



Potential of space science technology for water infrastructure management: A literature review

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ABSTRACT

This article examines the potential of space science technology for water infrastructure (WI) management. It defines space technology in detail, and when South Africa (SA) started using it as a tool. To explain the context, the different types of orbits, altitudes, and functions of satellites are given, as well as the challenges that satellites encounter in orbit, including the quantity and sizes of orbital debris also known as space junk. The article articulates the international and local challenges to WI and further introduces space technology as a tool that can assist to overcome the challenges. Legislation governing the application of space technology in SA is discussed and the different satellites owned by the various space agencies of Africa are outlined. A discussion on how space technology has boosted the economies and employment in Africa and South Africa is provided. How the various applications of the technology, such as remote sensing (RS), Earth observation (EO), Geo-Information sciences, navigation, communication, safety, and security can assist WI management are discussed. Details about the involvement of various African and SA universities and colleges in space science programmes that benefit the communities are explained. Also outlined are some experiments performed on the International Space Station (ISS) that benefit the Earth and that could be useful to WI management.

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Introduction

The issues surrounding water infrastructure are always challenging to local authorities and water boards. These issues are, amongst others, burst pipes, leaks, vandalism and theft, reluctance to pay bills, aging water infrastructure, lack of maintenance and poor planning (Venter, 2016). As a result, the communities suffer limited or no access to their homes due to road closures that result in traffic jams (Celik and Budayan, 2016; Brady, Burtwell and Thomson, 2001), unbarricaded trenches (Brady, Burtwell and Thomson, 2001), leaking water pipes (Alvisi et al., 2019), water cut-offs (Hamer et al., 2018), electricity supply interruptions (Muller, 2019; Folkman, 2018), and vandalism and theft (Mokgobu, 2017). Brady, Burtwell and Thomson (2001) noted an engineer who complained, "Excavations are left open for an unreasonable time due to the diversification with the utilities and lack of coordination between departments". Kganyago and Mhangara (2019) noted efforts to address data gaps and sustainable development programmes by most African countries progressively embracing Earth Observation (EO) and Geospatial technologies. The following African countries have established their space agencies with increasing investment: Nigeria, Egypt, Algeria, Kenya, South Africa, and Gabon. They are the 21st-century players in the space industry with their EO satellites. Woldai (2020) outlined notable progress made by Algeria, Egypt, Kenya, and SA with two receiving and tracking satellite stations per country, and one receiving station each in Nigeria and Gabon.

The introduction of space technology may provide solutions to some of the challenges being faced by South African (SA) local authorities. South Africa today is leading African space research and is benefitting tremendously from the investments. Africa's

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expansion into space activities has been realised by collaborating with organisations like the National Aeronautics and Space Administration (NASA) in conferences and at workshops in Africa to share knowledge (Ligate, 2015).

Space technology refers to spacecraft, satellites, space stations, backup infrastructure, tools, and processes established and utilised by the aerospace environment in spaceflight, satellites, or space exploration (Ojoyi, 2016).

According to the Parliamentary Monitoring Group (2014), in the meeting held on the 14th of September 2014, the South African Council for Space Affairs (SACSA) outlined the importance of space technology to South Africa (SA). The meeting adopted satellite communication, satellite aided position, timing and navigation, and earth observation as the three pillars of space technology. The benefits of space technology to society and the importance of policy formulation to regulate the industry were discussed. Parliamentary Monitoring Group (2014) further details the services offered by the three pillars of space technology, namely, food security, water security, urban management, disaster management, nature preservation, land use, drought, climate change, desertification, treaty conformance, human rights exposure, and environmental destructions.

The South African National Space Agency (SANSA) is an entity of the Department of Science and Technology (DST) and derives its mandate from the South African National Space Agency Act, 2008 [Act No. 36 of 2008] and National Space Strategy (Kganyago and Mhangara, 2019). The Act promotes the use and co-operation of space-associated activities, space science research, and improvement in scientific engineering and maintains a favourable atmosphere of technological development in the space industry within the national government policy framework. The Act specifies the reasons SANSA was established and provided the objects and functions and specified the way the entity should be managed (South Africa, Department of Science and Technology, 2008). South African National Space Agency was launched on the 9th of December 2010, and this saw the transformation of South Africa's space landscape (South African National Space Agency, 2011).

Since it is a worldwide occurrence that the space sector is undergoing swift change, global players must adapt to the changes, especially new entrants into the sector. South African National Space Agency (2020a) envisions four vital fundamentals that motivate space industry innovation, namely, national security and scientific goals, downstream space applications growth, human space exploration, and the fourth industrial revolution (4IR).

Considering the problems SA municipalities are having with water infrastructure and water service provisions and maintenance, every effort needs to be made to help to address these problems. Although space technology, especially earth observation and remote sensing, may assist with these problems, it does not appear that they are being effectively used yet. With the speed at which the space industry is developing in Africa, and especially in South Africa, an attempt needs to be made to provide a better understanding of the potential role of space technology in assisting with the management of water infrastructure management.

Therefore, this study aimed to examine the potential of space technology to manage water infrastructure in Africa and South Africa, as discussed in the extant literature, with sub-objectives being to:

- a) Identify how space technology can help with the management of water infrastructure.
- b) Determine how best space technology can be applied to overcome the various challenges in managing the WI in Africa and SA.

To achieve these objectives and to improve the understanding of space technology in water infrastructure management, a detailed literature search was conducted to explore the application of space technology in Africa, South Africa, and globally. Based on the identified literature a picture of the current and potential application of space science in the management of water infrastructure was developed.

Various searches were conducted for relevant literature on space technology in e-textbooks, e-journals, and e-newspapers, using several search themes that were established in advance. These themes helped guide the search. The themes used in the literature search were space technology; managing earth from space; managing water infrastructure from space. These themes produced several words guiding the search process. The words were space, space technology, managing earth, earth observation (EO), water infrastructure, managing water infrastructure from space, SANSA, ISS, remote sensing, and fourth industrial revolution (4IR).

Relevant data was extracted from Google.Com and Google Scholar (<https://scholar.google.com>), Scopus database and Sabinet search engines. However, other search engines such as Emerald and ProQuest were also visited but did not produce the required results. The reference lists of identified papers were also helpful in the search for the latest literature. Thus, it can be said that a form of snowball sampling was also used.

Once collected, the data was analysed, using NVivo qualitative analysis software, by categorising information from the literature into the relevant themes developed from the literature, as mentioned in Section 3.2. Thus, the information gathered from the literature was decomposed and then recomposed into the themes, as specified by Lee (1999).

The analysis found that much of the literature only covered the technical aspects of the topic. Literature related to the management aspects of water infrastructure was very limited and so it was necessary to be very selective and to extract the limited management successes and shortfalls included in the technical literature and apply it to this study. Furthermore, management principles were applied to the extant literature to find a way to develop a meaningful review and to draw significant conclusions from the literature.

Hereafter, the paper is presented in four main sections. First, the theoretical background is presented in three sections covering water infrastructure, how satellites operate as space technology and the current status of space technology in Africa and South Africa. Then, second, the practical, or empirical, application of space technology is presented via three sections covering the practical role of space technology, the relationship between water infrastructure and space technology and how space technology can help resolve the water infrastructure problems. The final sections cover conclusions and recommendations for further research.

Theoretical background

Managing Water Infrastructure

Management of water infrastructure requires a combination of organised managerial expertise and technical expertise. Management of infrastructure in South African (SA) cities has become problematic due to utilities' lack of skills (Zeraeburk et al., 2014; Venter, 2016), budget reductions (Meijer et al., 2020), and a lack of employee retention strategies (Phaladi, 2011). According to Venter (2016) SA experiences escalating water challenges because of a limited supply of technical skills, vandalism, and theft. Innovation is one of the gaps identified by various municipalities regarding water infrastructure. Some SA cities have been identified as examples of cities with innovative water infrastructure management (Mnguni, 2019). According to Githathu (2020) and South African National Space Agency (2020b) plans are underway to expand the data section, data visualisation centre, activation of satellite-based augmentation system over Southern Africa, new products and services, and human capital development and training. According to Mokgobu and Mason (2021), earth observation can enable satellites to locate, view and monitor the WI assets from space at any given distance and time for theft and vandalism prevention. This may see the SA space sector experience a paradigm shift with a recent boost of R4.5 billion from the government (Githathu, 2020). This technology can be an asset considering theft and vandalism experienced by many water infrastructures.

Ojogba et al. (2019) noted that as soon as satellites are launched, they become growth enablers that encourage economic development. Space technology could help to resolve the problems, experienced over many years, of challenges with water infrastructure. Observing the activities of the infrastructure requires advanced monitoring which is possible with the help of space technology. The following are phases of remote sensing and geospatial technologies, as outlined by Kurnaz and Rustamov (2008) that could benefit WI: Detection; Preparedness; Prevention; Protection and Response. Alsdorf, Rodríguez and Lettenmaier (2007) explain that many satellites are used for global observation of earth from space.

Dindar, Kaewunruen and Osman (2017) highlight the remote sensing (RS) for monitoring a railway system from space using satellites. This space technology records, observes, and identifies objects from extremely far away without having direct contact. The sun strikes the object on earth and the satellite's optical sensors detect and receive solar reflections and information gets transmitted to the receiver. Photographs are then taken by camera from space and sent to the earth using satellite dishes. Many remote sensing images (RSI) can be generated from this system. This technology is a perfect fit for monitoring the installed water infrastructure location against damaging activities such as vandalism and theft. Makapela et al. (2015) noted the two tools, RS and EO, as widely renowned tools for the provision of valuable data for the management of water resources. These tools are necessary for a water-stressed country like South Africa. Magidi and Ahmed (2019) suggest the use of high-resolution satellite, remotely sensed data for better identification of land patterns and features. According to Thakur et al. (2018) as the needs for remotely sensed data for water resources rise, they are projected to fit into the specialised RS missions of the forthcoming decades.

There are various fields of research as far as space technology is concerned (National Aeronautics and Space Administration, 2015). The use of mechanical means such as back-actors, excavators, etc. are costly and often result in broken pipes and electrical cables. A good example of the benefit of satellites is observing the plan view of a building remotely to locate a suitable position for the infrastructure (Shah, 2021). Chang (2015) proposes that space technology is, therefore, necessary to save time and locate the civil infrastructures such as buildings, railways, roads, bridges, dikes, dams, quays, and pipelines. Synthetic Aperture Radar Interferometry (InSAR) is a "precise and efficient technique to monitor deformation on Earth with millimetre precision". This technology therefore could help a municipality with monitoring aging pipe deformations, reservoir locations, etc. The use of this technology however requires an advanced degree of knowledge for its application. The next section presents the types of orbits, altitudes, functions, and the challenges of satellites.

Types of orbits, altitudes, functions, and challenges of satellites

Gleason (2021) and Reesman et al. (2021) agree that, since the space era inception over the past six decades, approximately 9800 satellites have been orbited. There are currently an estimated 3100 satellites in operation as recorded from March 2021, and approximately 6700 non-operational satellites still orbiting the Earth. Aglietti (2020) and European Space Agency (2020) estimated that by early February 2020 over 34 000 pieces of debris greater than 10 cm will exist in orbit, and a total of 900 000 particles ranging from 1 to 10 cm in diameter will also be orbiting the Earth. Further, a total population exceeding 128 million particles between 1 mm and 1 cm currently orbit the Earth. Aglietti (2020) raised a concern that the enormous speed at which the orbital debris travels may cause a detrimental effect on space assets such as satellites.

The National Aeronautics and Space Administration (n.d.) recorded the weight of the debris in the Earth’s orbit at over 8000 tons on the 1st January 2020, while the European Space Agency (2020) recorded the latest weight at 9100 tons. These objects, also known as “space junk” (Gorman, 2020), of sizes greater than 10 cm, are monitored on a routine basis by the U.S Space Surveillance Network using ground-based radars. Most debris orbits within 2000 kilometres (km) of the Earth’s surface and the largest amount of debris is in the 750 km -1000 km range (National Aeronautical and Space Administration n.d.). While satellites play a crucial role in providing information to the Earth, they also face various challenges. These challenges are the result of the 60 years of accumulation of space debris caused by various factors including collision, malfunctioning and explosion (Gorman, 2020). The predicaments associated with spacecraft colliding with each other, or with orbital debris, are most likely to happen (Drobyazko and Hilorme, 2021). This debris results from, among others, dormant satellites, rocket remains and collided or exploded particles of debris (Crisp et al., 2020; Vereen et al., 2018).

Satellites orbit the Earth at a variety of altitudes to collect information about the various phenomena on Earth. According to Space Operations (2018), the four main types of orbits that satellites are currently placed in are Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Highly Elliptical Orbit (HEO), and Geosynchronous Earth Orbit (GEO). Table 1 depicts the types of orbits, the altitudes, and the functions of each orbit.

Table 1: The different types of orbits, the altitudes, and the functions.

Orbit	Altitude	Use
Low Earth Orbit (LEO)	Up to 1609 km above the Earth’s surface	Communications. Intelligence, surveillance, and reconnaissance Human spaceflight. Weather collection.
Medium Earth Orbit (MEO)	Approximately 1609 to 35398 km above the Earth’s surface	Communications. Position, navigation and timing.
Highly Elliptical Orbit (HEO)	Long Ellipse altitudes 965.4 km at perigee (nearest to Earth), approx. 40225 km at apogee (farthest from Earth)	Communications. Intelligence, surveillance, and reconnaissance. Missile warning. Scientific.
Geosynchronous Earth Orbit (GEO)	Approximately 37007 km above the Earth’s surface	Communications. Intelligence, surveillance, and reconnaissance. Missile warning. Weather collection.

Source: Space Operations (2018)

Having obtained some understanding of the basics of WI management and space technology, the next section presents literature covering the use of space technology in Africa and South Africa.

Space technology in Africa and South Africa

South Africa was the only country to be denied satellite launch by the West German corporation - Orbital Transport und Raketen Actiengesellschaft (OTRAG) in 1981-1983 (Cohn, 1979). The African continent still lacks the resources to carry out its launches. As a result, Africa sources launch services from China, French Guiana, Kazakhstan, India, Russia, and the United States (Oyewole, 2017). The high growth of investments realised gives Africa a good playing field for expansion of space technology use. Africa’s expansion will further be realised if all states collaborate in the fields of agriculture, security, telecommunications, teaching and learning, earth observation and remote sensing. The information drawn from the satellites’ data helps authorities to draw up management plans and to influence policies. African countries have made good progress with their space programmes. There have been 41 African satellites launched, three of which have multilateral ownership (Space in Africa, 2019a). The African space industry 2019 report outlined the exponential growth of African countries from 1998 to May 2019. The African space industry collected more than US\$7 billion annual income, with a growth projection of 7.3%, expected to exceed US\$10 billion in 2024 (Space in Africa, 2019a). These positive moves outweigh the critics about Africa’s pursuit of space programmes when the basic issues of water and electricity supplies hang in the balance. Notwithstanding the continent’s struggle with limited skills and the institutions that offer space research (Okon, 2018), the major milestones are still being achieved. Oyewole (2017) has attested to the continent’s progressive involvement as an active role player in space research and development. Munsami and Offiong (2020) condemned the criticisms of the bystanders for raising questions about Africa’s affordability of the high costs involved in the space sector.

According to Munsami and Offiong (2020), the socio-economic challenges that the African continent face is a phenomenon widely spread across developing countries. This impasse could be alleviated through propagation and knowledge exchange on related technology programmes. Woldai (2020) reflected on the slow pace of African countries’ students who advance to the master’s and Doctoral programmes in space technology abroad to become professionals. The programmes will equip them with the knowledge to interpret information derived from the EO and RS datasets. Other universities have started to offer RS and GIS studies to fight the skills deficit and enhance Africa’s development. As a result, Africa will realise greater opportunities for growth in EO, RS and Geo-information sciences (Woldai, 2020). The African continent is gradually curtailing technology services consumed from other continents by committing to investment within its borders.

Egypt hosts the African Space Agency with approval granted by African heads of states during the African Union's last summit in January 2019 (Mnguni, 2019). The nineteen African countries form the African space programme with an escalating number of space technology businesses interested in offering services to the continent. Africa can solve serious problems in agriculture, security, telecommunications, and other fields with the assistance of current space technology. For example, satellites have assisted Mali herders to locate water for cattle. Further, satellite assistance in Africa's TV programmes and a satellite internet connection to rural classrooms was realised in Angola and Rwanda (Space in Africa, 2019b). Regarding the African space programmes, Table 2 outlines the country of ownership, names of satellites and the year each satellite was launched.

Table 2: African countries' satellites constructed, purchased, or rented

Satellite	Country or organisation	Year launched
ALSAT1	Algeria	2002
ALSAT2A	Algeria	2010
ALSAT1B	Algeria	2016
ALSAT2B	Algeria	2016
ALSAT1	Algeria	2016
ALCOMSAT-1	Algeria	2017
AngoSat-1	Angola	2017
GhanaSat-1	Ghana	2017
NILESAT 101	Egypt	1998
NILESAT 102	Egypt	2000
EGYPTSAT1	Egypt	2007
NILESAT201	Egypt	2010
EGYPTSAT2	Egypt	2014
EGYPTSAT-A	Egypt	2019
NARSSCube-2	Egypt	2019
NARSSCube-1	Egypt	2019
TIBA-1	Egypt	2019
ETRSS-1	Ethiopia	2019
IKUNS-PF	Kenya	2018
Maroc-TUBSAT	Morocco	2001
MOHAMMED V1-A	Morocco	2017
MOHAMMED V1-B	Morocco	2018
RascomStar-QAF-1	Multilateral	
RascomStar-QAF-1R	Multilateral	
NewDawn	Multilateral	
Nigeriasat-1	Nigeria	2003
NIGCOMSAT1	Nigeria	2007
NigeriaSat-2	Nigeria	2011
NigeriaSat-X	Nigeria	2011
NIGCOMSAT1R	Nigeria	2011
NigeriaEduSAT-1	Nigeria	2017
RwaSat-1	Rwanda	2019
SUNSAT	South Africa	1999
ZACUBE	South Africa	2003
SUMBADILA	South Africa	2009
KONDORE	South Africa	2014
nSight1	South Africa	2017
ZA-AEROSAT	South Africa	2017
ZaCube-2	South Africa	2018
XinaBox ThinSAT	South Africa	2019
SRSS-1	Sudan	2019

Source: Space in Africa (2019a)

Having looked at the background to both WI management and space technology and how they are used, the next section discusses the practical roles and applications of space technology with special reference to water infrastructure management.

Empirical review of practical applications

Practical Role of Space Technology

Space technology is currently used for various applications in SA such as earth observation, remote sensing, aviation industry, research and development, weather forecasting and many more. Various SA universities are part of the space science programme which is forming part of their curricula. South African National Space Agency (SANSA) has started recruiting students in maths and science to join their initiatives in space science.

The following practical roles could be performed by space technology in SA to manage water infrastructure: communication, health, safety, security, advanced water filtration and purification systems, detection of water levels in reservoirs, monitoring earth's natural resources such as groundwater, water leak detection, underground water pipes detection and monitoring water quality.

However, there are potential problems associated with the application of space activities. One of the major drawbacks of space technology is that the costs of operation are very high (Adebola and Adebola, 2021; South Africa, Department of Science and Technology, 2018; Oyewole, 2017). Another challenge posed by some satellites is their discontinuity in mapping some data (Malahlela et al., 2018). The advantage of space technology is that observations of larger areas can be made in a short space of time compared to humans doing it at the same time/ space. Sekhula (2013) added that another advantage of satellites is borderless devices without political limitations. Giardino et al. (2010) confirm the agility of remote sensing capability to reproduce spatial and temporal observations, whereas similar *in situ* observations of surface water quality is impossible at the same space and time dimensions.

Other challenges in the use of space technology are the teaching of outdated curricula by higher learning institutions, poor funding and insufficient resources for Earth observations, satellite communication, satellite systems, navigation and positioning, and space agencies. Furthermore, there is no sharing of datasets by space agencies due to the restrictive bureaucracy of obtaining EO data in other African states, except for SA (Woldai, 2020). Space science and technology can assist in research and development for services, as a monitoring tool, as an evaluation of serious land resources and for better decision making (South Africa, Department of Science and Technology, 2018). South Africa had been purchasing and importing space technology but has now started developing its own systems to support local industry requirements. There are three key priorities in space technology development that have been identified by the government, namely, environmental and resource management; health, safety, and security; and innovative and economic development.

A good example showing that SA has started to develop the local space industry is the Cape Peninsula University of Technology (CPUT) Satellite Programme. The programme is aligned to the National Space Strategy and receives funds from the Department of Science and Technology and the National Research Foundation (NRF) Centre (French South African Institute of Technology, 2019). According to Timeslive (2022b), a mission to launch the three nanosatellites onboard Elon Musk's Falcon 9 spaceflight on the 13th of January 2022 has been concluded. The SA higher education, science, and innovation minister Blade Nzimande announced that the three would be the beginning of the Maritime Domain Awareness Satellite (MDASat) constellation. The minister concluded that the launch site would be at Cape Canaveral in the United States and is driven by CPUT and that in future a complete constellation would be comprised of nine cube satellites. The CPUT satellite programme has been successful in graduating 60 students in the master's programme and developing, building, and launching three CubeSats (South African Institute of Technology, 2019). Timeslive (2022a) noted that the Acting Chief Engineer of the French South African Institute of Technology (FSAIT), Nyameko Royi, announced that the satellites would be monitoring any intruders on the South African Economic Zone's entire coastline. In a nutshell, the purposes of these satellites would be to "detect", "identify" and "monitor" the live movements of vessels (Timeslive, 2022b). The programme is jointly hosted by the FSAIT and the African Space Innovation Centre (French South African Institute of Technology, 2019).

Campbell (2019) advises of the launch of a non-profit making company, ZASpace Inc., in Pretoria. Its purpose is to encourage local space industry growth, particularly in geospatial technology for South Africa and Africa for skills development and innovative funding for beginners, and for small, medium, and micro-enterprises. During the launch, ZASpace Chief Executive Officer (CEO) Kamal Ramsingh announced that the world's geospatial market was valued at US\$193 billion in 2013 and had risen to US\$299 billion in 2017 and was anticipated to hit US\$500 billion by the year 2020. Campbell (2019) further supported Kamal Ramsingh's statement that the drivers for the geospatial sector worldwide are travel and hospitality, disaster management, mapping agencies, banking and financial services and insurance, defence and security, mining and energy, retail and logistics, e-government, utilities, infrastructure, and smart cities. All these drivers are listed according to size from the smallest to the largest. The sector also consists of global satellite navigation systems, geographic information systems and spatial analysis, Earth observation, and three-dimensional scanning.

Campbell (2019) further noted the US, UK, and the whole of Europe as the leading geospatial markets. However, Africa has the fastest growth, with an annual compound growth rate of 16.8% with the spatial analysis market accounting for 30% of the African market. The continental growth comparison between the years 2018 and 2020 for Africa's geospatial market is 21%, with 11% for Europe and 10% for the US. The ZASpace CEO further noted the shortage of skills in South Africa with an even greater shortage of skills in other African countries. Regarding global geospatial preparedness, South Africa is ranked in position thirty-one. Campbell (2019) highlighted the CEO of SANSA Dr Val Munsami's emphasis on the importance of the local space agency, considering the growth of the African space industry. He further stressed that one of the objectives of the National Space Policy was to improve the national space industry. The creation of SANSA from organisations that existed before was difficult because of the shortage of a business model, unpredictable business models, and fragmented business models split amongst the divisions, each with dissimilar operational needs.

To further support the strategic space priorities, three programmes have been developed to make space initiatives a success (South Africa, Department of Science and Technology, 2018). These three programmes are thematic, functional and support. Thematic programmes are earth surveillance, navigation, communication, space science and discoveries. Functional programmes entail aiding

technologies, mission improvement, space mission manoeuvre and space mission application. Support programmes include human capital advancement, infrastructure and partnering international communities.

Space technology has been used to solve social challenges in the areas of management, the environment, usage of natural assets, growing movement of individuals and products, increase in security threats and the move towards the knowledge economy. Space exploration has produced many benefits and continues to bear fruit internationally. Space exploration can solve many present and future challenges faced by South Africa. The costs associated with space activities are extremely high, but the returns associated therewith are worthwhile. Job creation, technological advancement, scientific familiarity, and space derivatives are some of the advantages associated with space technology (South Africa, Department of Science and Technology, 2018). For example, Atkinson et al. (2017) mentioned the Square Kilometre Array (SKA) project's 618 work opportunities that boosted the Northern Cape economy by R9 million rand between 2008 and 2010. Ojoyi (2016) maintains that many African countries are limited as far as space initiatives are concerned due to inadequate funding. They depend on external donations and for that reason adequate knowledge, infrastructure, tools, and education is unachievable. This technology is necessary for location, imagery, and security for infrastructure under threat of vandalism and other threats in the African continent. It is for these reasons that space technology is needed as a tool to help manage water infrastructure (South Africa, Department of Science and Technology, 2018).

The practical roles of space technology having been discussed, the next section discusses the link between WI and space technology.

Linking Water Infrastructure to Space Technology

Space technology can be applied to water infrastructure through the following activities: water quality detection in lakes (Malahlela et al., 2018); in lakes (Giardino et al., 2010); dams and pipelines location (Chang, 2015); imagery, location, and security (Ojoyi, 2016); security and management (South Africa, Department of Science and Technology, 2018). Another good example is the remote sensing of water quality assessment and chlorophyll-a (chl-a) with the application of Landsat 8 Operational Land Imager (OLI) data. The technology tested the red to near-infrared (NIR-red) bands in the Vaal Dam of SA for the categorisation of chl-a concentrations (Malahlela et al. 2018). Regarding water infrastructure specifically, there is little literature. However, detection of underground water sources is one of the advantages offered by space technology. Israeli scientists launched a freshwater leak detection and prevention technology from space. They have adopted a technology previously used on Mars and Venus for the detection of water. The technology was invented after an estimated annual worldwide freshwater loss of 32 billion cubic metres was reported by the World Bank in developing countries. Synthetic-Aperture Radar (SAR) has been adopted by universities and research institutions for the detection of water underground, as well as on other planets. The CEO of Utilis confirmed the technology's usefulness for underground treated water detection in urban settlements (Maccioni, 2019). This technology is necessary for the detection of water infrastructure, especially of pipes buried below the surface of the earth. According to Evagorou et al. (2019), space technology can achieve optical satellite images for bathymetric data to a depth of 30 metres below sea level. Azambuja (2017) notes that space technology saved community lives with the innovative filtration and purification systems developed aboard the space station. The partnership of aid organisations and NASA technology demonstrated the effectiveness of space research in response to global difficulties. This resulted in global collaborative efforts between Water Security Corporation and other organisations by organising systems with NASA water-processing technology. Froehlich, Siebrits and Lindgren (2019) noted health and water as part of the key needs of the African space sector and the special role they play in the Sustainable Development Goals 3 and 6 (SDG's). The technology could help fight waterborne diseases in most African states, which according to Akinyende and Adepoju (2010), still suffer the challenge of providing potable water supply. To turn things around the continent must intensify the required level of skills in space science and technology to manage the water resources. According to Adebola and Adebola (2021), water is one of few key commodities that has been earmarked for improvement in the policies of African space programs.

Another space technology benefit is remote image sensing of water quality from space using Hyperspectral Imager for the Coastal Ocean (HICO). HICO was invented by the U.S. Naval Research Laboratory for use in coastal ocean water quality assessment. The quality parameters for detection are water clarity, phytoplankton concentrations, light absorption, and distribution of cyanobacteria. HICO's obtained data is used by U.S. Environmental Protection Agency (EPA) researchers to develop a smartphone application for the detection of harmful concentrations of pollutants (Azambuja, 2017). The smartphone technology has provided positive results in California by detecting mercury contamination in water samples obtained from a tap, river, lake, and sea. The multi-functional use of the smartphone enables it to sense, track, and detect water contamination and provide real-time global data (Wei et al., 2014). Greenblat and Anzaldúa (2019) outline earth observation functions as a support of agricultural production, fisheries management, freshwater management, managing forests and monitoring detrimental activities.

The next section outlines how space technology can benefit communities and help resolve the challenges being faced by WI.

How Space Science Technology Can Assist in Resolving the Challenges

The use of space technology can aid managers in issues such as positioning of the infrastructure, remote sensing of underground water availability, and leak detection. This will be a valuable time-saving method for local authorities and other organisations. It has benefits for managers and policymakers in decision making. To this end, the technology has proven itself to be a good management tool in groundwater exploration, climate change and flood hazard monitoring (Woldai, 2020).

Space technology has previously been used locally and internationally to address the challenges of water infrastructure and management. According to the National Aeronautics and Space Administration (2019), the countries and communities that have enjoyed the benefits of space activities include sub-Saharan Africa and the Kurdish village of Kendala in Iraq. Iceland, Luo and Donchyts (2018) noted Morocco, India, Spain, and many other countries as also having benefitted from the use of space technology. In addition, National Aeronautics and Space Administration (2019) notes that an advanced water filtration and purification system developed for the International Space Station (ISS) is being used in sub-Saharan Africa for managing water resources. Also, a non-profit organization, Concern for Kids (CFK), sourced funds from NASA to help Iraq, Malaysia and Indonesia with aid and disaster relief programmes. The community of the Kurdish village of Kendala in Iraq drank dirty, fabric-sifted water together with their livestock. They were aided by NASA-developed technology that provides clean water, so that now they enjoy clean drinking water.

Iceland, Luo and Donchyts (2018) show a satellite image that, using space technology, detected a 60% drop in water level in 2016 of Al Massira dam, the second largest in Morocco. Various drops in dam levels in many parts of the world, such as Indira Sagar Dam in India, Mosul Dam in Iraq, and Buendia Dam in Spain, have been identified with the help of space technology (Iceland, Luo and Donchyts, 2018). This technology can be applied in SA cities for monitoring water levels in reservoirs without having to physically travel to the reservoirs for inspections. Similarly, the assistance offered by NASA engineers to the Kurdish village of Kendala (National Aeronautics and Space Administration, 2019), could be sourced for SA cities, organisations, and communities. This is an opportunity for the SA cities that experience the challenges of overworked water purification plants, and wastewater treatment plants due to high sewage volumes. The technology could help overcome the health risks faced by communities due to malfunctioning water purification systems.

Having discussed how the literature suggests space technology can contribute to WI management, and how this is being applied practically in other countries, the next section concludes the literature review by relating the findings to the study's aim and sub-objectives and making some recommendations for the use of space technology by the water infrastructure industry in South Africa, and, if fact, across Africa.

Conclusion

Concerning space technology, South Africa must dedicate this era of the 4IR to embrace this technology. Any barriers to the execution of this global transformation require a concerted effort to overcome the resistance. New African space initiatives must be undertaken in collaboration with the international community. African states must avail themselves of space technology to become future space champions. African countries must cooperate to make sure that resources to educate people in space sciences are directed to the youth and other relevant sectors of their populations. This would involve the introduction of space technology curricula in high schools and all institutions of higher learning, and the encouraging of researchers to follow a career in space technology with funding for inspiration.

Space technology must be used to benefit South Africa and their local authorities for the management of water infrastructure and water resources. South Africa should collaborate with other countries which are already ahead with space affairs to help train learners in various space technologies and activities, including, for example, to further the application of techniques used in the ISS for terrestrial water filtration and purification. The South African government must try to contain cost escalations for space technology to accommodate new entrants and people must be up skilled to operate this highly advanced technology.

This paper's objectives have been met by exposing some issues which are hindering the African continent from optimal participation in space affairs. The paper has identified African countries which are making slow progress in participation in space affairs. The exploitation of space technology in the management of water infrastructure also suggests other avenues for further research. This paper has provided a review of the literature on space activities which other researchers and authors can apply for their studies. Managers and water specialists may also apply this literature for better application of managerial functions and to influence policy decisions. Learners in schools and institutions of higher learning can also use this to increase their knowledge about space technology and its applications, especially in the field of water infrastructure management. The next section presents the recommendations for future research.

Empirical exploratory research and empirical explanatory research, both qualitative and quantitative, needs to be undertaken to:

- i. *Identify how big the potential industry of space-based water monitoring might be in Africa and South Africa,*
- ii. *Break the barriers preventing cooperation and business between African countries in space technology,*
- iii. *Explore in greater depth, the benefits of space science technology to water infrastructure,*
- iv. *Identify the possibilities of Africa's collaboration with developed countries in the space industry,*
- v. *Identify Africa's challenges for increased participation in space science technology.*

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