised in **Table 8**.

Table 8: Available information for energy sources in South Africa.

Renewable Energy Potential	Source	Interactive Web Resource	Type
Bio	https://bea.saeon.ac.za/wp-content/uploads/2021/03/Bio-Energy-Atlas.pdf	Yes	• Article/report (numerous) • Geospatial data for download • Metadata (standalone) • Online maps (standalone)
Geothermal	https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/16054.pdf	No	• Article/report (limited) • Article by Tshibalo et al. (2015) • Maps included in article/report • Limited metadata available in article/report
Hydro	https://hydro4africa.net/	No	• Article/report (limited) • Articles by Balance et al. (2000), and Kusakana & Vermaak (2013)

Renewable Energy Potential	Source	Interactive Web Resource	Type
Solar	https://globalsolaratlas.info/download/south-africa	No	• Article/report (numerous) • Maps (standalone) • Metadata available in article/report
Wave	http://www.crses.sun.ac.za/files/research/publications/technical-reports/SANEDI(WaveEnergyResource)_edited_v2.pdf	No	• Article/report (limited) • Report by CSSES () • Maps included in article/report • Limited metadata available in article/report
Wind	http://www.wasaproject.info/about_wind_energy.html	No	• Article/report (numerous) • Geospatial data for download • Metadata (standalone) • Online maps (standalone)

VOLUNTEERED GEOGRAPHIC INFORMATION

According to Knorr et al. (2016), the two renewable energy sources that show the greatest potential in South Africa are solar and wind energy. Another renewable energy source that has proven to have potential in diversifying the energy mix of the country yet contributes (relatively) little to the South African energy mix, is hydropower (Genaat et al., 2017; van Dijk et al., 2017). At present, information on hydropower-related geospatial layers and metadata are not accessible through a central repository or portal. Yet making information about hydropower freely available and accessible will encourage discussions regarding the future of the energy system of the country. To achieve this, this study has undertaken the development of an online interactive South African hydropower atlas that will be accessible to the public. It must be noted that a Volunteered Geographic Information (VGI) portal related to hydropower resources does exist – Hydro4Africa. Hydro4Africa is an online database managed by Wim Jonker Klune that allows the public to sign up to the database and provide information regarding hydropower schemes in Africa.

VGI, also known as citizen science, can successfully be used to collect geospatial data when such data are lacking. For example, VGI has been used in crisis and disaster management where available data were out of date (Antoniou and Skopeliti, 2015). The use of VGI can also bring down costs. However, VGI data must be used with caution. Since VGI data are submitted by volunteers, not all geographic spaces might be represented, as data submission is directly linked to the geographic spaces of those making submissions. Similarly, one must consider if the data submitted is representative of other non-volunteers. Furthermore, one must consider if volunteers are more likely to provide data on places or properties that interest them than those that do not. Finally, VGI does not ensure a certain level of data quality and it is difficult to ascertain the quality of submitted data (Sui, Elwood and Goodchild, 2012). Ostermann and Granell (2017) also argue that although the use of VGI continues to contribute to the increasing availability of geospatial data, which is a prerequisite to ensure the advancement of GIS, VGI makes it difficult for this data to be replicated and/or reproduced due to data quality constraints. In parallel lies the question of whether any standards of data collection are met. As such, while VGI is useful and plays a significant role, as a reliable information resource, portals derived from VGI should be used with extreme caution. As such, this project collates hydrologically related published or created datasets based on verifiable methods and literature, and subsequently makes these available through an online atlas for decision support purposes.

2.6. ASSESSING PLATFORMS FOR HOSTING THE ATLAS

Free and open-source software (FOSS) is software that grants the user the freedom to access, study and change the source code, and to use, copy and redistribute the software in any manner (GNU Project, 1996). In comparison, proprietary software is non-free (proprietary) software with usage, modification, and distribution limits that have been imposed by its vendor or developer(s). As with proprietary software, users of open-source software must accept the license terms and conditions, which normally differ significantly from those of proprietary software. According to Brovelli et al. (2017), FOSS for geospatial applications plays a key role in data collection, integration of information systems, stakeholder involvement, and dissemination of information. Such platforms and products are crucial, particularly for developing countries, since it enables these countries to develop their technologies instead of paying large amounts of money to import or purchase software. As a result, FOSS narrows the digital divide between developed and developing countries (Fong, 2009).

Some authors (e.g., Boulanger, 2005; Bwayla et al., 2019) argue that FOSS is more secure than proprietary software. In contrast Lynch (2015) argues that FOSS is not necessarily more secure; however, it is perceived to be more secure due to the fact it can be conveniently checked for security vulnerabilities by its users, without needing to blindly trust its developers or vendors. Noyes (2010); however, believes that FOSS is more easily exploitable. A study conducted by the author revealed that exploitation attempts on open-source software occur three days sooner than those on proprietary software do. Since access to the source code of proprietary software is limited, the security of proprietary software is highly dependent on its vulnerabilities remaining unknown with the hope of avoiding software attacks. However, this also has its downsides since the vendor does not benefit from knowledge and input from its users (Avner, 2019). Therefore, one cannot intuitively say one is more secure than the other since FOSS and proprietary software face different kinds of threats.

FOSS can be adapted to your necessities, it offers free support through its user communities; equally important, projects that make use of FOSS tend to have a greater number of users since it promotes ease of access. Nevertheless, this kind of software has a limited warranty since anyone can change it, it sometimes includes interruptive advertisements, which can affect the user experience, it is sometimes not compatible with all machines, upgrades and updates are normally not provided, and it appeals more to skilled users who know how to program (Bahmdi, 2020). Proprietary software, on the other hand, is more stable and capable of functioning well since it is not constantly changed by users, a warranty is guaranteed from its developers, it is compatible with most machines in some instances, easier to use, and provides greater functionality, regular upgrades and updates are provided. Like FOSS, this type of software is accompanied by several drawbacks that include paying for license and maintenance fees, the software cannot be modified or customized, offers features that may not be appealing to an average user meaning the user ends up paying for features that they will not use, and as previously mentioned, some specialists believe this type of software is less safe because users are fully dependent on the software developers for security. It is crucial to consider the project needs, flexibility, technical skills, and security when deciding whether to use FOSS or proprietary software. For the above reasons, several platforms were reviewed, to identify a suitable platform for hosting a South African hydropower atlas. This is discussed in the next section.

CHAPTER 3: MATERIALS AND METHODS

This research study involves the development of a South African Hydropower Atlas (SAHA). To achieve this, the study follows an inductive approach, which entails collecting information and data relating to South Africa's hydropower and hydrology which was then used to assess and model hydropower potential for South Africa. An empirical method was followed since scientific literature on hydropower, existing hydropower schemes, and methods used to determine hydropower potential were reviewed, providing evidence that hydropower projects have indeed been successfully implemented, worldwide and in South Africa. Furthermore, a constructive research approach was followed when developing the interactive hydropower atlas and creating the geospatial database.

Existing renewable energy atlases were assessed for common and preferred functionality for SAHA (

3.1. OBJECTIVE 1: ASSESSMENT OF KNOWN ATLASES, pg. 24), and a suitable platform for hosting the hydropower atlas identified by reviewing existing platforms. Datasets to be included in the hydropower atlas were identified, as were potential sources (**3.2. OBJECTIVE 2: SOURCING OF DATA**, pg. 36). Data related to existing hydropower-related geospatial and attribute data for South Africa were compiled in a centralised database, or are created, when not available. Literature was assessed for contextualisation and extraction of parameters required for achieving **3.3. OBJECTIVE 3: MODELLING SOUTH AFRICAN DAM HYDROPOWER POTENTIAL** (pg. 37). All datasets were uploaded to the chosen platform, and functionality and tools assessed for Objective 1 implemented in the creation of SAHA (**3.4. OBJECTIVE 4: DEVELOPING A WEB-BASED HYDROPOWER APPLICATION**, pg. 38). The hydropower atlas was subsequently assessed and tested for any errors or omissions and then adjusted until the result was satisfactory. **Figure 6** provides an overview of the different approaches that were followed to achieve the objectives of the research.

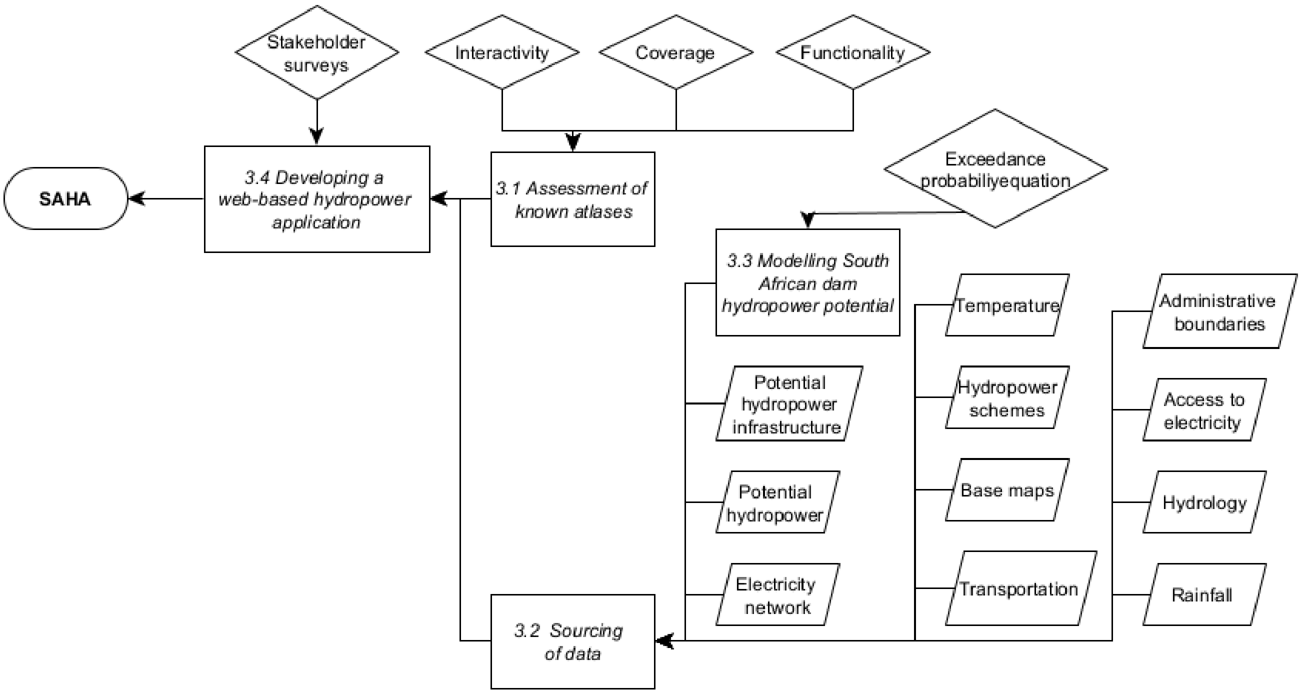


Figure 6: Overview of approaches followed to achieve the research objectives.

3.1. OBJECTIVE 1: ASSESSMENT OF KNOWN ATLASES

Objective 1 focuses on assessing existing renewable energy atlases for common and preferred functionalities for SAHA. The purpose of this objective is to identify functionalities and tools that other atlases have and those that will serve the purpose of SAHA. Assessing other atlases also aids in identifying areas for improvement, and functionalities that are relevant. Ultimately, the assessed atlases can be compared with the final hydropower atlas for better results. Furthermore, this objective also evaluates various platforms for hosting SAHA.

An online atlas can be described as an online resource or web map that displays geographic information that can be used for various purposes including decision making. Online atlases normally contain different data layers and functionalities, which vary according to the purpose of the atlas. Various online renewable energy resources were assessed to identify common and preferred functionalities for SAHA. The criteria used to assess online atlases include 1) interactivity, 2) functionality, and 3) coverage. Interactivity refers to the ability of an atlas to respond to the user's inputs. Functionality refers to the different functions and operations that the atlas has. Coverage refers to the area that is covered by the atlas. Regional coverage implies the atlas only covers a specific region, while continental coverage implies the atlas covers a specific continent.

Since hydropower contributes insignificantly to South Africa's energy mix and has received comparatively little attention in the country, there are no hydropower atlases in South Africa that can be assessed. Furthermore, some atlases require registration before access, whereas some cannot be accessed at all. **Table 9** summarises atlases that were successfully assessed.

Table 9: Examples of the assessed atlases.

Renewable energy type	Source	Interactive	Coverage	Description of Atlas
Bioenergy	Geothermal fields installations (URL: https://www.energy.gov/eere/solar/solar-energy-research-database)	Yes	Global	A web map showing the geothermal installations, by country, for electricity generation.
	BioEnergy Atlas for South Africa (URL: https://bea.saeon.ac.za/feasible-options-dashboard/)	Yes	Local	An Atlas that shows the bioenergy in south Africa.
Hydro	International Hydropower Association: Pumped storage tracking tool (URL: https://www.hydropower.org/hydropower-pumped-storage-tool)	Yes	Global	A web map, which shows the locations and statistics related to existing and planned pumped storage hydropower projects.
	WRC Mine Water Atlas (URL: http://minewateratlas.wrc.org.za/atlas/)	No	Local	The Atlas shows ground and surface water resources in South Africa.
Other	The SASSCAL Dam and Reservoir	Yes	Regional	An Atlas that provides access to data and information about dams in Angola, Botswana,

Renewable energy type	Source	Interactive	Coverage	Description of Atlas
	Atlas for southern Africa (URL: https://www.sasscal.org/drasa_prototype/)			Namibia, South Africa and Zambia
Renewable energy	Renewable Energy Generation Sites for South Africa (URL: https://www.energy.org.za/map-south-african-generation-projects)	Yes	Local	A web map indicating sites for renewable energy sites in South Africa including solar, small hydropower, land fill gas and bioenergy.
	H2 Atlas Africa (URL: https://africa.h2atlas.de/)	No	Regional	A web map that displays renewable energy sources in the Northeast Parts of Africa.
Solar	Global Solar Atlas for South Africa (URL: https://globalsolaratlas.info/map?c=11.609193,8.261719,3)	Yes	Global	A web application, which provides solar resource and photovoltaic power potential information.
Wind	Global Wind Atlas (URL: https://globalwindatlas.info/)	Yes	Global	A web application, which identifies areas with potential for wind power.
	The Wind Atlas for South Africa (URL: http://www.wasaproject.info)	Yes	Local	A web map application, which provides information related to wind that can assist planners, wind farm developers and other interested stakeholders.

As aforementioned, no South African hydropower atlas has yet been developed. This project focuses on the development of such an atlas, the SAHA. Online atlases normally contain different data layers and functionalities, which vary according to the purpose of the atlas. Functionality and tools common to assessed atlases were thus considered for inclusion in SAHA, as well as those specific to other hydropower atlases.

As discussed in **2.6. ASSESSING PLATFORMS FOR HOSTING THE ATLAS** (pg. 22 onward), there are advantages and disadvantages to FOSS and proprietary software. In addition to the information already provided, aspects such as security, stability, server requirements, data handling, user-friendliness, and accessibility must also be considered. The platforms evaluated are summarised in **Table 11** (pg. 27 onward)**.** This table provides an overview of the features, ease of use, and suitability of the identified platforms. **Table 10** provides example applications of each platform. In addition, the chosen suitable platform for hosting the South African Hydropower Atlas is revealed in the results chapter (see **4.2. OBJECTIVE 2: SOURCING OF DATA,** pg. 41 onward).

Table 10: Example applications of the different platforms identified.

Platform	Example
ArcGIS Online	https://www.arcgis.com/home/webmap/viewer.html?webmap=286415a3edcd43f89fa266edc0c89b08
CARTO	https://carto.com/demo/reveal-demo/
GeoDjango	https://www.youtube.com/watch?v=hl__H_wRqGM
GeoMoose	https://geomoose.com/features/example-sites/
gvSIG Online	https://www.youtube.com/watch?v=5qDumkOTJik
Leaflet.js	https://stephsaephan.github.io/leaflet-map-example/
Mapbox GL JS and Mapbox.js	https://demos.mapbox.com/elections-demo/
MapGuide Open Source	https://mapguide.osgeo.org/livegallery.html
MapX	https://unbiodiversitylab.org/
OpenLayers	http://elasticterrain.xyz/map/
QGIS Cloud	https://corona.giscloud.com/

Table 11: Assessed platforms for hosting web-based maps.

Platform	Description	Features	Ease of use and suitability to project
ArcGIS Online	ArcGIS Online is a well-known and widely used web-based Geographic Information System platform that allows users to create, use, share maps, scenes, layers, analytics and data (Esri, n.d.). The platform allows users to access workflow-specific apps, maps and data from around the world. It also provides a secure and private infrastructure to store data and maps. Since the Web AppBuilder for ArcGIS is developed on ArcGIS (API) for JavaScript and HTML5, project developers can develop GIS web applications that can be run on any device (Esri, n.d.). For more information regarding ArcGIS Online visit https://www.esri.com/en-us/arcgis/products/arcgis-online/.	• 2D and 3D data can be visualized. • Web maps can be shared with anyone, anywhere or kept private. • Project developers can access analysis tools that help provide insights into the data being used. • Supports the ESRI shapefile data format. • Offers interactivity and 3D scenes. • Provides analysis tools, measurement tools and many more other tools. • IT requirements such as security, authentication, and privacy are met. • Authors can manage who has access to the app and the activities that can be performed on the app. • It provides logging and other advanced reports. • Authors can add valuable context to their data by combining it with Esri's demographic and lifestyle data. • Data can be updated and added without disrupting the maps and apps that use the data.	• ArcGIS Server web services can be added to ArcGIS Online. • ArcGIS Server supports 64-bit Microsoft Windows operating systems, however, machines with an underscore (_) in their names are not supported. • ArcGIS Server is not supported on domain controllers. • ArcGIS Online offers a wide range of functionality that is readily available on the platform, without having to write a single line of code. • The platform is proven to be secure and has been trusted by even the most regulated industries. • This platform will, therefore, be able to provide most, if not all, the functionality that is required for the hydropower atlas and ensure that uploaded data are secure. • Nonetheless, issues with ArcGIS Online include proprietary formats, and difficulties of transferring data between Esri and other GIS software.

Platform	Description	Features	Ease of use and suitability to project
		• Web maps can be scaled to allow hundreds or even millions of users at the same time. • Supports most web browsers including Google chrome, Microsoft Edge, Microsoft Internet Explorer 11, Mozilla Firefox and Safari.	
CARTO	CARTO, formerly known as CartoDB, is an open-source platform that provides GIS, web mapping and spatial data science tools. The platform uses JavaScript in the frontend web application and Node.js based Application Programming Interface (API) in the backend, and for client libraries (Carto, n.d.). For more information on CARTO visit https://carto.com/.	• Offers SQL and tile maps API. • Authors can access and integrate its functionality with other applications. • Allows project developers to implement spatial analysis, geocode data, create polygons from points, detect clusters and outliers, create travel or distance buffers and intersect aggregate without writing a single line of code. • Supports data formats such as CSV, shapefiles, Keyhole Markup Language (KML) and GeoJSONs. • Supports the latest versions of Chrome, Firefox and Microsoft Edge web browsers.	• Coding is required to enhance the platform. • Requires the Nginx server. • The main aspect that stands out the most about this platform is the simple and easy to use drag and drop interface, which makes it easier to customize. • The platform can also be easily integrated with other applications. • This is a platform that does not require much work to set up. However, it is not known how secure the platform is.

Platform	Description	Features	Ease of use and suitability to project
GeoDjango	GeoDjango is a free geographic framework for developing web applications and intends to make it easier to build GIS web applications and to work with spatial data (Django, n.d.). Unlike other platforms, GeoDjango allows users to build custom applications from scratch. However, it does not provide any geospatial tools. This platform appeals more to developers who prefer the Python coding language. For more information on GeoDjango visit https://docs.djangoproject.com/en/3.1/ref/contrib/gis/.	• Supports OGC standards. • GeoDjango integrates very well with Django. • Extensible to enable the querying and manipulation of spatial data. • Provides Python interfaces for GIS geometry, raster operations and manipulation of data that are in different formats. • Supports KML, GML and GeoJSON and ESRI shapefiles. • User can edit geometry fields. • Supports most web browsers.	• Coding is required to customize and extend the functionality of the platform. • Requires PostgreSQL server. • Like gvSIG, GeoDjango appeals more to developers who prefer the Python coding language. • The platform does not provide any geospatial tools meaning the user has to programmatically build everything from scratch. This may prove to be time consuming and a difficult platform for users who are not familiar with Python.
GeoMoose	GeoMoose is a web-based platform for publishing and managing geographic data and is a combination of open-source JavaScript libraries such as OpenLayers and Dojo (GeoMoose, n.d.). This platform extends the functionality of MapServer and OpenLayers to provide built-in services such as selection operations and feature queries. Moreover, GeoMoose is lightweight and, therefore, makes it easier for servers to handle many users, data layers, and services without putting a strain on the server (GeoMoose, n.d.). The platform can also perform queries such as selections and buffering without the help of a server-side scripting language. For more information on GeoMoose visit https://www.geomoose.org/.	• Provides different tools including measuring, drawing, querying, fading, re-order, jump-to-zoom, coordinate readouts and many more. • Integrates with Mapserver. • Can publish many layers, almost unlimited. • Allows PDF printing. • Supports WMS and WFS. • Supports KML, GML and GeoJSON data formats.	• Coding is required to customize and extend the functionality of the platform. • Requires the Node.js, Nginx, Apache or IIS web servers. • One advantage that GeoMoose has over most of the other identified platforms is that it can handle hundreds of layers and/or services at a time very well. • The platform also provides most GIS functionality and an easily configurable user interface.

Platform	Description	Features	Ease of use and suitability to project
		• Supports the latest version of Firefox and Edge web browsers.	• It is not known how secure and stable this platform is.
gvSIG Online	gvSIG Online is an open source web-based platform that allows users to publish and manage their geographic data, by providing an interface that allows users to publish data layers, define symbology, create new map viewers and define permissions for each published resource (Dempsey, 2018). gvSIG Online is based on Python and uses the Django framework. For more information on gvSIG visit http://www.gvsig.com/en/products/gvsig-online.	• Allows a user to share geographic information in the cloud. • Provides 2D and 3D visualization, and animation of data. • Supports different data types including vector, raster and image formats. • Provides advanced tools for spatial analysis and remote sensing tools.	• Coding is required to customize and extend the functionality of the platform. • Integrates with Geoserver. • This platform appeals more to users who are familiar with the Python coding language. • It offers basic functionality; thus, if a user wishes to extend its functionality, they can do so programmatically. • Since gvSIG is not a widely used platform, it is not known how secure and stable the platform is, and how it handles multiple users.
Leaflet.js	Leaflet is a lightweight open-source JavaScript library that is widely used to develop interactive web maps. The platform supports Web Map Service (WMS) layers, GeoJSON layers, Vector layers, Tile layers, and many more with the implementation of plugins. The platform has made the development of GIS web applications easier, even for individuals with little knowledge of GIS. According to Dey (2016), Leaflet is comparable with OpenLayers since both are open source and client-side only JavaScript libraries; however, Leaflet is a smaller library that does not support services such as Web Feature Service (WFS). Tarasenko (2019) is of the opinion that leaflet.js is more suited for simple GIS applications. For more information on Leaflet.js visit https://leafletjs.com/.	• Can be used with other map providers such as Google, OpenStreetMap (OSM) and Mapbox. • Extensible with the help of plugins. • Supports Comma-Separated Values (CSV), TopoJSON, Well Known Text (WKT), and GPS Exchange (GPX) data formats with the help of plugins.	• Coding is required to customize and extend the functionality of the platform. • Requires a local web server such as Python's SimpleHTTPServer or WAMPServer. • Leaflet is easier to use compared to other platforms such as OpenLayers, and there is plenty of documentation available online explaining how to enhance and extend the functionality of the platform.

Platform	Description	Features	Ease of use and suitability to project
		• Web browsers such as Chrome, Firefox, Safari 5+ and Opera 12+ on desktops are supported. • Supports browsers such as Safari, Android, Chrome, Firefox on mobile phones. • Security vulnerabilities have been previously reported.	• This platform cannot, however, handle large datasets well, extending the functionality of the platform can also prove to be challenging to users with little programming knowledge. • This platform may not perform well when hosting the SAHA since some of the datasets that will be uploaded are large and, therefore, require a platform that can handle large datasets exceptionally well.
Mapbox GL JS and Mapbox.js	Mapbox GL JS and Mapbox.js are open-source JavaScript libraries for developing web-based interactive and customizable maps. Mapbox GL JS and Mapbox.js both offer many plugins that can be used to extend the functionality of your web applications such as drawing tools, Mapbox Geocoding and directions API (Mapbox, n.d.). Mapbox GL JS is more suitable for highly interactive web maps, while Mapbox.js extends the Leaflet.js library (Mapbox, n.d.). For more information on Mapbox visit https://docs.mapbox.com/help/how-mapbox-works/web-apps/.	• User can create or upload custom data. • Allows user to display 3D data. • Functionality can be extended with features such as geocoding, routing, spatial analysis and many more. • Features that are displayed on a map can be queried and filtered. • Geographic data can be animated. • The platform is safe and secure, all user accounts come with built-in encryption. • Maps can be shared publicly or privately.	• Requires Turf server-side to be run with Node server. • Mapbox GL JS and Mapbox.js offer most of the functionality that is required for the SAHA. • Data and user security are also provided; however, this platform is not easy to customize and requires extensive programming.

Platform	Description	Features	Ease of use and suitability to project
		• Provides data encryption. • Supports Safari 9 and above, the latest versions of Chrome and Firefox and Microsoft Edge 13 web browsers.	
MapGuide Open Source	MapGuide Open Source is an open-source web-based platform for developing and deploying web mapping applications, and geospatial web services. MapGuide offers an interactive viewer that supports feature selection, maps tips, and operations such as buffer, select within, and measurement tools (Rbray, 2007). Map Guide also supports many geospatial data formats, databases and open standards. For more information on MapGuide Open-Source visit https://mapguide.osgeo.org/.	• Supports browsers such as Microsoft Internet Explorer, Mozilla Firefox, Google Chrome and Safari web. • Allows data creation and manipulation. • Provides overlay functions such as intersection, union, difference and symmetric difference), convex hull, area, and distance functions. • Supports feature buffering and measuring tools. • Allows printing. • Supports WMS and WFS. • Provides feature dynamic labelling. • Supports ESRI .shp, SDF and SQLite vector file formats, and raster file formats via GDAL.	• Coding is required to customize and extend the functionality of the platform. • Customizable using CSS and JavaScript. • MapGuide requires the Apache HTTP Server, PHP 5.2.1, and Tomcat server. • MapGuide Open Source is a fast platform that was designed specifically for hosting GIS web maps. • The platform offers highly interactive web maps, supports most modern browsers and is secure.
MapX	MapX is a free and open-source online web mapping platform, which was developed to maximize the use of new digital technologies and cloud computing in the sustainable management of natural resources (Mapx, n.d.). MapX has assisted individuals in finding spatial solutions to challenges that are related to the natural environment. The main objective of MapX is to increase the involvement of citizens	• The platform is compatible with recent versions of Chrome and Firefox. • Map authors can place access restrictions on	• Coding is required to customize and extend the functionality of the platform. • Uses Apache server or Microsoft web server.

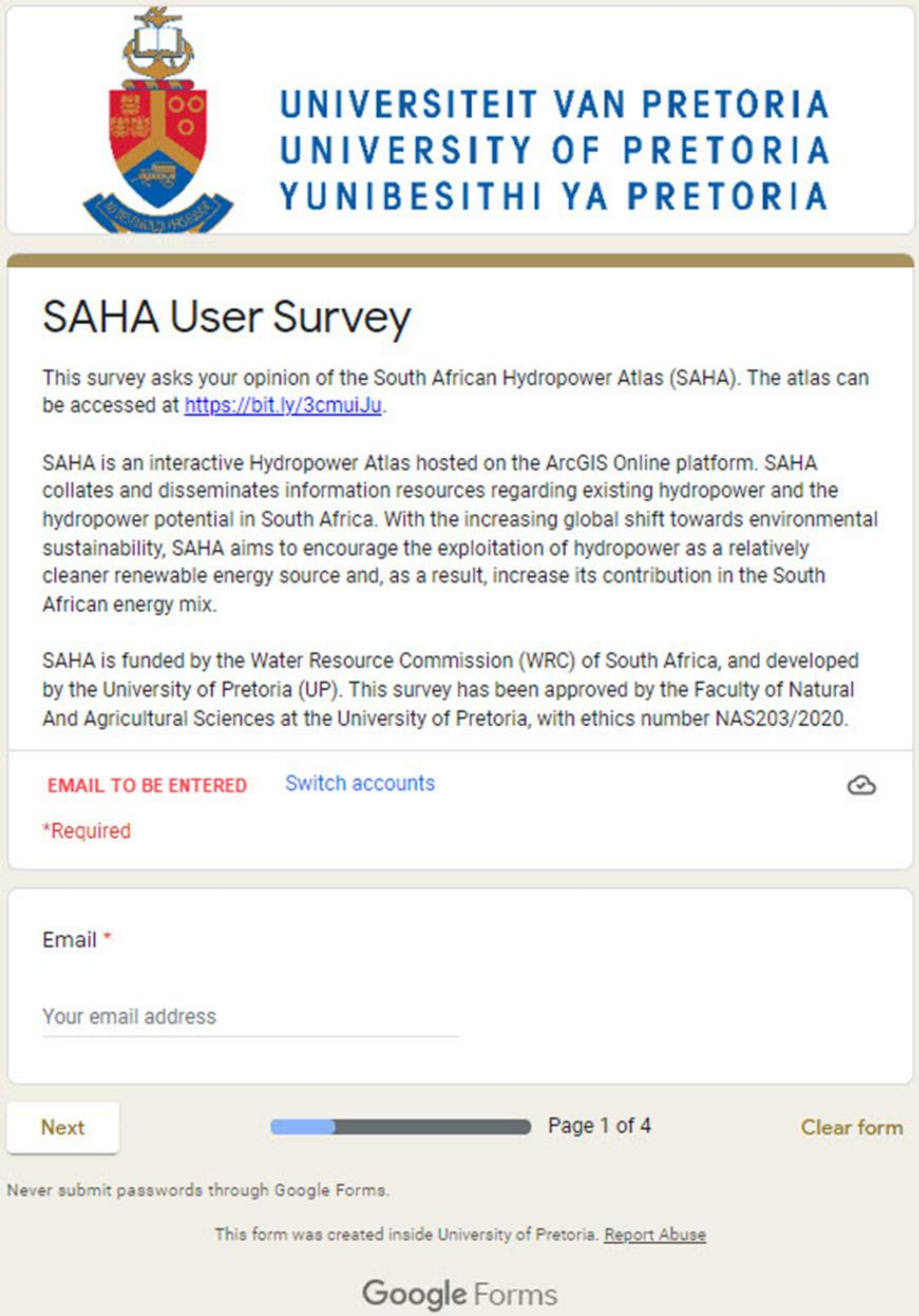
Platform	Description	Features	Ease of use and suitability to project
	and stakeholders in the preservation and management of the environment and natural resources (Mapx, n.d.). For more information on MapX visit https://www.mapx.org/faq/.	datasets that they publish on the platform. • Parameters of projects such as title, description, default position of the map, status of the project (private or public) can be managed. • A temporary connection can be created to edit a specific source layer using QGIS or any PostgreSQL clients such as psql and pgAdmin. • Offers real time tools for analysis, customized visualizations, and monitoring areas of interest. • Authors can create story maps and/or dashboards. • Data and access security are provided.	• MapX is attractive to most web map developers; however, it is designed for simple data analysis, visualization and sharing. Therefore, the platform may not have all the functionality required for the SAHA.
OpenLayers	OpenLayers is an open-source JavaScript library for developing interactive web maps. The platform provides developers with tools to develop web map applications from scratch, with the ability to customize every aspect of your map layers, controls, events, and has all the required features in its core functionality (OpenLayers, n.d.). However, displaying many vector features (greater than 200) increases the time it takes for layers to load on the platform and can, therefore, slow down the application. For more information on OpenLayers visit https://openlayers.org/.	• Can be integrated with any other closed or open-source application. • Supports most modern web browsers and mobile devices. • New features can be added. • Supports Google, Yahoo, Microsoft, WMS, ArcGIS Server, MapServer, and many more.	• Coding is required to customize and extend the functionality of the platform. • Has no server-side dependencies. • OpenLayers is a powerful platform that is specifically designed for complex interactive maps, it has most of the features required by web maps, including the SAHA, in its core functionality.

Platform	Description	Features	Ease of use and suitability to project
		• Can be styled much more than other mapping platforms such as Google Maps and Leaflet. • Can combine maps from different sources such as Google Maps, WMS overlays, vector data from KML, GML files or WFS.	• The disadvantage about this software is that it requires more time and work (code) to start up, security threats have also been previously reported by its users.
QGIS Cloud	QGIS Cloud is a free and open-source web-based GIS platform that allows users to publish maps, data and services over the internet (QGIS Cloud, n.d.). This is all possible by simply installing the QGIS Cloud plugin. If the author would like to limit access to their maps, then QGIS Cloud Pro is a more suitable option. For more information on QGIS Cloud visit https://qgiscloud.com/.	• The author can create complex maps, using QGIS desktop and its wide range of styling options. • An unlimited number of maps can be published over the internet at no cost. • The author has control over who can access and/or edit the data. • Maps can be shared either publicly (the public can access the web map) or privately (only certain individuals can access the web map). • QGIS cloud offers PostgreSQL 9 databases that are extended with PostGIS 2 and allows authors to create databases directly from the QGIS Cloud plugin. • QGIS Cloud pro allows the author to protect and restrict access to their	• Coding is required to customize the platform. • Uses QGIS server. • Most of the features that are offered by QGIS cloud are readily available, which means the author does not have to spend time writing code to extend the functionality of the platform. • It is a secure platform that allows the author to control who has access to the uploaded datasets. This is crucial since the data that will be used for the SAHA belongs to different parties that may not necessarily want it to be accessible to the target audience.

Platform	Description	Features	Ease of use and suitability to project
		maps by making use of passwords. • Functionalities can be added using plugins. • The author can share their maps and data over web services that are compliant with the Open Geospatial Consortium (OGC) such as WMS and Web Feature Service (WFS). • Supports most modern web browsers.	

3.2. OBJECTIVE 2: SOURCING OF DATA

Objective 2 entails creating a centralised database for existing hydropower-related geospatial and attribute data for South Africa. The purpose of this objective is to ensure that all the relevant data and information related to hydropower that would be useful to prospective users, such as investors, researchers, the government and the public, are included in the hydropower atlas. To achieve this objective, data sources are identified, and the data are created if not available (**3.3. OBJECTIVE 3: MODELLING SOUTH AFRICAN DAM HYDROPOWER POTENTIAL**, pg. 37). Once the data have been sourced and created, they are evaluated for errors and converted into a suitable format. This format relates to the final platform identified to host SAHA. Metadata are also captured per identified layer. This ensures users have access to basic information about the data itself, and where data are sourced from. **Table 12** provides an overview of data ideally to be included in SAHA. **APPENDIX B: STAKEHOLDER SURVEY**



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SAHA User Survey

This survey asks your opinion of the South African Hydropower Atlas (SAHA). The atlas can be accessed at https://bit.ly/3cmuiJu.

SAHA is an interactive Hydropower Atlas hosted on the ArcGIS Online platform. SAHA collates and disseminates information resources regarding existing hydropower and the hydropower potential in South Africa. With the increasing global shift towards environmental sustainability, SAHA aims to encourage the exploitation of hydropower as a relatively cleaner renewable energy source and, as a result, increase its contribution in the South African energy mix.

SAHA is funded by the Water Resource Commission (WRC) of South Africa, and developed by the University of Pretoria (UP). This survey has been approved by the Faculty of Natural And Agricultural Sciences at the University of Pretoria, with ethics number NAS203/2020.

EMAIL TO BE ENTERED Switch accounts

*Required

Email *

Your email address

Next Page 1 of 4 Clear form

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Figure 42: Page 1 (survey description) of the SAHA stakeholder survey.

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SAHA User Survey

Switch accounts

*Required

Participation consent

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 agreeing to participate in this survey. You also have the rights of access to your data.

By participating 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.

You will automatically receive a copy of this survey once you have completed it (clicked on 'Submit').

This survey has also been approved by the University of Pretoria, Faculty of Natural and Agricultural Sciences ethics committee (reference NAS203/2020).

For questions please contact Dr. Hansen at christel.hansen@up.ac.za, or Ms. Mahamba at u15223222@tuks.co.za.

Survey consent *

Do you agree to take part in this survey?

- ○ Yes
- ○ No

Back | Next | Page 2 of 4 | Clear form

Figure 43: Page 2 (survey respondent consent) of the SAHA stakeholder survey.

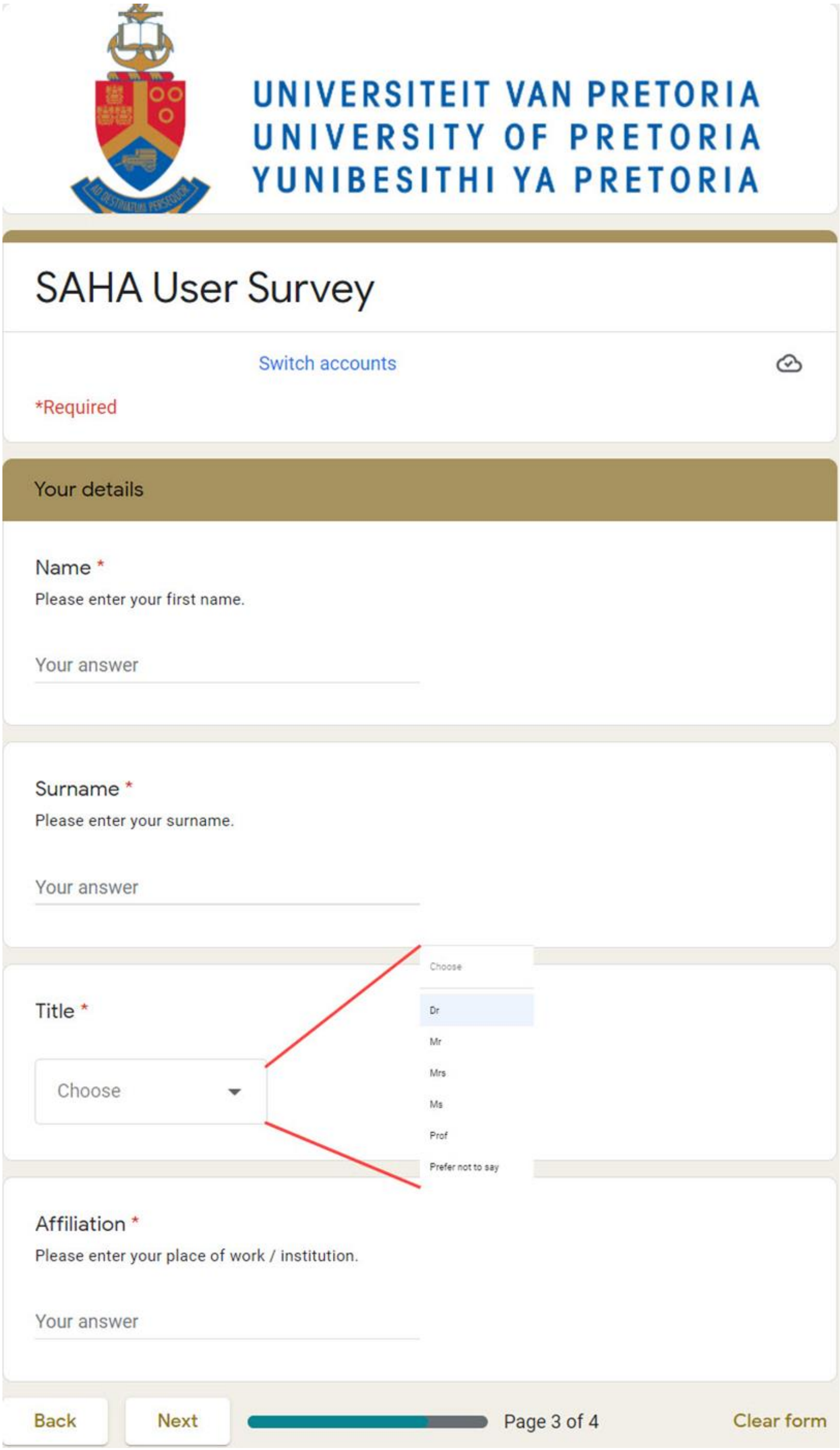
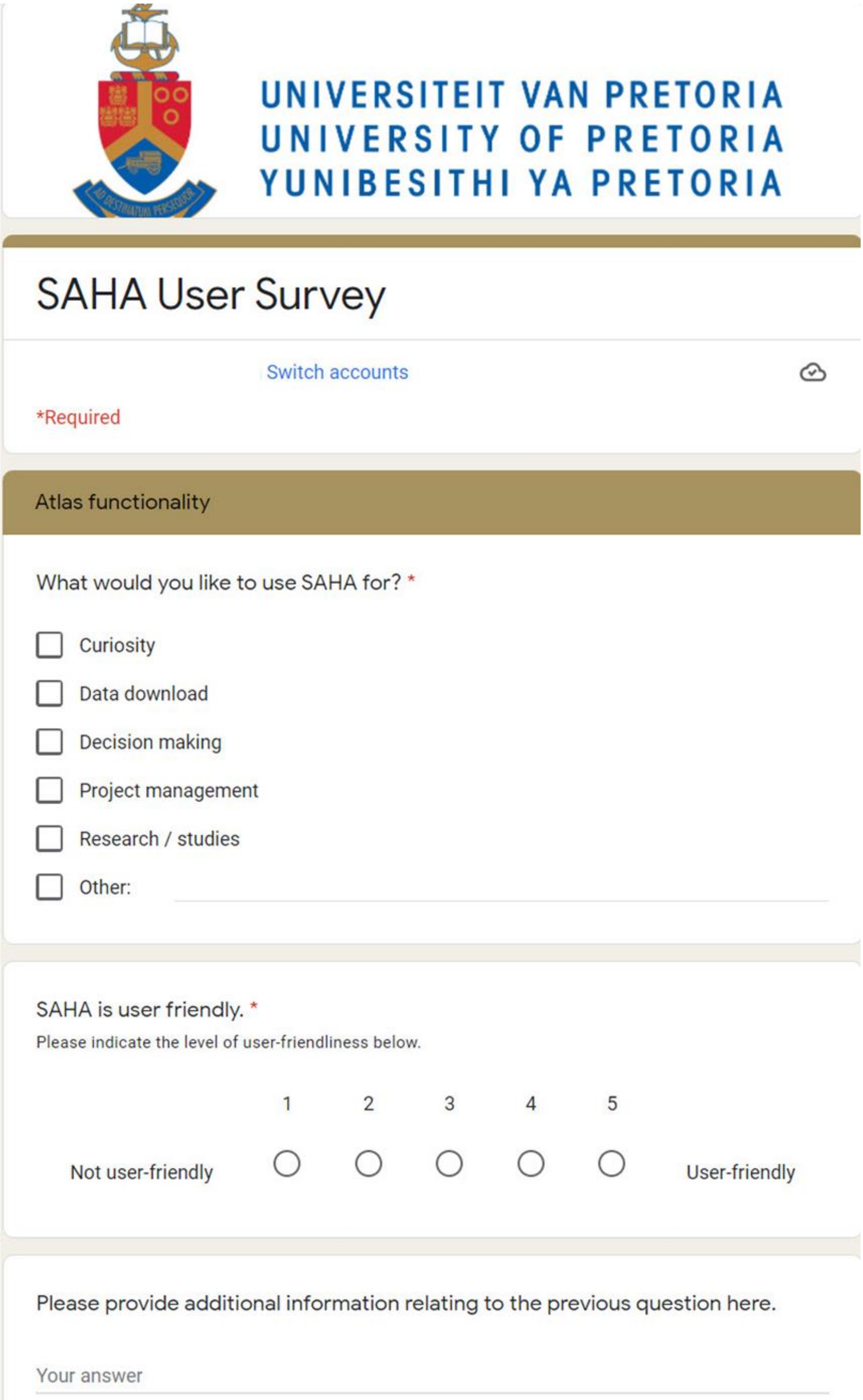


Figure 44: Page 3 (respondent details) of the SAHA stakeholder survey.



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SAHA User Survey

Switch accounts

*Required

Atlas functionality

What would you like to use SAHA for? *

- [ ] Curiosity
- [ ] Data download
- [ ] Decision making
- [ ] Project management
- [ ] Research / studies
- [ ] Other:

SAHA is user friendly. *

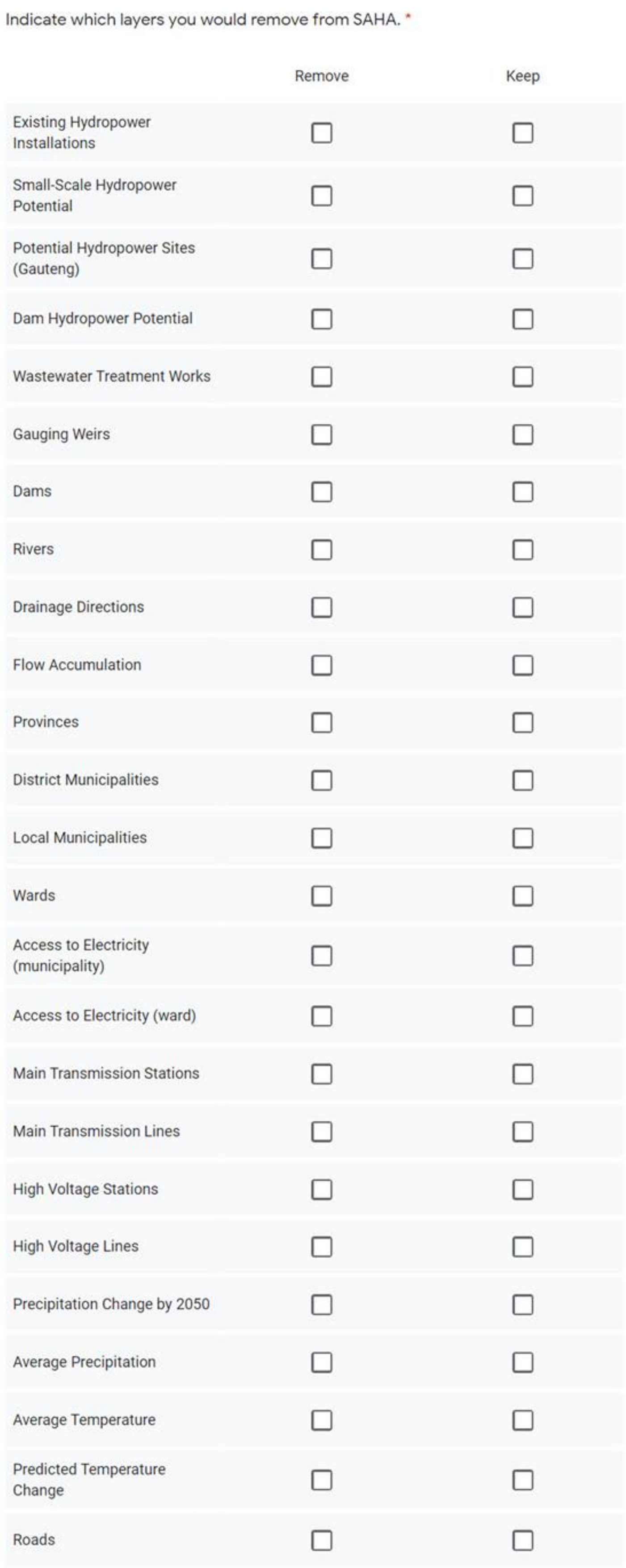
Please indicate the level of user-friendliness below.

	1	2	3	4	5	
Not user-friendly	○	○	○	○	○	User-friendly

Please provide additional information relating to the previous question here.

Your answer

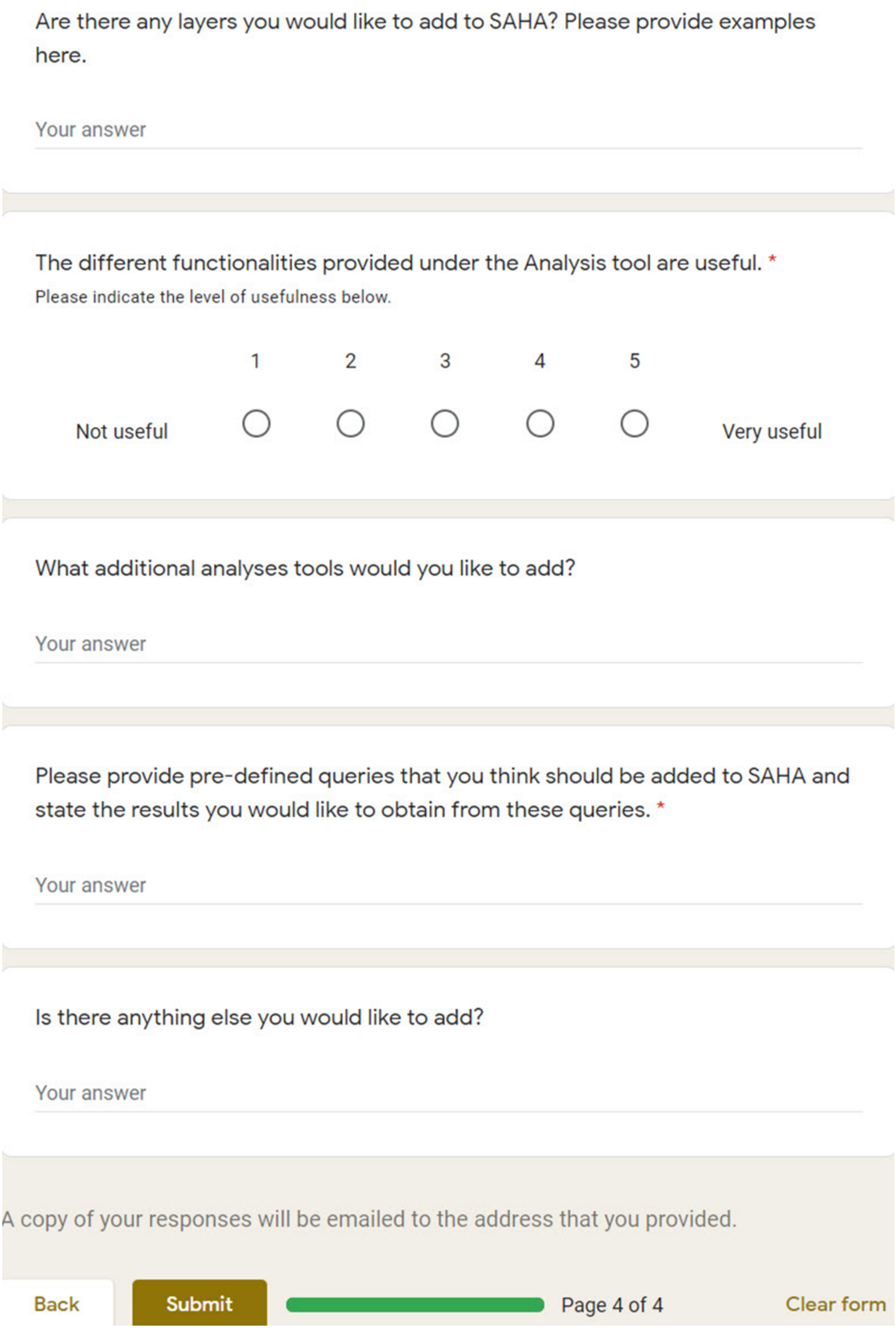
Figure 45: Page 4 (questions 1-3) of the SAHA stakeholder survey.



Indicate which layers you would remove from SAHA. *

	Remove	Keep
Existing Hydropower Installations	☐	☐
Small-Scale Hydropower Potential	☐	☐
Potential Hydropower Sites (Gauteng)	☐	☐
Dam Hydropower Potential	☐	☐
Wastewater Treatment Works	☐	☐
Gauging Weirs	☐	☐
Dams	☐	☐
Rivers	☐	☐
Drainage Directions	☐	☐
Flow Accumulation	☐	☐
Provinces	☐	☐
District Municipalities	☐	☐
Local Municipalities	☐	☐
Wards	☐	☐
Access to Electricity (municipality)	☐	☐
Access to Electricity (ward)	☐	☐
Main Transmission Stations	☐	☐
Main Transmission Lines	☐	☐
High Voltage Stations	☐	☐
High Voltage Lines	☐	☐
Precipitation Change by 2050	☐	☐
Average Precipitation	☐	☐
Average Temperature	☐	☐
Predicted Temperature Change	☐	☐
Roads	☐	☐

Figure 46: Page 4 (question 4) of the SAHA stakeholder survey.



Are there any layers you would like to add to SAHA? Please provide examples here.

Your answer

The different functionalities provided under the Analysis tool are useful. *

Please indicate the level of usefulness below.

	1	2	3	4	5	
Not useful	○	○	○	○	○	Very useful

What additional analyses tools would you like to add?

Your answer

Please provide pre-defined queries that you think should be added to SAHA and state the results you would like to obtain from these queries. *

Your answer

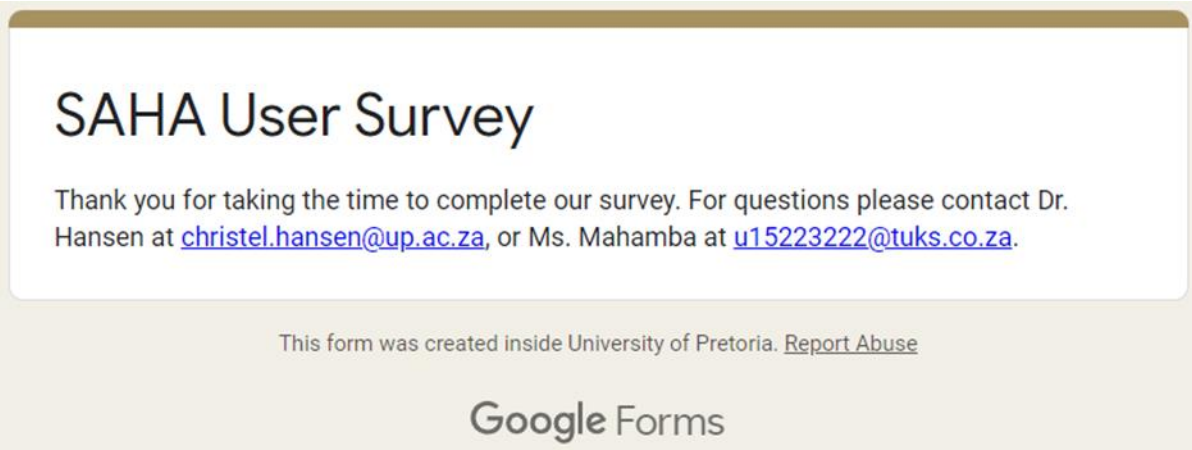
Is there anything else you would like to add?

Your answer

A copy of your responses will be emailed to the address that you provided.

Back Submit Page 4 of 4 Clear form

Figure 47: Page 4 (questions 4-10) of the SAHA stakeholder survey.



SAHA User Survey

Thank you for taking the time to complete our survey. For questions please contact Dr. Hansen at christel.hansen@up.ac.za, or Ms. Mahamba at u15223222@tuks.co.za.

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Figure 48: Message displayed once the respondent clicks on Submit.

APPENDIX C: EXAMPLE METADATA CAPTURED PER GEOSPATIAL LAYER AVAILABLE ON SAHA (pg. 90) provides an example of metadata captured for a geospatial layer.

Table 12: Datasets ideally to be included in hydropower atlases.

Dataset	Rationale
1. Administrative boundaries	Displaying administrative boundaries on the hydropower atlas makes it easier for the user to identify where the hydropower scheme(s) that are displayed on the Atlas are located.
2. Electricity Network	Knowing the power network of the country, and where both operating and planned power stations are located, assists in identifying suitable locations for further hydropower development.
3. Access to electricity	Knowing how access to electricity is distributed across South Africa makes it easier for project developers to identify areas where access to electricity needs to be increased, thus where hydropower projects need to be developed. This is based on the 2011 census data.
4. Hydrology	Displaying all relevant hydrological data is deemed necessary since hydropower is dependent on water resources; therefore, having such data available is helpful in both the planning and implementation phases of hydropower projects.
5. Rainfall	The amount of water available for hydropower exploitation is highly dependent on the availability of water. Therefore, the amount of rainfall received by an area determines whether the operation or implementation of hydropower schemes will be feasible.
6. Temperature	Temperature affects the availability of water resources. Therefore, an increase in temperature results in drier land and, therefore, a decrease in the availability of water – making the development of hydropower projects complex.
7. Hydropower schemes	Knowing the locations of existing hydropower stations is important to avoid implementing hydropower stations where they already exist. Having this data available is also fundamental for future hydropower development projects.
8. Potential hydropower infrastructure	Knowing infrastructure where both conventional and unconventional hydropower can be potentially developed is important for future hydropower projects.
9. Potential hydropower	This layer represents the hydropower potential for South Africa.
10. Transportation	This layer represents South Africa's road and rail network, and informs investors and hydropower developers on whether locations that have been chosen for hydropower development are accessible, or if roads and/or railway lines must be constructed to gain access to the locations.
11. Base maps	A basemap is a map that serves as a background over which spatial data layers (vector or raster data) can be overlayed. Adding a basemap is important since it serves as a reference map for the user.

3.3. OBJECTIVE 3: MODELLING SOUTH AFRICAN DAM HYDROPOWER POTENTIAL

Objective 3 entails assessing and modelling dam hydropower potential for South Africa. The purpose of this objective is to assess the hydropower potential of dams that have not been integrated with hydropower technology yet, in addition to those that have already been integrated with hydropower. Identifying dams that have exploitable hydropower potential will save investors and researchers costs and time.

Previous research studies recommend assessing the hydropower potential of a site for at least 5 years to account for seasonal, and rainfall variations (Khaniya et al., 2020). For this reason, dam potential hydropower for South Africa was assessed and modelled for a period of ten years (2010-2020), doubling the minimum time as identified in literature. This was done to account for weather variability in South Africa. Ideally, a period of 30 years should be evaluated, to account for climate variability. However, many dams have not been operational for such a period, making ten years the more realistic option. In addition, the most recent period, where data were available, was chosen to determine dam potential hydropower. This process entailed assessing the flow records of each dam that were available during the 2010-2020 period. The daily flow records were obtained from the Department of Water and Sanitation (DWS) and Water Research Council (WRC). Daily flow records were first converted to monthly flow by averaging the daily flow (m^3/s) of each month during the ten years (Aman and Malik, 2017). The exceedance probability (see **Equation 2**) was then calculated for each dam to determine the mean flow rate that was available at 90% of the time during the ten years.

Equation 2: Exceedance probability equation (Aman and Malik, 2017),

Where: P = exceedance probability, m = the rank of the inflow value, and n = the total number of data points.

$$P = 100 \times \left(\frac{m}{n+1}\right)$$

To obtain the flow rate available at 90 percent of the time, the mean monthly flow rates (m^3 /s) of each dam were first ranked in descending order (Kotei et al., 2016). This flow rate was then used as the discharge (Q) when applying **Equation 1** (pg. 18). This equation was applied to each dam to determine the potential power output.

Hydraulic efficiency of a turbine is defined as the ratio of the power produced by the turbine to the power supplied by the water at the inlet of a turbine (Rajput, 2006). Modern turbines are said to have energy conversion efficiencies that range between 80 % and 90 % and can sometimes be as high as 95 % (Nazari-Heris and Mohammadi-Ivatloo, 2017). Pelton turbines operate by directing jets of water onto a runner, this jet of water then strikes the runner tangentially causing it to rotate. The water is then released into the tailrace and almost all the energy in the water is exhausted (Loots et al., 2015). Pelton turbines are ideal for sites with high head; however, there are some exceptions (Loots et al., 2015). For this research, the Pelton type turbine was assumed for the dam hydropower potential assessment for South Africa (Aman and Malik, 2017). In addition, the turbine efficiency (η) was assumed to be 80 % (see **Table 7**, pg. 19).

Table 13 represents the South African drainage regions (also see **Figure 3**, pg. 16), as well as the gauging stations within those regions, which were assessed. Each gauging station belongs to one dam; therefore, a total of 261 DWS dams were assessed. Of the 22 drainage regions in South Africa, all had accessible records except for F (Buffels). All attempts to access these records proved unsuccessful. Thus, no dams were assessed for this drainage region.

Table 13: DWS Drainage regions and the total number of gauging stations (n=261) within each region.

Drainage Region	**Number of Stations**
A Limpopo	38
B Olifants	30
C Vaal	36
D Orange	18
E Olifants/Doorn	3
F Buffels	Records inaccessible
G Berg	9
H Breede	16
J Gouritz	15

Drainage Region	Number of Stations
K Coastal rivers	8
L Gamtoos	4
M Swartkops	5
N Sondags	3
P Boesmans	3
Q Fish	8
R Nahoon/Keiskamma	8
S Great-Kei	10
T Mzimvubu/Umbashe	5
U Mvoti/Mgeni/Mkomazi	10
V Tugela	11
W Usutu/Phongolo/Mfolozi	11
X Sabie/Krokodil/Mfolozi	10
Total	**261**

3.4. OBJECTIVE 4: DEVELOPING A WEB-BASED HYDROPOWER APPLICATION

Objective 4 entails developing a web-based hydropower application (Atlas) that will serve as an information product. Once preferred functionality and tools are assessed (Objective 1), and the database is created (Objective 2), platforms such as ArcGIS online, QGISWeb, Mapbox, and MapX were assessed to identify a suitable platform for presenting the data and host the Atlas (see **Table 11**, pg. 27). The hydropower atlas must be user-friendly to ensure that the public, including those who are not familiar with web map applications, can use it. Therefore, the user was considered throughout the design and development of the atlas.

STAKEHOLDER SURVEY

Once a prototype of SAHA had been developed, a survey was sent to the relevant stakeholders assessing the usability and functionality of SAHA. Feedback received was subsequently used to improve SAHA. A link to the survey can be accessed at https://forms.gle/2ZkLTjPaDnSz3JT79. Note that the survey is no longer accepting responses and can thus not be completed. For reference, the questions posed in the survey are also given here.

A few items to note:

1. The survey consists of 4 pages (see **APPENDIX B: STAKEHOLDER SURVEY,** pg. 90), as well as a conclusion screen.
    a. Page 1 informs the respondent of the purpose of the survey (refer to **Figure 42**, pg. 90).
    b. Page 2 requires the respondent's consent (refer to **Figure 43,** pg. 91). If consent is not given, the survey terminates.
    c. Page 3 collects the respondent's details (refer to **Figure 44,** pg. 92).
    d. Page 4 consists of a series of questions regarding the functionality and ease of use of SAHA (refer to **Figure 45,** pg. 93).
    e. Once the respondent submits the survey, a thank-you message is displayed (refer to **Figure 48**, pg. 96), and a copy of the survey sent to the respondent's E-Mail account.
2. Questions indicated with a red Asterix (*) are compulsory and must be answered by the respondent.
3. The survey deadline was 03 December 2021 and no longer accepts responses.

Once improvements to the South African Hydropower Atlas had been made based on stakeholder feedback from the first survey, a second survey, which is accessible at https://forms.gle/28TBzZNe2VKMezA46, was sent again to the relevant stakeholders. The second survey is similar to the first one and assesses the usability and functionality of SAHA and asks the stakeholders to provide a preferred acronym for the atlas for final use. The letter sent to stakeholders is given in **APPENDIX A: SURVEY LETTER SENT TO STAKEHOLDERS** (pg. 89).

CHAPTER 4: RESULTS

This section presents the results of the dissertation. The results include the South African Hydropower Atlas (SAHA), and the hydropower potential of South African dams located in 21 drainage regions.

4.1. OBJECTIVE 1: ASSESSMENT OF KNOWN ATLASES

Table 14 is a summary of common and preferred functionalities for the SAHA, based on the assessment of the atlases given in **Table 9** (pg. 24).

Table 14: Common and preferred functionalities of evaluated atlases.

Functionality	Description
	BASIC FUNCTIONALITY
Splash screen	The splash screen serves as a welcoming screen and contains the map description, copyright, and disclaimer information.
About	This functionality provides basic information relating to SAHA.
Item Description	This functionality provides metadata for the different layers of the hydropower map.
Basemaps	These are different basemaps that the user can choose from such as OpenStreetMap (OSM), ESRI, or CARTO.
Display attribute data	Attribute data, in the form of tables or pop-ups, are displayed when a user clicks on a feature that is displayed on the atlas.
Export	This function allows the user to export the default map view in JPEG, PNG, or PDF format.
Extract	This function allows the user to extract data from the atlas. Only data that is available for download (as set by the author of the atlas) can be extracted.
Home	Clicking the home function takes the user to the default extent, which is set by the author and any measurements or layers that were added to the map by the user are cleared.
Legend	The legend shows the different layers of the hydropower map. The user can sort the layers either in ascending or descending order, collapse or close the entire legend, and group similar layers together.
Panning	This function allows the user to pan the map.
Printing	This function allows the user to directly print the map view from the web. The print layout options are set by the Atlas author, including necessary copyright and terms of information and use.
Scale bar	This is a scale of the map, which changes when the user changes the map extent. The user can also change the scale unit of measurement.
Search bar	The search bar normally searches Google Maps, returning any result that exists within Google.
Attribute table	This is a table that contains attribute data about the features that are displayed on the map.
Sharing	This function allows the user to share the link to the web app across various platforms such as Twitter, email, Facebook, and LinkedIn.
Social media	This allows the user to interact with the author and all relevant stakeholders via Facebook, LinkedIn, email, or by making use of a Twitter hashtag.
Terms of use	These are the terms and conditions of the atlas, which appear as soon the Atlas is launched. The user must agree to the terms and conditions before gaining access to the atlas.
Zoom in	This functionality allows the user to zoom into the map.
Zoom out	This functionality allows the user to zoom out of the map.
Zoom to current location	When this function is clicked, the map will be zoomed to the user's current location, provided the user allows the browser to access their location.
Zoom to previous extent	This functionality allows the user to zoom back to their previous extent (view).
Switch to full screen	This function allows the web browser being used to make use of the entire screen of a device to display the web map, the user can exit this view by pressing the escape (esc) key.
	TOOLS
Add data layer(s)	The user can add their data layers to the map; the author predetermines the data format.

Functionality	Description
Attribute selection	This functionality allows the user to select features displayed on the map according to attributes that they are looking for.
Bookmarks	This functionality allows the user to identify a geographic location that they want to save and reference later.
Full screen	This functionality expands the user's screen view to full screen.
Measuring tool	This tool allows the user to measure the distance between certain features; for instance, the user can measure the distance between different hydropower schemes. The measuring tool also allows the user to calculate the area. The user can choose the measuring unit.
Buffer tool	This tool allows the user to create buffers around features; for instance, a user can create buffers around hydropower schemes or potential sites. This function requires the user to input a buffer distance.
Overlay analysis	This functionality allows the user to apply Union (relational algebraic operator 'union,' increasing the output relation) and Intersect (relational algebraic operator 'intersection,' returns a subset) operations.
Pre-set queries	These are built-in queries (set by the Atlas author) that allow the user to query and retrieve information from the data layers.
Select	The select tool enables the user to interactively select map features and perform actions on them.

Some functionalities were not available for some of the platforms. Therefore, the decision regarding which platform is suitable for hosting SAHA was made based on the available information with a specific focus on features, functionality, ease of use, and suitability of the platform. Thus, the two most suitable platforms that were identified are QGIS Cloud, which is free and open-source software, and ArcGIS Online, which is proprietary software. Although these two platforms have similar functionalities, ArcGIS Online is a more secure, reliable, and trusted platform for hosting web maps. According to Esri (2020), ArcGIS Online continually earns security and privacy certifications, software updates, and maintenance is done by Esri meaning the user does not have to address such issues. The platform also handles multiple data layers and users well. This is an important aspect since the chosen platform must be able to handle multiple users and function without any disturbances (such as crashing). For the above reasons, ArcGIS Online was chosen as the most suitable platform for hosting SAHA.

4.2. OBJECTIVE 2: SOURCING OF DATA

Table 15 represents the datasets that ideally comprise SAHA, as well as the rationale behind the selected datasets (as already presented in **Table 12**, pg. 36). A summary of attributes for each data layer is provided and data sources listed. Where no source was identified, this is indicated. Such datasets are not currently included in SAHA. However, in future iterations of the atlas, such datasets should be provided as well. The chosen platform is ArcGIS Online, meaning all data were converted to the .shp format. The .shp format is required to ensure data can be uploaded to the chosen platform.

Table 15: Geospatial layers included in SAHA.

Dataset	Rationale	Attributes	Data Source(s)
1. Administrative boundaries	Displaying administrative boundaries on the hydropower atlas makes it easier for the user to identify where the hydropower scheme(s) that are displayed on the Atlas are located.		
a. Provinces	This layer represents the boundaries of provinces in South Africa.	• Name	• Municipal Demarcation Board
b. Metropolitan Municipalities	This layer represents the boundaries of metropolitan municipalities in South Africa.	• Name • Province • Code	• Municipal Demarcation Board
c. District Municipalities	This layer represents the boundaries of district municipalities in South Africa.	• Name • Province • Code	• Municipal Demarcation Board

Dataset	Rationale	Attributes	Data Source(s)
d. Local Municipalities	This layer represents local municipal boundaries in South Africa.	• Name • Province • Code	• Municipal Demarcation Board
e. Wards	This layer represents wards in South Africa.	• Name • Code • Ward number	• Municipal Demarcation Board
2. Electricity Network	Knowing the power network of the country, and where both operating and planned power stations are located, assists in identifying suitable locations for further hydropower development.		
a. Power stations	This layer represents existing power stations, which contribute to the supply of electricity throughout South Africa.	• Name • Category • Load	• Eskom
b. Main transmission stations	This layer represents main power stations.	• Type • Voltage • Status	• Eskom
c. High voltage stations	This layer represents sub-power stations.	• Type • Voltage • Status	• Eskom
d. Main transmission lines	This layer represents main transmission lines that transmit electricity throughout South Africa.	• Type • Voltage • Status	• Eskom
e. High voltage lines	This layer represents high voltage transmission lines that transmit electricity throughout South Africa.	• Type • Voltage • Status	• Eskom
f. Access to Electricity for lighting	This layer represents the percentage of households that have access to electricity for lighting at the South African ward level.	• Ward ID • Province • Percentage Access	• This layer was created based on 2011 census data.
3. Hydrology	Displaying all relevant hydrological data is deemed necessary since hydropower is dependent on water resources; therefore, having such data available is helpful in both the planning and implementation phases of hydropower projects.		
a. Dams	This layer represents the locations and information about lakes and dams.	• Name • Capacity • Type	• Department of Water and Sanitation (DWS)
b. Rivers	This layer represents rivers within South African borders.	• Name • Old Name • Length	• DWS
c. Primary catchments	This layer represents the boundaries of each primary catchment.	• Primary code	• DWS
d. Flow accumulation	This layer defines the amount of upstream area (in number of cells) draining into each cell. To have this layer in km^2, we multiplied it by the surface of one cell.	• Flow accumulation	• Hydrosheds.org
e. Catchment outfall points	This layer represents catchment outfall points	• Primary river • Catchment	• Data created

Dataset	Rationale	Attributes	Data Source(s)
	within South African boundaries.		
4. Rainfall	The amount of water available for hydropower exploitation is highly dependent on the availability of water. Therefore, the amount of rainfall received by an area determines whether the operation or implementation of hydropower schemes will be feasible.		
a. Minimum precipitation	This layer represents the global minimum precipitation per month (cm).	• Minimum Precipitation	• Copernicus climate Change Service (2020)
b. Predicted rainfall change by 2050	This layer represents the predicted precipitation change over the next couple of years. This will aid in determining whether the locations that have been identified to be suitable for hydropower development will still be suitable in a couple of years to come.	• Predicted rainfall	• Atlas of Global Conservation
c. Average precipitation	This layer represents the global mean annual precipitation from 1981-2010.	• Contour minimum • Contour maximum	• Copernicus Climate Change Service
5. Temperature	Temperature affects the availability of water resources. Therefore, an increase in temperature results in drier land and, therefore, a decrease in the availability of water.		
a. Average temperature change in Sub-Saharan Africa	This layer represents the average temperature change in Sub-Saharan Africa. This layer is regularly updated by the FAO.	• Average temperature change	• FAO
b. Mean Annual temperature	This layer represents the annual average temperature in Southern Africa.	• Annual average temperature	• R.E. Schulze and M. Maharaj (2004). Mean Annual Temperature (C). School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal. doi: 10.15493/SARVA.BEEH.10000312.
c. Predicted temperature change by 2050	This layer represents the predicted temperature change between 2020 and 2050.	• Predicted temperature change by 2050	• CCAFS, CIAT, IPCC, WorldClim
6. Hydropower schemes	Knowing the locations of existing hydropower stations is important to avoid implementing hydropower stations where they already exist. Having this data available is also fundamental for future hydropower development projects.		
a. Existing Hydropower Installations	This layer represents operational hydropower schemes.	• Name • Type • Province	• Brown (2019)
7. Potential hydropower infrastructure	Knowing infrastructure where both conventional and unconventional hydropower may be developed is important for future hydropower projects.		

Dataset	Rationale	Attributes	Data Source(s)
a. Conventional	These layers represent infrastructure where conventional hydropower can be developed.		
Storage schemes (dams)	This layer represents locations where storage schemes hydropower may be developed.	• Name • Location	DWS
Pumped storage (2 GWh 6h, 5 GWh 6h, 15 GWh 18h, 50 GWh, 180 GWh 18h)	These layers represent locations where pumped storage hydropower may be developed.	• Location • Head • Slope • Water volume • Energy storage potential	100% Renewable Energy group from the Research School of Electrical, Energy and Materials Engineering at the Australia National University
b. Unconventional	These layers represent potential infrastructure where unconventional hydropower may be developed.		
Water transfer schemes	This layer represents locations of bulk transfer schemes where hydropower can be potentially developed.	• Volume	WRC
Wastewater Treatment Works (WWTW)	This layer shows locations where hydropower stations may be integrated in WWTW.	• Name • Location • Category • Owner	DWS
Gauging Weirs	This layer represents locations of weirs where hydropower can be potentially developed.	• Name • Location • Status	WRC
8. Potential hydropower	This layer represents the hydropower potential for South Africa.		
a. Dam hydropower potential (2010-2020)	Layer representing the hydropower potential of all dams in South Africa. Alternatively, an existing dam layer can be populated with attribute data related to the calculated dam hydropower potential.	• Name • Province • Type of site • Category	Data created (Objective 3, pg. 6)
b. Potential dam sites	This layer represents potential dam sites in South Africa.	• Scheme Name • Category • Owner	Data created by Anja Kamffer from information sourced from the DWS.
c. Potential conduit site	This layer presents potential conduit hydropower sites in Gauteng.	• Name • Province • Owner • Category	Data created by Anja Kamffer from information sourced from Joburg Water, City of Tshwane IMQS, and Rand Water.
d. Potential weir site	This layer presents potential weir hydropower sites in South Africa.	• Name • Province • Owner • Category	Data created by Anja Kamffer from information sourced from the DWS.
e. Potential water treatment works (WTW) site	This layer presents potential conduit WTW sites in South Africa.	• Name • Province • Owner • Category	Data created by Anja Kamffer from information sourced from the DWS Blue Drop Reports.

Dataset	Rationale	Attributes	Data Source(s)
f. Potential Wastewater treatment works (WWTW) site	This layer presents potential WWTW hydropower sites in South Africa.	• Name • Province • Owner • Category	Data created by Anja Kamffer from information sourced from the DWS Green Drop Reports
g. Small-scale hydropower potential (2000)	This layer presents small-scale hydropower potential in South Africa.	• Hydropower potential	Kusakana & Vermaak (2013)
Transportation	Theses layers inform investors and hydropower developers on whether locations that have been chosen for hydropower development are accessible, or if roads or railway lines must be constructed to gain access to the locations.		
a. Roads	This layer represents South Africa's Road network.	• Name • Type	Open Africa
b. Railway lines	This layer represents South Africa's railway network.	• Length • Type	Mandala Geo Analysis
BASEMAPS			
a. Open Street Map (OSM)	This is an OSM base layer showing streets, boundaries, and labels for places and roads.	OSM/ESRI	a. Open Street Map (OSM)
b. Imagery with labels and transportation	This is a base layer showing administrative boundaries, roads, and labels for places and roads.	ESRI	b. Imagery with labels and transportation
c. Dark Gray Canvas	This is a base map with a darker background and minimal colours, which allows attention to be drawn to the content (layers) that will be displayed on the atlas. Moreover, this base layer would be suitable for viewing the Atlas at night.	ESRI	c. Dark Gray Canvas

The table below represents data that could not be sourced for inclusion in SAHA.

Table 16: Data ideally to be included in the Atlas but could not be sourced.

Dataset	Rationale	Attributes	Potential Data Sources
Desalination plants	This layer represents locations of desalination plants where hydropower can be potentially developed.	• Name • Location • Hydropower Installed (Yes/No)	• WRC
Eskom proposed Locations for hydropower schemes	This layer represents proposed suitable locations for hydropower schemes.	• Name • Province • Type	• Eskom
Irrigation channels	This layer shows locations where hydropower can be integrated in irrigation channels.	• Name • Location • Hydropower Installed (Yes/No)	• DWS • Department of Agriculture, Land Reform and Rural Development (DALRRD)

Dataset	Rationale	Attributes	Potential Data Sources
Planned power stations	This layer represents planned power stations.	• Name • Location • Province	• Eskom
Planned transmission lines	This layer represents planned transmission lines.	• Name • Province	• Eskom
Run-of-river	This layer represents locations where run-of-river hydropower may be developed.	• Name • Location • Hydropower potential	• DWS
Underdeveloped hydropower schemes	This layer represents underdeveloped hydropower schemes.	• Name • Type • Province	• Eskom
Water supply and distribution systems	This layer shows locations where hydropower stations can be integrated in supply and distribution systems.	• Name • Location • Hydropower Installed (Yes/No)	• DWS

4.3. OBJECTIVE 3: MODELLING SOUTH AFRICAN DAM HYDROPOWER POTENTIAL

According to the South African Energy Sector report 2019, South Africa is the 12th most attractive investment for renewable energy in the world. As of 2019, the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) attracted investment to the value of R 209.7 billion (Department of Energy, 2019). This further heightens the need for comprehensive and accessible information of renewable energy sources in South Africa, particularly hydropower since there currently exists limited information resources concerning this renewable energy source. Providing investors access to such information will result in successful and effective exploitation of South African renewable energy sources concerning hydropower.

One of the objectives of this dissertation is to assess and model South African dam hydropower potential. To achieve this, flow records of existing South African dams that were recorded during the 2010-2020 period were assessed to determine whether hydropower potential is present within these dams. Retrofitting hydropower technology to existing water infrastructure precludes the need for the construction of new infrastructure, which can be costly and environmentally degrading (Samora et al., 2016). South Africa has an abundance of over 4 000 dams, of which more than 500 are government owned (Water Research Commission, 2018). Flow data for government dams is largely accessible; however, data of privately owned dams are scarce. As such, although South Africa has more than 4 000 dams, the hydropower potential assessment of South African dams is primarily based on DWS flow records that could be obtained at the time of the assessment. The results of the assessment are presented below (see **Table 17**).

Given that several research studies indicate that there are opportunities for both conventional and unconventional hydropower development in South Africa (see Kotze, 2011; van Dijk et al., 2014; Zvimba and Musvoto, 2020), it was envisaged that the hydropower potential assessment will result in the identification of South African dams with potential for hydropower development. The results of the dam hydropower potential assessment indicate that a total of 84 dams show potential for hydropower development during the 10 years under investigation, while 170 dams showed no hydropower potential.

Table 17: South African dams (n=84) with hydropower potential (modelled on 2010-2020 flow data).

Category	Number of Dams
Large	3

Category	Number of Dams
Small	8
Mini	14
Micro	37
Pico	22

Approximately 96% of the dams that were assessed present opportunities for small-scale hydropower development. Whereas only 3 of the 84 dams pose opportunities for large-scale hydropower development, *i.e.*, the dams have a hydropower potential that is between 10 and 100 megawatts (MW). These include the Pongolapoort dam (10.02 MW), Vaal dam (15.59 MW) and the Gariep dam (96.07 MW) which has the highest hydropower potential overall (see **Table 18**). Therefore, a total of 121.68 MW of large hydropower potential is evident for the three South African dams.

Table 18: Dams with large hydropower potential (modelled on 2010-2020 flow data).

Dam	Province	Hydropower Potential (MW)
Pongolapoort Dam	Kwazulu Natal	10.02
Vaal Dam	Free State	15.59
Gariep Dam	Free State	96.07
Total		**121.68**

The hydropower assessment further revealed that eight dams have potential for small (1-10 MW) hydropower development, which amounts to 34.91 MW (see **Table 19**). These dams include the Loskop Dam (1.07 MW), Driel Dam (1.44 MW), Elandsdrift Dam (1.67 MW), Albertfalls Dam (1.69 MW), Flag Boshielo Dam (1.90 MW), Brandvlei-Wit Dam (8.62 MW), Bloemhof Dam (9.16 MW) and Bloemhof Dam (9.36 MW). Dams within the Gauteng and Free State provinces have no potential for small hydropower development.

Table 19: Dams with small hydropower potential (modelled on 2010-2020 flow data).

Dam	Province	Hydropower Potential (MW)
Loskop Dam	Mpumalanga	1.07
Driel Dam	Kwazulu Natal	1.44
Elandsdrift Dam	Eastern Cape	1.67
Albertfalls Dam	Kwazulu Natal	1.69
Flag Boshielo Dam	Limpopo	1.90
Brandvlei-Wit Dam	Western Cape	8.62
Bloemhof Dam	North West	9.16
Boegoeberg Dam	Northern Cape	9.36
Total		**34.91**

An additional total hydropower potential of 4579.36 (kW) is evident for 14 South African dams for mini (100 kW-1 MW) hydropower development (see **Table 20**). These dams include the Laing Dam, Ntshingwayo Dam, Inanda Dam, Qedusizi Dam, Buffeljags Dam, Roodeplaat Dam, Wriggleswade Dam, De Hoop Dam, Ohrigstad Dam, Rhenosterkop Dam, Ncora Dam, Welbedacht Dam, Clanwilliam Dam, and the Boskop Dam. Moreover, the province that has the greatest mini hydropower potential during the 10 years is the Western Cape (1397.27 kW). The Western Cape is then followed by Eastern Cape (958.25 kW), Free State (767.47 kW), Mpumalanga (640.69 kW), Kwazulu Natal (568.84 kW), Gauteng (128.19 kW), and the North West (118.65 kW), respectively. No dams with mini hydropower potential are identified within the Northern Cape and Limpopo provinces.

Table 20: Dams with mini hydropower potential (modelled on 2010-2020 flow data).

Dam	Province	Hydropower Potential (kW)
Boskop Dam	North West	118.65
Wriggleswade Dam	Eastern Cape	119.35

Dam	Province	Hydropower Potential (kW)
Ntshingwayo Dam	Kwazulu Natal	126.08
Roodeplaat Dam	Gauteng	128.19
Buffeljags Dam	Western Cape	159.52
Qedusizi Dam	Kwazulu Natal	192.27
De Hoop Dam	Western Cape	247.80
Inanda Dam	Kwazulu Natal	250.49
Ohrigstad Dam	Mpumalanga	270.26
Rhenosterkop Dam	Mpumalanga	370.43
Ncora Dam	Eastern Cape	415.26
Laing Dam	Eastern Cape	423.64
Welbedacht Dam	Free State	767.47
Clanwilliam Dam	Western Cape	989.95
Total		**4579.36**

The total micro (5 kW-100 kW) hydropower potential within South African dams was estimated to be 1181.39 kW during the 2010 - 2020 period (see **Table 21**). This encompasses 44% of the dams that showed potential for hydropower development during the 10 years. The province that has the greatest micro hydropower potential is the Eastern Cape with a total of 383.08 kW (32.42% of the total). This is followed by the Mpumalanga with a total of 282.72 kW, Limpopo (173.58 kW), Western Cape (132.35 kW), KwaZulu Natal (111.45 kW), Northern Cape (70.17 kW), Gauteng (17.52 kW), and North West (10.53 kW) respectively. The Free State presents no potential for micro hydropower development within its dams during the 10 years investigated.

Table 21: Dams with micro hydropower potential (modelled on 2010 – 2020 flow data).

Dam	Province	Hydropower Potential (kW)
Garden Route Dam	Western Cape	5.00
Craigie Burn	Kwazulu Natal	5.55
Mearns Weir	Kwazulu Natal	6.38
Westoe Dam	Mpumalanga	6.40
Buffelskloof Dam	Mpumalanga	7.33
Xonxa Dam	Eastern Cape	7.62
Spioenkop Dam	Western Cape	8.47
Binfield Park Dam	Eastern Cape	8.47
Klerkskraal Dam	North West	10.53
Ernest Robertson Dam	Western Cape	13.43
Duivenhoks Dam	Western Cape	15.16
Tours Dam	Limpopo	16.19
Buffelspoort Dam	Gauteng	17.52
Wolwedans Dam	Western Cape	17.63
Tonteldoos Dam	Limpopo	18.51
Witbank Dam	Mpumalanga	19.88
Dap Naude Dam	Limpopo	22.57
Gcuwa Dam	Eastern Cape	23.82
Hans Merensky Dam	Limpopo	25.38
Wagendrift Dam	Kwazulu Natal	25.74
Calitzdorp Dam	Western Cape	26.98
Hazelmere Dam	Kwazulu Natal	27.52
Nandoni Dam	Limpopo	32.75
Groendal Dam	Eastern Cape	35.80
Blyderivierspoort Dam	Mpumalanga	38.55
Misverstand-Stuwal	Western Cape	45.68
Gilbert Eyles Dam	Kwazulu Natal	46.26
Katrivier Dam	Eastern Cape	47.96
Bridle Drift Dam	Eastern Cape	51.83
Middelburg Dam	Mpumalanga	54.12

Dam	Province	Hydropower Potential (kW)
Magoebaskloof Dam	Limpopo	58.18
Vygeboom Dam	Mpumalanga	60.91
Oxkraal Dam-Ciskei	Eastern Cape	62.36
Sandile Dam	Eastern Cape	70.11
Douglas Weir	Northern Cape	70.17
Waterdown Dam	Eastern Cape	75.11
Da Gama Dam	Mpumalanga	95.53
Total		**1181.39**

The results of the dam hydropower potential assessment further revealed that there are opportunities for pico (less than 5 kW) hydropower development within South African dams. The combined pico hydropower potential for these dams is estimated at 21.96 kW (see **Table 22**). Furthermore, the greatest potential for pico hydropower development is evident for the Mpumalanga province (6.96 kW), followed by the Free State (5.73 kW), Eastern Cape (5.05 kW), Limpopo (3.57 kW), Western Cape (0.41 kW), and Kwazulu Natal (0.23 kW), respectively. There is no potential for pico hydropower within Gauteng, North West, and Northern Cape dams during the 10 years investigated.

Table 22: Dams with pico hydropower potential (modelled on 2010-2020 flow data).

Dam	Province	Hydropower Potential (kW)
Loch Athlone	Free State	0.001
Vlugkraal Dam	Mpumalanga	0.01
Sterkspruit No.2-Dam	Mpumalanga	0.08
Kogelberg Dam	Western Cape	0.10
Elandskuil Dam	Free State	0.15
Lake Merthlev	Kwazulu Natal	0.23
De Mistkraal	Eastern Cape	0.26
Nahoon Dam	Eastern Cape	0.29
Albasini Dam	Limpopo	0.29
Klipkopjes Dam	Mpumalanga	0.30
Pietersfontein Dam	Western Cape	0.31
Nqweba Dam	Eastern Cape	0.53
Kwena Dam	Mpumalanga	0.60
Xilinxa Dam	Eastern Cape	0.77
Vergelegen Dam	Free State	0.94
Rust De Winter Dam	Mpumalanga	1.40
Gubu Dam	Eastern Cape	1.49
Lake Arthur Dam	Eastern Cape	1.71
Inyaka Dam	Mpumalanga	1.91
Jericho Dam	Mpumalanga	2.66
Mutshedzi Dam	Limpopo	3.28
Kalkfontein Dam	Free State	4.64
Total		**21.96**

Essentially, 4% of the assessed dams have potential for large hydropower development, followed by 10% of dams for small hydropower development, 44% for micro hydropower, 16% for mini hydropower, and 26% for pico hydropower development. Thus, based on the assessment of the 2010-2020 flow data for dams where such data were available, there exist greater opportunities for the development of micro hydropower within South African dams as opposed to large, small, mini and pico hydropower. The total hydropower potential of South African dams modelled on the 2010-2020 flow data is thus estimated at 162.37 MW (see **Table 23**).

Table 23: South African Dam Hydropower potential (modelled on 2010-2020 flow data) by province.

Province	Potential Hydropower (MW)	Number of Dams	Rank
Free State	112.43	7	1
KwaZulu Natal	13.83	12	2
Western Cape	10.15	13	3
Northern Cape	9.43	2	4
North West	9.29	3	5
Eastern Cape	3.02	19	6
Limpopo	2.08	9	7
Mpumalanga	2.00	17	8
Gauteng	0.15	2	9
Total	**162.37**	**84**	

Installed South African hydropower was then compared to South African dam hydropower potential modelled on 2010-2020 DWS flow data. However, this comparison could only be conducted for three dams due to missing and/or inaccessible data (see **Table 24**).

Table 24: Installed Hydropower compared to South African Dam Hydropower Potential (modelled on 2010-2020 flow data).

Name	Installed Hydropower (MW)	Hydropower Potential (MW) modelled on 2010-2020 flow data
Zeekoegat WWTW	0.0069	-
Blackheath WWTW	0.712	-
Steenbras WWTW	0.34	-
Wemmershoek WTW	0.208	-
Boston	4.2	-
First Falls	6	-
Merino	3.6	-
Ncora	2	0.42
Sol Plaatjie	2.5	-
Stortemelk	4.5	-
Colley Wobbles/Mbashe	42	-
Drakensberg	1000	-
Gariep	360	96.07
Hazelmere	10	0.03
Ingula	1332	-
Neusberg	12.57	-
Palmiet	400	-
Second Falls	11	-
Steenbras	180	-
Vanderkloof	240	-

It also is important to note that the flow records from the gauging stations within the Buffels drainage region could not be accessed; therefore, the dams within this region were not assessed for hydropower potential. In addition, 39 gauging stations had no flow records, meaning that the hydropower potential assessment could not be modelled for an additional 39 dams where the gauging stations are located. Consequently, there is a high probability that the hydropower potential within South African dams is much greater than is estimated here since a substantial number of dams could not be assessed due to missing and/or inaccessible data. A data layer was subsequently created to represent the 84 South African dams that exhibit hydropower potential for the 2010-2020 period (see **Figure 21**, pg. 59).

4.4. OBJECTIVE 4: DEVELOPING A WEB-BASED HYDROPOWER APPLICATION

The final objective of this study was to develop a web-based hydropower application that will serve as an information product. To achieve this objective, this dissertation assessed several existing online renewable energy atlases that have been developed worldwide, to identify common and preferred functionality for the web-based hydropower application. An overview of the resulting web-based atlas, SAHA, which was developed using the ArcGIS Online platform is presented below. Please access the interactive Atlas online at https://bit.ly/3tCGzSQ. A brief description of SAHA and its functionality is also given below. It is important to note that SAHA is a work in progress, meaning updates are continuously being made to the Atlas; as a result, the screenshots provided below might slightly differ from the live version of the Atlas. A detailed help manual which provides instructions on how to navigate the Atlas and its functionality is accessible at https://bit.ly/3Og9Gnh.

MAP DESCRIPTION, COPYRIGHT AND DISCLAIMER

Upon launching SAHA, a default splash screen with the map description, copyright, and disclaimer information is displayed (**Figure 7**). The purpose of the splash screen is to briefly introduce SAHA to the user and make them aware of vital information such as the disclaimer and copyright and distinguishes SAHA from other existing web-based renewable energy atlases. On the bottom left corner of the splash screen, the user is asked to acknowledge the disclaimer before being granted access to the Atlas.

Figure 7: A default splash screen with the map description, copyright, disclaimer information, as well as the Water Research Commission and University of Pretoria logos.

HOME PAGE

Clicking the *OK* button on the bottom right corner of the splash screen grants the user access to the home page (**Figure 8**, pg. 52). The home page is the default main page of SAHA. A home page is an important part of any website since it is the first page that the user sees before they explore any other features of a website. For this reason, a minimalistic design was chosen for the SAHA home page; similar items such as tools and functionality have been placed or grouped, and a toned-down colour scheme was chosen, which consists of colours that blend easily together; namely, blue, grey, and white. The logo and headline are conveniently placed on the top pane. In addition, appropriate icons have been used to make it easy for the user to know what the purpose of each icon is. When the user hovers over an icon a descriptive name of the icon pops up.

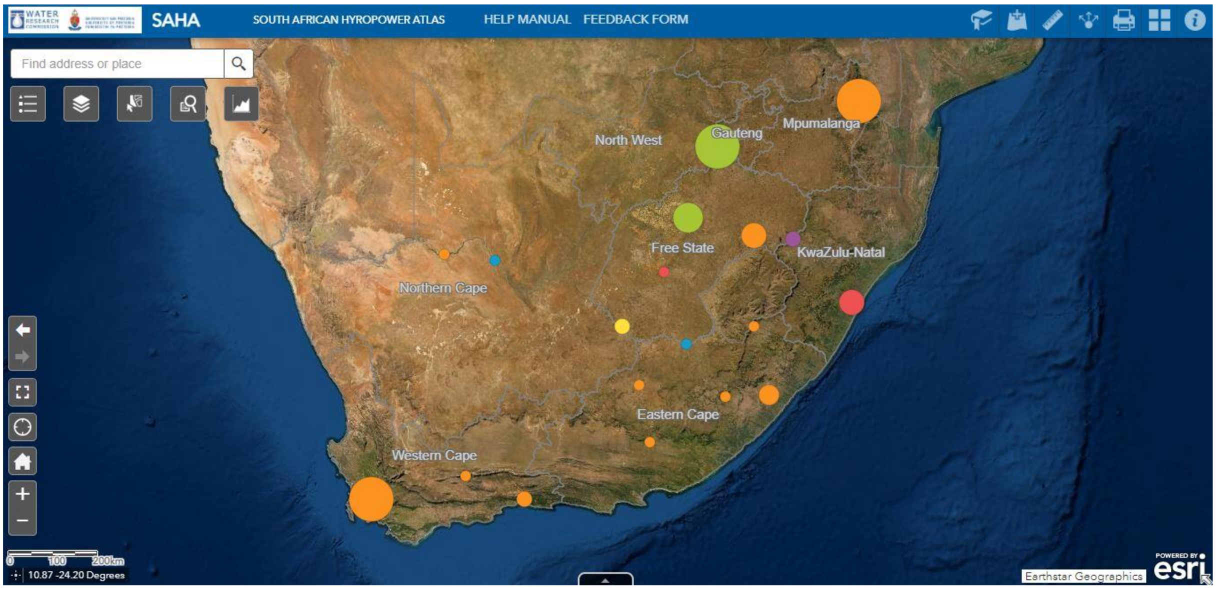


Figure 8: SAHA home page.

NAVIGATION TOOLS

SAHA offers several navigation tools to help the user effortlessly navigate through SAHA (**Figure 9**, pg. 52). These navigation tools include the *Previous or next extent (A), Switch to full screen (B), My location (C), Default extent (D),* and *Zoom in or out (E)* functions. The *Previous* or *Next extent* feature jumps to the previous or next extent of SAHA. The *Full* extent feature maximises the Atlas in your browser. The *My location* feature zooms into the user's current location once the user has accepted their web browser's request to access their location. The *Default extent* feature takes SAHA back to its default view which is the *Home page* view. Finally, the *Zoom in* or *out* feature allows the user to zoom in and/or out of SAHA.

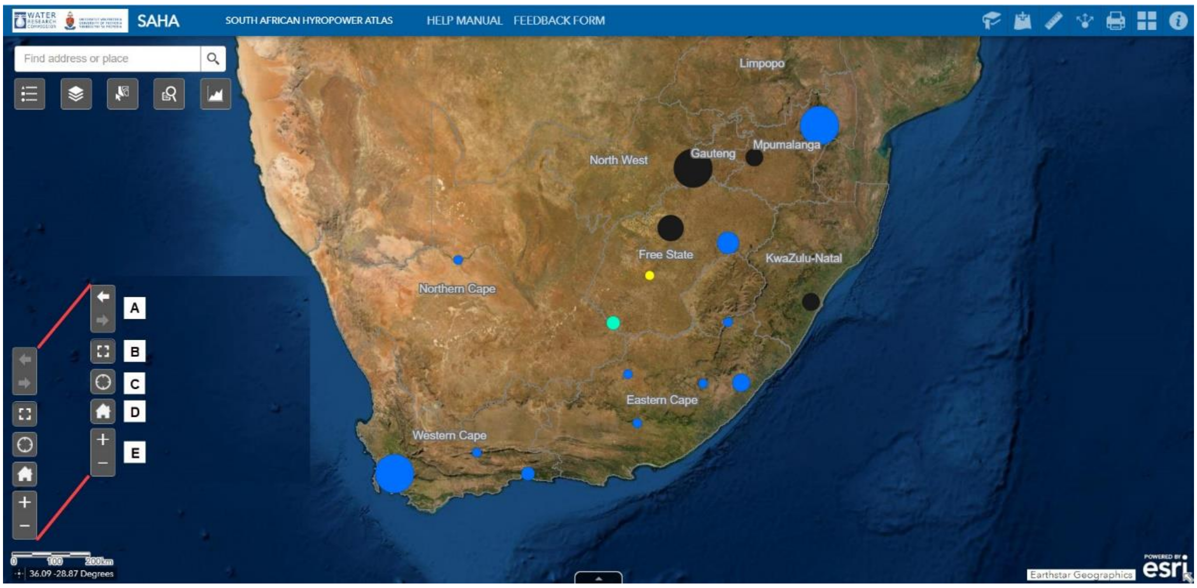


Figure 9: Navigation Tools: Previous or next extent (A), Switch to full screen (B), My location (C), Default extent (D), Zoom in or out (E).

EXTENDED FUNCTIONALITY

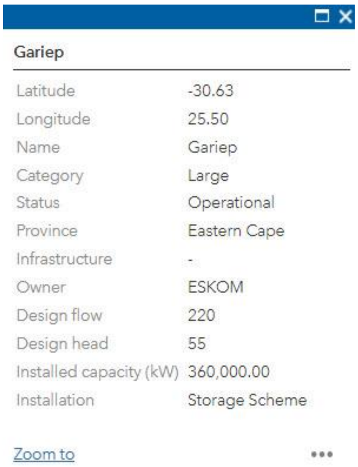


Figure 10: A pop-up displaying attribute data for the Gariep storage scheme.

The SAHA covers an extensive area and displays several data layers relating to hydropower in South Africa. The information relating to existing hydropower and the hydropower potential in the country that is presented by the atlas is at times exhaustive. Therefore, the atlas makes use of a legend, layer list, and pop ups among other tools and functionalities, to effectively present relevant information relating to existing and potential hydropower in South Africa, and to avoid overwhelming the user with information.

The *Search bar (F), Legend (G), Layer list (H)*, *Select (I), Query (J)* and *Chart (K)* tools are found on the top-left side of SAHA (see **Figure 11**).

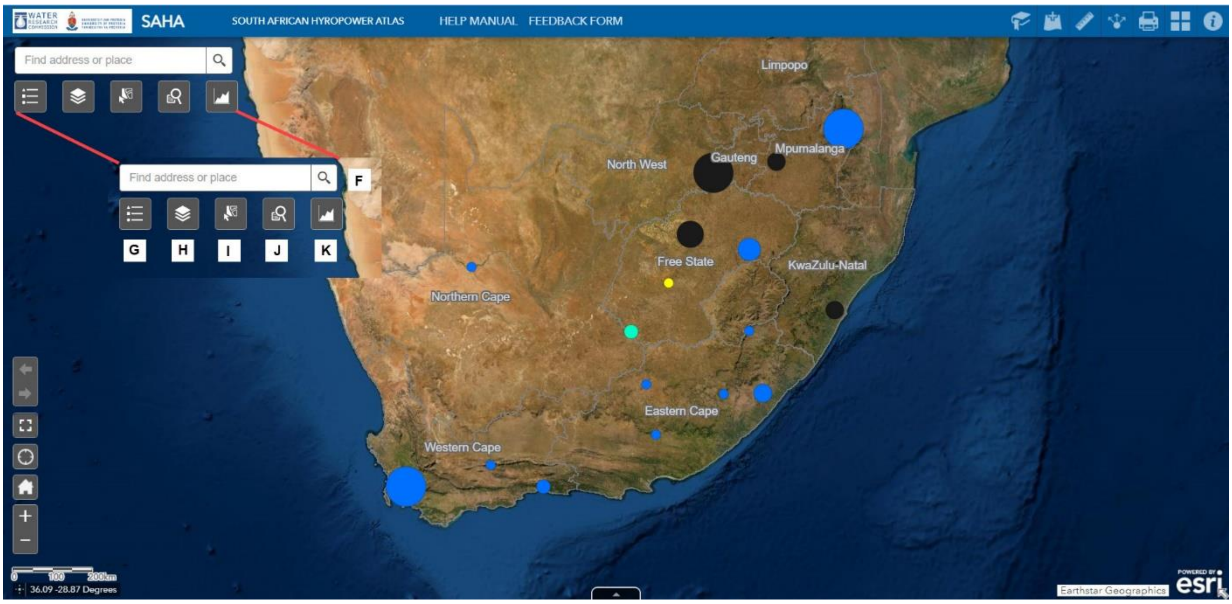


Figure 11: The Search bar (F), Legend (G), Layer list (H), Select (I), Query (J) and Chart (K).

The *Search bar* allows the user to search the address or name of the place that they would like to be displayed on the map. Once the search query is processed, the place of interest is automatically zoomed into. Moreover, since this feature is built on Google Search, it allows the user to search for any place in the world, and not only places in South Africa. The Legend tool displays the symbology of all layers that are currently active (set to be visible) in the map extent. The *Layer list* tool is a list of all the data layers and associated legend of each layer. The tool allows the user to individually enable and disable layers from displaying, the layers can also be disabled simultaneously. Each layer is symbolised to make it easier for the user to discern the different features within each data layer. The *Select* tool gives you the option to select from the features on your map. The user can individually decide which layers you wish to select from, or you can make all layers selectable. Similarly, individual layers can be turned off. The *Query* function stores pre-defined queries that the user can run to obtain desired results about hydropower in South Africa (**Figure 12**, pg. 54). To illustrate, Figure 12 shows results obtained from running a query that returns only operational hydropower schemes out of all existing hydropower schemes in South Africa. The results are highlighted by a darker blue polygon.

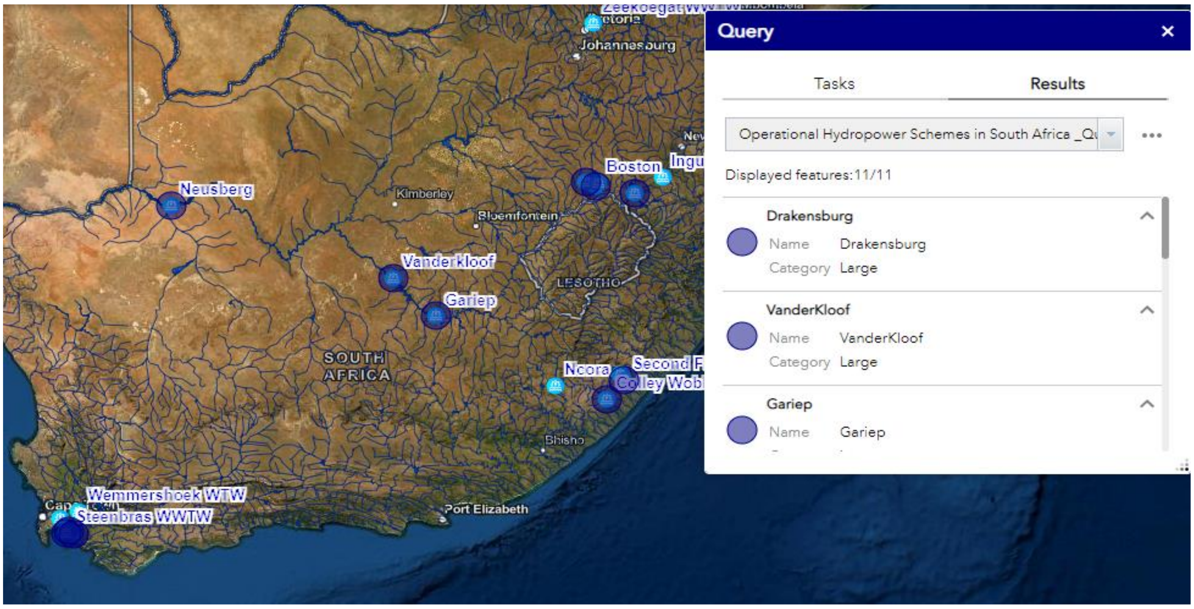


Figure 12: Results obtained by using SAHA's Query tool.

The *Chart* widget provides a variety of predefined charts. The user can display graphs for data from your whole map view, or for an area based on a graphic you draw on the map. Once a graph is displayed, its colour, display of axes, and display of the legend can be configured; the graph can also be maximised in to fill your screen.

THE TOP MENU

The top right menu consists of the *Bookmarks (L), Add data (M), Measure (N), Share (O), Print (P), Basemaps (Q),* and *About (R)* buttons (**Figure 13**).

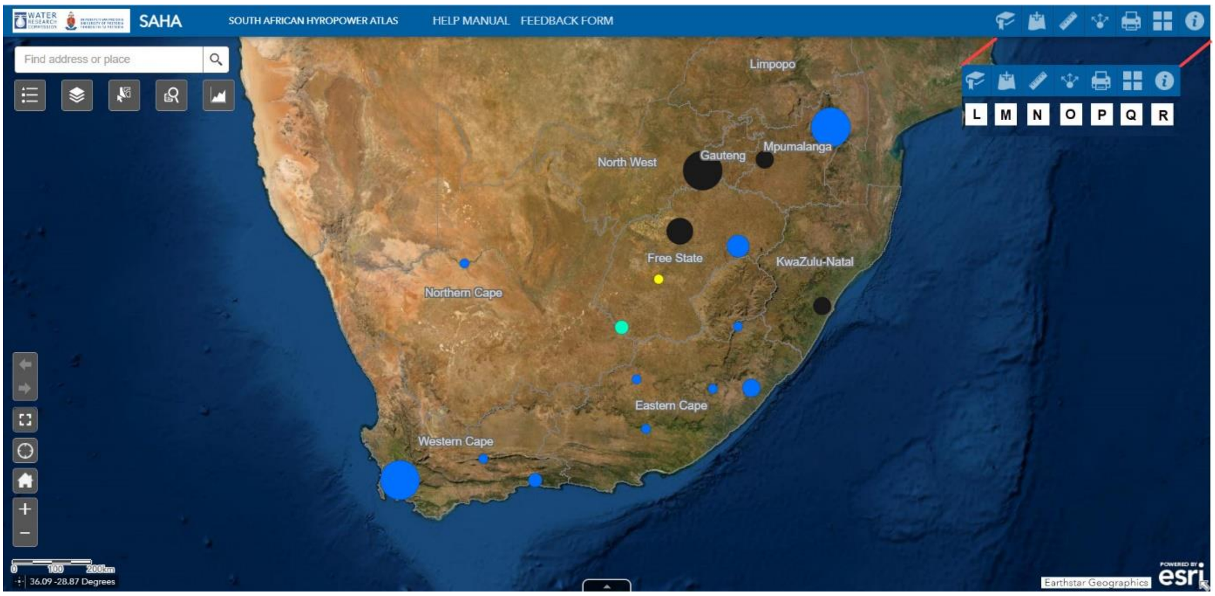


Figure 13: Bookmark (L), Add data (M), Measure (N), Print (O), Share (P), Basemaps (Q), and About (R) functionality.

The *Bookmark* tool allows the user to bookmark or add a list of areas of interest; this allows the user to easily navigate to these areas in future. The *Add data* function enables the user to add their data to

SAHA. The data can be in shapefile format, comma separated values (CSV), KML, GPX or GeoJSON file format, or added as a web service. However, the user cannot save the data permanently to SAHA. This is to ensure data integrity and quality regarding volunteered geographic information (VGI), as discussed in **2.5. ASSESSING EXISTING** (pg. 20 onward). The *Measurement* tool can be used to measure distance, area, or to determine the coordinates of a particular area of interest. **Figure 14** shows the results obtained from using the *Measurement* tool; the user can choose a measurement unit of their choice. The *Share* function, on the other hand, is for social media connection; the user can easily share content provided by SAHA with the public via platforms such as Twitter, E-Mail, and Facebook. This feature is important since the goal is to make SAHA accessible to as many members of the public as possible. The *Print* function allows the user to directly print their current map view from the web. The *Basemap* gallery consists of a variety of basemaps that the user can choose from. Finally, The *About* icon provides information about SAHA and the platform used to host it.

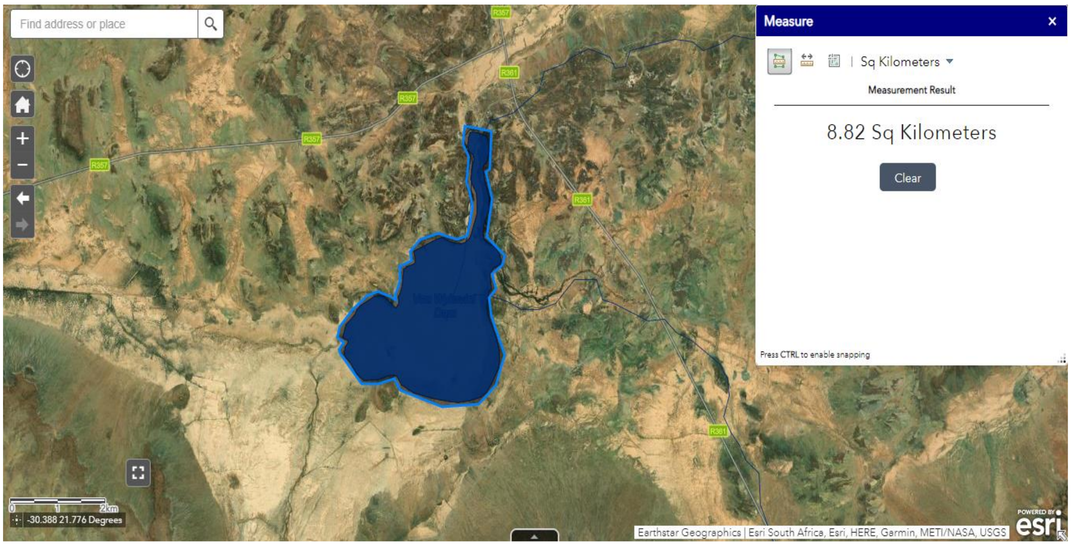


Figure 14: Results obtained from calculating an area using SAHA's Measurement tool.

ADDITIONAL TOOLS

SAHA also displays the *Show map overview (S),* the *Attribute table (T)*, a *Scale bar (U),* a *Help manual (V)*, and *Feedback form (W)* (**Figure 15**, pg. 55).

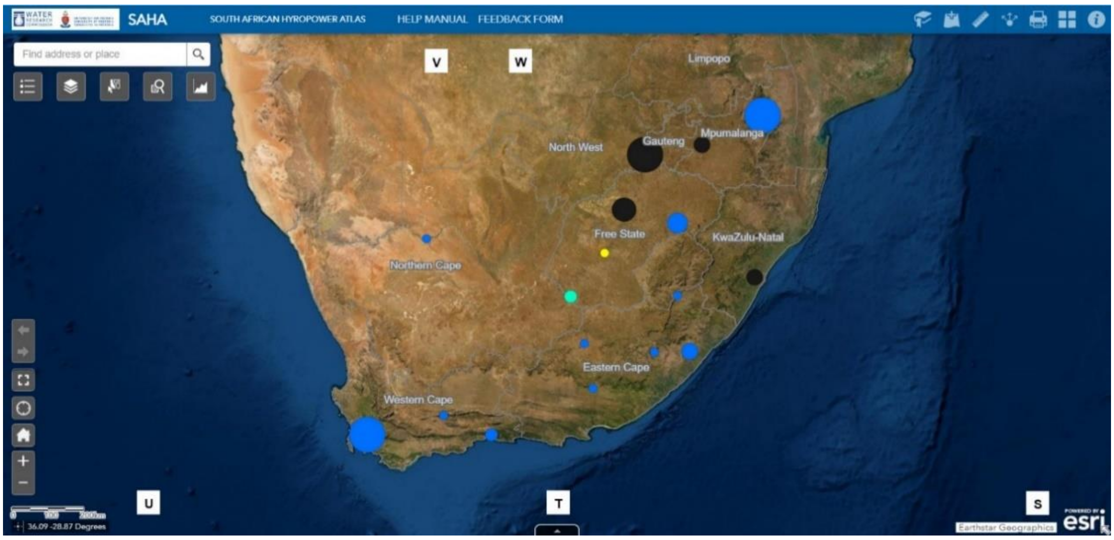
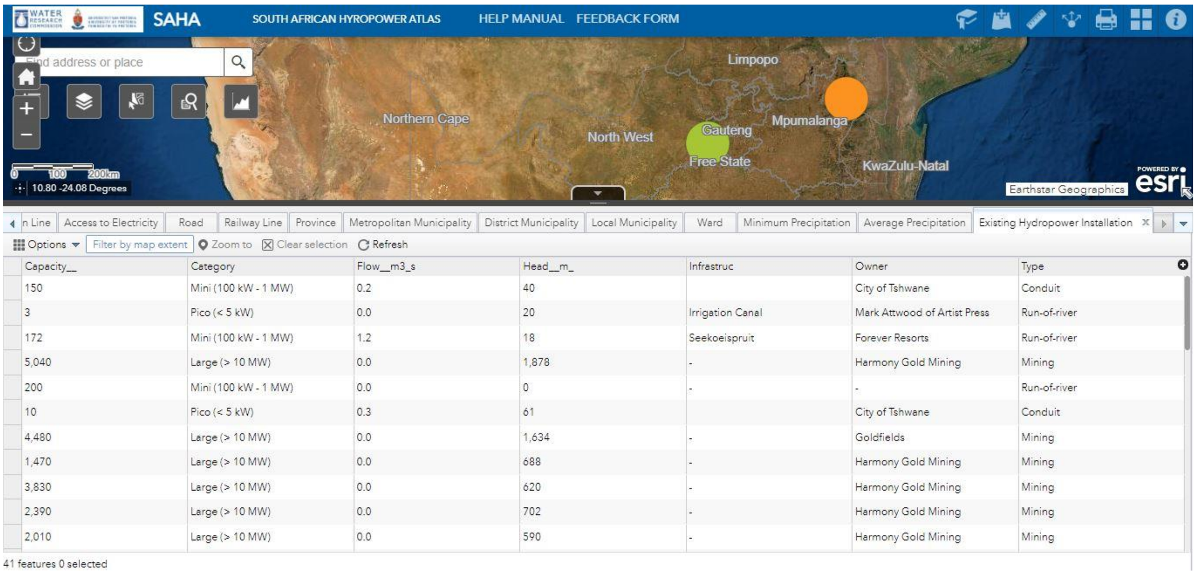


Figure 15: Additional tools available on SAHA. Show Map Overview (S), the Attribute table (T), a Scale bar (U), a Help manual (V), and a Feedback form (W).

The *Show map overview (S)* function, represented as an arrow at the bottom right corner of SAHA, displays the user's view, highlighted by a rectangular shape concerning surrounding areas. The *Attribute table (T)* contains attribute data about the features that are displayed on SAHA (see **Figure 16**). The attribute table can be refreshed, allows the user to select and zoom in to features that they would like to study in detail, and the user can clear the selected features. The user is also given the option to hide some of the fields (columns) of the attribute table, this allows the user to focus on the columns that they are interested in and deems relevant. In addition, the attribute table has a *Filter by map extent* function, which displays features that are only visible at the user's current map extent instead of displaying all the features on the table. The *scale bar (U)*, situated at the bottom left corner, represents the relationship between the distance on the Atlas and the corresponding distance on earth, displayed as a ruler in metric units. The scale bar dynamically updates as the user zooms in or out of the map. The *HELP MANUAL (V)* contains a link to a comprehensive help manual. Finally, the *FEEDBACK FORM (W)* opens a document that allows the user to log errors or make recommendations for improvement regarding SAHA.



Capacity__	Category	Flow__m3_s	Head__m_	Infrastruc	Owner	Type
150	Mini (100 kW - 1 MW)	0.2	40		City of Tshwane	Conduit
3	Pico (< 5 kW)	0.0	20	Irrigation Canal	Mark Attwood of Artist Press	Run-of-river
172	Mini (100 kW - 1 MW)	1.2	18	Seekoeispruit	Forever Resorts	Run-of-river
5,040	Large (> 10 MW)	0.0	1,878	-	Harmony Gold Mining	Mining
200	Mini (100 kW - 1 MW)	0.0	0	-	-	Run-of-river
10	Pico (< 5 kW)	0.3	61		City of Tshwane	Conduit
4,480	Large (> 10 MW)	0.0	1,634	-	Goldfields	Mining
1,470	Large (> 10 MW)	0.0	688	-	Harmony Gold Mining	Mining
3,830	Large (> 10 MW)	0.0	620	-	Harmony Gold Mining	Mining
2,390	Large (> 10 MW)	0.0	702	-	Harmony Gold Mining	Mining
2,010	Large (> 10 MW)	0.0	590	-	Harmony Gold Mining	Mining

Figure 16: An example attribute table of one of the layers embedded in SAHA.

LAYERS OF INTEREST

South Africa has a total of 1215 wastewater treatment works (**Figure 17,** pg. 57). Recent research (see Bousquet et al., 2017; Mérida García et al., 2021), indicates that there are sometimes opportunities for unconventional hydropower development in this type of water infrastructure, hence their inclusion in SAHA.

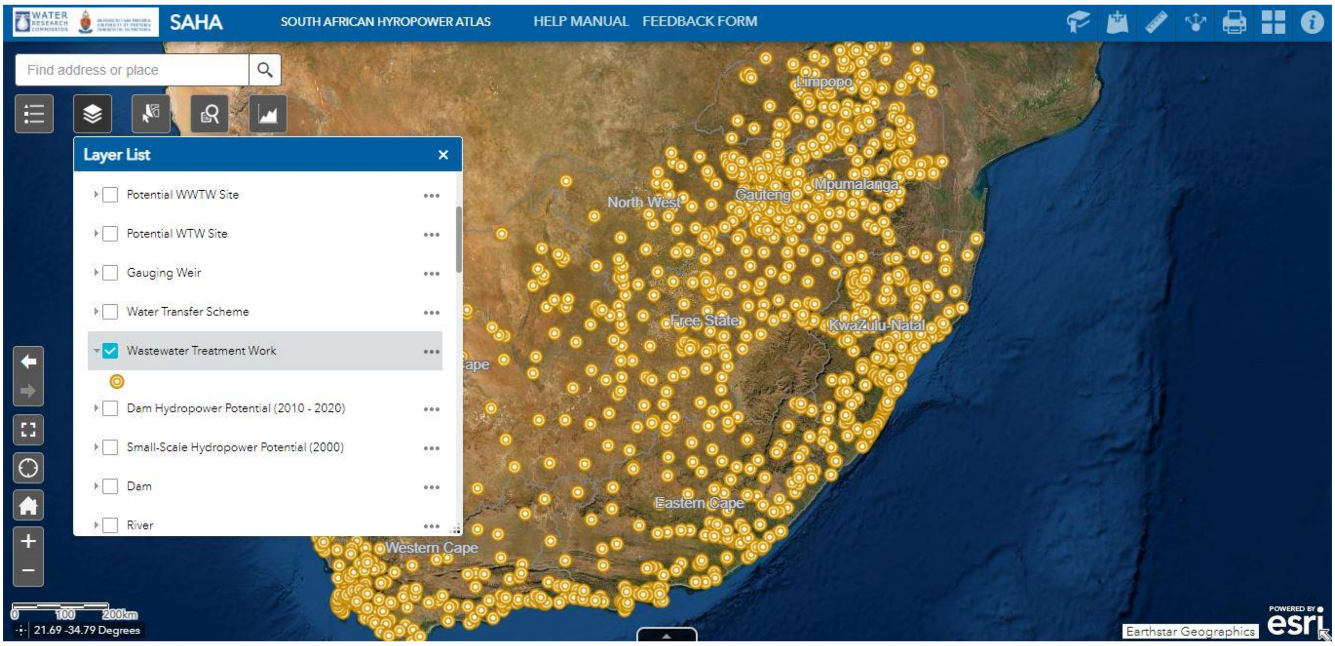


Figure 17: Wastewater Treatment works in South Africa.

Figure **18** represents all the gauging weirs in South Africa.

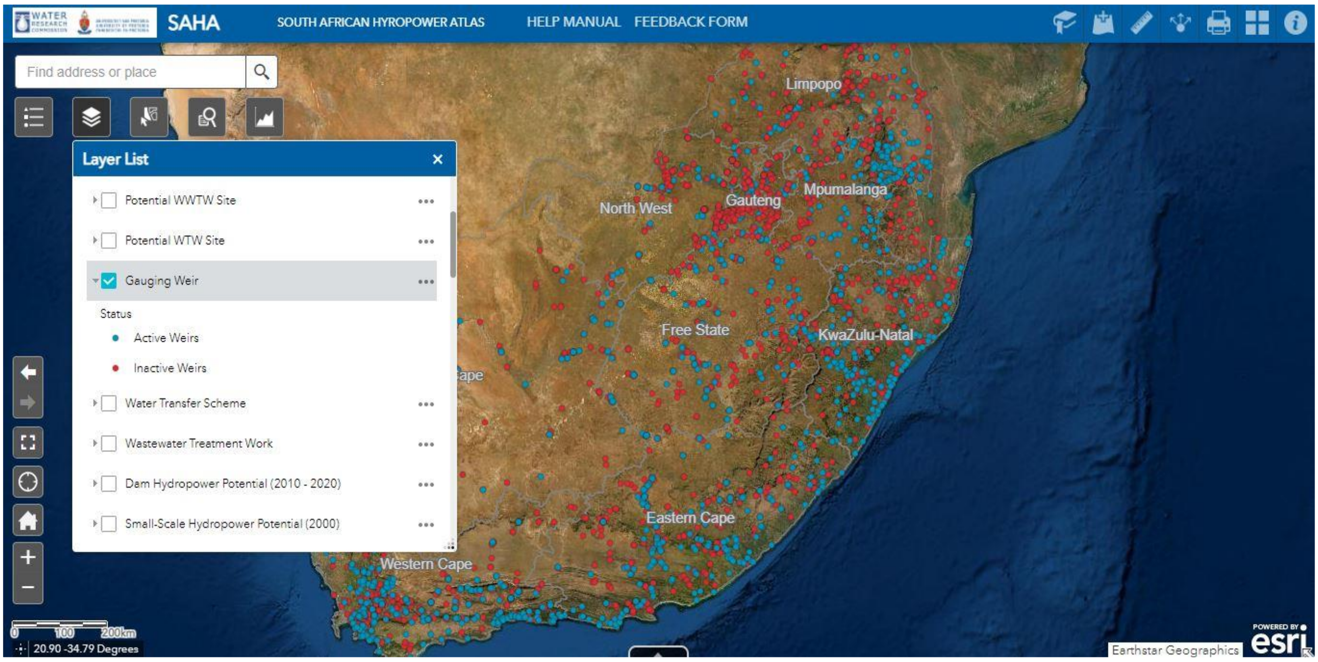


Figure 18: Active and inactive Gauging weirs in South Africa.

Potential sites, within existing water infrastructure, where hydropower technology could be retrofitted were identified. The potential sites include weirs, wastewater treatment works, dams and conduit sites and have been symbolised according to their potential power output (**Figure 19**, pg. 58).

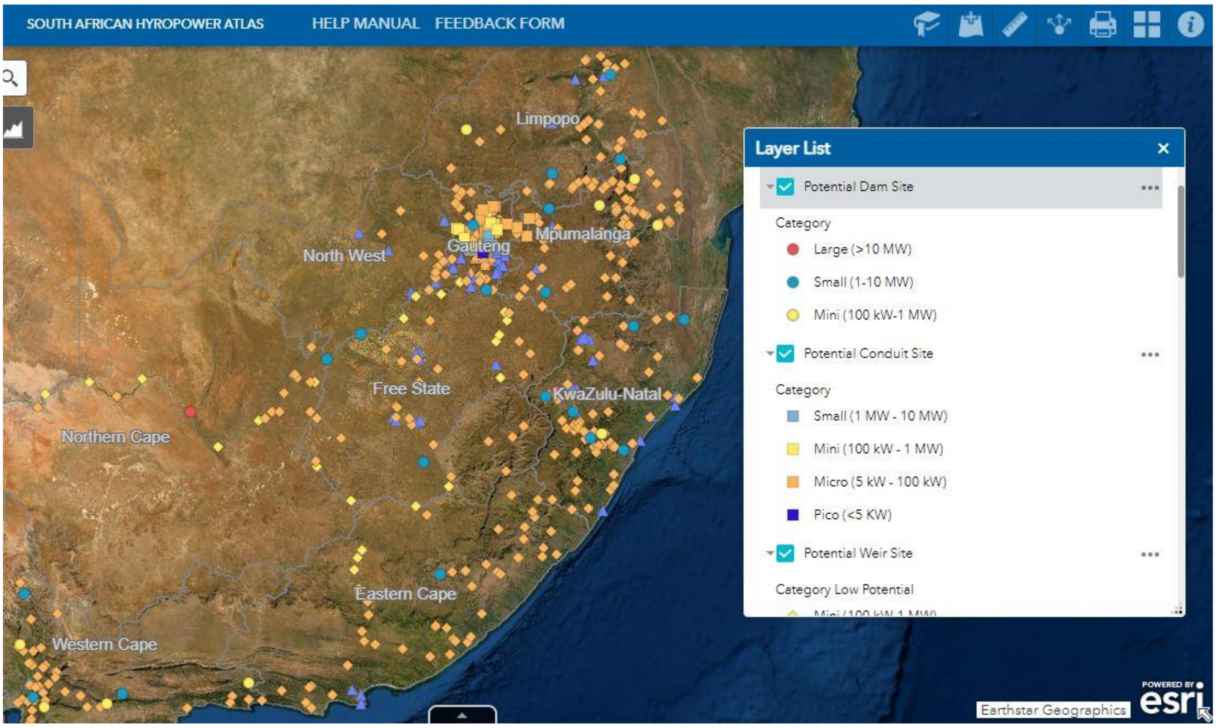


Figure 19: Potential hydropower sites in South Africa.

A data layer indicating the percentage of South African households that have access to electricity for lighting has been created to indicate where access to electricity is most and/or least common at ward level (see **Figure 20**). This layer is named *Access to Electricity* and is based on the 2011 census data.

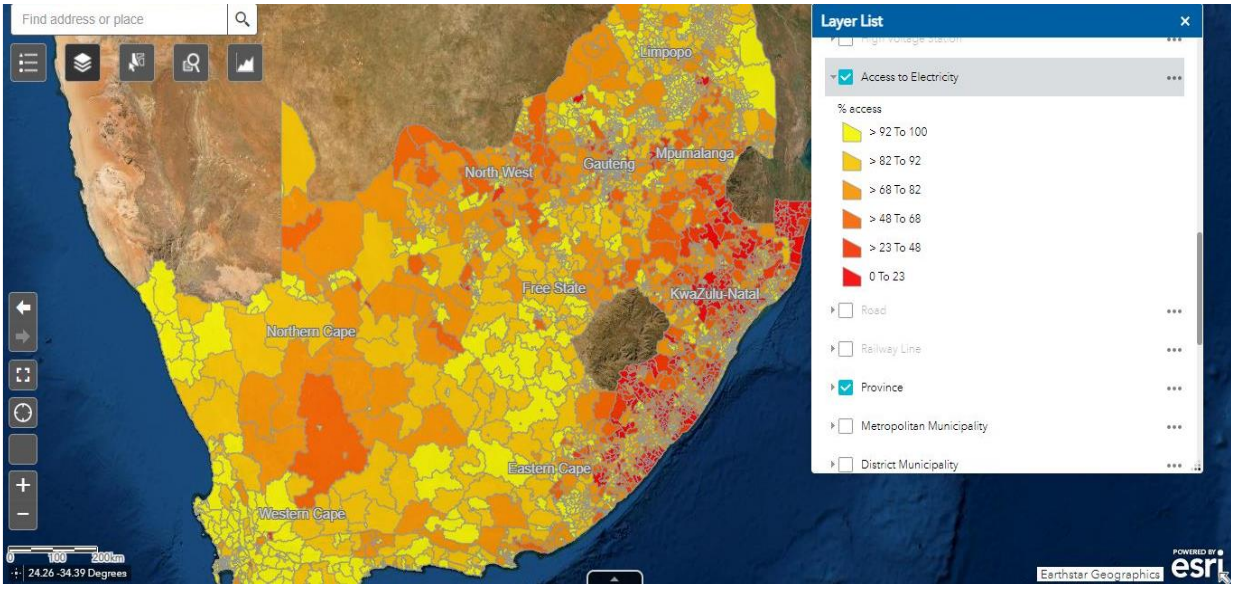


Figure 20: Access to electricity at ward level.

Figure 21 (pg. 59) represents a layer of South African dams with hydropower potential and their respective categories. This is the output of Objective 3 (refer to **4.3. OBJECTIVE 3: MODELLING SOUTH AFRICAN DAM HYDROPOWER POTENTIAL**, pg. 46 onward).

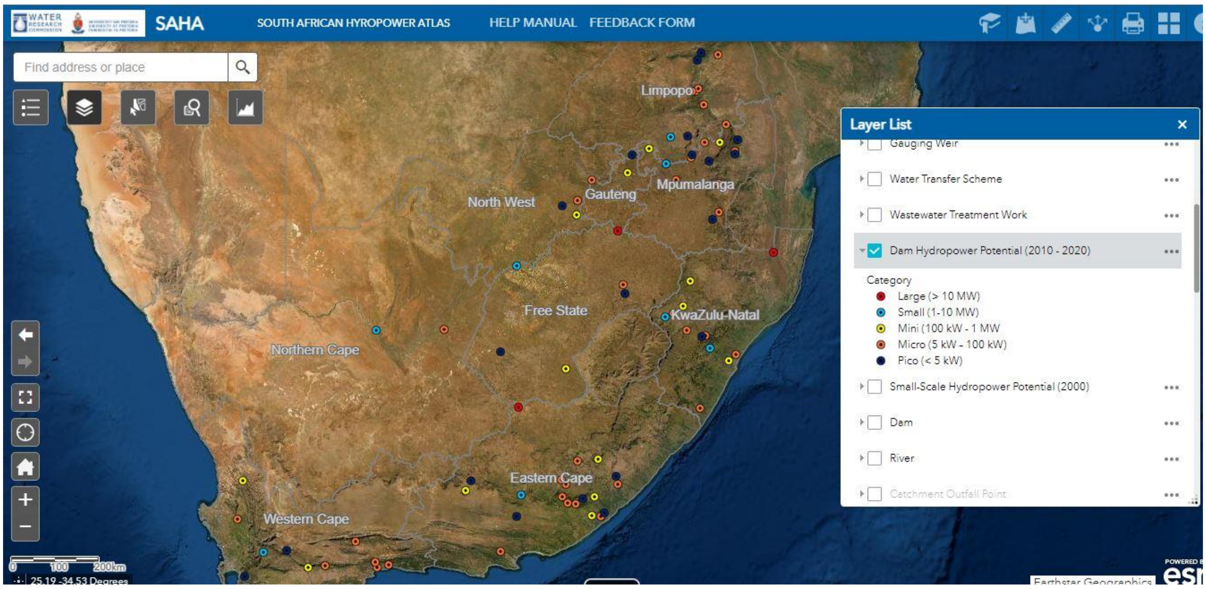


Figure 21: South African dam hydropower potential, based on flow records available from the DWS for 2010-2020.

SAHA STAKEHOLDER SURVEY 1 RESULTS

A stakeholder survey was conducted to involve the stakeholders of SAHA in the development process of SAHA and to assess the user-friendliness and functionality of SAHA. A summary of the feedback provided by the respondents is given in **Figure 22** to **Figure 30** (pg. 60 - 62).

Only three responses were received (**Figure 22**, pg. 60). However, since the survey was sent to known stakeholders of SAHA, their feedback remains valuable. All respondents indicated that they would use SAHA for data downloads, as well as research purposes, while none were simply curious about the product (**Figure 23**, pg. 60). Envisaged uses of SAHA further include decision making (two respondents), and project management (one respondent). None indicated that SAHA is not user-friendly, although the user-friendliness can be improved, with two respondents selecting the middle value of the Linkert scale (**Figure 24**, pg. 60). Reasons for the answers presented in **Figure 24** are given in **Figure 25** (pg. 61). In comparison, the feedback received relating to the analyses functionality of SAHA varied (**Figure 26**, pg. 61). Feedback in this regard is presented in **Figure 27** (pg. 61). Furthermore, respondents were given the opportunity to make recommendations on the type of analyses queries they would like to be added to SAHA (see **Figure 28**, pg. 61). Additional recommendations are given in **Figure 29** (pg. 62).

Finally, respondents were asked if the geospatial layers currently available on SAHA should be removed or kept. Feedback received indicates that most are suitable for inclusion on SAHA (refer to **Figure 29**, pg. 62). Geospatial layers where at least one respondent indicated that it should be removed, *i.e.,* are not suitable for inclusion in SAHA, include one response indicating 'Remove'*: Dams, Rivers, Wards, Drainage Directions, Precipitation Change by 2050, Monthly Precipitation in Africa and Near East, Average Temperature in Sub Saharan Africa,* and *Predicted Temperature Change*. The respondents suggested that run-of-river hydropower potential, gauging weirs/dams historical dataset, Selected Irrigation Canals, and Selected Distribution/ Water Storage Service Reservoirs data layers are added to the Atlas. The addition of the Ingula Hydropower Station to Atlas was also recommended. From the feedback obtained from the survey, it can be also gathered that two of the respondents are affiliated with the University of Pretoria while one is affiliated with the University of Zambia. A user help manual was added to the Atlas to assist with easier navigation around the Atlas. Furthermore, the analyses tool was replaced with the chart tool.

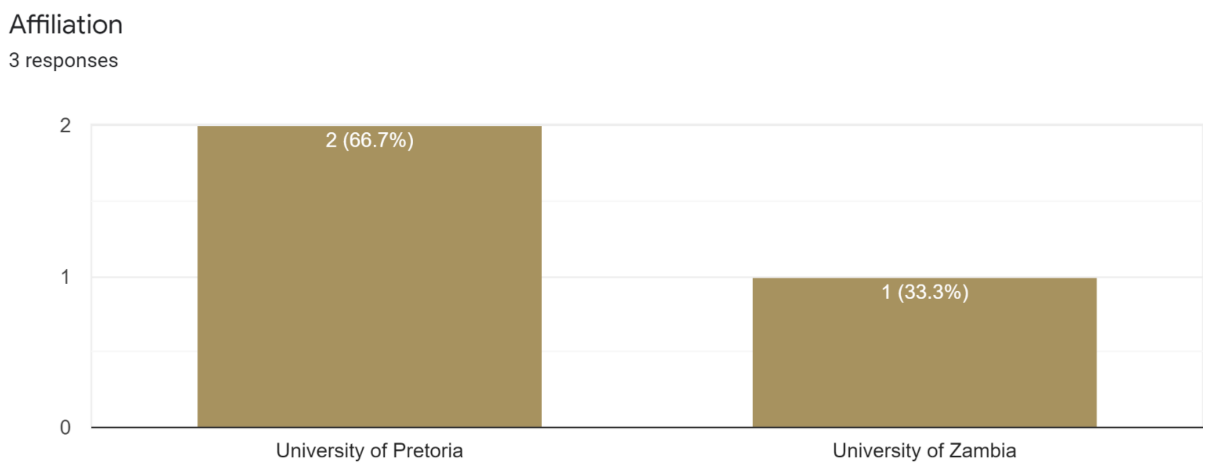


Figure 22: Affiliation of SAHA Stakeholders.

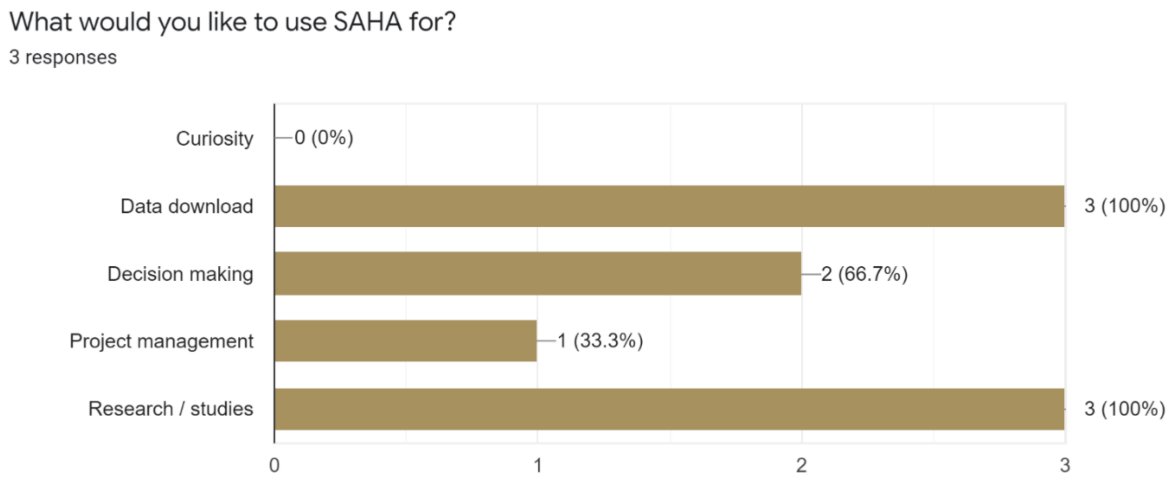


Figure 23: SAHA Stakeholder feedback on what they would use SAHA for.

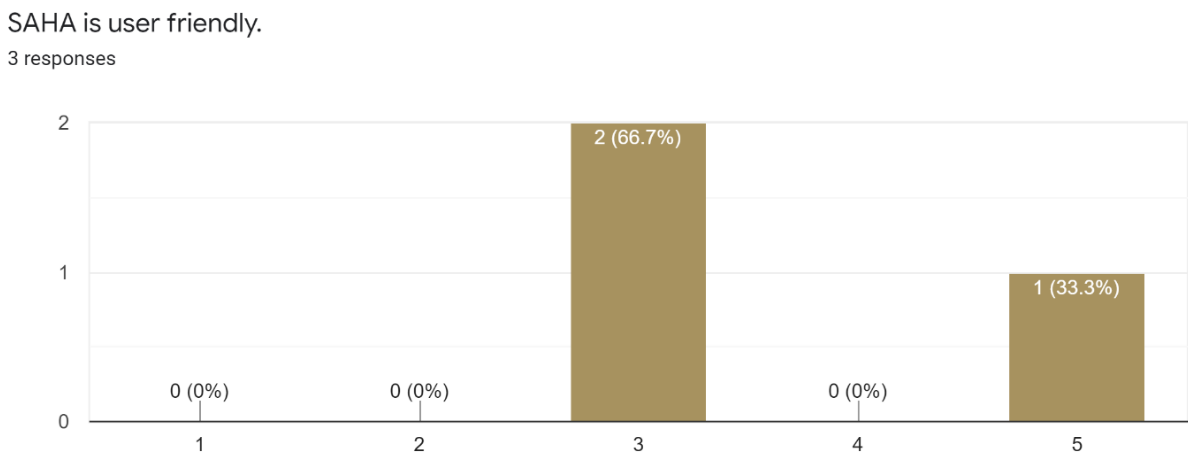


Figure 24: Feedback on user-friendliness of SAHA.

Please provide additional information relating to the previous question here.

2 responses

Takes some trial and error to figure it out

There were no instructions on how to proceed once the website has loaded. Clicking on the bookmark of the provinces does not zoom to the whole view of the province. There is no visible legend loaded showing what the different colours means for the potential hydro-power sites.

Figure 25: Descriptive feedback regarding the user-friendliness of SAHA.

The different functionalities provided under the Analysis tool are useful.

3 responses

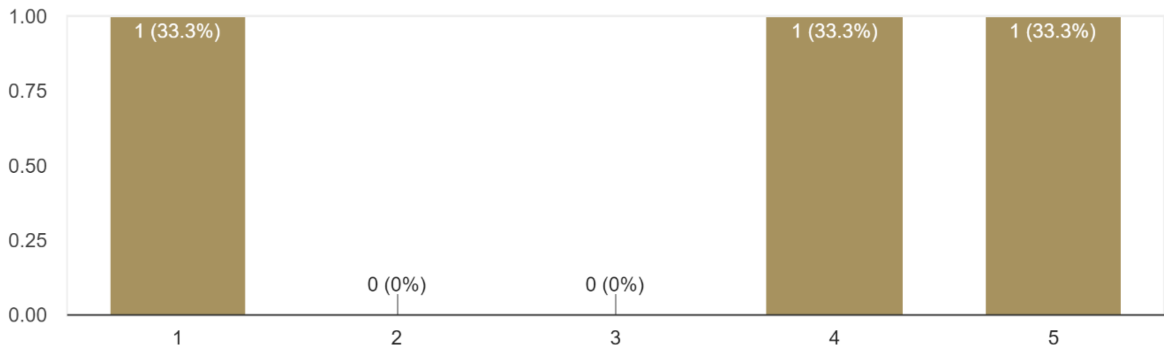


Figure 26: Feedback on usefulness of SAHA functionality.

What additional analyses tools would you like to add?

1 response

The analysis tool requested me to sign in to an ArcGIS account, which I do not have the credential for, so the analysis tools could not be used.

Figure 27: Stakeholder recommended analyses tools to be added to SAHA.

Please provide pre-defined queries that you think should be added to SAHA and state the results you would like to obtain from these queries.

3 responses

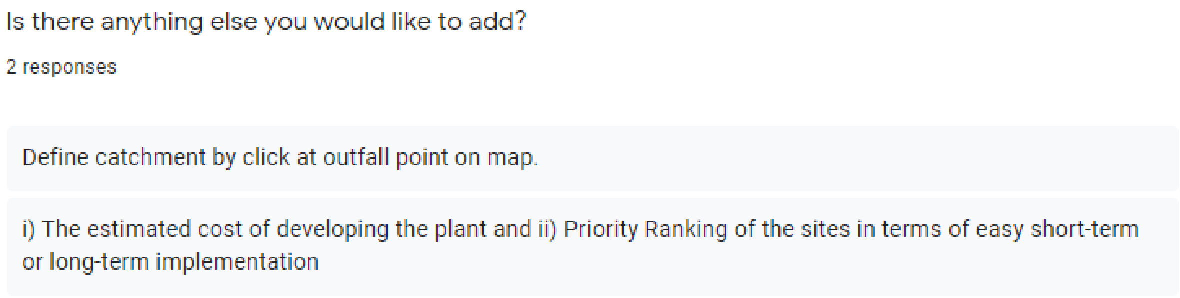
Hydropower by area

Allow the user to download all the layers as SHP-files and also upload their own layers for a improved functionality within the online platform.

Ingula Pump Storage was not visible, all existing hydro-power schemes, should be listed, classified by type, size & provisince.

Query to indicate the available hydropower potential and the estimated cost of developing the plant

Figure 28: Stakeholder recommended pre-defined queries.



Is there anything else you would like to add?

2 responses

Define catchment by click at outfall point on map.

i) The estimated cost of developing the plant and ii) Priority Ranking of the sites in terms of easy short-term or long-term implementation

Figure 29: Additional recommendations for SAHA

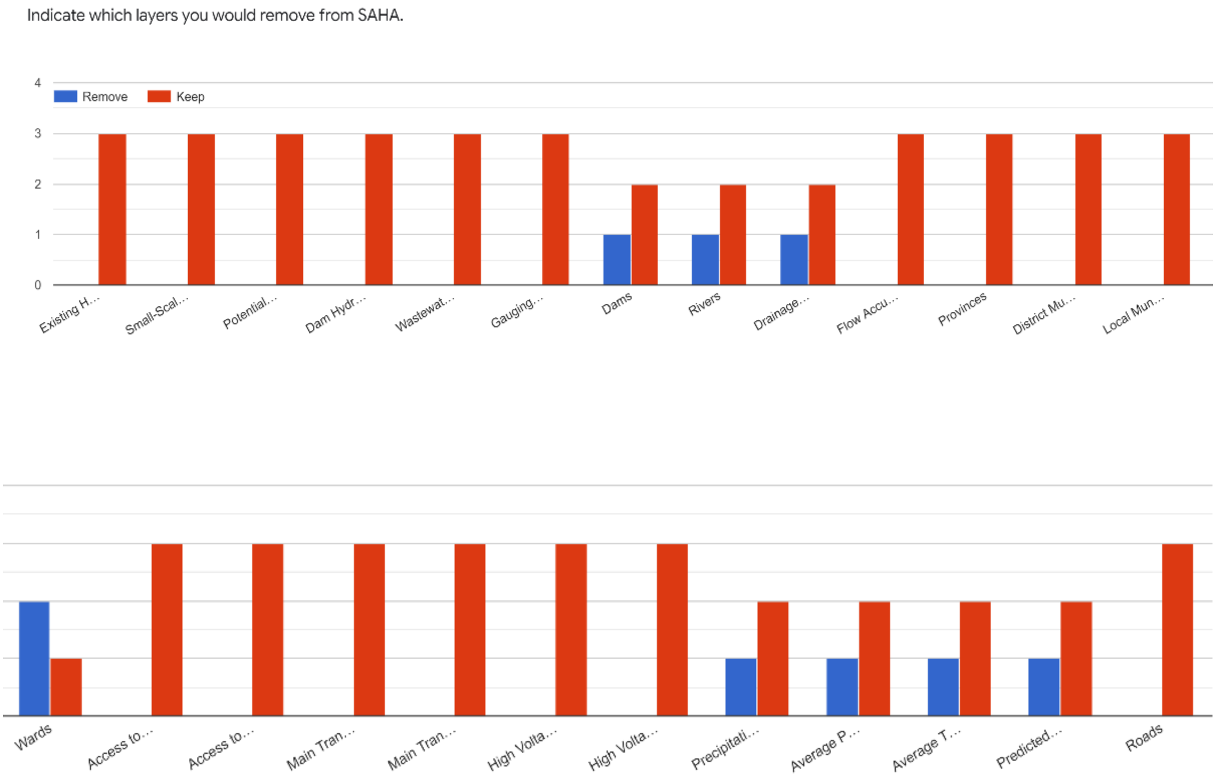


Figure 30: Data layers displayed by SAHA that should be removed or kept.

CHANGES IMPLEMENTED

A user help manual highlighting the functionality and tools offered by the Atlas was created to assist users to navigate the Atlas with ease, based on feedback provided in **Figure 25** (pg. 61). When the user clicks the *HELP MANUAL* button, the help manual is loaded onto a different web page and can be downloaded in portable document format (.pdf) (**Figure 31,** pg. 63).

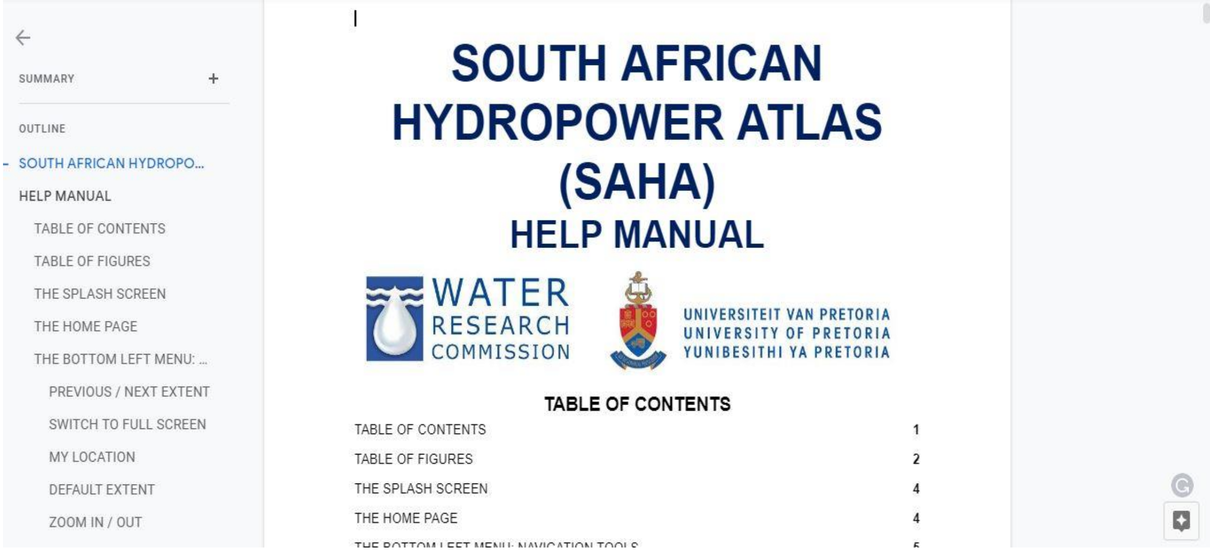


Figure 31: User help manual.

Another tool that was added to the atlas was the *Legend,* which displays the symbology of active layers, in other words, layers that have been selected by the user and are displayed on the atlas (**Figure 32**). This was based on a user comment given in **Figure 25** (pg. 61).

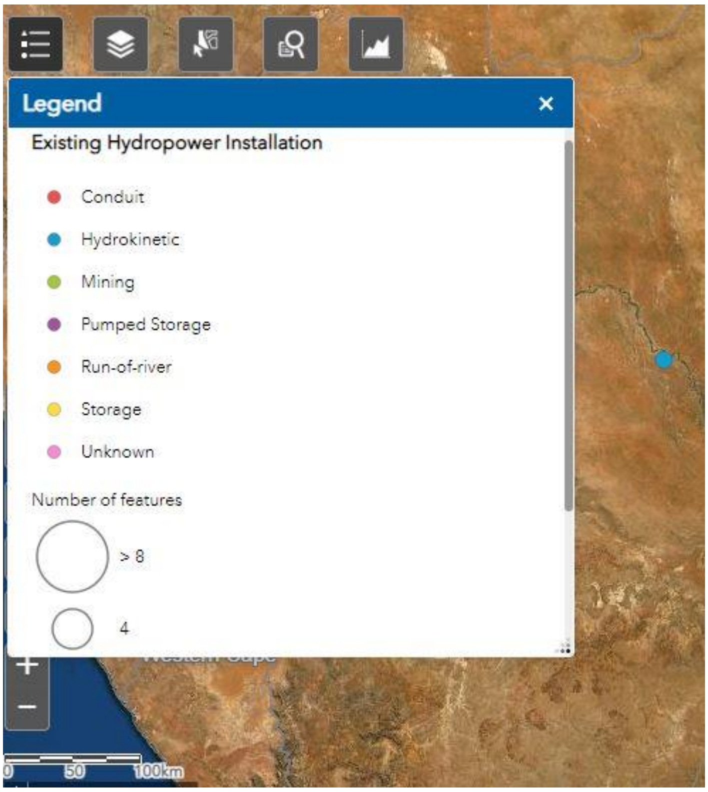


Figure 32: Legend.

The original atlas contained an analysis tool, which provided geospatial analyses options. However, the survey feedback suggested that not all respondents were able to access this tool (**Figure 27,** pg. 61). This was due to licensing restrictions and a requirement of an ArcGIS Online account. The end user was considered throughout the different development stages of SAHA thus accessibility to the atlas is a prime concern. For this reason, the analysis tool was replaced with the chart tool (see **Figure 33**), which is relatively easier to access and does not require the user to create an ArcGIS Online account.

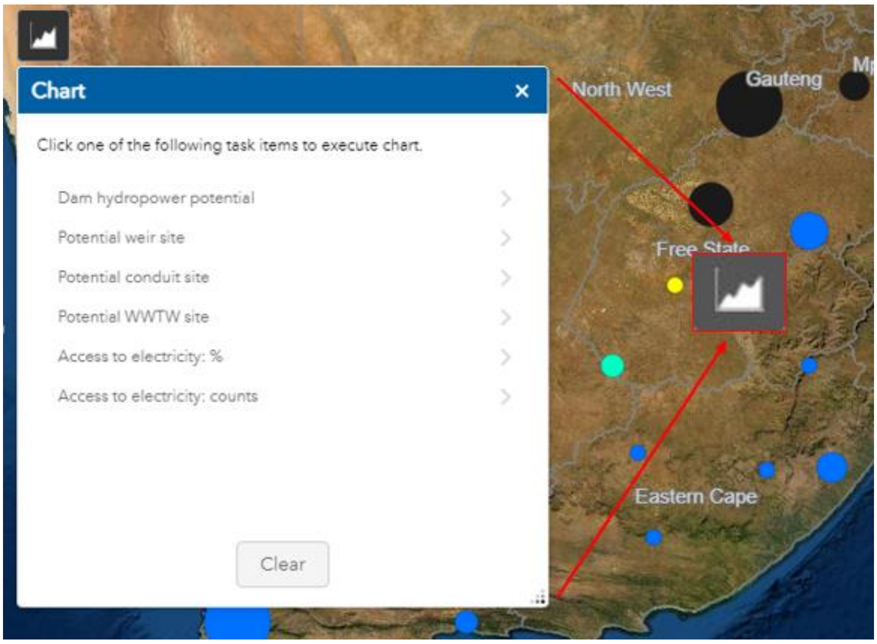


Figure 33: Chart tool and its different items.

The chart tool utilises graphics such as pie charts, bar graphs, and line charts to display quantitative attributes of layers making it easier for the user to comprehend and identify trends within the data. For example, one of the items that have been graphically presented by the chart tool are the attributes of the *Dam Hydropower Potential (2010-2020)* layer (**Figure 34**).

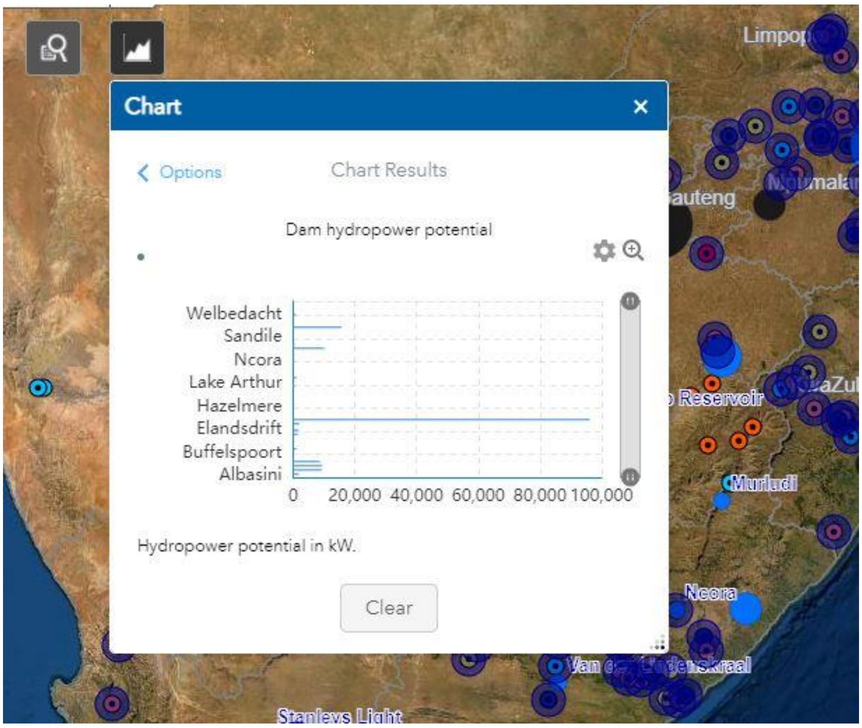


Figure 34: A graphical representation of Dam hydropower potential.

Table 25 and **Table 26** summarise the feedback received from the respondents and the action taken to address the feedback.

Table 25: Feedback on SAHA user-friendliness.

Respondent Comment	Solution/ Action
Takes some trial and error to figure out.	A help manual has been created to assist users with ease of navigation around SAHA (See **Figure 31**, pg. 63).
There were no instructions on how to proceed once the website had loaded.	
Clicking on the bookmark of the provinces does not zoom to the whole view of the province.	Zoom levels have been adjusted for all the bookmarks.
There is no visible legend loaded showing what the different colours mean for the potential hydropower sites.	A Legend was added to SAHA.
Ingula pump storage was not visible.	The Ingula hydropower station has been added to the *Existing Hydropower Installations* layer.
The analysis tool requested me to sign into an ArcGIS account so the tools were inaccessible and could not be used.	The tool was removed, and a *Chart* tool added instead (see **Figure 33**).

Table 26: Pre-defined queries recommended by SAHA Stakeholders.

Recommended Query	Solution/Action
Allows user to download displayed layers in shapefile format and upload their own layers.	Download implemented through the *Select* tool, uploading of data already possible through the *Add Data* button (see **THE TOP MENU**, pg. 54).
Classifies existing hydropower schemes by province.	Implemented
Classifies existing hydropower schemes by size.	Implemented
Classifies existing hydropower schemes by type.	Implemented
Defines catchment at outfall point on map.	Implemented
Indicates available hydropower potential.	Implemented
Indicates estimated cost of developing a hydropower plant.	Not Implemented
Lists existing hydropower schemes.	Implemented
Priority ranking of the sites in terms of easy, short-term or long-term implementation.	Not Implemented
Shows hydropower by area.	Implemented

SAHA STAKEHOLDER SURVEY 2 RESULTS

Feedback from the second stakeholder survey is presented here. Unfortunately, due to the ongoing nature of the project, the survey was still active (access the survey at https://forms.gle/28TBzZNe2VKMezA46) when this dissertation was submitted. As such, only one response was received by submission. Nevertheless, this response is still useful. Further responses will be used to improve further iterations of SAHA.

A summary of the feedback provided by the respondents is given in **Figure 35** below to **Figure 41** (pg. 68). Similar to the first survey, SAHA is to be used as a decision making tool (**Figure 35**), with a middling user friendliness (**Figure 36**). Reasons for the score given for user-friendliness are given in **Figure 37** (pg. 67). Again, the *Ward* layer was recommended for removal, as well as *the Average Temperature in sub-Saharan Africa* (**Figure 38,** pg**.** 67).The functionalities under the query and graphing tools scored well (**Figure 39** and **Figure 40** respectively, pg. 67). Finally, the survey concludes with a choice of acronym for SAHA. Many suitable acronyms are already taken by various organisations, such as SAHA[2], HASA[3], HYSA[4], HPASA[5], and SAHPA[6]. As such, survey respondents, as stakeholders to the current Atlas, were asked to select a choice of name for the Atlas, among a list as given below. The first choice was given to HYPASA, with the last to HYPSA.

- HYDASA - HYdropower Atlas of South Africa
- HYPASA- HYdropower Atlas of South Africa
- HYPSA- HYdropower South Africa
- SAHYA - South African HYdropower Atlas
- SAHYDA - South African HYDropower Atlas
- SAHYPA - South African HYdroPower Atlas

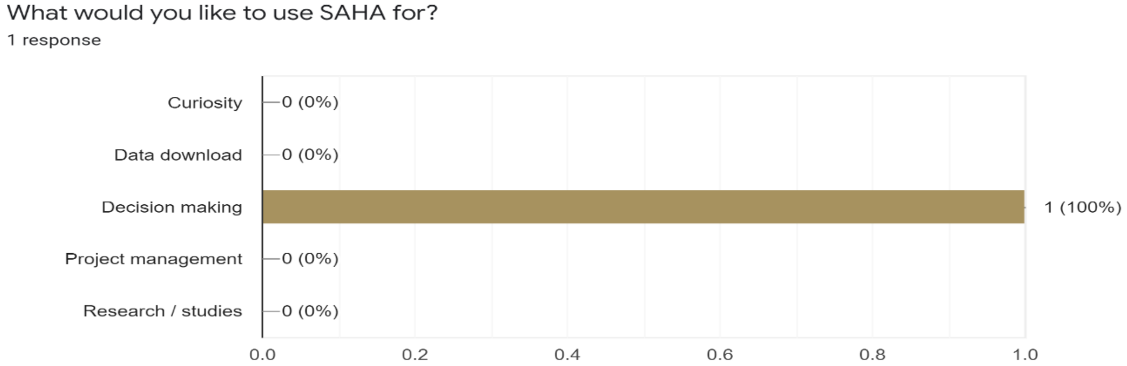


Figure 35: SAHA stakeholder feedback on what they would use SAHA for.

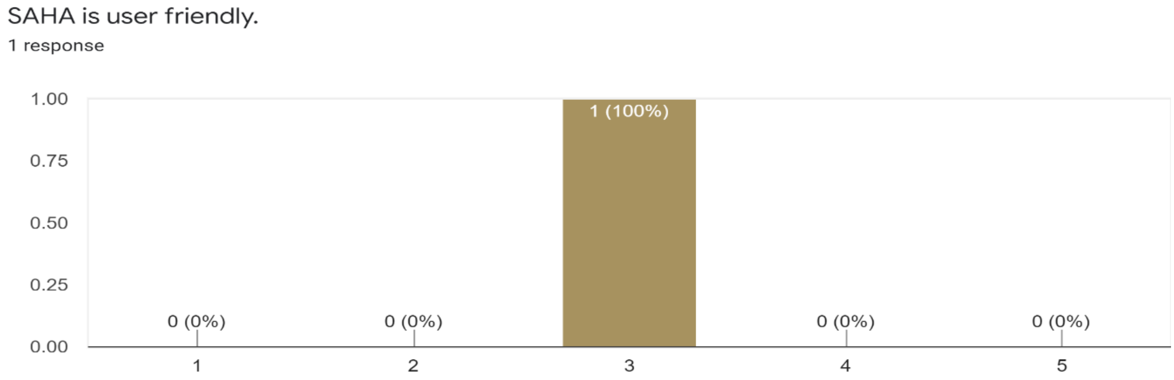
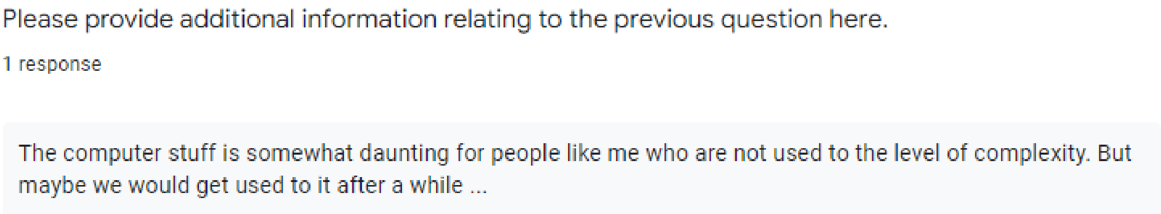


Figure 36: Feedback on user-friendliness of SAHA.

[2] South African Healthcare Association: http://sahas.co.za/; South African History Archive: https://www.saha.org.za/; South African Hockey Association: https://www.sahockey.co.za/about-us/contact-us/45-office/1-saha-head-office
[3] Hospital Association of South Africa: https://hasa.co.za/
[4] Hydrogen South Africa: https://www.hysasystems.com/
[5] Health Products Association of South Africa: https://www.hpasa.co.za/
[6] South African Hang Gliding and Paragliding Association: https://www.sahpa.co.za/


Please provide additional information relating to the previous question here.

1 response

The computer stuff is somewhat daunting for people like me who are not used to the level of complexity. But maybe we would get used to it after a while ...

Figure 37: Additional information on the user friendliness of SAHA.

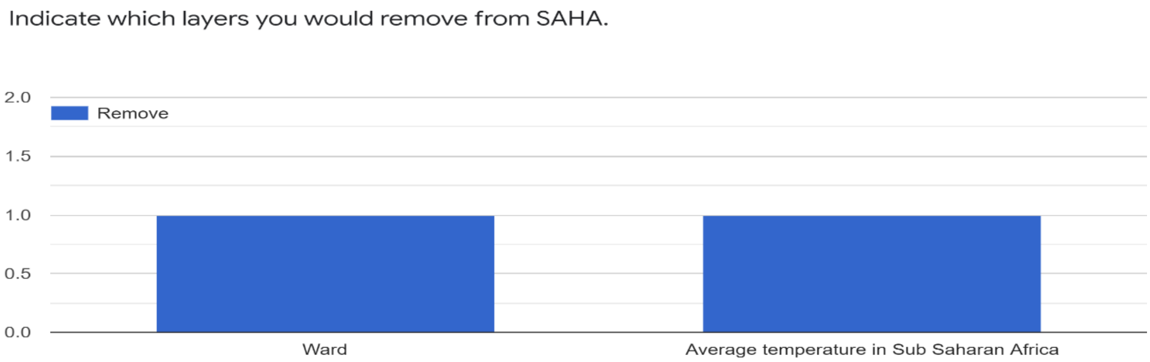


Figure 38: Data layers displayed by SAHA that should be removed.

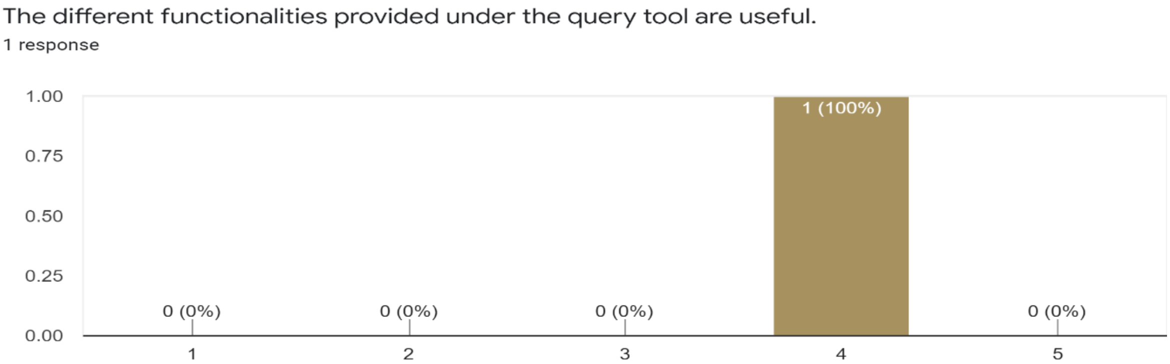


Figure 39: Feedback on usefulness of SAHA query tool.

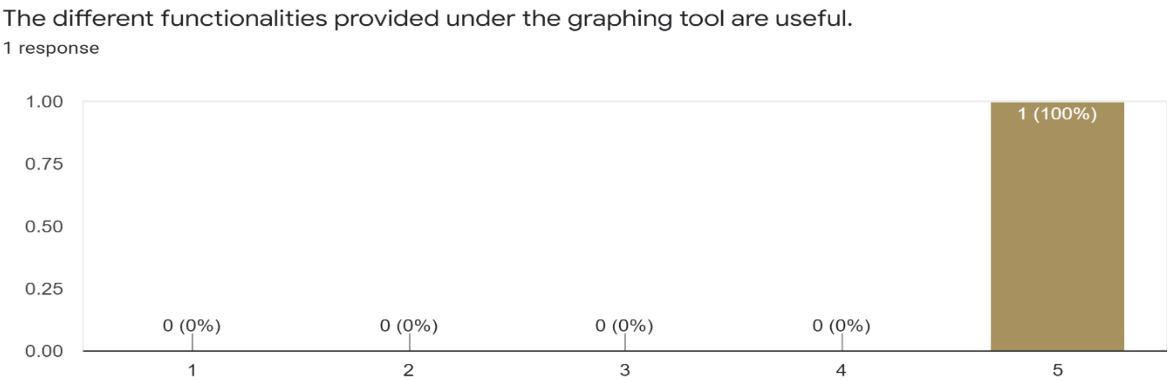


Figure 40: Feedback on usefulness of graphing tool.

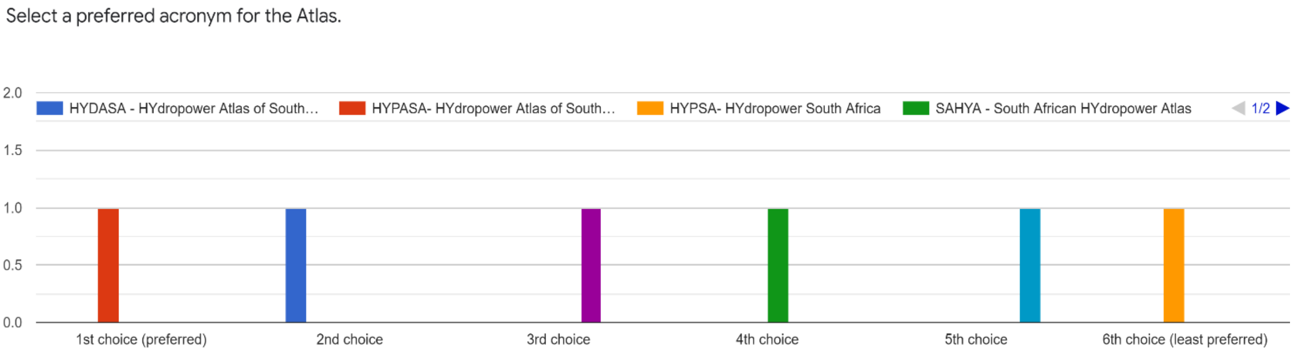


Figure 41: Feedback on preferred acronym for the South African Hydropower Atlas.

This chapter has demonstrated that the four objectives of this research study were successfully accomplished. The assessment of known renewable energy atlases led to the identification of suitable tools and functionality that have been implemented in the Atlas. The spatial datasets that were sourced for addition to the Atlas have been successfully displayed in the atlas and accomplish the desired aim of the Atlas which is to aid decision making and future projections. SAHA was then supplemented by stakeholder surveys that were used to improve the platform. Furthermore, the results obtained from assessing and modelling south African dam hydropower have identified dams where hydropower could be developed while creating opportunities for increased access to electricity and job creation in those areas.

CHAPTER 5: DISCUSSION

The energy mix of a country influences the constant availability of energy sources at affordable prices and has several implications for environmental sustainability. As the energy mix of a country or society is diversified the risk of load-shedding / scheduled blackouts are minimised, in other words, if one energy source collapses a country with a diversified energy mix can continue without disruption, making it less vulnerable to supply disruptions. In addition, environmental degradation and electricity tariff increments are minimised. Ultimately, diversification of the energy mix of a country is important as it stimulates economic growth, introduces low carbon energy sources, and encourages political independence. Increasing the share of hydropower and other renewable energy sources in the South African energy mix would make the country less susceptible to load-shedding.

Although the development of hydropower can be controversial due to its accompanying social and environmental drawbacks, such as the displacement of people, impact on fish, carbon and methane emissions from decomposed plants, and risk of flooding, hydropower is still a widely used renewable energy source worldwide (Devi, 2017; Bernhard, 2020). In Africa, many countries rely on hydropower as their main source of energy, these include the Democratic Republic of Congo (DRC), Ethiopia, Malawi, Mozambique, Namibia, and Zambia where 90 percent of national electricity generation stems from hydropower (Conway et al., 2017). Initiatives like the Programme for Infrastructure Development in Africa (PIDA) have been put in place to further increase the generating capacity of hydropower by at least 6 percent per annum to keep up with the rising electricity demand in the continent.

As with the Grand Inga III project (see **THE DEVELOPMENT OF HYDROPOWER,** pg. 10) , it can be argued that in some instances, factors that hinder hydropower development in African countries include the lack of steady markets for the electricity to be generated and lack of capital investment. The electricity to be generated by the Grand Inga III project could be transmitted to more developed African countries that have a strong electricity demand such as South Africa, Egypt, and Nigeria. It was reported that in the year 2014 South Africa confirmed an agreement with the DRC and committed to purchasing over 50 % of the output of the Grand Inga III project, which is equivalent to 2,500 MW (Tricard, 2016). However, recently there has been controversy surrounding the Grand Inga III project. According to a report issued by the Congo Research Group and Phuzumoya Consulting (2020), which examines South Africa’s involvement in the Grand Inga III project, purchasing electricity from the project is accompanied by several risks and would result in five percent higher tariffs by the year 2030. According to the report, for the transmission of energy from the Grand Inga III project to be possible, a new transmission line from Inga to the Congo border, and then to South Africa would be needed since existing lines would not be able to handle the energy. In addition, new transformers and substations would be needed. Essentially, R 807 million would be needed to make this long-distance transmission possible. South Africa’s commitment to the project has since been clouded by both negative and positive critiques.

It is, therefore, evident that one of the options for South Africa to avoid increased costs while attempting to meet increasing electricity demand, would be to exploit its existing renewable energy resources. To regulate this process, the National Energy Act 34 of 2008 was promulgated and is aimed at ensuring that energy planning and research are conducted, that renewable energy resources are available, generated, and consumed sustainably to stimulate economic growth and alleviate poverty (National Energy Act, 2008). Although South Africa is a semi-arid country, the 2019 Integrated Resource Plan (IRP) suggests that South Africa is shifting towards an increase in the contribution of hydropower to its energy mix. The anticipated increase in the contribution of hydropower highlights the need for reliable information resources on South African hydropower to assist with effective hydropower planning in the country. Furthermore, the recent amendments made by the South African government, which entail allowing private electricity generation projects to generate up to 100 MW of power, without the need for a license, have encouraged the emergence of more project developers, exploitation of alternative energy sources, and thus increased participation in the South African energy sector.

DAM HYDROPOWER POTENTIAL

The literature reviewed by this research (see van Vuuren, Blersch and van Dijk, 2011; Bagher et al., 2015; Loots et al., 2015) has demonstrated that retrofitting hydropower into existing water infrastructure and systems is a more favourable option as opposed to constructing new infrastructure such as dams or reservoirs, for hydropower generation, due to the associated economic, environmental and social costs. This justifies the assessment of hydropower potential within existing South African dams (see **3.3. OBJECTIVE 3: MODELLING SOUTH AFRICAN DAM HYDROPOWER POTENTIAL,** pg**.** 37 onward). The amount of hydropower that can be extracted from a site is dependent on the water discharge or flow, and the water head available at a site. Therefore, sites that are located on flatter slopes and have no water flow make it impractical for hydropower to be extracted. The province that showed the greatest potential for hydropower development within its dams, during the 10 years investigated, is the Free State (112.43 MW), followed by the KwaZulu Natal (13.83 MW), Western Cape (10.15 MW), Northern Cape (9.43 MW), North West (9.29 MW), Eastern Cape (3.02 MW), Limpopo (2.08 MW), Mpumalanga (2.00 MW) and Gauteng (0.15 MW), respectively. Studies by Balance et al. (2000), and Kusakana (2014) indicate that small-scale conventional hydropower potential is mostly concentrated in the Mpumalanga, Kwazulu Natal, Eastern Cape, and Western Cape provinces. Similarly, the results of the dam hydropower potential assessment conducted by this dissertation indicate that the provinces that had a higher concentration of dams that presented potential for hydropower development during the 10 years investigated (2010-2020) are located in the Mpumalanga (17 dams), KwaZulu Natal (12 dams), Eastern Cape (19 dams), and Western Cape (13 dams) provinces (see **4.3. OBJECTIVE 3: MODELLING SOUTH AFRICAN DAM HYDROPOWER POTENTIAL**, pg. 46 onward). The dams within these four provinces make up more than 72% of the South African dams that were identified to have hydropower potential. Kusakana (2014) maintains that these provinces have the potential for conventional micro hydropower development, which can play a significant role in providing electricity for domestic consumption. van Dijk et al. (2014) are also of this opinion and further add that this type of hydropower is suitable for supplying electricity to remote communities, particularly those in rural areas. Moreover, the findings of this dissertation reveal that a total 1181.39 kW of micro hydropower potential was observed within South African dams during the 10 years with a substantial amount of this potential observed within Eastern Cape dams. Micro hydropower schemes are generally efficient for local electrification and have low running costs (Uamusse, 2019).

Large hydropower projects are generally developed to power medium to large urban areas and to supply electricity to national grids. Rather surprisingly, the results of the dam hydropower potential assessment, modelled on the 2010-2020 flow data, revealed that only three South African dams hold potential for large hydropower which amounts to 121.68 MW. These three dams happen to be some of the largest dams in the country: namely, the Vaal Dam, Gariep Dam, and Pongolapoort Dam. The Vaal Dam is the second-largest dam by area in South Africa and is located on one of the strongest rivers in the country - the Vaal River. A case study conducted by van Vuuren, Blersch and van Dijk (2011) undertook the feasibility analysis of retrofitting the Vaal Dam with hydropower. According to the authors, the main driver for the feasibility analysis was the availability of flow all year round within the Vaal Dam meaning there is always flow available for hydropower generation. The Vaal Dam passed environmental requirements and was also found to be not vulnerable. The authors then concluded that retrofitting the Vaal Dam would be feasible.

The Gariep Dam is the largest in South Africa and has been retrofitted with four generators, each with a generating capacity of 90 MW (Eskom, 2018). In 2018, Pongolapoort Hydro in agreement with the DWS proposed the development of a 4 MW per hour hydropower scheme in the Pongolapoort dam (SAHRIS, 2018). Similarly, van Vuuren, Blersch and van Dijk (2011) proposed retrofitting the dam with a hydropower station. After conducting a feasibility analysis, the authors found the proposed project to be socially and financially feasible with an estimated return rate of 23 %, which is notably higher than the minimum of ten percent. However, environmental feasibility was found to be unacceptable. Nonetheless, should retrofitting, where it is feasible to do so, some of the assessed South African dams be officially undertaken, the estimated hydropower potential presented by this dissertation could serve as a recent estimate of how much hydropower the dams could potentially generate.

Small hydropower, on the other hand, was estimated to be 34.91 MW during the ten years. In addition, all this potential is linked to eight dams. Small hydropower projects could be used to supply electricity to small South African communities and regional grids where it is feasible to do so. Like small hydropower, mini hydropower projects generally have good potential to supply electricity in mountainous areas or areas where extending the electricity grid would be uneconomical (Resour, 2012). The total hydropower potential for mini hydropower in South African dams is approximated to be 4579.36 kW.

Pico hydropower is a term used to describe a small hydropower system that generates power that is under 5 kW. In South Africa, the pico hydropower potential modelled on the 2010-2020 flow data amounts to 10.71 kW. Pico hydropower projects normally do not require a lot of water storage and, therefore, have the least environmental impact compared to other small-scale hydropower projects. Farmers are said to be heavily reliant on this type of hydropower and sometimes utilise it to generate electricity from potential energy stored in water storage tanks, with water heads that are as low as 3 meters (Roshan, 2016). Other farmers utilise pico hydropower systems to pump underground water through boreholes, for irrigation and other farming needs, instead of using electricity from the grid (Kusakana, 2017). Accordingly, South African farmers with the capacity to generate pico hydropower should be encouraged to harness this form of hydropower and decrease their reliance on electricity from the national grid. Since pico hydropower stations have relatively small electricity generation capacities, they are generally used for domestic loads too (Williamson et al., 2019). Market analysis conducted in Malaysia has proven that pico hydropower is the most suitable and inexpensive option for rural or remote area electrification in developing nations (Kadier et al., 2018). Likewise, the South African government and project developers can explore developing pico hydropower, in rural and remote areas with limited to no electricity access, where such hydropower potential exists.

Essentially the total potential power output observed within South African dams over the 10 years (2010-2020) investigated is estimated to be 162.37 MW. The apparent variations in the potential hydropower output of the assessed dams are associated with the differences in water flow, water head, and geographical locations as some dams are located on steeper terrain and in regions with abundant water resources. Equally important, the difference in the results obtained by this dissertation from previous studies that assess the hydropower potential of South Africa can be associated with weather and rainfall variability over the 2010–2020 period on which this project is based. For instance, the modelled South African dam hydropower potential was compared with currently installed hydropower at three dams; namely, Ncora, Gariep and Hazelmere (see **Table 24,** pg. 50). From the results of the comparison, it was deduced that the modelled hydropower differs significantly from the installed hydropower. The significant variations between the installed hydropower and modelled South African dam hydropower potential can be attributed to inaccuracies within the DWS flow data used to model the dam hydropower potential, and/or variations in flow discharge owing to rainfall variability over the ten years investigated.

It is also worth mentioning that in reality some of the assessed dams, such as the Nqweba dam, are silted up and thus have lessened storage and generation capacity which might have been overestimated by the dissertation. Additionally, most gauging stations had missing flow data meaning the potential power output of the corresponding dams could not be modelled. While large dams such as the Vanderkloof dam, which have previously proven to be excellent hydropower producers, also could not be assessed for the 2010-2020 period due to their flow records not being available for the period. It can therefore be inferred that micro hydropower potential was the most common within the assessed South African dams, followed by pico, mini, small and large hydropower potential (see **Table 17,** pg. 47). It can be deduced that job creation would be seen in the areas where the development of dam hydropower potential would be feasible. Ultimately, modelling and assessing South African dam hydropower (Objective 3) has led to the identification of potential sites (dams) where hydropower could be retrofitted. Thus, the results obtained from the fulfilment of this objective can be used to drive insight and support strategic decision making where hydropower projects are concerned.

ACCESS TO ELECTRICITY

Although the percentage of South African households that have access to electricity has increased from 76,7% in 2002 to 90% in 2020 (see Statistics South Africa, 2021), there still exists a gap between electricity supply and demand in some communities. The barriers to electricity access in South Africa have been associated with apartheid spatial planning resulting in certain populations being placed in remote geographic locations, low population densities that make it uneconomical to supply electricity, natural geographic barriers such as valleys and mountains, cable theft, illegal connections, and political interference with electrification programs (Barnes and Foley, 2004). Fundamentally, access to electricity was assessed at the ward level to identify wards where electricity access needs to be improved in South Africa. The resulting *Access to Electricity* layer (see **Figure 20**, pg. 58), created based on the results of the 2011 Census, indicates that wards where no more than 23,22% of households have access to electricity are more common in the Eastern Cape and KwaZulu Natal Provinces. These are the two provinces where research studies, including this study, have found small-scale hydropower potential to be concentrated (Kusakana, 2014; Mutombo and Numbi, 2019). Similarly, to the recommendations of Klunne (2009), it is proposed that small-scale hydropower projects be developed to increase access to electricity in these wards, ideally pico hydropower projects since they are generally the least expensive to develop and operate.

The findings of the 2020 General Household Survey suggest that the percentage of households that have access to electricity in the Eastern Cape province increased from 76,6% in 2011 to 92,9% in 2020, while the percentage of households in KwaZulu Natal increased from 78,4% in 2011 to 92,6% in 2020. On account of the observed increase in access to electricity in the two provinces, it is believed that a similar assessment of access to electricity at the ward level based on a more recent census (*i.e.,* 2022 census) would yield notably different results. From the findings of the 2020 General Household Survey, it can be further deduced that South Africa experienced a 5% increase in access to electricity from the year 2019 (85%) to 2020 (90%), with all provinces seeing increased access to electricity during this period except for the Free State province (Statistics South Africa, 2021). The Free State province experienced a decline (-0.9%) in access to electricity during this one-year period. Moreover, the province has been experiencing a considerable decline (-3.1%) in access to electricity since 2011. This 10-year declining trend suggests that the province might be failing to meet its electricity demand. Equally important, the results of the dam hydropower assessment reveal that the Free State province possesses the greatest dam hydropower potential, amounting to 112.43 MW in seven dams. With that being the case, installing hydropower in the identified Free State dams could assist the province with increasing its access to electricity, as a result meeting its electricity demands eventually.

To contribute meaningfully to the current energy situation and alleviate load-shedding while increasing electricity access, this dissertation echoes previous research and proposes the development of small-scale hydropower in South African dams that hold potential for hydropower development, particularly pico hydropower for rural electrification on account of this type of hydropower being low maintenance and least environmentally degrading, and mini hydropower for electricity supply in remote areas seeing that mini hydropower projects have previously proven to be efficient at supplying electricity over long distances (see Resour, 2012; Sujith et al., 2016). Conversely, large hydropower projects could be used to provide backup electricity during periods where load-shedding is dominant; for example, during winter seasons when electricity usage is at its peak or during extreme weather conditions such as the recent April 2022 heavy rainfall that resulted in widespread flooding in KwaZulu Natal and Eastern Cape (Sutherland, 2022). Moreover, the hydropower projects could also be used to supply electricity back into the national grid when electricity production is in excess, thus increasing energy security.

DEVELOPMENT OF THE SOUTH AFRICAN HYDROPOWER ATLAS (SAHA)

There is a growing body of research aimed at investigating South African hydropower, existing hydropower installations, hydropower technologies, and potential hydropower development opportunities. However, none of the results of these studies have been presented in the form of an interactive web application. This research study makes provision for this research gap through the developed South African Hydropower Atlas. SAHA is an interactive web map application that displays data related to South African hydropower. The information presented by SAHA is aimed at making people aware of the hydropower status of South Africa and future development opportunities (see

LAYERS OF INTEREST, pg. 57). Upon assessing several platforms for hosting the atlas, the most suitable platform for SAHA was identified to be ArcGIS Online (see **4.1. OBJECTIVE 1: ASSESSMENT OF KNOWN ATLASES**, pg. 40). SAHA has been built using the ArcGIS Online WebApp builder based on a JavaScript Application Programming Interface (API). Several web mapping platforms were considered for hosting SAHA, these include QGIS which is one of the most utilised free and open-source Geographic Information Systems software. However, some of the platforms were accompanied by security threats, restrictions on the size of datasets that can be uploaded or hosted, and additional costs to utilising the platforms. The ArcGIS WebApp builder offers readily available tools, features, and GIS functionality that make it superior to the other assessed web mapping platforms.

The advantages of having SAHA as a web application as opposed to a traditional desktop application or downloadable mobile application are that web applications do not need to be installed and, therefore, do not occupy storage on devices, can be accessed from any device by typing the web address (URL) on a web browser, are not reliant on any hardware and systems specifications, offer automatic updates, and do not require much processing power. Ultimately the only prerequisite to accessing SAHA is Internet access. According to a survey conducted by Statista (2021) there are 38.13 million active Internet users in South Africa and the most common way in which they access the Internet is by using a smartphone.

The findings of a General Household Survey conducted by Statistics South Africa in 2019 reveal that 87.8% of South African households have exclusive access to smartphones, with the exclusive use of cellular phones being most common in Mpumalanga (95,3%), Limpopo (94,4%) and North West (91,9%) (Statistics South Africa, 2020). The General Household Survey further revealed that 63,3% of South African households access the internet through public Wi-Fi, at home, in the workplace, in educational institutions or Internet cafés (Statistics South Africa, 2020). Furthermore, general access to the internet was more prominent in Gauteng (74,8%), Western Cape (74,3%), and Mpumalanga (67,4%), and lowest in Limpopo (43,2%) and Eastern Cape (52,5%). Thus, while not all citizens have access to the Internet, coverage is acceptable and projected to increase, making SAHA fairly accessible to the public. Therefore, there is an implication that there exists an audience for SAHA in the country and most of them will be able to access SAHA. SAHA is a fairly easily accessible web application that does not require the user to create or sign into an account to gain access. The only prerequisite to accessing the atlas is accepting and agreeing to the terms and conditions as presented in **Figure 7,** pg. 51. Nevertheless, Internet access issues that may affect use or access to the atlas could arise during load-shedding hours since network connectivity is affected during these hours.

The assessment of existing renewable energy atlases assisted in choosing the appropriate tools and functionality for SAHA. Some of the functionalities that have been specifically chosen and implemented to effectively deliver the information presented by SAHA include, among other functionalities, an attribute table for all the data layers, zooming functionality, pop-ups which display customised attribute data of the selected feature, a symbolised legend and data labels – some of the labels are only visible when the features of interest are viewed at a certain zoom level (see **Table 14,** pg. 40 *and HELP MANUAL*). The layer and label visibility range of each data layer on SAHA have been pre-adjusted; however, the user can adjust this to their liking. Due to the default adjustments, the names of some of the data layers appear light grey on the *layer list* instead of black and the data layers will not be displayed on SAHA until the user zooms to the set display level. The different display levels are World, Continent, Country, State (Provincial), Metropolitan area, City, Town and Neighbourhood level. Once the user has zoomed to the appropriate level, the name of the data layer will then appear black on the *Layer List*. Upon launching SAHA, only the provincial boundaries and existing hydropower Installations layers are displayed to avoid clustering – this is the default view. Nonetheless, the user can still select and deselect any layer(s) that they would like to display. In addition, each layer on the *Layer List* has the following shortcuts: the user can zoom to the layer, adjust the transparency of the layer, set the visibility range, disable pop-ups, hide labels, move a layer up and down, and view the attribute table of the layer. SAHA also has a geolocation feature that identifies the user's location and zooms into it, provided the user grants their web browser access to their location.

Geospatial data layers that have been successfully sourced and added to SAHA are described in **Table 15** (pg. 41). These data layers are a representation of reality and serve as a reference to existing and potential hydropower in South Africa. Some of the added layers were identified upon assessing other existing renewable energy atlases (see **2.5. ASSESSING EXISTING RENEWABLE ENERGY RESOURCES,** pg. 20 onward). Additionally, the data layers have been primarily added to aid in the successful geo-visualization and information delivery. Data layers that were created include five potential hydropower sites layers which consist of the *Potential Dam Site, Potential Conduit Site, Potential Weir Site, Potential WWTW Site* and *Potential WTW Site*, *Access to Electricity by Wards,* and *Dam Hydropower Potential (2010-2020)* geospatial data layers. The *Potential Hydropower Sites* layers were created to propose sites where conventional and unconventional hydropower can be installed in the country. The *Dam Hydropower Potentia*l layer is a representation of the results of Objective 3 which entails modelling South African dam hydropower potential. Whereas the *Access to Electricity by Wards* layer is based on the 2011 census and indicates the percentage of South African households that have access to electricity for lighting at the ward level (see **Figure 20,** pg. **58**). From the *Access to Electricity by Wards* layer, it can be observed that wards where access to electricity for lighting is between 0% and 23% are more concentrated in the KwaZulu Natal and Eastern Cape provinces. Contrastingly, these two provinces hold hydropower potential, at 12 and 19 dams respectively, which amounts to 16.85 MW (see **Table 23**, pg. 50). The hydropower potential latent within these dams could be used to supply electricity in the wards where electricity access is low. Consequently, installing hydropower schemes within these dams is put forward for consideration to increase access to electricity within the wards, provided the dams have not been developed yet, and social and environmental impact assessments are passed. Additionally, wards, where access to electricity for lighting is at least 92%, are common in all the different provinces of the country. Data layers that could not be sourced, and therefore not added to SAHA, are indicated in **Table 16** (pg. 45). For instance, planned Eskom power stations and transmission lines could not be added to SAHA due to security reasons; for instance, knowing where transmission lines and stations will be constructed might pose security threats to Eskom.

SAHA STAKEHOLDER SURVEYS

Once a prototype of SAHA had been developed, two online-based stakeholder surveys were conducted to evaluate the user-friendliness and functionality of SAHA, and to make improvements to it based on the feedback (see **APPENDIX A: SURVEY LETTER SENT TO STAKEHOLDERS,** pg. 89). Advantages of conducting the survey are that it is a convenient method of data collection, it is cost-effective, it can be completed remotely at the comfort zone of the respondent, and subjectivity is minimised. Furthermore, it is believed that the anonymity of the survey allowed respondents to provide candid and workable responses. It is important to note that all respondents gave participation consent before completing the survey. Responses to both surveys were low. As such, the feedback is not representative of the larger population. Nevertheless, since the survey was sent to stakeholders of the atlas, their feedback remains valuable. The feedback provided by the stakeholders has contributed immensely to the development and improvement of the atlas, and suggestions were implemented where possible.

In the first survey, two respondents indicated that they would use SAHA for decision-making purposes (see **SAHA STAKEHOLDER SURVEY 1 RESULTS**, pg. 59). This thus concurs with the earlier argumentation of the study that SAHA is indeed a decision-making tool. The respondents suggested that 8 out of the 26 data layers displayed by the Atlas be removed. Removals that were considered relevant include the *Precipitation Change by 2050* and *Predicted Temperature Change*. If further respondents suggest their removal, these changes will be implemented in future iterations of SAHA. Two respondents indicated that the *Wards* layer should be removed; however, the census data displayed by SAHA is linked to ward level therefore the *Wards* layer is necessary, and the layer not removed. Equally important, removal of the *Dams, Rivers, Drainage Directions, Monthly Precipitation in Africa* and *Near East, and Average Temperature in Sub Saharan Africa* data layers was deemed not necessary since these data layers serve the purpose of providing an overview of the geographical area covered by the atlas. It can be further inferred that some of the respondents might have had trouble navigating SAHA since some of the additions that the respondents suggested are already present; for example, one respondent said that there was no symbolisation for the *Potential Hydropower Sites in Gauteng* layer whereas a symbolised legend was present for all data layers when the survey was conducted. For this reason, a user help manual (see **ADDITIONAL TOOLS**, pg. 55) has been created to improve the user-friendliness of SAHA. When the user clicks the *HELP MANUAL* button, the help manual is loaded onto a different web page and can be downloaded by the user in portable document format (.pdf). One respondent indicated that they could not access the analysis tool although ArcGIS online accounts are free for all users and the user should simply sign up to gain access to the analysis tool. However, upon much deliberation, the analysis tool was replaced with the chart tool to eliminate the signing up process, therefore, making it easier for users to access all tools offered by the atlas. The chart tool displays quantitative attributes, such as potential hydropower, from selected data layers in the form of bar graphs, pie charts, or line charts. Ultimately, the comments made by the respondents (see **Table 25,** pg. 65) on the user-friendliness of SAHA were resolved.

The SAHA stakeholders were also requested to recommend pre-defined queries to be added to the query tool of the Atlas (see **Table 26,** pg. 65). Most out of the ten recommended queries were implemented and can be found on the list of queries under the query tool. Queries that were not implemented include a query that allows users to download the displayed layers in shapefile format and upload their layers. SAHA allows users to add layers to their version of SAHA using the *Add data* function on the top pane; however, these layers do not get saved to the public version of the Atlas since volunteered geographic information can contain inaccuracies and should therefore be used with caution and assessed for reliability before addition to SAHA. Meanwhile, data download is hampered by copyright meaning only those layers that are available can be downloaded. As such, the *Select* tool was set to allow exporting of data. To allow for copyright limitations, only layers that can be downloaded can thus be selected. A query that defines a catchment by a click at an outfall point was also implemented. Finally, a query that indicates the estimated cost of developing a hydropower plant, and one that ranks sites in terms of easy, short-term, or long-term implementation, could not be implemented since estimating the cost of developing a hydropower plant and ranking of the potential sites in terms of easy, short-term or long-term implementation is outside the scope of this project and was, therefore, not conducted. Nonetheless, the research study considered and implemented the recommendations made by the SAHA stakeholder respondents where it was practical to do so.

Feedback from the second survey sent to the stakeholders after the stakeholder meeting in April 2022 revealed that the user-friendliness of SAHA was rated a 3 on a 5 point Likert scale, while the preferred use for SAHA was once again identified to be decision making (see **SAHA STAKEHOLDER SURVEY 2 RESULTS**, pg. 65). The survey feedback further revealed that a neutral rating for user-friendliness was selected owing to the perceived complexity of the functionality provided by SAHA. As such, in addition to the help manual as described above, short help videos should be compiled that focus on the various aspects of the Atlas, to assist in its use. Due to time constraints and scope limitations, this has not been implemented at present. The majority of the data layers displayed by SAHA were perceived suitable except for only two layers; namely, *Wards* and *Average Temperature in Sub-Saharan Africa*. As aforementioned, the removal of the *Wards* layer is deemed not suitable as it is a reference layer and the created *Access to Electricity* layer is linked to ward level. Removal of the *Average Temperature in Sub-Saharan Africa* will be considered. No additional layers were recommended for exhibition by SAHA. The usefulness of the Query and Graphing tools were rated 4 and 5 respectively on the Likert scale suggesting that the tools are perceived to be useful. Lastly, the most preferred acronym for the South African Hydropower Atlas was identified to be HYPASA – the **HY**dro**P**ower **A**tlas of **S**outh **A**frica.

Ultimately, the development of SAHA has resulted in the identification of data required for decision making where South African hydropower is concerned, existing hydropower developments, water infrastructure and systems where hydropower can be potentially harnessed, and an indication of hydropower potential available within some of South Africa's dams. This will in turn make the operators and owners of water infrastructure fully cognizant of the potential for hydropower development and encourage further development of hydropower.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

South Africa is a relatively energy-intensive country (Campell, Booysen and Vosloo, 2017; Zhang et al., 2021). The country has an abundance of renewable energy sources yet some of these resources are latent. Fortunately, the current energy situation in the country has opened doors for independent power producers and investment in renewable energy sources, intending to decarbonise the country to replace coal with renewable energy sources. However, for South Africa to transition into a decarbonised economy, the use of conventional electricity generation methods, such as the burning of coal, cannot be abruptly and completely abandoned due to billions of Rands that have already been invested in setting up infrastructure for electricity generation through coal.

Coal contributes over 80% to the South African energy mix, making it the main source of energy in the country (Eskom, 2018). Therefore, this research study recommends the gradual shift away from this reality by incorporating and supplementing conventional electricity generation with renewable energy sources such as hydropower. In doing so, South Africa would be moving closer to reaching its SDG goal number seven which is aimed at ensuring "universal access to clean, affordable, reliable and modern energy services by 2030" (United Nations, 2018). In the South African context, increasing the contribution of hydropower to the energy mix through the development of small hydropower schemes, since they are relatively low in cost to operate and have a lesser environmental impact, would increase access to electricity in rural and remote areas throughout the country, more especially in the Free State province where electricity access has seen a decline over the last ten years, and in KwaZulu Natal and Eastern Cape where wards with low access to electricity are dominant. The country would also be alleviating the impact of global warming, and diseases linked to high pollution levels attributed to energy generation.

This project identified sites where both conventional and unconventional hydropower can be developed in South Africa. In addition, WTW, WWTW, water transfer schemes, and gauging weirs where unconventional hydropower could be developed were identified for South Africa. Identifying potential sites where hydropower can be developed attracts investment in this type of renewable energy, incidentally, severe power outages and accompanying threats are reduced. Furthermore, this research study demonstrated that small hydropower turbines can be integrated into water systems, which supply drinking water, treated wastewater, stormwater, and irrigation water. In doing so, the project presented potential sites where unconventional hydropower can be developed in South Africa, in the future. Other examples of areas where unconventional hydropower can be installed (but are not assessed here) include flow gauging systems, weirs, desalination plants, bulk transfer schemes, mines, and irrigation systems such as chutes, diversion, bridges, and canals.

ETHICAL CONSIDERATIONS

While the project has illustrated the creation of SAHA, there are several considerations.

1. Some of the available data on hydropower schemes are out-of-date, incomplete, or even inaccurate. Furthermore, some of the data are available in formats that are not user-friendly, such as the .OBS file format used by the Water Research Commission (WRC) for their flow records files dataset. As such, it is recommended that datasets contributing to SAHA are standardised to a generic format and their currency improved. Furthermore, it is suggested that all datasets undergo *ISO 19157:2013 Geographic information - Data quality* evaluation.
2. Information relating to South African dams is often incomplete and patched for the period investigated by the research study. This means the resultant hydropower potential might not be a true reflection of the actual hydropotential of the assessed dams due to inherent errors.
3. Environmental and social impact assessments need to be performed before implementing a hydropower project. Therefore, extracting hydropower at some of the dams that showed hydropower potential may not be feasible since environmental and social impact

assessments are not within the scope of this dissertation and were, therefore, not performed.

4. If the spatial database contains data and information that are inaccurate, the hydropower Atlas will be an unreliable information product, meaning users of the Atlas will only be able to view the Atlas and not rely on it for tasks such as project planning and decision making. As such, metadata describing the process of data collation and creation must be made available and integrated into SAHA. While all attempts were made to populate each layer added to SAHA with the requisite metadata, this was only possible if the original source, where layers were not created, provided this information.
5. To ensure compliance with the POPI Act, the feedback obtained from the SAHA stakeholder surveys has been used for the sole purpose of this dissertation.
6. The feedback form integrated into the Atlas does not record personal information, again to comply with the POPI Act.

SAHA collates information accessible at the time of release. Future climate change scenarios need to be considered, as is the currency of data uploaded to the Atlas. Regardless, the Atlas represents the first accessible platform that collates data related to the siting and evaluation of hydropower resources in South Africa and is, as such, a unique and valuable resource.

RECOMMENDATIONS

Finally, to improve SAHA this dissertation makes several recommendations.

1. Dam hydropower potential of all South African dams, not only those where flow data are available through the DWS, should be modelled.
2. Dam hydropower potential for South Africa based on drainage regions and flow data that could not be accessed or obtained when this research was conducted should be modelled.
3. Identifying more sites where unconventional hydropower can be developed in South Africa.
4. A run-off-river hydropower potential in the South African context needs to be modelled. This is already in development and the layers will be added to the Atlas once complete.
5. Sourcing of datasets that could not be sourced for inclusion in SAHA (see **Table 16,** pg. 45).
6. Access to electricity at a lower level such as the Small Area Level (SAL), based on a recent census such as the 2022 census, should be done.
7. The project recommends allowing users to input information and data related to South African hydropower to improve SAHA although the data would have to undergo data quality evaluation to ensure ISO 19157:2013 is met.
8. Addition of the following pre-defined queries to SAHA:
   a. Indicates estimated cost of developing a hydropower plant.
   b. Priority ranking of the sites in terms of easy, short-term or long-term implementation.
9. Furthermore, it is recommended that another research study focuses on conducting cost and environmental feasibility analyses on the potential hydropower sites and South African dam hydropower potential that have been identified by this dissertation.

Notwithstanding the recommendations and considerations listed above, it is anticipated that providing information on existing hydropower and hydropower potential in the form of a comprehensive and user-friendly web map application like SAHA will play a critical role in assisting stakeholders to make informed decisions concerning hydropower projects and the future of hydropower in South Africa. Furthermore, the recent COP26 climate conference has given further urgency to shifting towards cleaner renewable energy sources. It is consequently believed that the development of the interactive and web-based South African Hydropower Atlas (SAHA) will play an integral role in shifting South Africa towards a carbon-free economy.

REFERENCES

ALIYU, A.K., MODU, B. & TAN, C.W. 2018. A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, 81, 2502-2518.

AMAN, M. & MALIK, R.K. 2017. Assessment of Hydropower Potential of Topchi Site at the Bamyan River in Bamyan, Afghanistan*. International Journal of Engineering Research and General Science*, 5, 68-70.

AVNER, G. 2019. *Your Guide to Open Source Vs Proprietary Software Security* [Online]. Available: https://resources.whitesourcesoftware.com/blog-whitesource/open-source-vs-proprietary-code-security [Accessed 10 October 2020].

ANTONIOU, V. & SKOPELITI, A. 2015. MEASURES & INDICATORS OF VGI QUALITY: AN OVERVIEW. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences, 2.

BAGHER, A.M., VAHID, M., MOHSEN, M. & PARVIN, D. 2015. Hydroelectric energy advantages and disadvantages. *American Journal of Energy Science*, 2(2), 17-20.

BALLANCE, A., STEPHENSON, D., CHAPMAN, R.A. & MULLER, J. 2000. A geographic information systems analysis of hydropower potential in South Africa. *Journal of Hydroinformatics*, 2(4), 247-254.

BAMHDI, A. 2020. Requirements capture and comparative analysis of open source versus proprietary service oriented architecture. *Computer Standards & Interfaces*, 103468.

BARNES, D. & FOLEY, G. 2004. Rural electrification in the developing world: a summary of lessons from successful programs. *Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), World Bank, Washington, DC*.

BARNES, B., MATHEE, A., THOMAS, E. & BRUCE, N. 2009. Household energy, indoor air pollution and child respiratory health in South Africa. *Journal of Energy in Southern Africa*, 20, 4-13.

BARTA, B., VAN DIJK, M. & VAN VUUREN, F. 2011. Renewable energy: hydropower. *Civil Engineering (Siviele Ingenieurswese)*, 20, 37-41.

BEIDARI, M., LIN, S.J. & LEWIS, C. 2017. Decomposition analysis of CO2 emissions from coal-sourced electricity production in South Africa. *Aerosol and Air Quality Research*, 17(4), 1043-1051.

BELLINI, E. 2021. *South Africa raises threshold for distributed generation to 100 MW* [Online]. Available: https://www.pv-magazine.com/2021/08/16/south-africa-raises-threshold-for-distributed-generation-to-100-mw/ [Accessed 01 November 2021].

BERNHARD, A. 2020. *The most powerful renewable energy* [Online]. Available: https://www.bbc.com/future/article/20200713-the-most-powerful-renewable-energy [Accessed 7 March 2021].

BLIGNAUT, J. 2012. Climate change: the opportunity cost of Medupi and Kusile power stations. *Journal of Energy in Southern Africa*, 23(4), 67-75.

BLIGNAUT, J.N., KOCH, S.F., RIEKERT, J.W., INGLESI-LOTZ, R. & NKAMBULE, N.P. 2013. The external cost of coal-fired power generation: the case of Kusile: Part 2.

BONTHUYS, G.J., VAN DIJK, M. & BHAGWAN, J.N. 2016. A feasibility and implementation model of small-scale hydropower development for rural electrification in South Africa: A case study of Kwa Madiba SSHP Plant. *Water SA*, 42(4), 528-541.

BOULANGER, A. 2005. Open-source versus proprietary software: Is one more reliable and secure than the other?. *IBM Systems Journal*, 44, 239-248.

BOUSQUET, C., SAMORA, I., MANSO, P., ROSSI, L., HELLER, P. & SCHLEISS, A. J. 2017. Assessment of hydropower potential in wastewater systems and application to Switzerland. *Renewable Energy*, 113, 64-73.

BOYLE, L. 2021. *First-of-its-kind agreement sees South Africa receive $8.5bn to ditch coal at Cop26* [Online]. Available: https://www.independent.co.uk/climate-change/news/south-africa-coal-cop26-fossil-b1949875.html [Accessed 10 November 2021].

BRIDGE, G., ÖZKAYNAK, B. & TURHAN, E. 2018. Energy infrastructure and the fate of the nation: Introduction to special issue. *Energy research & social science*, 41, 1-11.

BROVELLI, M. A., MINGHINI, M., MORENO-SANCHEZ, R. & OLIVEIRA, R. 2017. Free and open source software for geospatial applications (FOSS4G) to support Future Earth. *International Journal of Digital Earth,* 10**,** 386-404.

BROWN, C. 2019. 'Reporting on Operational and Potential Hydropower Schemes in South Africa'. Honours mini-dissertation, University of Pretoria, Pretoria.

BWALYA, T., AKAKANDELWA, A. & DOBREVA-MCPHERSON, M. 2019. Adoption and Use of Free and Open Source Software (FOSS) Globally: An Overview and Analysis of Selected Countries. Zambia Journal of Library & Information Science (ZAJLIS), ISSN: 2708-2695, 3.

CALITZ, J.R. & WRIGHT, J.G. 2021. *Statistics of utility-scale power generation in South Africa H1-2021* [Online]. Available: https://researchspace.csir.co.za/dspace/handle/10204/12067 [25 October 2021].

CALVIN, K.V., PACHAURI, S., DE CIAN, E. & MOURATIADOU, I. 2013. The effect of African growth on future global energy, emissions, and regional development. Climate Change.

CAMPBELL, K., BOOYSEN, W. & VOSLOO, J. 2017. Evaluating the feasibility of the 12L tax incentive for energy-intensive industries. *South African Journal of Industrial Engineering,* 28**,** 15-28.

CAPITANESCU, F. 2015. Enhanced risk based SCOPF formulation balancing operation cost and expected voluntary load-shedding. *Electric Power Systems Research*, 128, 151-155.

CARTO. *Unlock the power of spatial analysis* [Online]. Available: https://carto.com/ [Accessed 15 August 2020].

CHOULOT, A., DENIS, V. & PUNYS, P. 2012. Integration of small hydro turbines into existing water infrastructures. InTech.

CONGO RESEARCH GROUP & PHUZUMOYA CONSULTING. 2020. I Need You, I Don't Need You: South Africa and Inga III. South Africa.

CONWAY, D., DALIN, C., LANDMAN, W. A. & OSBORN, T. J. 2017. Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption. *Nature Energy*, 2, 946-953.

COYLE, E. D. & SIMMONS, R. A. 2014. Understanding the global energy crisis, Purdue University Press.

CUI, W., MENG, Q., FENG, Q., ZHOU, L., CUI, Y. & LI, W. 2019. Occurrence and release of cadmium, chromium, and lead from stone coal combustion. *International Journal of Coal Science & Technology*, 6, 586-594.

SOUTH AFRICAN DEPARTMENT OF ENERGY (DOE). 2013. Integrated resource plan for electricity (IRP) 2010e2030. Update Report 2013.

DEMPSEY, C. 2018. *Web-based GIS* [Online]. Available: https://www.gislounge.com/web-based-gis/ [Accessed 17 August 2020].

DEY, S. 2016. *LeafletJS: A new dimension in Maps API* [Online]. Available: https://www.xoriant.com/blog/mobility/leafletjs-new-dimension-maps-api.html [Accessed 14 August 2020].

DEPARTMENT OF ENERGY. 2019. *Energy sources* [Online]. Available: http://www.energy.gov.za/files/electricity_frame.html [Accessed 19 March 2020].

DEPARTMENT OF ENERGY. 2019. Independent Power Producers Procurement Programme (IPPPP): An overview. South African Department of Energy Pretoria.

DEVI, T. G. 2017. Hydro-Power A Clean And Renewable Energy Source. Everyman's Science, 15.

DEVELOPMENT BANK OF SOUTHERN AFRICA. 2014. *Integrated annual report* [Online]. Available: http://issuu.com/developmentbankofsouthernafric/docs/dbsa_integrated_annual_report_2013- [Accessed 01 August 2021].

DE SOUSA, W.C. & Reid, J. 2010. Uncertainties in Amazon hydropower development: Risk scenarios and environmental issues around the Belo Monte dam. *Water Alternatives*, 3(2).

DJANGO. *GeoDjango* [Online]. Available: https://docs.djangoproject.com/en/3.1/ref/contrib/gis/ [Accessed 16 August 2020].

DONNENFELD, Z., CROOKES, C. & HEDDEN, S. 2018. A delicate balance: Water scarcity in South Africa. *ISS Southern Africa Report*, 2018(13), 1-24.

DUKU, M. H., GU, S. & HAGAN, E. B. 2011. A comprehensive review of biomass resources and biofuels potential in Ghana. *Renewable and sustainable energy reviews,* 15**,** 404-415.

DU VENAGE, G. 2020. South Africa Comes to Standstill with Eskom's Load Shedding. *Engineering and Mining Journal*, 221, 18-18.

EBERHARD, A., KOLKER, J. & LEIGLAND, J. 2014. South Africa's renewable energy IPP procurement Program: Success factors and lessons.

EBINGER, J. & VERGARA, W. 2011. Climate impacts on energy systems: key issues for energy sector adaptation. World Bank, Washington, D.

EBHOTA, W.S. & INAMBAO, F.L. 2017. Facilitating greater energy access in rural and remote areas of sub-Saharan Africa: Small hydropower. *Energy & Environment*, 28(3), 316-329.

ENERGYPEDIA. 2020. *South Africa Energy Situation* [Online]. Available: https://energypedia.info/wiki/South_Africa_Energy_Situation [Accessed 20 March 2020].

ESKOM. 2010. *Pumped Storage Schemes: Drakensberg and Palmiet* [Online]. Available: http://www.eskom.co.za/AboutElectricity/FactsFigures/Documents/OtherDocs/Pumped_Storage_Schemes_-_Palmiet__Pumped_Storage [Accessed 19 June 2020].

ESKOM. 2018. *Gariep Hydroelectric Power Station* [Online]. Available: https://www.eskom.co.za/whatweredoing/electricitygeneration/powerstations/pages/gariep_hydroelectric_power_station.aspx [Accessed 20 October 2020].

ESRI. *What is ArcGIS Online?* [Online]. Available: https://doc.arcgis.com/en/arcgis-online/reference/faq.htm#anchor1 [Accessed 10 October 2020].

EWALD, B. 2018. The value of health damage due to sulphur dioxide emissions from coal-fired electricity generation in NSW and implications for pollution licences. *Australian and New Zealand Journal of Public Health*, 42(3), 227-229.

FÄRE, R., GROSSKOPF, S. & PASURKA JR, C. A. 2010. Toxic releases: an environmental performance index for coal-fired power plants. *Energy Economics*, 32, 158-165.

FASHINA, A., MUNDU, M., AKIYODE, O., ABDULLAH, L., SANNI, D. & OUNYESIGA, L. 2019. The drivers and barriers of renewable energy applications and development in Uganda: a review. *Clean Technologies,* 1**,** 9-39.

FONG, M.W.L. 2009. Digital divide: The case of developing countries. *Issues in Informing Science and Information Technology*, 6(2), 471-478.

GECOSISTEMA. *GIS and Cloud Web Application* [Online]. Available: https://gecosistema.com/gis-geospatial-and-remote-sensing/gis-and-cloud-web-application/ [Accessed 15 August 2020].

GEOMOOSE. *Welcome to GeoMoose* [Online]. Available: https://www.geomoose.org/ [Accessed 16 August 2020].

GERNAAT, D.E., BOGAART, P.W., VAN VUUREN, D.P., BIEMANS, H. & NIESSINK, R. 2017. High-resolution assessment of global technical and economic hydropower potential. *Nature Energy*, 2(10), 821-828.

GININDZA, B. 2021. *Allowing companies to produce up to 100MW may not be SA's panacea* [Online]. Available: https://www.iol.co.za/business-report/energy/allowing-companies-to-produce-up-to-100mw-may-not-be-sas-panacea-b6fd9d88-99f4-4560-9d0b-588850f22133 [Accessed 01 November 2021].

GNU PROJECT. 1996. *What is free software? The free software definition* [Online]. Available: https://www.gnu.org/gnu/thegnuproject.en.html [Accessed 13 August 2020].

GOLDBERG, A. 2016. The economic impact of load-shedding: The case of South African retailers (Doctoral dissertation, University of Pretoria).

GOODALL, M. & MOORE, E. 2019. Integrating the Sustainable Development Goals into Teaching, Research, Operations, and Service: A Case Report of Yale University. Sustainability: *The Journal of Record*, 12(2), 93-96.

GROENEWALD, Y. 2012. Coal's hidden water cost to South Africa. MUSANA, F. & STEELE, M.(eds.).

GÜNEY, T. 2019. Renewable energy, non-renewable energy and sustainable development. International Journal of Sustainable Development & World Ecology, 26, 389-397.

GVSIG ASSOCIATION. *gvSIG Onli*ne [Online]. Available: http://www.gvsig.com/en/products/gvsig-online [Accessed 16 August 2020].

HOGEBOOM, R.J., KNOOK, L. & HOEKSTRA, A.Y. 2018. The blue water footprint of the world's artificial reservoirs for hydroelectricity, irrigation, residential and industrial water supply, flood protection, fishing and recreation. *Advances in water resources*, 113, 285-294.

HÖÖK, M. & TANG, X. 2013. Depletion of fossil fuels and anthropogenic climate change—A review. *Energy policy*, 52, 797-809.

HUANG, H. & YAN, Z. 2009. Present situation and future prospect of hydropower in China. *Renewable and Sustainable Energy Reviews*, 13(6-7), 1652-1656.

HYDROPOWER, I.E.A. 2000. The environment: present context and guidelines for future action. Subtask 5 Report, Volume 2. Main Report: International Energy Agency.

INGLESI, R. & POURIS, A. 2010. Forecasting electricity demand in South Africa: A critique of Eskom's projections. *South African Journal of Science*, 106(1-2), 50-53.

INTERNATIONAL HYDROPOWER ASSOCIATION. 2015. *Democratic Republic of the Congo* [Online]. Available: https://www.hydropower.org/country-profiles/democratic-republic-of-the-congo [Accessed 20 April 2021].

IPCC. 2021. *Climate change widespread, rapid, and intensifying – IPCC* [Online]. Available: https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/ [Accessed 10 November 2021]

JAIN, S. & JAIN, P.K. 2017. The rise of renewable energy implementation in South Africa. *Energy Procedia*, 143, 721-726.

KADIER, A., KALIL, M. S., PUDUKUDY, M., HASAN, H. A., MOHAMED, A. & HAMID, A. A. 2018. Pico hydropower (PHP) development in Malaysia: Potential, present status, barriers and future perspectives. *Renewable and Sustainable Energy Reviews*, 81, 2796-2805.

KAUNDA, C.S., KIMAMBO, C.Z. & NIELSEN, T.K. 2012. Hydropower in the context of sustainable energy supply: a review of technologies and challenges. ISRN Renewable Energy, 2012.

KAZMI, H., MEHMOOD, F., TAO, Z., RIAZ, Z. & DRIESEN, J. 2019. Electricity load-shedding in Pakistan: Unintended consequences, opportunities and policy recommendations. *Energy Policy,* 128**,** 411-417.

KHANIYA, B., PRIYANTHA, H. G., BADUGE, N., AZAMATHULLA, H. M. & RATHNAYAKE, U. 2020. Impact of climate variability on hydropower generation: a case study from Sri Lanka. *ISH Journal of Hydraulic Engineering,* 26, 301-309.

KIM, K., PARK, T., BANG, S. & KIM, H. 2017. Real options-based framework for hydropower plant adaptation to climate change. *Journal of management in engineering*, 33(3), 04016049.

KLUNNE, W.J. 2009. Small hydropower for rural electrification in South Africa-using experiences from other African countries.

KOTEI, R., AGYARE, W. A., KYEI-BAFFOUR, N., ATTA-DARKWA, T. & ATAKORA, E. T. 2016. Estimation of flow-duration and low-flow frequency parameters for the Sumanpa stream at Mampong-Ashanti in Ghana for the 1985-2009 period.

KOTZE, P. 2011. The potential of small hydropower plants in South Africa: hydropower. *Water Wheel*, 10, 18-20.

KRUPA, J. & BURCH, S. 2011. A new energy future for South Africa: The political ecology of South African renewable energy. *Energy Policy,* 39**,** 6254-6261.

KUSAKANA, K. & VERMAAK, H. J. 2013. Hydrokinetic power generation for rural electricity supply: Case of South Africa. *Renewable energy*, 55, 467-473.

KUSAKANA, K. 2014. A survey of innovative technologies increasing the viability of micro-hydropower as a cost effective rural electrification option in South Africa. *Renewable and Sustainable Energy Reviews*, 37, 370-379.

KUSAKANA, K. 2017. Using PV with borehole pumped hydro storage systems for small farming activities in South Africa. 2017 IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia), 2017. IEEE, 1-6.

KUSRE, B.C., BARUAH, D.C., BORDOLOI, P.K. & PATRA, S.C. 2010. Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India). *Energy*, 87, 298–309.

LARENTIS, D.G., COLLISCHONN, W., OLIVERA, F. & TUCCI, C.E. 2010. Gis-based procedures for hydropower potential spotting*. Energy*, 35(10), 4237-4243.

LEAFLET. *An open-source JavaScript library for mobile-friendly interactive maps* [Online]. Available: https://leafletjs.com [Accessed 13 August 2020].

LIOUSSE, C., ASSAMOI, E., CRIQUI, P., GRANIER, C. & ROSSET, R. 2014. Explosive growth in African combustion emissions from 2005 to 2030. Environ. Res. Lett. 9, 035003.

LOOTS, I., VAN DIJK, M., BARTA, B., VAN VUUREN, S.J. & BHAGWAN, J.N. 2015. A review of low head hydropower technologies and applications in a South African context. *Renewable and Sustainable Energy Reviews*, 50, 1254-1268.

LUCAS, P. L., NIELSEN, J., CALVIN, K., MCCOLLUM, D. L., MARANGONI, G., STREFLER, J., VAN DER ZWAAN, B. C. & VAN VUUREN, D. P. 2015. Future energy system challenges for Africa: insights from Integrated Assessment Models. *Energy Policy*, 86, 705-717.

LYNCH, J. 2015. *Why is open source software more secure?* [Online]. Available: https://www.infoworld.com/article/2985242/why-is-open-source-software-more-secure.html#:~:text=Open%20source%20also%20allows%20anyone,testing%20and%20fixing%20the%20code. [Accessed 10 October 2020].

MACKAY, H. & MOLOI, B. The importance of instream flow requirements for decision making in the Okavango River Basin. Proceedings of first workshop, Green Cross International Water for Peace Project: Okavango Pilot Project, Maun, Botswana, September, 2002.

MANWA, H. 2014. Impacts of Lesotho Highlands water project on sustainable livelihoods. *Mediterranean Journal of Social Sciences,* 5**,** 640.

MAPBOX. *Web applications* [Online]. Available: https://docs.mapbox.com/help/how-mapbox-works/web-apps/ [Accessed 15 August 2020].

MAPX. *What is MapX?* [Online]. Available: https://www.mapx.org/faq/ [Accessed 15 August 2020].

MARCATELLI, M. 2020. Medupi power station and the water-energy nexus in South Africa. Transformation: *Critical Perspectives on Southern Africa*, 102,1-26.

MASINDI & DUNCKER. 2016. *State of Water and Sanitation in South Africa* [Online]. Available: https://www.researchgate.net/publication/311451788_State_of_Water_and_Sanitation_in_South_Africa [Accessed 17 June 2020].

MATCHAYA, G., NHAMO, L., NHLENGETHWA, S. & NHEMACHENA, C. 2019. An Overview of Water Markets in Southern Africa: An Option for Water Management in Times of Scarcity. *Water*, 11(5), 1006.

MATONA, T. 2015. *Load Shedding Status: Inactive Stage* [Online]. Available: http://www.durban.gov.za/City_Services/electricity/Load_Shedding/Pages/default.aspx [Accessed 19 June 2020].

MÉRIDA GARCÍA, A., RODRÍGUEZ DÍAZ, J. A., GARCÍA MORILLO, J. & MCNABOLA, A. 2021. Energy Recovery Potential in Industrial and Municipal Wastewater Networks Using Micro-Hydropower in Spain. *Water*, 13, 691.

MINVILLE, M., KRAU S., BRISSETTE, F. & LECONTE, R. 2009. Behaviour and performance of a water resource system in Quebec (Canada) under adapted operating policies in a climate change context. *Water Resource Management*, 24(7),1333–1352.

MKHIZE, V. 2021. COP26: South Africa hails deal to end reliance on coal [Online]. Available: https://www.bbc.com/news/world-africa-59135169 [Accessed 10 November 2021].

MNISI, N. 2020. *Water scarcity in South Africa: a result of physical or economic factors?* [Online]. Available: https://hsf.org.za/publications/hsf-briefs/water-scarcity-in-south-africa-a-result-of-physical-or-economic-factors#:~:text=The%20observed%20water%20scarcity%20in,aquifers%20or%20other%20water%20sources. [Accessed 18 June 2020].

MORAN, E.F., LOPEZ, M.C., MOORE, N., MÜLLER, N. & HYNDMAN, D.W. 2018. Sustainable hydropower in the 21st century. *Proceedings of the National Academy of Sciences*, 115(47), 11891-11898.

MUKHEIBIR, P. 2013. Potential consequences of projected climate change impacts on hydroelectricity generation. *Climatic change*, 121, 67-78.

MULLER, J. 2017. ESKOM: Electricity and Technopolitics in South Africa.

MULLER, M. 2019. *South Africa's real water crisis: not understanding what's needed* [Online]. Available:https://theconversation.com/south-africas-real-water-crisis-not-understanding-whats-needed-126361 [Accessed 18 June 2020].

MURPHY, P. M., TWAHA, S. & MURPHY, I. S. 2014. Analysis of the cost of reliable electricity: A new method for analyzing grid connected solar, diesel and hybrid distributed electricity systems considering an unreliable electric grid, with examples in Uganda. *Energy,* 66**,** 523-534.

MUSTAPA, S. I., PENG, L. Y. & HASHIM, A. H. 2010. Issues and challenges of renewable energy development: A Malaysian experience. Proceedings of the International Conference on Energy and Sustainable Development: Issues and Strategies (ESD 2010), 2010. IEEE, 1-6.

MUTOMBO, N. M. A. & NUMBI, B. 2019. Assessment of renewable energy potential in Kwazulu-Natal province, South Africa. *Energy Reports*, 5, 874-881.

NATIONAL ENERGY ACT. 2008. *National Energy Act 2008* [Online]. Available: http://www.energy.gov.za/files/policies/NationalEnergyAct_34of2008.pdf [Accessed 23 July 2021].

NAZARI-HERIS, M. & MOHAMMADI-IVATLOO, B. 2017. Design of Small Hydro Generation Systems. Distributed generation systems: design, operation and grid integration, 301.

NDAGUBA, E.A. 2018. Load Shedding and Community Health Centres in South Africa: A Conceptual Scholarship (2014–2016).

NOMJANA, L. 2020. *The Renewable Energy Independent Power Producer Procurement (REIPPP) programme was launched in 2011, out of a need and desire to procure alternative sustainable energy - while simultaneously contributing to social and economic development in South Africa* [Online]. Available: https://futuregrowth.co.za/newsroom/reippp-comes-of-age/ [Accessed 16 June 2020].

NOYES, K. 2010. *Is FOSS' Openness a Security Weakness?* [Online]. Available: https://linuxinsider.com/story/is-foss-openness-a-security-weakness-70797.html [Accessed 10 October 2020].

NYEMBE, T. 2018. The Socio-Economic Impacts of Medupi Power Station on Lephalale.

ODEKU, K.O. 2019. The impact of electricity tariff increase on indigent women in South Africa. *Gender and Behaviour*, 17(4), 14137-14146.

OLUFEMI, A.C., MJI, A. & MUKHOLA, M.S. 2019. Health risks of exposure to air pollutants among students in schools in the vicinities of coal mines. *Energy Exploration & Exploitation*, 37(6), 1638-1656.

OPENLAYERS. *A high-performance, feature-packed library for all your mapping needs* [Online]. Available: https://openlayers.org/ [Accessed 16 August 2020].

OSTERMANN, F. O. & GRANELL, C. 2017. Advancing science with VGI: Reproducibility and replicability of recent studies using VGI. *Transactions in GIS*, 21, 224-237.

OWUSU, P.A. & ASUMADU-SARKODIE, S. 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*, 3, 1167.

PEGELS, A. 2010. Renewable energy in South Africa: Potentials, barriers and options for support. *Energy policy*, 38(9), 4945-4954.

PEIDONG, Z., YANLI, Y., YONGHONG, Z., LISHENG, W. & XINRONG, L. 2009. Opportunities and challenges for renewable energy policy in China. *Renewable and Sustainable Energy Reviews,* 13**,** 439-449.

POLLET, B. G., STAFFELL, I. & ADAMSON, K. A. 2015. Current energy landscape in the Republic of South Africa. *International Journal of Hydrogen Energy,* 40**,** 16685-16701.

PRAJAPATI, R.N. 2015. Delineation of run of river hydropower potential of Karnali basin-Nepal using GIS and HEC-HMS. Eur. J. Adv. Eng. *Technol*, 2, 50-54.

PRETORIUS, I., PIKETH, S., BURGER, R. & NEOMAGUS, H. 2015. A perspective on South African coal fired power station emissions. *Journal of Energy in Southern Africa,* 26**,** 27-40.

QGIS CLOUD. *What is Qgis Cloud?* [Online]. Available: https://qgiscloud.com/ [Accessed 14 August 2020

RAHMAN, M. H. 2016. Exploring sustainability to feed the world in 2050. *Journal of Food Microbiology*, 1.

RAJPUT, R. 2006. Power system engineering. Firewall Media.

RBRAY. 2007. *MapGuide Project Home* [Online]. Available: https://mapguide.osgeo.org/ [Accessed 17 August 2020 2020].

RESOUR, T. 2012. Hydrological feasibility of a mini hydropower plant on Tiljuga River, Bihar, India. WATER & ENERGY INTERNATIONAL.

RIEKERT, J.W. & KOCH, S.F. 2012. Projecting the external health costs of a coal-fired power plant: The case of Kusile. *Journal of Energy in Southern Africa*, 23(4), 52-66.

ROSHAN, V.R., SURESH, K., IPE, S. KURUP, K. & GEORGE, A. 2016. *Pico-hydro electric power generation from residential water tank. Int. J. Chem*. Sci, 14, 421-426.

ROSPRIANDANA, N. & FUJII, M. 2017. Assessment of small hydropower potential in the Ciwidey subwatershed, Indonesia: a GIS and hydrological modelling approach. *Hydrological Research Letters*, 11, 6-11.

RYCROFT, M. n.d. *Run-of-river hydropower systems* [Online]. Available: https://www.ee.co.za/article/run-river-hydropower-systems.html [Accessed 19 June 2020]

RYCROFT, M. 2014. The potential of small hydro power plants in southern Africa. Energize May 2014, 18-22.

SAHRIS. 2018. *Phongola Hydropower Station* [Online]. Available: https://sahris.sahra.org.za/cases/phongola-hydropower-station [Accessed 06 August 2021].

SAHU, R. & QEP, C. 2018. Eskom power station exceedances of applicable atmospheric emission license (AEL) limit values for PM, SO2 & NOx During April 2016 to December 2017. Energy & Air Quality Issues Alhambra.

SAMMARTANO, V., LIUZZO, L. & FRENI, G. 2019. Identification of Potential Locations for Run-of-River Hydropower Plants Using a GIS-Based Procedure. *Energies*, 12(18), 3446.

SAMORA, I., MANSO, P., FRANCA, M. J., SCHLEISS, A. J. & RAMOS, H. M. 2016. Energy recovery using micro-hydropower technology in water supply systems: The case study of the city of Fribourg. *Water*, 8, 344.

SANCOLD. 2019. *Dams in South Africa* [Online]. Available: https://www.sancold.org.za/about/about-dams/dams-in-south-africa [Accessed 23 June 2020].

SGUAZZIN, A. 2021. *South Africa Power Giant Is Now World's Biggest Sulfur Dioxide Emitter, CREA Says* [Online]. Available: https://www.bloomberg.com/news/articles/2021-10-05/eskom-is-now-world-s-biggest-sulfur-dioxide-emitter-crea-says#:~:text=Eskom%20Holdings%20SOC%20Ltd.%2C%20South,Energy%20and%20Clean%20Air%20said. [Accessed 06 November 2021].

SHAIKH, P.H., NOR N.B.M., SAHITO, A.A., NALLAGOWNDEN, P., ELAMVAZUTHI, I. & SHAIKH, M.S. 2017. Building energy for sustainable development in Malaysia: A review. *Renewable and Sustainable Energy Reviews*, 75,1392-1403.

SHRESTHA, R. S. 2010. Electricity crisis (load shedding) in Nepal, its manifestations and ramifications. *Hydro Nepal: Journal of Water, Energy and Environment,* 6**,** 7-17.

SHIKWAMBANA, L., MHANGARA, P. & MBATHA, N. 2020. Trend analysis and first time observations of sulphur dioxide and nitrogen dioxide in South Africa using TROPOMI/Sentinel-5 P data. *International Journal of Applied Earth Observation and Geoinformation*, 91, 102130.

STATISTA. 2021. Digital population in South Africa as of January 2021 [Online]. Available: https://www.statista.com/statistics/685134/south-africa-digital-population/ [Accessed 22 April 2021].

STATISTICS SOUTH AFRICA. 2018. *Electricity: Coal uses inches lower as solar, wind and diesel rise* [Online]. Available: http://www.statssa.gov.za/?p=11292 [Accessed 19 March 2020].

STATISTICS SOUTH AFRICA. 2020. General Household Survey 2019. Statistics South Africa.

STATISTICS SOUTH AFRICA. 2021. General Household Survey 2020. Statistics South Africa.

STEFFEN, B., BEUSE, M., TAUTORAT, P. & SCHMIDT, T. S. 2020. Experience curves for operations and maintenance costs of renewable energy technologies. *Joule,* 4**,** 359-375.

STEHR, A., DEBELS, P., ROMERO, F. & ALCAYAGA, H. 2008. Hydrological modelling with SWAT under conditions of limited data availability: Evaluation of results from a Chilean case study. *Hydrological Sciences journal*, 53, 588–601.

STEYN, L. 2021. *2021 brought 1 130 hours of load-shedding - a new record. 2022 may be even worse* [Online]. Available: https://www.news24.com/fin24/economy/south-africa/2021-brings-unprecedented-load-shedding-and-its-likely-to-continue-in-the-new-year-20211216 [Accessed 10 January 2022].

STODDARD, E. 2021. *It's 100MW or bust: Power to the people after embedded generation threshold set in stone* [Online]. Available: https://www.dailymaverick.co.za/article/2021-08-12-its-100mw-or-bust-power-to-the-people-after-embedded-generation-threshold-set-in-stone/ [Accessed 01 November 2021].

SUI, D., ELWOOD, S. & GOODCHILD, M. 2012. Crowdsourcing geographic knowledge: volunteered geographic information (VGI) in theory and practice, Springer Science & Business Media.

SUJITH, K., TUNTUN, K., AVINASH, K., SWAPNIL, S., KUNAL, K. & SATYA, P. 2016. Technical and economic feasibility of Pico hydro power plants integrated to Green buildings. *International Research Journal of Engineering and Technology (IRJET)*, 3, 77-79.

SUTHERLAND, C. 2022. ANALYSIS | *Catherine Sutherland: Were Durban floods 'initially invisible' to city* authorities? [Online]. Available: https://www.news24.com/news24/analysis/analysis-catherine-sutherland-were-the-floods-in-durban-initially-invisible-to-those-governing-the-city-20220421 [Accessed 27 April 2022].

SZABO, S., BÓDIS, K., HULD, T. & MONER-GIRONA, M. 2011. Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension. *Environmental Research Letters,* 6**,** 034002.

TARASENKO, A. 2019. *Leaflet vs OpenLayers*. *What to choose?* [Online]. Available: https://www.geoapify.com/leaflet-vs-openlayers/ [Accessed 25 August 2020].

THATCHER, A., NAYAK, R. & WATERSON, P. 2020. Human factors and ergonomics systems-based tools for understanding and addressing global problems of the twenty-first century. *Ergonomics,* 63**,** 367-387.

THIN, K.K., ZIN, W.W., SAN, Z.M.L.T., KAWASAKI, A., MOIZ, A. & BHAGABATI, S.S. 2020. Estimation of Run-of-River Hydropower Potential in the Myitnge River Basin. *Journal of Disaster Research*, 15(3), 267-276.

TOKLU, E. 2017. Biomass energy potential and utilization in Turkey. *Renewable Energy*, 107, 235-244.

TRICARD, M. 2016. *Democratic Republic of Congo - Cornucopia of Africa* [Online]. Available: https://www.andritz.com/hydro-en/hydronews/hydropower-africa/democratic-rep-congo# [Accessed 20 April 2021].

TRIPATHI, A. D., MISHRA, R., MAURYA, K. K., SINGH, R. B. & WILSON, D. W. 2019. Estimates for world population and global food availability for global health. The role of functional food security in global health. Elsevier.

TSHIBALO, A., DHANSAY, T., NYABEZE, P., CHEVALLIER, L., MUSEKIWA, C. & OLIVIER, J. 2015. Evaluation of the geothermal energy potential for South Africa. *Evaluation,* 19**,** 25.

UAMUSSE, M. M., TUSSUPOVA, K., PERSSON, K. M. & BERNDTSSON, R. 2019. Mini-grid hydropower for rural electrification in mozambique: meeting local needs with supply in a Nexus approach. *Water*, 11, 305.

UNION OF CONCERNED SCIENTISTS. 2019. *Coal Power Impacts* [Online]. Available: https://www.ucsusa.org/resources/coal-power-impacts [Accessed 19 March 2020].

UNITED NATIONS. 2018. *Sustainable Development Goals* [Online]. Available: https://sustainabledevelopment.un.org/?menu=1300 [Accessed 20 March 2020].

UAMUSSE, M. M., TUSSUPOVA, K., PERSSON, K. M. & BERNDTSSON, R. 2019. Mini-grid hydropower for rural electrification in mozambique: meeting local needs with supply in a Nexus approach. *Water*, 11, 305.

USGS. 2019. *Hydroelectric Power: How it works* [Online]. Available: https://www.usgs.gov/special-topic/water-science-school/science/hydroelectric-power-how-it-works?qt-science_center_objects=0#qt-science_center_objects [Accessed 19 March 2020].

VAN DER MERWE, M. 2019. *More South Africans have access to electricity, but they're less happy about it* [Online]. Available: https://www.news24.com/fin24/economy/more-south-africans-have-access-to-electricity-but-theyre-less-happy-about-it-20190528 [25 October 2021].

VAN DER MERWE, M. 2021. *SA is getting R131bn from rich nations to ditch coal: Here's where it will go* [Online]. Available: https://www.news24.com/fin24/economy/explainer-sa-is-getting-r131bn-from-rich-nations-to-ditch-coal-heres-where-it-will-go-20211103 [Accessed 10 November 2021].

VAN DIJK, M. 2014. Conduit hydropower: An alternative sustainable renewable energy source. Conduit hydropower an Altern. *Sustain. Renew. energy source*, 9, 27-31.

VAN DIJK, M., BHAGWAN, J. & DEDEKIND, C. 2016. Utilising the water infrastructure for hydropower energy generation.

VAN VUUREN, S.J., BLERSCH, C.L. & VAN DIJK, M. 2011. Modelling the feasibility of retrofitting hydropower to existing South African dams. *Water SA*, 37(5), 679-692.

VAN VUUREN, S.J., LOOTS, I., VAN DIJK, M. & BARTA, B. 2013. Scoping study: energy generation using low-head hydro technologies. WRC Report No KV 323/13. Water Research Commission: Pretoria.

VAN VUUREN, S.J., VAN DIJK, M., LOOTS, I., BARTA, B. & SCHARFETTER, B.G. 2014. Conduit hydropower development guidelines. WRC Report No TT597, 14.

VON SPERLING, E. 2012. Hydropower in Brazil: overview of positive and negative environmental aspects. *Energy Procedia*, 18,110-118.

WATER POWER TECHNOLOGIES OFFICE. 2020. *Types of Hydropower plants* [Online]. Available: https://www.energy.gov/eere/water/types-hydropower-plants [Accessed 19 June 2020].

WATER RESEARCH COMMISSION. 2018. *Dams in South Africa* [Online]. Available: http://www.wrc.org.za/?mdocs-file=35409 [Accessed 02 May 2021].

WILLIAMSON, S. J., LUBITZ, W. D., WILLIAMS, A. A., BOOKER, J. D. & BUTCHERS, J. P. 2019. Challenges Facing the Implementation of Pico-Hydropower Technologies. *Journal of Sustainability Research*, 4.

WRIGHT, J. G., CALITZ, J. R., FOURIE, R. & CHILOANE, L. D. 2019. Integrated Resource Plan 2019: Initial CSIR insights and risks/opportunities for South Africa.

YUKSEL, I. 2010. Hydropower for sustainable water and energy development. *Renewable and Sustainable Energy Reviews*, 14, 462-469.

ZHANG, X., LIN, M., WANG, Z. & JIN, F. 2021. The impact of energy-intensive industries on air quality in China's industrial agglomerations. *Journal of Geographical Sciences,* 31**,** 584-602.

ZOMERS, A. 2014. Remote access: Context, challenges, and obstacles in rural electrification. *IEEE Power and Energy Magazine,* 12**,** 26-34.

ZVIMBA, J. N. & MUSVOTO, E. V. 2020. Modelling energy efficiency and generation potential in the South African wastewater services sector. *Water Science and Technology*, 81,876-890.

APPENDIX A: SURVEY LETTER SENT TO STAKEHOLDERS

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YUNIBESITHI YA PRETORIA

Faculty of Natural and Agricultural Sciences

+27-12-420-4255
christel.hansen@up.ac.za

12 April 2022

Dear Stakeholder!

You have been identified as a stakeholder to the South African Hydropower Atlas (SAHA). Funded by the Water Resource Commission (WRC) of South Africa, and developed by the University of Pretoria (UP), SAHA is an interactive Hydropower Atlas hosted on the ArcGIS Online platform, and aims to collate and disseminate information resources regarding existing hydropower and the hydropower potential in South Africa.

This survey asks your opinion of the South African Hydropower Atlas (SAHA). The Atlas can be accessed at https://bit.ly/3tCGzSQ. This is the second survey sent to stakeholders. Responses from the first survey were, where possible, integrated into SAHA. The help manual of SAHA can be accessed on the top pane of the Atlas.

To provide feedback, please use this form: https://forms.gle/28TBzZNe2VKMezA46. Your feedback will be held in strictest confidence. Your participation will be much appreciated.

Please note that this is not the last version of SAHA, but rather the framework, and based on your feedback, we will make improvements to this framework. Additional data layers are also continuously identified and added to SAHA as they become available.

The next project meeting is scheduled for **25 April**. We ask you to please complete the survey by this time so that any questions raised during the survey can be discussed then. The survey will be available until **6 May.**

For questions, please contact Dr Hansen at christel.hansen@up.ac.za, or Ms Mahamba at u15223222@tuks.co.za.

Yours,

Dr Hansen & Ms Mahamba

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University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 4255
christel.hansen@up.ac.za
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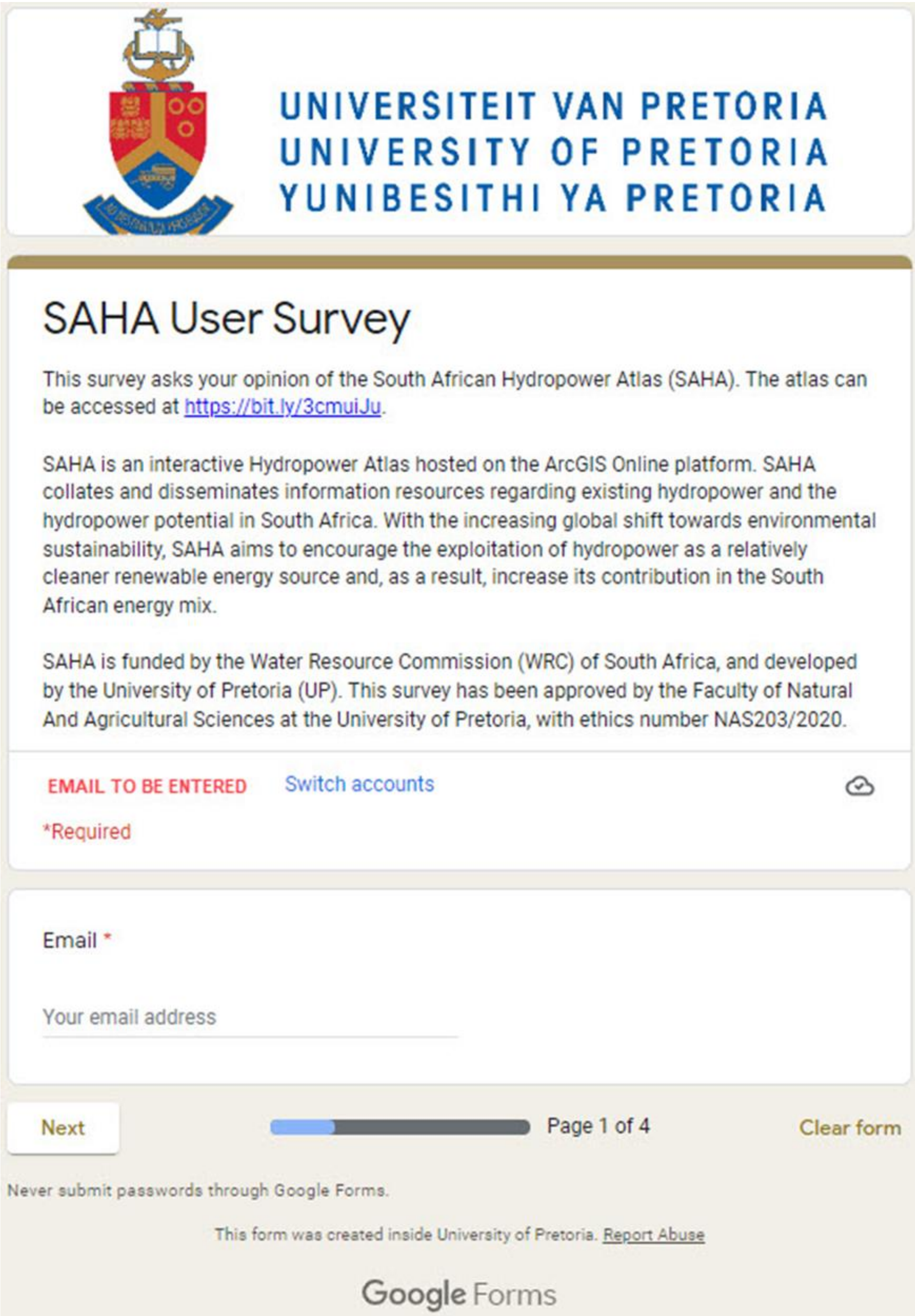
Fakulteit Natuur- en Landbouwetenskappe
Lefapha la Disaense tša Tlhago le Temo

APPENDIX B: STAKEHOLDER SURVEY



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SAHA User Survey

This survey asks your opinion of the South African Hydropower Atlas (SAHA). The atlas can be accessed at https://bit.ly/3cmuiJu.

SAHA is an interactive Hydropower Atlas hosted on the ArcGIS Online platform. SAHA collates and disseminates information resources regarding existing hydropower and the hydropower potential in South Africa. With the increasing global shift towards environmental sustainability, SAHA aims to encourage the exploitation of hydropower as a relatively cleaner renewable energy source and, as a result, increase its contribution in the South African energy mix.

SAHA is funded by the Water Resource Commission (WRC) of South Africa, and developed by the University of Pretoria (UP). This survey has been approved by the Faculty of Natural And Agricultural Sciences at the University of Pretoria, with ethics number NAS203/2020.

EMAIL TO BE ENTERED Switch accounts

*Required

Email *

Your email address

Next Page 1 of 4 Clear form

Never submit passwords through Google Forms.

This form was created inside University of Pretoria. Report Abuse

Google Forms

Figure 42: Page 1 (survey description) of the SAHA stakeholder survey.

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SAHA User Survey

Switch accounts

*Required

Participation consent

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 agreeing to participate in this survey. You also have the rights of access to your data.

By participating 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.

You will automatically receive a copy of this survey once you have completed it (clicked on 'Submit').

This survey has also been approved by the University of Pretoria, Faculty of Natural and Agricultural Sciences ethics committee (reference NAS203/2020).

For questions please contact Dr. Hansen at christel.hansen@up.ac.za, or Ms. Mahamba at u15223222@tuks.co.za.

Survey consent *

Do you agree to take part in this survey?

- Yes
- No

Back | Next | Page 2 of 4 | Clear form

Figure 43: Page 2 (survey respondent consent) of the SAHA stakeholder survey.

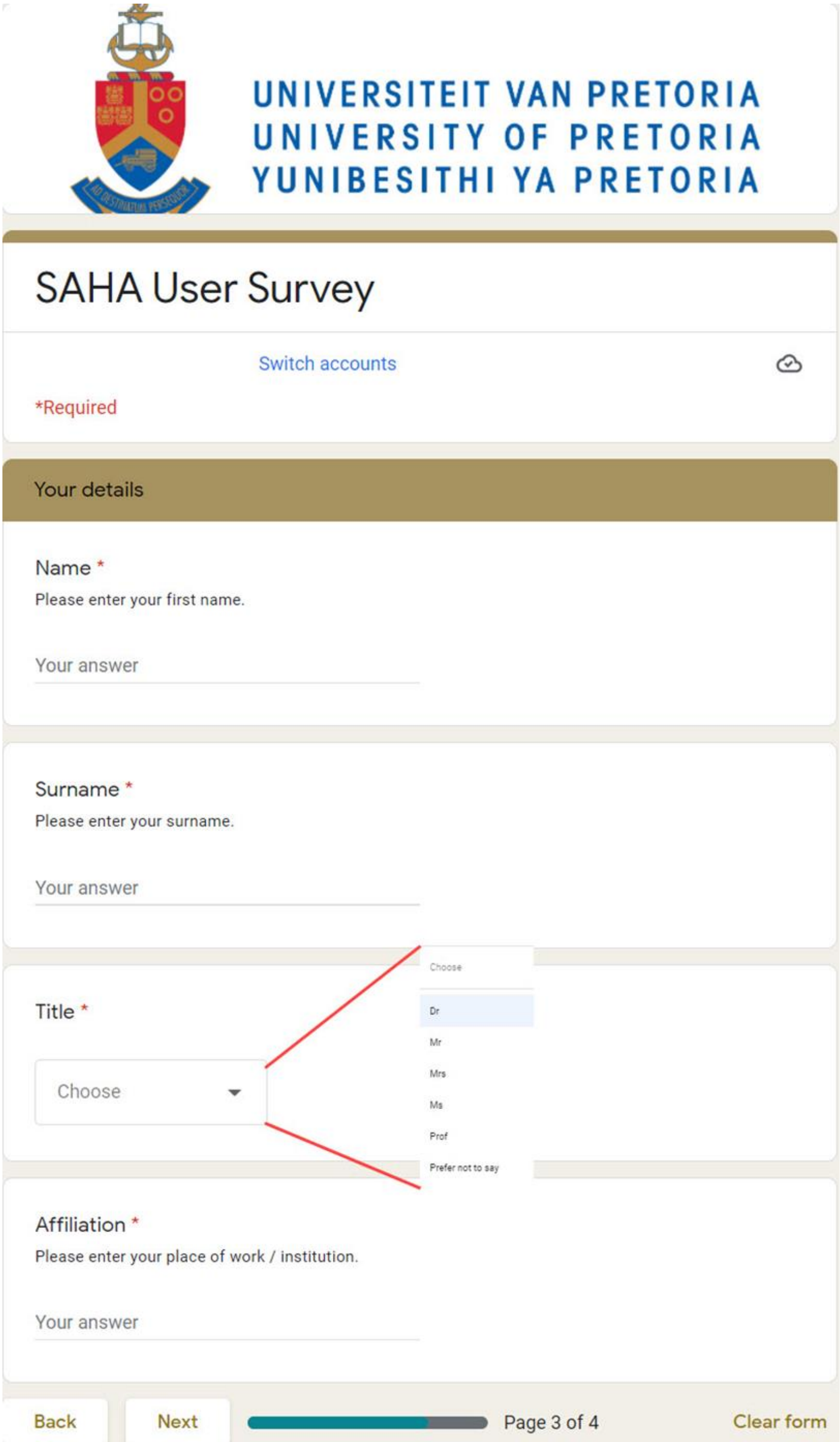
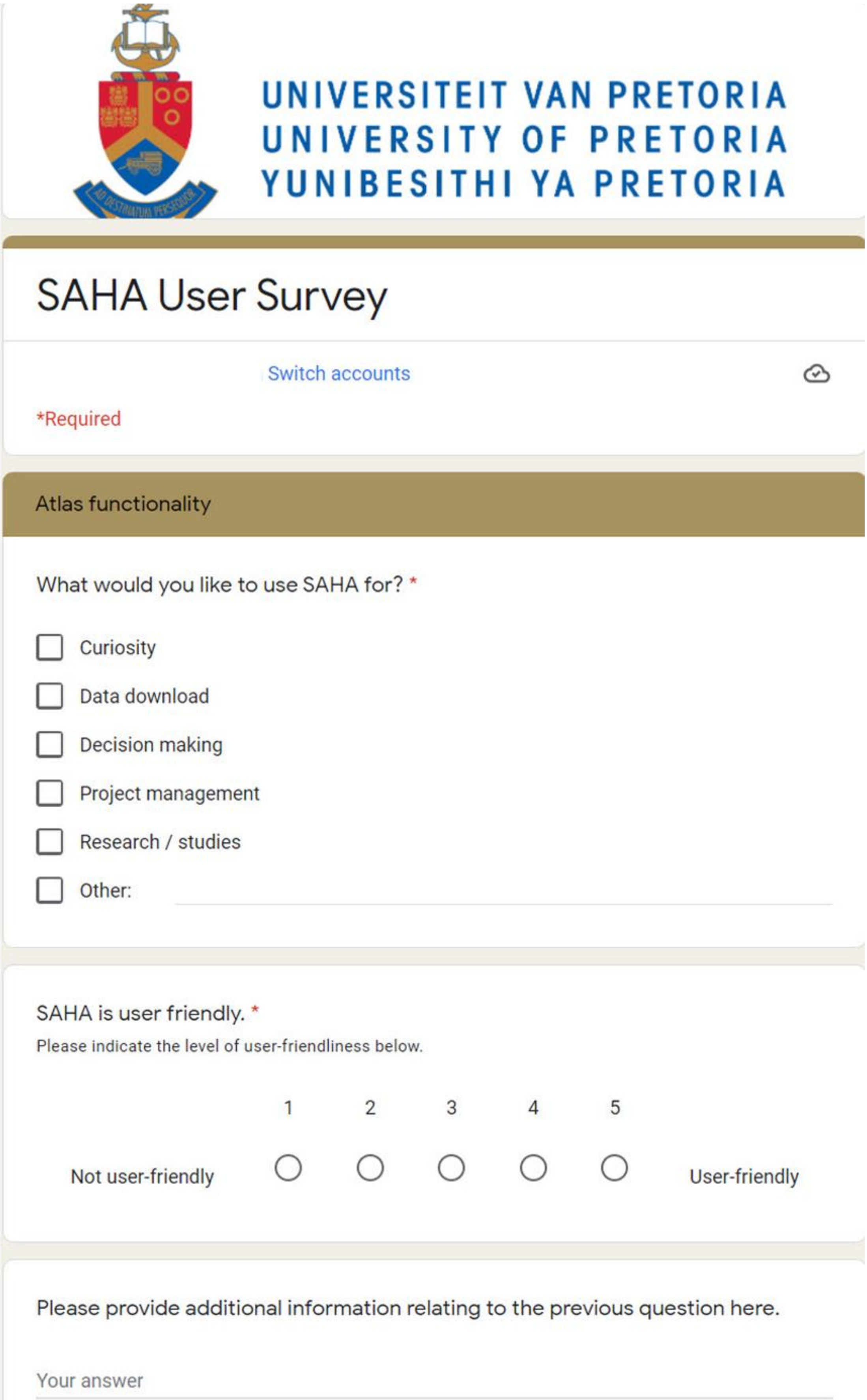


Figure 44: Page 3 (respondent details) of the SAHA stakeholder survey.



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SAHA User Survey

Switch accounts

*Required

Atlas functionality

What would you like to use SAHA for? *

- [ ] Curiosity
- [ ] Data download
- [ ] Decision making
- [ ] Project management
- [ ] Research / studies
- [ ] Other:

SAHA is user friendly. *

Please indicate the level of user-friendliness below.

	1	2	3	4	5	
Not user-friendly	○	○	○	○	○	User-friendly

Please provide additional information relating to the previous question here.

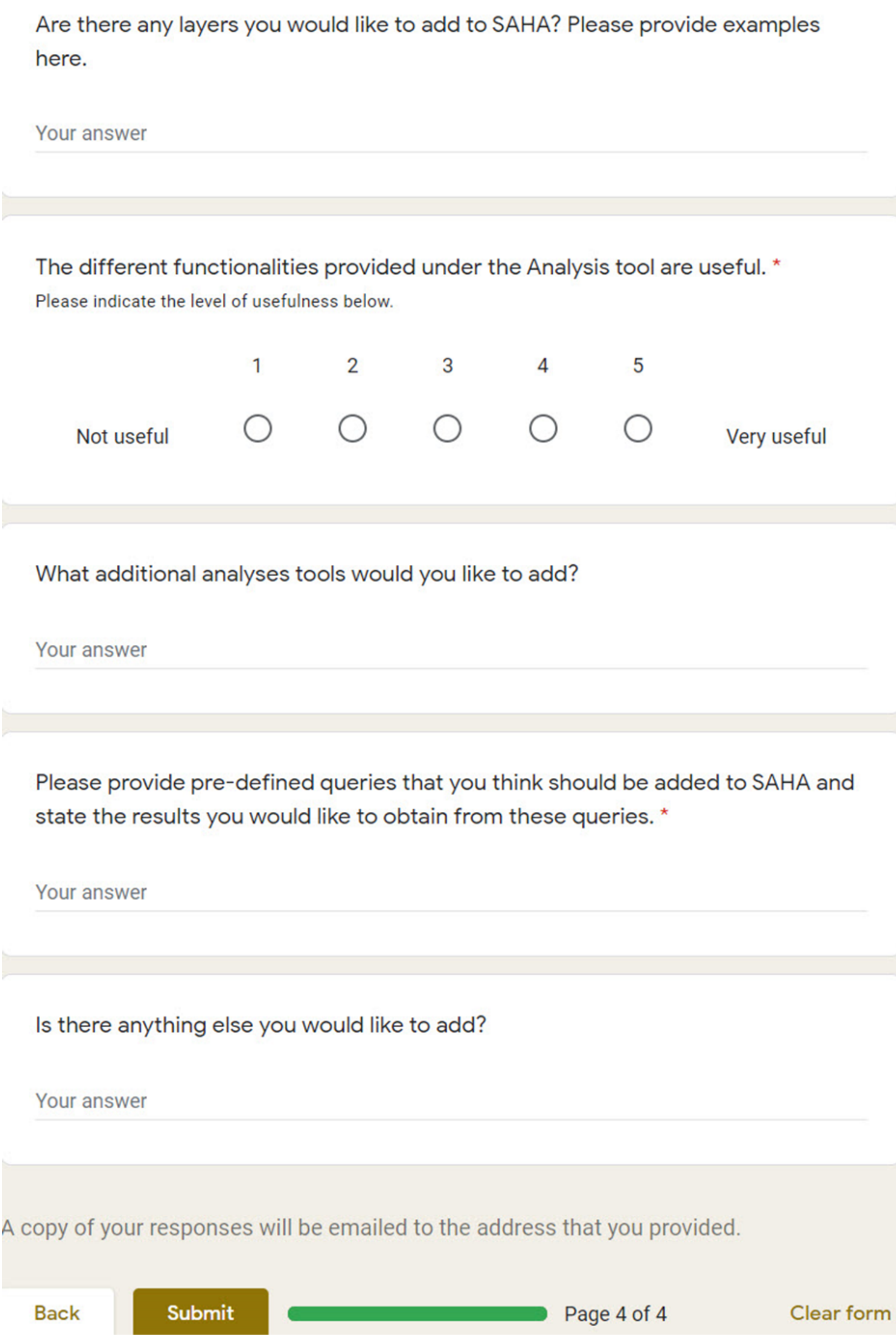
Your answer

Figure 45: Page 4 (questions 1-3) of the SAHA stakeholder survey.

Indicate which layers you would remove from SAHA. *

	Remove	Keep
Existing Hydropower Installations		
Small-Scale Hydropower Potential		
Potential Hydropower Sites (Gauteng)		
Dam Hydropower Potential		
Wastewater Treatment Works		
Gauging Weirs		
Dams		
Rivers		
Drainage Directions		
Flow Accumulation		
Provinces		
District Municipalities		
Local Municipalities		
Wards		
Access to Electricity (municipality)		
Access to Electricity (ward)		
Main Transmission Stations		
Main Transmission Lines		
High Voltage Stations		
High Voltage Lines		
Precipitation Change by 2050		
Average Precipitation		
Average Temperature		
Predicted Temperature Change		
Roads		

Figure 46: Page 4 (question 4) of the SAHA stakeholder survey.



Are there any layers you would like to add to SAHA? Please provide examples here.

Your answer

The different functionalities provided under the Analysis tool are useful. *

Please indicate the level of usefulness below.

	1	2	3	4	5	
Not useful	○	○	○	○	○	Very useful

What additional analyses tools would you like to add?

Your answer

Please provide pre-defined queries that you think should be added to SAHA and state the results you would like to obtain from these queries. *

Your answer

Is there anything else you would like to add?

Your answer

A copy of your responses will be emailed to the address that you provided.

Back | Submit | Page 4 of 4 | Clear form

Figure 47: Page 4 (questions 4-10) of the SAHA stakeholder survey.

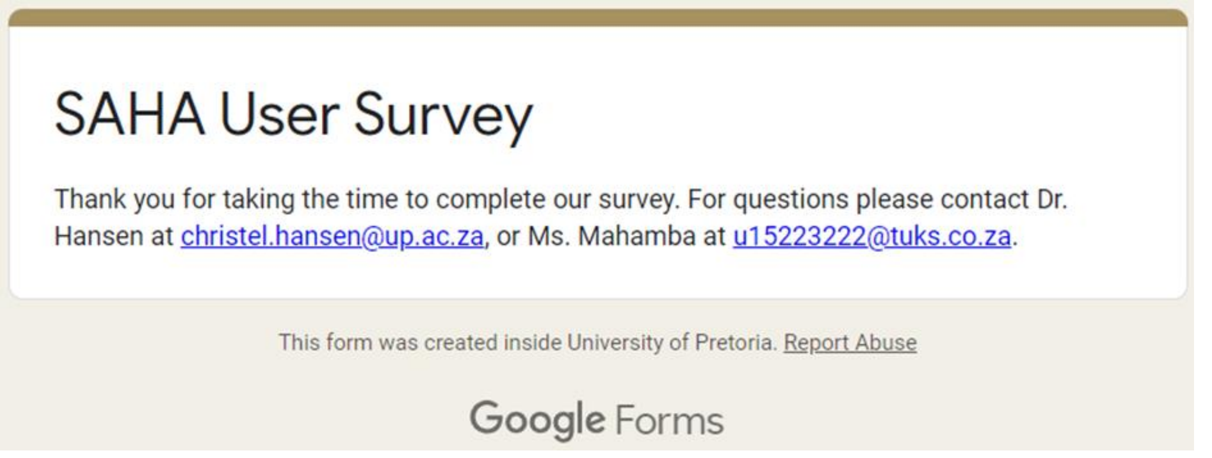


Figure 48: Message displayed once the respondent clicks on Submit.

APPENDIX C: EXAMPLE METADATA CAPTURED PER GEOSPATIAL LAYER AVAILABLE ON SAHA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        <CreaTime>19553800</CreaTime>
        <ModDate>2022-01-13</ModDate>
        <ModTime>15:27:59.50</ModTime>
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        <ArcGISstyle>ISO 19139 Metadata Implementation Specification GML3.2</ArcGISstyle>
        <ArcGISProfile>ISO19139</ArcGISProfile>
        <MapLyrSync>false</MapLyrSync>
        <SyncOnce>TRUE</SyncOnce>
    </Esri>
    <mdFileID>1642080421508r06289327103724762</mdFileID>
    <mdChar>
        <CharSetCd value="004"/>
    </mdChar>
    <mdContact>
        <role>
            <RoleCd value="007"/>
        </role>
    </mdContact>
    <mdDateSt>2022-01-13</mdDateSt>
    <mdTimeSt>15:27:00.100</mdTimeSt>
    <dataIdInfo>
        <idCitation>
            <resTitle>Dam Hydropower Potential Modelled 2010-2020</resTitle>
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                <reviseDate>2022-01-13T15:27:17.496+02:00</reviseDate>
            </date>
        </idCitation>
```

<idAbs>A data layer representing South African dams with hydropower potential modelled on 2010-2020 DWS flow records.</idAbs>

<idPurp>Hydropower potential of South African Dams modelled on 2010-2020 DWS flow records.</idPurp>

<idCredit>Department of Water and Sanitation</idCredit>

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</dataChar>

<searchKeys>

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<keyword>#HydropowerPotential</keyword>

</searchKeys>

<resConst>

<Consts>

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</Consts>

</resConst>

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<LegConsts>

<accessConsts>

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