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The Potential of Information and Communication Technology to Promote Sustainable Natural Resources Management and Its Unintended Consequences

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Abstract. A formidable tool with the potential to improve conservation and sustainable management of natural resources is information and communication technology (ICT). It is possible to address the problems of resource depletion and biodiversity loss by using ICT in many elements of environmental conservation, such as monitoring, data collection, and public awareness. However, it's crucial to consider the unexpected repercussions that could result from the broad use of ICT in this setting. In order to promote sustainable natural resource management and conservation, this study will examine any unintended implications of ICT. The study also identifies and examines four important areas of concern, including digital divide, data privacy and security, e-waste management, and ecological footprint, based on pertinent research and case examples. The research seeks to educate policymakers, practitioners, and academics about the importance of using ICT in environmentally conscious ways by emphasizing these unintended consequences particularly in African countries.

Keywords. Information Communication Technology, Climate Change, Natural Resource Management, Remote Sensing, GIS, Biodiversity, Environmental Conservation, Geographic Information Systems, Infomatics, E-Waste, Innovation

Introduction

ICT's galloping development offers special prospects for advancing conservation and management of natural resources. Communities, researchers, and politicians can be strengthened in their efforts to safeguard and manage natural resources by using ICT, which has the potential to improve data collection, analysis, and dissemination. It's crucial to understand, nevertheless, that the use of ICT technology could also have unexpected repercussions. In order to maximize the advantages of ICT in sustainable resource management and conservation, this study examines these unintended consequences and offers insights into the problems that must be overcome.

ICTs, or information and communication technologies, have completely changed how we interact with the environment and manage natural resources. ICT provides a wide range of options to increase the sustainability and effectiveness of resource utilization, from monitoring systems to mapping tools and remote sensing. As a potent instrument to address environmental issues including climate change, biodiversity loss, and land degradation, ICT use has gained

more traction in recent years (UNESCO, 2015). In the past, Grant (1999) categorized resources according to their respective types: organizational, financial, physical, technological, human, and reputational.

Information and communication technology (ICT) are widely acknowledged as being a major force in advancing sustainable resource management and conservation. Others have suggested classifying intangible resources according to human, organisational, technological, and relational capital (Fernández et al., 2000). This acknowledgement is based on ICT's capacity to improve environmental data collection, analysis, and distribution as well as informed decision-making and effective stakeholder communication (Molas-Gallart et al., 2016; Osei-Tutu et al., 2020).

Due to its potential to address sustainability concerns, the topic of environmental informatics, which focuses on the application of ICT in environmental management, has attracted growing attention in recent years (Osei-Tutu et al., 2020). Natural resources serve as the foundation for human activity (George, Schillebeeckx, & Liak, 2018). Precision agriculture is one of the primary fields where ICT has been used to enhance sustainable management and conservation of natural resources. This comprises real-time monitoring of crop growth, soil quality, and weather patterns using various technologies, including remote sensing, Geographic Information Systems (GIS), and Global Positioning System (GPS).

According to research by Molas-Gallart et al. (2016), this strategy has been demonstrated to improve agricultural output, decrease water and fertilizer consumption, reduce environmental pollution, and support the preservation of biodiversity. According to a report by Ernst & Young (2013: 21) on emerging sustainability trends that was cited in George, Schillebeeckx, and Liak (2018), there is a "increased risk and proximity of natural resource shortages," making it essential to assess the dependability and accessibility of strategic business materials and develop risk management strategies to handle supply disruption scenarios.

Similar to this, it has been demonstrated that the use of ICT tools, such as mobile applications and social media platforms, improves community engagement in resource management. These tools allow communities to report illegal activity, acquire and share environmental information, and take part in decision-making processes (Hernandez-Moreno et al., 2020). By encouraging a sense of ownership and responsibility among community members, the increased engagement is anticipated to support sustainable management and conservation of natural resources.

ICT has the potential to support the sustainable management and conservation of natural resources, and its use in the field of environmental informatics is attracting more and more attention. Precision farming, mobile apps, social media platforms, and remote sensing technologies have all shown how ICT may improve protected area management, boost community engagement, and raise agricultural productivity (Liu et al., 2021). It is anticipated that the incorporation of ICT into natural resource management would help to accomplish the Sustainable Development Goals (SDGs).

Major environmental issues that the world is currently dealing with include climate change, water pollution, habitat destruction, and deforestation (Singh & Singh, 2017). Natural resources are being destroyed at an alarming rate as a result of expanding demand, population growth, and urbanization. Globally, organizations, individuals, and policymakers are increasingly concerned about the sustainable management and conservation of natural resources. Information and communication technologies (ICT) have the power to address these issues by delivering cutting-edge tools and solutions that can support conservation and

sustainability efforts. For the earth and its inhabitants to survive, natural resources must be managed sustainably and conserved (Kamali, 2016).

ICT can significantly contribute to overcoming these difficulties by offering creative approaches and instruments that encourage sustainability. To fully realize this promise, authorities must solve infrastructure, pricing, and affordability issues and encourage the adoption of ICT-based solutions. In order to improve sustainable management and conservation of natural resources, this study will first examine the potential of ICT and later highlight its pitfalls.

An important component of improving our understanding of how we may use technology to address the ecological problem is the study of the potential of ICT in encouraging sustainable management and protection of natural resources. Policymakers can create policies and strategies that maximize the positive effects of technology while minimizing its negative effects by identifying the major areas where ICT can be implemented. This study will aid in educating decision-makers, environmentalists, and developers on the best techniques and approaches that may be used to fully use ICT in advancing sustainable development and also adequately prepare for unintended consequences. Not much research has been carried out that highlights the repercussions of ICT use in promoting sustainable Natural Resources Management(NRM) with a focus on African countries.

Literature Review

How ICT Can Help Manage Natural Resources

Ecology, economics, and social sciences must all be integrated into the complicated process of managing natural resources (Schlueter et al., 2012; Manfredo et al., 2014). Since they offer the means required to gather, store, analyse, and disseminate information about natural resources, information and communication technologies (ICTs) have grown in importance as a part of natural resource management (Dewan & Riggins, 2005). In this literature review, the function of ICT in managing natural resources is examined, with particular attention paid to how technology affects information management, decision-making, and stakeholder involvement.

Information Management

Information and communication technology, according to Meena and Singh (2013), offer a potent tool for managing data regarding natural resources. Large volumes of data may be collected and stored using them, and this data can then be utilized for monitoring and evaluating the condition of natural resources (Kumar & Singh, 2012). According to FAO (2016), remote sensing technologies can be used to track changes in plant cover and land use on a regional or global level. Bhatta, Saraswat, and Babel (2012) reckon geographic information systems (GIS) can also be used to map and examine the spatial distribution of natural resources. ICTs also facilitate the sharing of information among stakeholders, including governments, NGOs, and local communities, which can improve the coordination and effectiveness of natural resource management (Barron, 2012).

Data collection, analysis, and distribution are only a few of the ways that ICTs have been applied to natural resource management (Meena & Singh, 2013). In order to give reliable and up-to-date information on natural resources, Sonti (2015) claims that remote sensing technologies like satellite imaging and geographic information systems (GIS) are employed in data collecting and processing. Furthermore, mobile technology like smartphones and tablets are employed in field data gathering, enabling real-time data collection and analysis, as Daneels

et al. (2017) point out. ICTs are also employed in NRM for knowledge sharing and communication. Information, ideas, and knowledge about NRM are shared and disseminated using social media platforms including Twitter, Facebook, and LinkedIn (Willard, 2009). In addition, online forums, wikis, and blogs offer a place for discussion and collaboration on NRM-related issues.

Decision-making

An essential component of sustainable development in Africa is the management of natural resources. The continent is abundant in natural resources, including forests, minerals, wildlife, and water bodies, claim Olalekan et al. (2019). However, Chandra and Idrisova (2011) assert that a number of issues, including poor policies, shoddy institutional structures, and constrained capability, have made management of these resources difficult. The use of information and communication technologies (ICTs) has come to light recently as a potential means of enhancing decision-making in the management of natural resources (Yigitcanlar, 2009).

ICTs have demonstrated to enhance natural resource management decision-making. ICTs, according to Mukherjee and Chakraborty (2017), can aid in the identification and prioritization of management actions by giving decision-makers access to precise and cutting-edge information. Predictive modelling approaches, for instance, can be used to evaluate how various management scenarios will affect natural resources, enabling decision-makers to choose the best course of action (Ghimire, 2017). Decision-makers can use ICTs to assess the success of prior management initiatives and change their methods as necessary (Nagendra and Ostrom, 2012).

Different facets of managing natural resources have used information and communication technologies. To track changes in forest cover over time, remote sensing technologies like satellite photography can be employed in forestry (Chirici et al., 2016). The management and conservation of forests can be influenced by this information. The mapping of forest areas and the detection of hotspots for deforestation or forest degradation are both possible with GIS (Sekajugo et al., 2017). Policymakers can use this information to focus their efforts in the areas where they are most needed.

ICTs have also been used to manage water resources. According to Makurira et al. (2016), systems that use mobile phones to track water levels in rivers and lakes have been created. Early warning systems can use this information to forecast floods or droughts. Similar to this, GIS, according to Owuor et al. (2018), can be used to map water resources and pinpoint regions with water shortages or conflicts over water use.

ICTs have also been used to manage mineral resources. For instance, mineral resources can be located and their distribution mapped using remote sensing technology (Kasimu et al., 2018). The management and exploitation of minerals can be influenced by this information. Additionally, mining activities can be mapped using GIS, and risky areas for the environment or society can be found there (Musingwini et al., 2018).

Stakeholder Participation

ICTs can improve stakeholder involvement in the management of natural resources. ICTs can enable stakeholders to take part in the management process by giving them access to information and decision-making tools (Hossain and Bose, 2014). Local communities can map their own natural resources and participate in management by using participatory mapping technologies like OpenStreetMap (Mukherjee and Chakraborty, 2017). Similar to this,

stakeholders can provide feedback on management decisions and report environmental breaches by using mobile phone applications, which can be utilised to gather real-time data from them (Cohen and Ball, 2014).

According to Cummin et al. (2022), stakeholder involvement is crucial for managing natural resources because it guarantees that the interests of all parties involved are taken into account. ICT may significantly contribute to stakeholder engagement by giving stakeholders a place to share information, work together, and participate in decision-making processes.

ICT can be utilized to increase stakeholder involvement in natural resource management by offering forums for dialogue and teamwork. Information sharing and stakeholder engagement about problems with natural resources management can be done using social media platforms like Twitter, Facebook, and LinkedIn (Kamau & Ondimu, 2019). According to Mwakaje and Mwakalinga (2019), mobile phones can also be utilized to share information on natural resource management and gather stakeholder feedback.

The involvement of stakeholders in decision-making processes can also be facilitated by ICT. Online forums, webinars, and virtual meetings can be used to bring stakeholders from various regions together to address issues related to natural resources management, claim Kamau and Ondimu (2019). ICT can also be utilized to give stakeholders access to data and information regarding managing natural resources, which can assist them in making wise decisions (Mwakaje and Mwakalinga, 2019).

ICT in Natural Resource Management

Information Sharing and Communication among Stakeholders

In managing natural resources, ICT has a number of advantages. It encourages information exchange and communication among stakeholders, which is one of its most important advantages. Using ICT in natural resources management can improve stakeholder communication, leading to better decision-making processes, claim Kiptot et al. (2018). Geographic Information Systems (GIS) and Remote Sensing (RS), two ICT techniques, offer stakeholders precise and timely information on natural resources, including land use patterns, vegetation cover, soil types, and water supplies (Kiptot et al., 2018). Resource allocation, environmental impact analyses, and land-use planning are just a few examples of the decision-making procedures that require this data.

ICT tools offer real-time communication among stakeholders in addition to giving them reliable information. According to Kiptot et al. (2018), information on natural resources management projects like tree-planting campaigns or water conservation programs can be shared using mobile phones and social media sites like Twitter and Facebook.

Promotes Transparency and Accountability

Transparency and accountability are promoted by the use of ICTs in natural resource management. Geographic Information Systems (GIS) are an ICT tool that has been used to track illicit logging and changes in forest cover in various African nations, including Cameroon (Nkem et al., 2010). It consequently gave authorities the ability to pursue illegal loggers and advance sustainable forest management techniques.

The management of natural resources must include transparency and accountability. Transparency, in the opinion of Alemu and Kassa (2018), guarantees that information is available, timely, accurate, and comprehensive. On the other hand, accountability is the need that people or organizations accept responsibility for their actions and decisions (Alemu & Kassa, 2018). Transparency and accountability are crucial in the administration of natural

resources in order to fight corruption, advance good government, and guarantee sustainable growth.

Increasing transparency and accountability in the management of natural resources has been shown to be possible with the help of ICT. Technology can improve stakeholder communication, promote access to information, and boost public participation in decision-making, claim Mwakaje and Ngowi (2014). According to Geist and Lambin (2002), precise data on land-use changes may be obtained using remote sensing technology, and this information can be utilized to track deforestation activities.

ICT can also improve accountability by encouraging financial transaction transparency. Electronic payment systems might lessen corruption by removing middlemen and guaranteeing that beneficiaries receive payments directly, claim Oyelaran-Oyeyinka et al. (2010). Similar to this, mobile money networks can let citizens keep tabs on how much the government is spending on initiatives to manage natural resources (Oyelaran-Oyeyinka et al., 2010).

Promotes Stakeholder/Community Participation

The promotion of community engagement, which is increasingly recognized as a critical component of natural resource management in Africa, is another important function of ICT. Mwangore et al. (2016) claim that ICT technologies like mobile phones have been utilized to encourage community involvement in wildlife conservation initiatives in Tanzania. Communities can report instances of poaching or illicit wildlife trading to authorities via cell phone-based reporting systems, which can result in swift action against offenders.

According to Mwangore (2017), ICTs can increase community involvement in NRM by improving information availability, fostering transparency, and fostering communication among stakeholders. The writer argues that using ICTs can help traditional communication methods get beyond problems like language boundaries, illiteracy, and lack of access to information. In a similar vein, Kiptot et al. (2013) emphasise the advantages of utilising ICTs for community involvement in NRM in Kenya. The authors point out that ICTs can boost stakeholder collaboration, facilitate knowledge and experience exchange throughout communities, and improve decision-making procedures.

In a different investigation by Odera et al. (2019), the researchers look into how mobile phones might improve community involvement in NRM in Uganda. The study discovered that communities may make knowledgeable decisions about the use of natural resources by using mobile phones to communicate information on weather patterns, market pricing, and other pertinent data.

Potential Emerging Technologies to Support NRM

The management of natural resources is a difficult and complex topic that calls for the fusion of numerous disciplines and methods (Thiault et al., 2020). Emerging technologies have the potential to enhance natural resources management in various ways, including data collecting, analysis, and visualization, as well as communication and decision-making processes, according to Tripathi and Bhattarya (2004). Utilizing developing technology can be especially advantageous in the African environment, where natural resources are frequently under stress due to population increase, climate change, and other causes.

Emerging technologies can help with data collecting and analysis for natural resource management in Africa, claim Mwendera et al. (2020). Also according to the writers, remote sensing tools like satellite imaging and drones can give precise information on a wide range of

environmental factors, including vegetation cover and land use. This data can be used to track evolution over time and spot potential intervention or safety zones.

Once more, cutting-edge technologies can aid in the communication and decision-making processes for natural resource management. According to Kiptot et al. (2018), mobile phone applications can be used to gather information on resource use and management practices from local populations. In order to help decision-making processes, the data can subsequently be shared with policymakers and other stakeholders.

By increasing the effectiveness of resource usage, emerging technologies can also aid in the management of natural resources. For instance, using sensors and data analytics in precision agriculture techniques can assist farmers in maximizing the use of water and fertilizer, decreasing waste, and boosting yields (Gebbers & Adamchuk, 2010).

Methodology

The study used a qualitative research methodology that included document analysis, key informant interviews, and representatives from the Environmental Management Agency (EMA), Zimbabwe Parks and Wildlife Management Authority (ZPWMA), Zimbabwe National Water Authority (ZINWA), Forestry Commission, Ministry of Land, Water and Climate, Ministry of Lands, Agriculture and Rural Settlement, and Non-governmental Organisations (NGOs). The phenomenological paradigm, which asserts that reality is socially produced through individual or group conceptions of the situation, is seen as the foundation of qualitative research (Spencer, Pryce, and Walsh, 2014).

The key informants who were chosen for interviews were chosen using convenient and intentional sampling approaches. A total of 35 authorities took part in this study. As a result, key informants were able to provide information about the potential for ICT to support sustainable management and conservation of natural resources and its repercussions through in-depth interviews using a qualitative approach. Although the participants' identities are kept confidential in this study, it is crucial to analyse their opinions. The opinions of the participants were analyzed thematically throughout the study.

Results and Discussions

A variety of frequent comments were obtained in response to the study's core question on the potential for ICT to support sustainable management and conservation of natural resources and the possibility of unintended consequences. Both key informants from various departments and secondary data sources revealed seven overarching themes. Among them was the potential for ICT to advance:

Land Resources Management

As mentioned by Rahman et al. (2013), the participants emphasized how Information and Communication Technologies (ICTs) have the potential to revolutionize land resources management by offering tools and methodologies for gathering, analyzing, and disseminating data and information. The study's findings, which showed that the majority of the key informants from all institutions said the following, underline this:

“The increased adoption and application of information and communication technologies has the potential to increase the efficiency of land use planning, improve monitoring and evaluation, and facilitate communication and coordination among stakeholders. Again, remote sensing technologies such as satellite imagery, aerial photography, and Light Detection and Ranging(LiDAR) can provide high-resolution data on land use, land

cover, and terrain that can be used for mapping, monitoring, and modelling the environment. There are however potential pitfalls that come with the use of ICT that policymakers and stakeholders should be aware of when crafting policies”

The study's findings also demonstrate that GIS may be used to analyse the connections between various geographical information in order to spot patterns and trends of change within a particular ecosystem. GIS can offer useful insights into managing land resources, including whether the land is degrading and whether there is main or secondary succession of the ecosystem, by combining and analyzing these data sources.

The maps produced help the land managers make educated decisions during analysis so that any land use practices would cause little to no disruption to the ecology and ecosystems as economic growth moves forward. Therefore, based on elements like soil type, terrain, climate, and water availability, GIS can be used to pinpoint places that are appropriate for particular land uses.

The use of GIS for environmental impacts assessment was again mentioned by a number of key informants from the EMA, ZPWMA, and government ministries. It can be used to simulate the potential environmental effects of various land uses by looking at elements like soil erosion, water quality, habitat fragmentation, and biodiversity loss. As a result, the insightful data is applied to guide land use planning decisions and lessen the damaging effects of human activity on the environment. GIS can also be used to track long-term changes in land usage. GIS can detect changes in land use patterns, such as deforestation or urban sprawl, by comparing satellite pictures or aerial photographs taken at various dates.

These results add to Geist and Lambin's (2002) argument that accurate data on land-use changes may be obtained through the use of GIS and remote sensing technology, which can then be utilized to track deforestation activities. Authorities and decision-makers can utilize this information to evaluate the efficacy of land use regulations and management measures.

One of the informants mentioned how GIS technology improves efforts to safeguard the environment. Applications for GIS make it possible to locate potential environmental dangers such pollution sources, hazardous waste sites, and disaster-prone locations. The data is crucial for creating emergency response plans and mitigation methods that lessen the effects of environmental disasters. Additionally, it offers ample time for teams working on disaster risk reduction to prepare properly and informs decision-makers during the creation of public policies.

As Mudenda et al. (2016) have pointed out, mobile technology like smartphones and tablets can be adopted for data collection and dissemination, enabling fieldworkers to gather data in real-time and share it with others. As indicated by Kiptot et al. (2016) in the study findings, social media platforms can also be utilised to interact with stakeholders and encourage communication and collaboration between them.

The use of ICTs can also aid in the creation of environmental/land information systems, which can serve as a centralized platform for storing, managing, and sharing land-related data (Binns et al., 2013). These environmental and land information systems can enhance land use planning and decision-making, as well as increase stakeholders' access to land-related information.

Forestry Cover Management

Forest cover management is a crucial issue in sustainable development, and the use of Information and Communication Technologies (ICT) has the potential to improve successful management practices. ICT can also be harnessed to improve forest monitoring, improve

communication and collaboration among stakeholders, facilitate decision-making, and promote policy creation.

The Forestry Commission main informants examined stated:

“Information and communication technologies have a potential to promote forest cover management through remote sensing technologies. These provide accurate and current information on forest cover, including changes in forest area, deforestation rates, and forest health.”

This suggests that the data gathered through remote sensing is worthwhile and can be applied to successfully inform policy decisions, focus conservation efforts, and check on regulatory compliance (Khatiwada et al., 2013).

The study's findings demonstrate how ICT may support forest cover management by implementing Geographic Information Systems. The outcomes provide more evidence in favour of Schwarz et al.'s (2015) claim that GIS may be used to map forest cover and pinpoint regions that are vulnerable to deforestation or degradation. Once more, it can be adopted to analyse spatial data and spot patterns and trends in the alteration of forest cover.

ICT has the potential to foster collaboration and communication among stakeholders involved in managing forest cover and natural resources more generally, according to the majority of key informants (85%). Online forums and webinars can help professionals share knowledge, they said, and social media platforms can be used to involve local populations in conservation initiatives (Wicaksono et al., 2020).

The study's findings are also in line with those of Liu et al. (2018), who claimed that ICT can support decision-making processes connected to managing natural resources, including managing forest cover. The decision support systems can be used to analyse large data sets and offer suggestions for resource allocation, conservation tactics, and planning of the use of land.

ICT has a lot of potential for promoting forest cover management. ICT can assist more efficient and sustainable forest management practices by providing accurate information, fostering collaboration and communication, helping decision-making processes, and encouraging policy formulation.

Water Resources Management

Information and communication technology has the potential to be extremely important in advancing the management of water resources. Information and communications technology (ICT) can be used to gather, store, analyse, and disseminate data regarding water resources, which can assist decision-makers in making wise choices about water allocation, conservation, and management. In order to reduce water waste, ICT also enables commercial water end users like farmers to deploy effective water technologies like drip irrigation.

The study also demonstrates how ICT may support water resource management by deploying GIS and remote sensing technology. Aerial and satellite photography are two examples of remote sensing technologies that can be used to monitor water supplies across broad areas. As mentioned by Gao et al. (2013), the information acquired can be exploited to pinpoint locations that are experiencing water stress and to create plans for water management and conservation. Water resource mapping and spatial analysis of correlations between various factors, such as land use and water supply, are both possible with GIS. As a result, the data may be adopted to create models for estimating future water availability and to pinpoint regions that require water management measures (Haque et al., 2018).

Through social media platforms, ICT can improve collaboration and communication between communities and stakeholders involved in managing water resources in order to

increase public awareness of the value of water conservation (Molenaar et al., 2015). ICT can also help with the creation of decision support systems (DSS) for managing water resources. Decision-makers have access to pertinent data and information through the use of DSS, which are computer-based tools. These systems can assist decision-makers in assessing various water resource management scenarios and determining the best course of action for reaching organizational objectives (Sarker et al., 2016).

Wildlife Resources Management

The management of wildlife resources has reportedly been given new opportunities by information and communication technology, according to a small percentage of important informants from the ZPWMA. These include the capacity to assist in more efficient and effective monitoring, tracking, and management of animal resources. The use of GIS and remote sensing technology could enable the provision of up-to-the-minute data and details regarding the distribution, behaviour, and health of animal populations. Additionally, it can be useful in detecting dangers to animals and formulating plans to lessen those dangers.

It has also been noted by researchers that remote sensing technology, such as satellite photography, can be used to monitor changes in land use patterns and detect changes in vegetation cover that may damage wildlife habitats. This is in line with Gallo-Cajiao et al.'s (2018) findings. Similar to humans, animals can have GPS tracking devices attached to them to follow their whereabouts and behaviors (Breed et al., 2019). By using this information, conservation programs can be made more effective, and policymakers and relevant authorities can be informed.

The study's findings are also in line with those of Raza et al. (2017), who proposed that mobile applications be created to allow farmers to report instances of crop loss brought on by wildlife. The data is used by conservationists to identify regions with a high occurrence of conflict and develop measures for mitigating it.

The creation of decision support systems is a potential use of ICT in wildlife resource management. These systems analyse data using algorithms and modelling techniques, then recommend the best course of action (Gallo-Cajiao et al., 2018). For instance, decision support systems can pinpoint regions where wildlife populations may be severely impacted by habitat restoration activities.

Mineral Resources Management

ICT has the ability to advance mineral resource management by enhancing mineral discovery, extraction, and processing, as well as by enhancing the monitoring and evaluation of mining operations, according to the key informants. According to Yousefi et al. (2019), GIS technology offers a thorough and accurate representation of geological data, which can help in finding possible mineral resources for excavations. By giving comprehensive information on the locations of mines, infrastructure, and transportation routes, it can also aid in planning and managing mining operations. GIS can also be used to track how mining activities affect the environment, including how they affect deforestation, water contamination from sources, and soil erosion.

The respondents emphasized that ICT can support mineral resource management by identifying geological features that may point to the presence of minerals in satellite photos. The use of technology can aid in mapping mineral reserves, tracking changes in land usage, and

evaluating the effects of mining on the environment. Additionally, real-time updates on mining activities and environmental monitoring can be provided by mobile applications.

ICT offers a great deal of promise to support the management of mineral resources through the use of GIS technology, remote sensing, improved communication, and stakeholder collaboration. These technological advancements have the potential to improve exploration efforts, mining monitoring and evaluation, and damage mitigation on the environment.

Fisheries and Fresh Water Systems Management

ICT use has the ability to support the management of freshwater systems and fisheries, according to the key informant. ICT has the potential to support the management, monitoring, and assessment of freshwater resources and fisheries. On fish populations, water quality, and other environmental aspects that have an impact on these resources, it can offer real-time data. ICT can also help with the creation of sustainable fishing methods, the execution of successful management plans, and the detection of trends and patterns that can help with management decisions.

The researcher added that by installing sensors in lakes and rivers to track changes in temperature or nitrogen levels, ICT implementation can also be employed to regulate freshwater systems. ICT can help with the enforcement of rules pertaining to these resources in addition to encouraging sustainable fishing methods and freshwater system management. While enforcement organizations can use mobile applications to monitor adherence to fishing regulations, satellite photography can be used to spot unlawful fishing activity.

Climate Change Adaptation

Measures taken to lessen the negative effects of climate change on natural and human systems are referred to as adaptation to climate change. Information and communication technology have the ability to aid climate change adaptation through improving communication, facilitating access to information, and assisting in decision-making. International organizations like the International Telecommunications Union (ITU) and the United Nations Framework Convention on Climate Change (UNFCCC) are aware of this possibility. By enhancing early warning systems for extreme weather events, ICT can support climate change adaptation. According to ITU (2013), alerts can be sent over mobile phone networks to people living in areas at danger of landslides or flooding. Geographic Information Systems (GIS) are used to map sensitive areas and suggest adaptation solutions, which, according to IPCC (2014), is one way that ICT might promote climate change adaptation.

Also according to the study's findings, ICT can improve communication between parties involved in climate change adaptation. Online platforms, according to Klein et al. (2015) who supported the findings, can promote collaboration between researchers, policymakers, and practitioners, enabling the sharing of knowledge and best practices. Social media can be used to promote behaviour changes towards more sustainable practices and increase knowledge of the effects of climate change (Bougherara et al., 2018).

Additionally, ICT can aid in the decision-making procedures involved in adaptation to climate change. Decision support systems can give decision-makers knowledge about the advantages and disadvantages of various adaptation alternatives, assisting them in making wise choices (IPCC, 2014). Big data analytics, according to UNFCCC (2017), can also be used to find patterns and trends relating to the effects of climate change, supporting evidence-based decision-making.

Natural Resources Governance

The findings demonstrate that ICT is a key factor in advancing the governance of natural resources. The qualitative findings showed that through information exchange, training, and teaching, ICT use has improved environmental awareness and knowledge. ICT has also made it easier for different parties, such as governments, NGOs, and the commercial sector, to network and cooperate together. These parties can cooperate to advance the sustainable use of natural resources and their preservation. The study's findings also show that ICT facilitates the various natural resource governance processes by:

Data collection and analysis: Data on wildlife, biodiversity, ecosystems, and climate may all be collected, managed, and analyzed with the aid of information and communication technologies (ICT). Making decisions based on this knowledge will result in better natural resource planning and management. In support of the study's findings, Mukherjee and Chakraborty (2017) stated that ICTs can assist decision-makers in identifying and prioritizing management actions by giving them access to precise and cutting-edge information.

Monitoring and enforcement: Using satellite imaging and other remote sensing methods, ICT can assist in the monitoring of natural resources. This can aid in the detection of unlawful activities including poaching, deforestation, and illegal fishing as well as the enforcement process. In support of the present study, Makurira et al. (2016) claimed that systems based on mobile phones have been developed to track the levels of water in rivers and lakes.

Education and awareness-raising: Information and communication technologies (ICT) can be used to inform the public about the value of natural resources and sustainable management techniques. Use of social media, internet platforms, and mobile apps for sharing data and resources can all fall under this category.

Networking and collaboration: By enabling the exchange of information and best practises, fostering cooperation in conservation initiatives, and facilitating networking between conservation organizations, scientists, and local populations, ICT can help conserve the environment. The results support Willard's (2009) claim that ICTs are used in NRM for communication and knowledge sharing. Social media sites like Twitter, Facebook, and LinkedIn are used to share knowledge about NRM and trade ideas. The author also suggested that websites like blogs, forums, and wikis offer a place for discussion and collaboration on NRM-related issues.

Tools and Techniques used for Natural Resources Management

Understanding the intricate relationships between many environmental factors and foretelling the effects of human activity on natural systems require these tools and methods. Among the most popular ICT methods and tools for environmental modelling are:

Geographic Information Systems (GIS): For environmental modelling, GIS is a potent tool that enables researchers to gather, store, examine, and visualize spatial data. GIS can be used to model the effects of environmental change as well as to map environmental features including land use, vegetation cover, and water resources. Once more, GIS may be used to map the extent of forests, identify those that are at risk of deterioration or deforestation, and keep track of how land uses change over time. According to research by Munoz-Robles et al. (2019), the usage of GIS has been demonstrated to increase the accuracy of forest monitoring data and offer useful information for decision-making.

Remote Sensing: In order to gather information on environmental factors including temperature, precipitation, and vegetation cover, remote sensing uses satellite or airborne sensors. Models of environmental processes, such as climate change, land use change, and

ecosystem dynamics, can be created using the data. Furthermore, remote sensing technology offers a cheap and effective approach to keep an eye on huge forest regions. It makes it possible to gather information on land use changes, deforestation rates, and forest cover. It has been demonstrated that using remote sensing increases the accuracy of forest monitoring and decreases the time and resources needed for field surveys (Gupta et al., 2013).

Data Mining: When analyzing enormous datasets to find patterns or trends in the data, data mining uses statistical approaches. This method can be used to establish connections between environmental factors and forecast upcoming trends in those conditions.

Machine Learning: Making predictions based on data patterns requires the application of algorithms in machine learning. This method can be used to create forecasting models for environmental processes like air pollution, water toxicity, and climate change.

Simulation Modelling: Simulating how environmental systems will react to changes in the environment or to human activity includes constructing computer models of those systems. This method can be applied to evaluate various scenarios and discover potential effects of policy choices.

Mobile Applications: In recent years, mobile applications have gained popularity as a tool for gathering data in the field. Mobile applications enable field employees to collect and share data in real-time, cutting down on the time needed for data entry and analysis. Data on tree growth, species composition, and indications of the health of the forest, such as soil moisture content and temperature, can be collected using mobile applications. It has been demonstrated that the use of mobile applications increases the precision and effectiveness of forest monitoring (Bhattarai et al., 2020).

Unintended Consequences of ICT Use in Promoting Sustainable Resource Management

1. **The Digital Divide:** The widening of the digital divide is one unexpected result of the use of ICT in natural resource management. Access to technology and ICT infrastructure varies widely across nations, regions, and communities. Marginalized communities may not be included in conservation initiatives due to unequal resource distribution, which would increase social and economic divides already present. There are a number of issues that need to be resolved despite the potential advantages of employing ICT for stakeholder participation in natural resource management. One of these is that some stakeholders do not have access to ICT infrastructure and services (Kamau and Ondimu, 2019). The effectiveness of employing ICT for stakeholder participation may be constrained by this digital divide. Another issue is that certain stakeholders lack the knowledge and skills necessary to use ICT successfully, according to Mwakaje and Mwakalinga (2019). As a result, this may restrict stakeholders' access to information regarding the management of natural resources or their ability to participate in decision-making processes.

According to Mwakaje and Ngowi (2014), the ineffectiveness of ICT interventions may also be hampered by the high cost of ICT infrastructure and the sparse availability of technology in rural regions. To guarantee that stakeholders have the abilities to use ICT efficiently, capacity building is also required (Mwakaje and Ngowi, 2014). Despite the advantages of utilizing ICT in the management of natural resources, a number of obstacles prevent effective information exchange and communication between stakeholders. Lack of access to ICT infrastructure in rural regions is one of the major problems. Many rural areas in Africa lack access to basic ICT infrastructure, such as electricity and internet connectivity, according to Chikodzi et al. (2019).

2 .Environmental Impact: The study registered concerns by respondents on ICT infrastructure, such as data centres and communication networks, using a lot of energy and resources. In the context of managing and conserving natural resources, further research should be carried out to examine the ecological footprint of ICT. The necessity for energy-efficient technology, renewable energy sources, and environmentally friendly design principles should be debated in order to reduce the environmental impact of ICT systems.

3.Privacy and Data Security: According to the respondents, ICT-based solutions frequently entail the gathering and sharing of delicate environmental data. The use of data can considerably enhance conservation initiatives, but it also brings up issues with security and privacy. Unauthorized access, data breaches, or the abuse of sensitive information can all result from insufficient data protection procedures. In order to secure data privacy while maximising the advantages of ICT, there is a need to investigate the implications of data privacy and security in the context of natural resource management and conservation.

4. Handling of E-Waste: Other respondents made reference to the accelerated speed of technical advancement and the brief useful lives of electronic gadgets as factors in the expanding e-waste problem. This dilemma may be made worse by the use of ICTs in natural resource management, as outdated or malfunctioning equipment is frequently thrown out without being properly recycled or disposed of. There is therefore a need to investigate potential environmental effects of e-waste and emphasize the significance of including ethical e-waste management techniques in ICT efforts.

Conclusion

Despite the fact that ICT technology has a great deal of promise to improve conservation and sustainable management of natural resources, it is necessary to identify and deal with any unintended consequences that may result from its use. Key areas of concern include the digital divide, data security and privacy, e-waste management, and ecological footprint. Policymakers, practitioners, and academics may maximize the benefits of ICT while preserving the long-term viability of biodiversity and natural resources by being aware of and proactively reducing these unintended consequences.

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