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Trends in use of remotely sensed data in wetlands assessment and monitoring in Zimbabwe

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Abstract

The paper assesses trends in use of earth observation data in wetland conditions monitoring and assessment in Zimbabwe from 1980 to 2019. Reviewed literature shows academia and research institutions (69.8%), government agencies (14%) and international development partners (16.3%) as the main users of remotely sensed data in wetland ecological assessments and monitoring. There is more reliance by the abovementioned stakeholders on freely available low-cost resolution imagery from Landsat (62.9%) and Moderate Resolution Imaging Spectroradiometer (14.3%). Other stakeholders, however, are reliant on high-resolution imagery like Rapid Eye (5.7%) and aerial photography (11.4%). Satellite images in wetland management in Zimbabwe are used for land use land cover change detection (42.1%), vegetation health monitoring (21.1%), water quantity monitoring (5.3%), water quality monitoring (13.2%) and wetland mapping (18.4%). The identified challenges faced by different stakeholders to effectively utilise EO data include high cost of high-resolution imageries, limited expertise, inadequate equipment and software. Since the cost of high-resolution satellite imagery mainly constraints the acquisition of suitable satellite data to assess the small wetlands that dominate Zimbabwe's landscape, there is need to promote use of recently launched freely available high-resolution Sentinel data to improve the ecological assessment of wetland conditions.

Résumé

Cette étude analyse les tendances d'utilisation des données d'observation de la Terre dans la surveillance et l'évaluation de l'état des terres humides au Zimbabwe de 1980 à 2019. La littérature passée en revue montre que les universités et les instituts de recherche (69,8%), les organismes gouvernementaux (14%) et les partenaires internationaux de développement (16,3%) sont les principaux utilisateurs des données obtenues par télédétection dans le cadre de l'évaluation et de la surveillance écologique des terres humides. Les intervenants mentionnés ci-dessus s'appuient davantage sur les images de basse résolution disponibles gratuitement de Landsat (62,9%) et du spectroradiomètre imageur à moyenne résolution (14,3%). Cependant, d'autres intervenants s'appuient davantage sur des images de haute résolution comme Rapid Eye (5,7%) et la photographie aérienne (11,4%). Dans le cadre de la gestion des terres humides au Zimbabwe, les images satellites sont utilisées pour la détection des changements dans l'utilisation des terres et la couverture terrestre (42,1%), la surveillance de l'état de la végétation (21,1%), la surveillance de la quantité d'eau (5,3%), la surveillance de la qualité de l'eau (13,2%) et la cartographie des terres humides (18,4%). Les défis identifiés auxquels sont confrontés les différents intervenants pour utiliser efficacement les données d'OT sont notamment le coût élevé des images de haute résolution, des compétences limitées, ainsi que des équipements et logiciels inadéquats. Étant donné que le coût des images de haute résolution constitue le principal obstacle à l'acquisition de données satellitaires adéquates pour évaluer les petites terres humides qui dominent le paysage du Zimbabwe, il est nécessaire de promouvoir l'utilisation des données Sentinel de haute résolution récemment mises à disposition gratuitement pour améliorer l'évaluation écologique de l'état des terres humides.

KEYWORDS
earth observation data, satellite data, stakeholders, wetland assessment and monitoring, Zimbabwe

1 | INTRODUCTION

Since the turn of the 20th century, the world has lost more than 50% of its original wetlands due to human activities (Mitsch et al., 2015; Mitsch & Gosselink, 1993). Africa, Asia, North America and South America record about 80% wetland loss (Davidson, 2014). These rates are, however, debatable as some scholars think that they might be higher due to lack of a global inventory for wetlands (Davidson, 2014; Hu et al., 2017). The remaining wetlands face increasing pressure from both indirect and direct human activities such as farming on wetland sites, release of untreated effluent discharge into wetlands and overpumping of water from wetlands (Hu et al., 2017; Ramsar Convention on Wetlands, 2018; Wójcicki & Woskowicz-Ślęzak, 2018). Urgent action to prevent further loss and degradation of wetlands is therefore required by all nations (Myers et al., 2013).

Wetlands are important ecosystems that support the interaction of humans, animals and plants through the provision of ecosystem services (Mitsch et al., 2015; Turpie et al., 2010; Wood, 2001). These services include provisioning (freshwater, food, herbs, fibre, fuel, thatch grass, genetic resources), regulating (flood and erosion control, water purification, climate regulation, air quality maintenance, pest and disease control, pollination), supporting (water and nutrient cycling, habitats, soil formation and retention, primary productivity) and cultural (ecotourism, recreation, religious and spiritual values, education, aesthetic values; Chen et al., 2012; Mitsch et al., 2015; Ogawa & Male, 1986; Woodward & Wui, 2001; Xu et al., 2020). Despite their numerous benefits, wetlands remain fragile ecosystems that require sensitive and sustainable management (Darradi et al., 2006; Davidson, 2014; Gadzirayi et al., 2006).

Globally, wetland conditions are assessed and monitored using the guidelines from the Ramsar convention (Finlayson et al., 2011; Ramsar Convention on Wetlands, 2018). The Ramsar convention offers a framework for managing wetlands globally through its wise use concept which encourages parties to adopt national wetland policies (Mitra et al., 2005; Ramsar Convention on Wetlands, 2018; Xu et al., 2019). Since the inception of the Ramsar convention, wetland management approaches have been changing to incorporate current environmental regulations and wishes of stakeholders involved (Mitra et al., 2005). This has seen wetland management incorporating the use of remote sensing.

The Ramsar convention also extends its potential to Africa and is responsible for the wise use of Ramsar sites in Africa (Denny, 1993). Countries that are parties to the convention have adopted wetland management approaches taken from the Ramsar convention to achieve wise use of wetlands. Wetland management approaches such as Indigenous Knowledge Systems (IKS), remote sensing, environmental laws and policies are applied in Africa to manage the wetlands. Among the wetland management approaches employed in Africa, the use of Earth Observation (EO) data is the least employed yet it is the most effective in wetland assessment and monitoring (Ozesmi & Bauer, 2002; Thamaga & Dube, 2018). Factors hindering the adoption of EO data in wetland management in Africa include but are not limited to the following: costs of analysing remote sensed data which involve hardware, software, qualified specialists and training especially when dealing with large data sets (Klerk & Buchanan, 2017).

Wetland management has therefore called for the involvement of various stakeholders. Stakeholders are individuals, organisations or institutions that support or oppose a research project or are potentially affected by the management of wetlands (Darradi et al., 2006; Devarani & Basu, 2009; Lucrezi et al., 2019). Generally, the wetland stakeholders include development partners, river basin organisations, sub-basin organisations, local and international NGOs, community-based organisations, the private sector, academic and research institutions (MacDonald, 2007; Merrey, 2008). In a Zimbabwean context, Mbereko et al. (2007) report that there are about 12 institutions working with the communities in managing

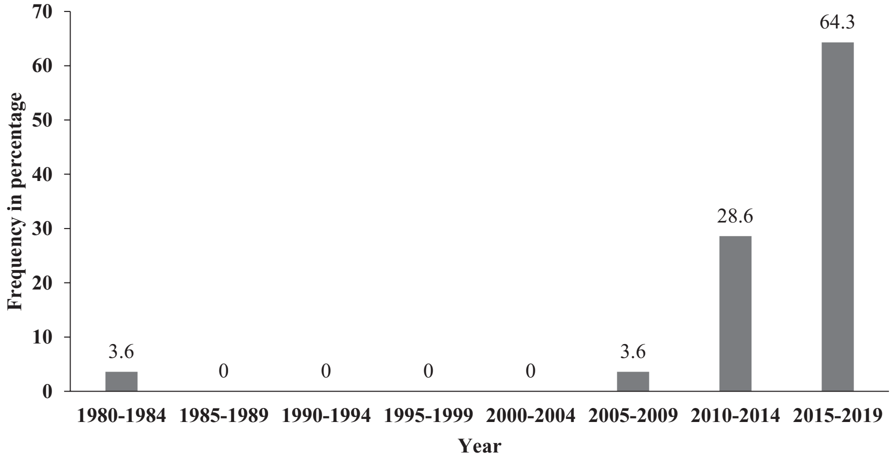

FIGURE 1 Number of wetland publications that used remote sensing in Zimbabwe between 1980 and 2019

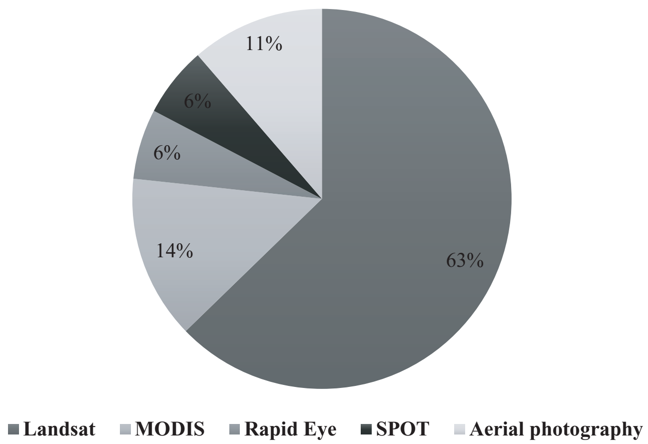

FIGURE 2 Types of satellite data used in wetland monitoring and assessment in Zimbabwe

wetlands, whose knowledge of EO application may be important in wetlands protection. These stakeholders can be grouped into the following categories: government institutions, traditional organisations, NGOs and local leadership.

Owing to the capabilities of EO data to cover a larger area in wetland assessment and monitoring, there is need to assess how different stakeholders have been embracing it to abate wetland degradation and loss. This study therefore aims to assess trends in use of satellite data in the assessment and monitoring of wetlands' ecological conditions in Zimbabwe between 1980 and 2019. The study also analyses the roles of stakeholders involved in wetland assessment and monitoring and their contributions to sustainable wetland management. It is also within the scope of this study to assess the level of use of EO data by various stakeholders and identify factors hindering effective use of EO data in wetland assessment and monitoring in Zimbabwe. The study further analyses the types of EO data used in Zimbabwe and the reasons stakeholders select them. The findings of the study will ultimately explain the extent of use of EO data in Zimbabwe. The specific objectives are as follows: establishing the stakeholders involved in wetland assessment, the nature of remote sensed data used and the components of wetlands assessed.

2 | LITERATURE SEARCH

Data were obtained from online publications that were reviewed between 1980 and 2019 (Figure 1). Journal articles published by ELSEVIER, Taylor and Francis, and Springer were reviewed. Keywords used to search for relevant literature include satellite data, wetland assessment and monitoring, stakeholders and Zimbabwe. Authors' affiliations were used to identify stakeholders' categories and institutions utilising EO data in wetland assessment and monitoring. The authors gleaned from journal articles information under the methods sections to derive the type of satellite images used and the components of the wetlands that were assessed. Technical and scientific reports from the Natural Resources Board (1980–2006) and the Environmental Management Agency (2007–2019) were assessed on methodologies used to monitor wetlands. The journal articles and statutory agencies' reports were searched using the Midlands State University online library portal.

3 | RESULTS AND DISCUSSION

3.1 | Nature of remote sensed data used in wetland assessment and monitoring by different stakeholders

Knowledge on wetland conditions in Zimbabwe as described by Marambanyika et al. (2016) is built on a partial view of reality and has hindered effective wetland management. Although EO data in wetland assessment and monitoring prove to be an effective tool, access to remote sensed data in Zimbabwe is limited. Literature shows that there is limited use of EO data in wetland management in Zimbabwe. Choice of EO data used is largely dependent on costs of EO data although there is a wide range of satellite images available ranging from low resolution to high resolution. Types of satellite images used in wetland assessment and monitoring in Zimbabwe are mainly Landsat (Chikodzi & Mapfaka, 2018; Dube et al., 2017; Masocha, Dube, Makore, et al., 2018; Masocha, Dube, Nhiwatiwa, et al., 2018), Medium Resolution Imaging Spectroradiometer (MODIS; Shoko et al., 2015), Satellite Pourl'Observation de la Terre (SPOT; Chikodzi

& Mufori, 2018; Mhlanga et al., 2014), RapidEye (Marambanyika & Beckedahl, 2016b; Marambanyika et al., 2016) and aerial photography (Marambanyika & Beckedahl, 2016b; Marambanyika et al., 2016; Mutisi, 2014; Sibanda, 2018). Landsat images constitute 62.9% of satellite images used, MODIS (14.3%), RapidEye (5.7%), SPOT (5.7%) and aerial photography (11.4%) of images used in wetland assessment and monitoring in Zimbabwe (Figure 2). Therefore, Landsat has widespread application than MODIS in Zimbabwe, although the two are available online for free.

RapidEye and SPOT images are high-resolution images and are not available for free hence their limited application in wetland assessment and monitoring in Zimbabwe. Although EO data is used in wetland assessment and monitoring in Zimbabwe, literature evidence shows that it is being limited by the use of low-resolution images and costs that come with high-resolution images. Low-resolution images are available for free but they have misclassification challenges (Thamaga & Dube, 2018) that may make it hard to identify key wetland features, hindering their effectiveness in wetland assessment and monitoring.

Just like in Zimbabwe, the use of remotely sensed data in wetland ecological assessment and monitoring has been improving in the Southern African Development Community (SADC) countries such as Angola, Botswana, Democratic Republic of Congo, Namibia, South Africa, Tanzania, Zambia (Mayer & Lopez, 2011). A range of satellite imageries from low resolution to high resolution are utilised. These satellite imageries include but are not limited to the following: National Oceanic and Atmospheric Administration (NOAA; Milzow et al., 2006; Ringrose et al., 2003), Advanced Microwave Scanning Radiometer (AMSR; Hiyama et al., 2014), Satellite Pour l'Observation de la Terre (SPOT; Talukdar, 2004), Environmental satellite (ENVISAT; De Roeck et al., 2008; Milzow et al., 2006), aerial photography (Ringrose et al., 2003), Landsat (Awadallah & Tabet, 2015; Bwangoy et al., 2010; Grundling et al., 2013; Hansen et al., 2008; Kashaigili & Majaliwa, 2010; Msofe et al., 2019; Munyati, 2000; Pullanikkatil et al., 2016; Schneibel et al., 2017), Sentinel (Leemhuis et al., 2017; Naidoo et al., 2019), MODIS (Hansen et al., 2008; Hiyama et al., 2014; Hu et al., 2013) and Worldview (Mutanga et al., 2012; Naidoo et al., 2019).

As also observed in Zimbabwe, there is generally high dependence on low-resolution imageries across the SADC region. It was noted that Landsat is utilised in almost half (46.7%) of the EO applications (Klerk & Buchanan, 2017). Reliance on high-resolution imageries such as World view, SPOT, ENVISAT, NOAA, Sentinel and AMSR is low as shown by a frequency of 11%. Generally, studies utilising high-resolution imageries focus on their effectiveness in detecting wetland parameters that are critical for ecological assessments. For

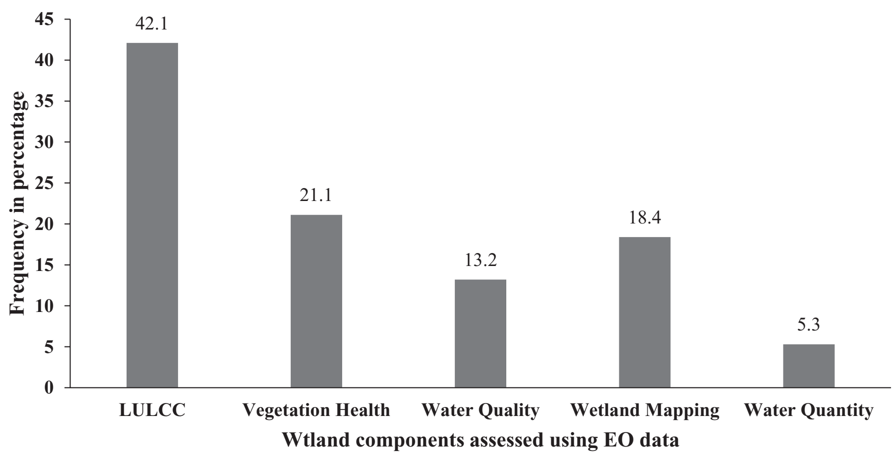

FIGURE 3 Wetland components assessed using EO data in Zimbabwe

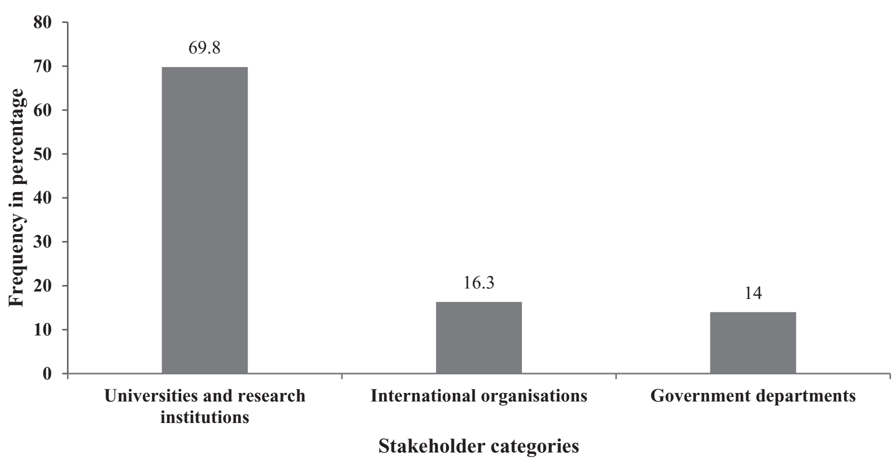

FIGURE 4 Stakeholder categories involved in wetland assessment and monitoring using EO data in Zimbabwe

instance, Mutanga et al. (2012) explored in South Africa the possibility of estimating biomass in a densely vegetated wetland area using normalised difference vegetation index (NDVI) computed from WorldView-2 imagery, which contains a red edge band centred at 725 m. Although the results demonstrated the utility of WorldView-2 imagery and random forest regression in estimating and ultimately mapping vegetation biomass at high density, reliance on low-resolution sensors in Zimbabwe and other SADC countries continues mainly influenced by the costs associated with the purchasing of relevant high-resolution images (Meier & Kinzelbach, 2010).

3.2 | Wetlands components assessed using remote sensed data

EO data have proven to have various uses in wetland assessment and monitoring in Zimbabwe (Figure 3). These uses include land use land cover change (LULCC) analysis (Fakarayi et al., 2015; Gumindoga et al., 2014; Kibena et al., 2013; Marambanyika & Beckedahl, 2016a; Ndhlovu, 2012; Tendaupenyu et al., 2017), vegetation health monitoring (Chapungu & Nhamo, 2016; Masocha et al., 2017; Mpakairi, 2019; Shekede et al., 2008; Tendaupenyu et al., 2017), water quality monitoring (Dlamini et al., 2016; Masocha, Dube, Makore, et al., 2018; Masocha, Dube, Nhiwatiwa, et al., 2018; Masocha, et al., 2017), wetland mapping (Chikodzi & Mapfaka, 2018; Lupankwa et al., 2000; Masocha, Dube, Makore, et al., 2018; Masocha, Dube, Nhiwatiwa, et al., 2018) and water quantity monitoring (Mpakairi, 2019).

Literature shows that EO data are being utilised more in LULCC analysis and it shows 42.1% usage by stakeholders (Figure 4). For instance, Fakarayi et al. (2015) used Landsat TM, to quantify land use and land cover changes in Driefontein wetland, Zimbabwe, between 1995 and 2010. The objective of the study was to assess if land tenure changes as a result of the Fast Track Resettlement Programme, that commenced in March 2000, had affected land cover and uses in the Driefontein wetland. After co-registering Landsat images, Fakarayi et al. (2015) classified satellite images using unsupervised K-means, Supervised Angle Mapper and visual interpretation and came up with five classes of land cover. All the classes that were identified show changes from 1995 to 2010. Grassland decreased by 71.2%, wetland area decreased by 55.3% while cultivated area increased by 97.9%. Woodland cover expanded by 5% while area covered by water shows 85% increase. However, the availability of satellite images was affected by cloud cover and that influenced the use of images captured on cloud-free days.

Vegetation health assessment constitutes 21.1% of the uses of EO data in wetland management in Zimbabwe. For example, Chapungu and Nhamo (2016) used Landsat 8 Thematic Mapper imagery with 30 m spatial resolution to assess the impact of climate change on plant species richness in the Mutirikwi sub-catchment, Zimbabwe. Images for the years 1987, 1998, 2006 and 2014 were used to track changes in the abundance of plant species over the years. To select study units, a GIS-based nested nonaligned block sampling design was used. After the identification of study units, the number of plant species was calculated using the Point Centre Quarter Method. Images were analysed using the Integrated Land and Water System (ILWIS) to come up with Normalised Difference Water Index (NDWI) values. The results then indicated an association between climate change and species richness. NDWI values indicated the loss of wood and grass species and the invasion of desert shrubs. Although NDWI was successful in showing the effect of climate change on species richness, Chapungu and Nhamo (2016) indicated that it is not as effective as other climate indices such as the Climate Extremes Index (CEI) and the Greenhouse Climate Response Index (GCRI).

Stakeholders using satellite data in water quality monitoring in Zimbabwe constitute 13.2%. Dlamini et al. (2016) used the cheap and readily available broadband multi-spectral MODIS data and in situ measurements in quantifying and monitoring water quality in

TABLE 1 Software used in processing of satellite images to extract wetland information

Software	Examples of references	Cost of software acquisition
ArcGIS	Mhlanga (2014), Shoko et al. (2015), Mandishona (2017), Masocha et al. (2017), Chikodzi and Mufori (2018), Mpakairi (2019)	Commercial
ENVI	Ndhlovu (2012), Marambanyika and Beckedahl (2016), Masocha, Dube, Makore, et al. (2018), Masocha, Dube, Nhiwatiwa, et al. (2018), Sibanda (2018)	Commercial
ILWIS	Ndhlovu (2012), Kibena et al. (2013), Gumindoga et al. (2014), Mhlanga (2014), Shoko et al. (2015), Chapungu and Nhamo (2016), Dlamini et al. (2016), Marambanyika et al. (2016), Tendaupenyu et al. (2017), Chikodzi and Mapfaka (2018), Sibanda (2018)	Free
LOWTRAN 7	Lupankwa et al. (2000)	Free
QGIS	Masocha, Dube, Makore, et al. (2018), Masocha, Dube, Nhiwatiwa, et al. (2018)	Free

Lake Chivero, Zimbabwe. MODIS images were used to quantify inland lake chlorophyll-*a* concentrations as a proxy for predicting lake pollution levels. Satellite images were then used to identify the predominant and temporal patterns in chlorophyll-*a* variability. ILWIS was used to calibrate MODIS images to come up with NDVI values. Landsat images were also used in the study to analyse the historic land cover changes that might have had an impact on pollution. Land cover types were identified and classified using the supervised classification maximum likelihood algorithm classifier. Field measurements were also used in the study to select sample sites which were chosen based on sources of pollution. Field measurements included collecting samples of water and extracting chlorophyll-*a*. Combining both in situ and remote sensing data, findings of this study showed high concentrations of chlorophyll-*a* in the lake compared to its surroundings. This means that the water quality in Lake Chivero is compromised by the presence of chlorophyll-*a*.

About 18% of Zimbabwean stakeholders involved in wetland management use EO data in wetland mapping. A study conducted by Chikodzi and Mapfaka (2018) in Masvingo district, Zimbabwe sought to analyse spatial and temporal variations of wetlands using Landsat images. The satellite images were used to calculate Modified Normalised Difference Water Index (MNDWI) which is useful in extracting and delineating waterlogged areas. From the MNDWI values extracted, wetlands distribution and behaviour were mapped over a period of 30 years. Climatic data (rainfall and temperature variations) were also used in the study to detect the effect of climate change on wetland variations. This was a successful study because it managed to map wetland variations over a period of 30 years. Although there were no significant changes in the sizes of the wetlands between 1984 and 2014, variations occurring between those years were noted and mapped. The study noted that the application of finer resolution images can improve the mapping of wetlands, including small ones.

Water quantity monitoring constitutes 5.3% of uses of EO data in wetland assessment and monitoring in Zimbabwe. Masocha, Dube, Makore, et al. (2018), Masocha, Dube, Nhiwatiwa, et al. (2018) conducted a study in Runde catchment, Zimbabwe to identify and quantify surface water bodies. They used Landsat 8 OLI (Operational Land Imager) images to extract spectral indices that delineate land surface water. These indices include the NDVI, MNDWI, Water Ratio Index (WRI), Automated Water Extraction Index (AWEI) and Land Surface Water Index (LSWI). A total of 23 Landsat 8 OLI images were selected, and from them, a total of 121 reference water bodies were digitised using a high spatial resolution Google Earth imagery. Of all the indices used, LSWI was the most effective in detecting and delineating surface water bodies as it can detect and delineate small surface water bodies at both small and large scale. This study was successful because it managed to map surface water bodies and their distribution even at country level using the LSWI. Results of this study highlighted that much of the surface water bodies are concentrated in the central and northern parts of Zimbabwe. The south-western and the south-eastern parts of the country have less surface water bodies.

Just like in Zimbabwe, most (44.4%) of the EO applications in the SADC region are on LULCC compared to other wetland parameters such as water quantity monitoring (3.7%) and flood regimes monitoring (7.4%). Examples of wetland components assessed using EO data in the SADC region include but are not limited to the following: wetland mapping (De Roeck et al., 2008; Bwangoy et al., 2010; Grundling et al., 2013; Landmann et al., 2013; Pullanikkatil et al., 2016), land use land cover change analysis (LULCC; De Roeck et al., 2008; Grundling et al., 2013; Kashaigili & Majaliwa, 2010; Landmann et al., 2013; Leemhuis et al., 2017; Msofe et al., 2019; Munyati, 2000; Pullanikkatil et al., 2016; Schneibel et al., 2017), vegetation monitoring (Hansen et al., 2008; Mutanga et al., 2012; Naidoo et al., 2019), water quantity monitoring (Grundling et al., 2013; Hiyama et al., 2014), flood regimes monitoring (Meier & Kinzelbach, 2010; Talukdar, 2004) and identification of wetland features (Ringrose et al., 2003; Talukdar, 2004).

As shown in Table 1, about 57% of the wetland studies used free software to analyse remotely sensed data and of these 83% used ILWIS. The remaining 43% used commercial software such as ArcGIS, Environment for Visualizing Images (ENVI) and LOWTRAN 7. Therefore, the results show that wetland studies using remotely sensed data in Zimbabwe mainly rely on free software, ILWIS in particular. To improve the EO-based analyses of wetland ecological studies, there is a need to explore utilisation of a wide range of other free software that have been applied in other countries such as Geographic Resources Analysis Support System (GRASS) GIS (Neteler et al., 2012), Google Earth Engine (Hardy et al., 2020), System for Automated Geoscientific Analyses (SAGA) GIS (LaRocque et al., 2020) and Water Observation and Information System (WOIS; Guzinski, Kass, Huber, Bauer-Gottwein, Jensen & Naeimi, 2014; Guzinski, Kass, Huber, Bauer-Gottwein, Jensen, Naeimi, Doubkova, et al., 2014; Makapela et al., 2015).

3.3 | Categories of stakeholders involved in wetland assessment and monitoring using remote sensed data

Zimbabwe embraces a multi-institutional approach as far as wetland management is concerned (Marambanyika & Beckedahl, 2016a). Involvement of different stakeholders in natural resources management in Zimbabwe is included under Section 8(1) of the EMA Act (20:27) which advocates for the promotion of cooperation among public departments, local authorities, private sector, NGOs and other organisations (Government of Zimbabwe, 2002). The Government of Zimbabwe is therefore actively involved in wetland assessment and monitoring through its various departments. Government departments involved in wetland management include the Environmental Management Agency (EMA), Zimbabwe National Water Authority (ZINWA), Zimbabwe Republic Police (ZRP), Rural District Councils (RDCs), Urban Councils and Agricultural Technical and Extension Services (AGRITEX; Gadzirayi et al., 2006; Love et al., 2006; Marambanyika et al., 2012). The Government of Zimbabwe has been effectively involved in wetland management through laws and regulations. The repealed Natural Resources Act (20:13) provided for the conservation of a wide range of resources including wetlands from 1980 to 2006 (Nickerson, 1994; Scoones & Cousins, 1994) when the EMA Act (20:27) took over. Currently, the Government of Zimbabwe provides for the management of wetland conditions under Section 113 of the EMA Act (Government of Zimbabwe, 2002).

Researchers from institutions of higher learning such as universities and research institutes form another important group of stakeholders involved in wetland assessment and monitoring in Zimbabwe. Researchers and institutions of higher learning carry out projects that promote wetland health. Studies done in Zimbabwe to show the effectiveness of satellite data in detecting invasive species in wetlands (Dube et al., 2017), monitoring plant species in wetlands (Mandishona, 2017) and mapping wetlands (Masocha et al., 2017) were carried out by academic researchers supported by different local universities and NGOs. These institutions include, for example, Lupane State University (Ndlovu & Manjeru, 2014), Midlands State University (Marambanyika & Beckedahl, 2016b), University of Zimbabwe (Masocha et al., 2017), among other local universities. In addition to funding research work done by local universities in Zimbabwe, NGOs are responsible for supporting wetland cultivation under food security and poverty eradication programmes (Marambanyika et al., 2016).

Other relevant stakeholders in wetland assessment and monitoring in Zimbabwe are the local communities surrounding wetlands. Sixty per cent of the country's wetlands are communal wetlands (Gadzirayi et al., 2006; Matiza & Crafter, 1994) rendering them under the jurisdiction of communities. Communities surrounding wetlands in Zimbabwe believe that they have spiritual connections with wetlands in their jurisdiction and ancestors of the land (Gadzirayi et al., 2006). Hence, their management strategies are passed on from generation to generation and they are believed to be inspired by ancestral spirits of the area. The Government of Zimbabwe works closely with communities and intervenes in wetland management through EMA. Among the various mechanisms used by locals to manage wetlands is IKS (Ndlovu & Manjeru, 2014). IKS creates a basis for local-level decision-making in natural resources management.

From reviewed literature, almost 70% of stakeholders utilising EO data in wetland assessment and monitoring in Zimbabwe are the academia and research institutions (Figure 4). Literature shows that they usually work closely with international development agencies and various government departments. In SADC region, the main groups utilising remotely sensed data in wetland research are universities (Awadallah & Tab et, 2015; De Roeck et al., 2008; Milzow et al., 2006; Nhamo et al., 2017), international organisations (Landmann et al., 2013; Leemhuis et al., 2017; Milzow et al., 2006; Meier & Kinzelbach, 2010; Nhamo et al., 2017) and research institutions (Bwangoy et al., 2010; Landmann et al., 2013; Leemhuis et al., 2017; Naidoo et al., 2019; Pullanikkatil et al., 2016). Just like in Zimbabwe, academia and research institutions in the African region constitute 75.8% of EO data users in wetlands whereas international organisations represent the remaining 24.1% (Klerk & Buchanan, 2017).

Universities perform research work to prove the effectiveness of EO data in wetland assessment and monitoring (Dube et al., 2017; Masocha et al., 2019). International organisations such as the World Bank (Masocha et al., 2017; Murwira et al., 2014), International Water Management Institute (Gumindoga et al., 2014), Birdlife (Fakarayi et al., 2015) and Waternet (Ndhlovu, 2012) have been shown to work closely with stakeholders in monitoring wetland conditions using satellite data. These work together with universities and researchers providing funds for research work. International organisations constitute about 16% of the stakeholders involved in wetland assessment and monitoring in Zimbabwe. The Zimbabwean Government though actively involved in wetland management, literature shows that it has limited knowledge of satellite data in wetland assessment and monitoring. Only the EMA, a government agency, applied Landsat to map the wetlands of the Harare province, Zimbabwe. Of all stakeholders utilising EO data in wetland assessment and monitoring, the Zimbabwean Government through its various departments lags behind with about 14%. It can therefore be concluded that the little knowledge of EO data available in Zimbabwe is highly utilised by researchers from different local universities together with international NGOs.

3.4 | Challenges encountered in the use of Earth Observation data in wetland assessment and monitoring in Zimbabwe

The effective use of EO data in wetland assessment and monitoring in Zimbabwe is highly undermined by lack of knowledge and the use of low-resolution sensors in monitoring wetlands' ecological conditions. The main reason behind the adoption of low-resolution images is that most of them are available for free while high-resolution images come at a price (Kamusoko et al., 2013). Although low-resolution images are available for free, they are coarse hence cannot be used to assess and monitor small wetlands that constitute the majority of wetlands in Zimbabwe. Identification of wetland features is usually difficult as some parameters are not be well detected using low-resolution images. This causes misclassification of features, for example, a burnt area can be mistaken for pools of water. Studies that have used low-resolution images in wetland management in Zimbabwe include (Dube et al., 2017; Gumindoga et al., 2014; Masocha et al., 2017) and these have focused on the hydrological impacts of urbanisation on catchments, detecting and mapping the spatial extent of the water hyacinth as well as mapping of wetlands.

The high cost of high-resolution satellite imagery also affects the availability of data at appropriate scales, and this has led to the shortage or absence of reliable EO data for use in wetland monitoring. Zimbabwe is a poor country (Kamusoko et al., 2013) highly challenged by high inflation rates and generally low living standards (Munangagwa, 2009). Therefore, costs related to satellite images are too high for many individuals and institutions wishing to undertake wetland research. Costs related to satellite images processing are not only purchasing costs but they also involve hardware, software, qualified specialists and training especially when dealing with large data sets (Masocha et al., 2017). The implication of costs on choice and effective utilisation of EO data in wetlands assessments are also widely documented in the SADC region (Klerk & Buchanan, 2017; Di Martino et al., 2007; Hiyama et al., 2014; Meier & Kinzelbach, 2010; Thamaga & Dube, 2018).

The use of satellite data in wetland assessment and monitoring is further affected by EO applications knowledge deficiency in the country. Four (4) studies carried out in Zimbabwe revealed that knowledge deficiency seriously affects the application of satellite data in wetland assessment and monitoring (Dlamini et al., 2016; Mandishona, 2017; Shekede et al., 2008; Shoko et al., 2015). This may explain why evidence from literature has also shown that from 1980 to 2007 the use of EO data in wetland assessment and monitoring was very limited (Figure 1). The use of EO data in wetland assessment and monitoring gained popularity from 2008 and continues to increase its capabilities in the country. This is because the country is advancing its technological capacities and has sought to manage natural resources including wetlands using EO data. This is seen through the introduction of Zimbabwe National GeoSpatial Agency (ZINGSA) in 2018. Moreover, eight universities and one research institution are now offering training in GIS and remote sensing in Zimbabwe. This is in sharp contrast with the situation at the turn of the 21st Century when only one university had introduced GIS and remote sensing in its curriculum.

Limited expertise was also noted as a problem in Africa where out of 72 university programmes offered in 360 universities, only 17 programmes integrated remote sensing and GIS teaching (Klerk & Buchanan, 2017). Therefore, Guzinski, Kass, Huber, Bauer-Gottwein, Jensen and Naeimi (2014), Guzinski, Kass, Huber, Bauer-Gottwein, Jensen, Naeimi, Doubkova, et al. (2014) noted lack of technical capacity as a challenge undermining the effective implementation of EO data in natural resources conservation, including wetlands in Africa. Despite the improvements in EO training, there is lack of gender-disaggregated data on EO capacity development in both Zimbabwe and the SADC region.

4 | CONCLUSIONS AND RECOMMENDATIONS

This study sought to analyse trends in use of remote sensed data in wetland assessment and monitoring in Zimbabwe from 1980 to 2019. Use of satellite data is still low although improvement can be noticed from 2010 to date. This indicates that wetland assessment and monitoring, between 1980 and 2009, has been largely dependent on in situ field monitoring systems that are labour intensive and expensive, limited in extend of spatial coverage. This explains much reliance on freely available low-resolution imagery such as Landsat and MODIS compared to purchased high-resolution SPOT and RapidEye imagery. There is limited use of satellite data by government agencies. Development agencies usually support the government departments, academia and research institutions to implement EO-based wetland research. The current satellite applications in wetlands are in LULCC detection, water quality monitoring, vegetation health monitoring and inventory. There is a need for satellite-based wetland research to monitor moisture regimes, fire incidences, invasive species monitoring and biodiversity change among other many applications.

The authors therefore recommend that the Government of Zimbabwe fully supports institutional training on EO data use in wetlands ecological assessments and monitoring as it is central to decision-making that may influence change of processes and structures. The local communities can also be considered in EO-based capacity building initiatives to enhance local scale appreciation and application of EO derived services. It is also recommended that researchers fully utilise their capabilities and reveal the effectiveness of EO data in wetland assessment and monitoring. Future wetland studies should also utilise the new crop of free software such as C++, Formula Translation (Fortran), Geographic Resources Analysis Support System (GRASS) GIS, Google Earth Engine, Python, R, System for Automated Geoscientific Analyses (SAGA) GIS and Water Observation and Information System (WOIS). Lastly, there is a need to promote use of recently launched freely available high-resolution Sentinel data obtained from Copernicus to enhance effective assessment and monitoring of small wetlands largely omitted due to more reliance on low-resolution satellite imageries.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. Data sources accessed by the authors are also provided in the reference list provided below.

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