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Assessment of Water Quality of Otamiri River along Selected Reach Using Drone Technology

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Abstract
This research work focuses on the study of water quality in the Otamiri River in Imo State, Nigeria. It highlights the concerns about pollution due to anthropogenic and industrial activities, the need for innovative monitoring methods like drone technology, and the global challenges in water quality. The study emphasizes the implications for public health and environmental policies, aiming to assess and monitor the distribution of contaminants along the river using drones, and compare these findings with laboratory analyses. This approach is seen as a transformative step in water management practices, contributing to international knowledge in water quality management. The document also discusses the integration of drone technology in environmental monitoring to bridge local challenges with global solutions.

Keywords: Water Quality, Otamiri River, Drone Technology Pollution, Environmental Monitoring, Public Health, Contaminan

1. Introduction

1.1. Background of Study

Otamiri River is a major water source for the population of Imo State, Nigeria. However, there are growing concerns about the levels of pollution in Otamiri River due to anthropogenic activities and industrialization. Ongoing industrial activities along the riverbank have raised serious environmental concerns over the safety and quality of the river water, which constitutes a major source of water supply to the inhabitants of the area. This study aims to model flow parameters along the Otamiri River using drone technology. The study seeks to investigate how contaminants are distributed along the Otamiri River and correlated with the distance from its source.

The study will help to determine the sources of pollution along Otamiri River, its self-purification index, and the levels of contamination in varying distances along its course. Water is a vital resource for life and development, but its quality is often threatened by various natural and anthropogenic factors. One of the water bodies that is facing such challenges is the Otamiri River, which flows through Imo State in south-eastern Nigeria. The river serves as a source of water for domestic, agricultural, industrial, and recreational purposes for the people living along its banks. However, the river is also exposed to various sources of pollution, such as effluents from industries, municipal waste, agricultural runoff, and urban stormwater. These pollutants can affect the physicochemical and bacteriological qualities of the river water and sediment, posing potential health risks to humans and aquatic life.

The assessment of water quality is usually done by collecting samples and analysing them in laboratories using standard methods. However, this approach has some limitations, such as inflated cost, time consumption, spatial variability, and human error. Moreover, conventional water quality monitoring does not provide a comprehensive picture of the spatial and temporal dynamics of water quality parameters, especially in complex and heterogeneous environments like rivers.

Therefore, there is a need for alternative and innovative methods of water quality assessment that can overcome these limitations and provide more accurate and reliable information. One such method is the use of drone technology, which is an emerging field of remote sensing that involves the use of unmanned aerial vehicles (UAVs) equipped with various sensors and cameras to collect data from the air. Drone technology has several advantages over conventional methods, such as high spatial and temporal resolution, low cost, flexibility, safety, and ease of operation.

1.2. Global Challenges in Water Quality

Water quality is a pressing global issue, with the United Nations identifying clean water as one of its Sustainable Development Goals. Around the world, rivers, lakes, and groundwater sources face threats from industrial discharge, agricultural runoff, and inadequate waste management. The contamination of these water bodies with pollutants such as heavy metals, nitrates, and microbial pathogens poses a risk to ecosystems and human health, hindering socioeconomic development. International bodies like the World Health Organization (WHO) have established guidelines for water quality, emphasizing its critical role in ensuring public health, maintaining biodiversity, and securing livelihoods for communities.

1.3. Drone Technology as a Solution

The application of drone technology is an innovative response to these challenges. Drones offer a modern solution for environmental monitoring that is being adopted worldwide. Their ability to carry various sensors and cameras makes them versatile for collecting high-resolution data on water quality parameters over large and inaccessible areas. Compared to traditional methods, drones provide a rapid, cost-effective, and comprehensive means of gathering environmental data, thereby enhancing the capability for continuous monitoring and immediate response to water quality issues.

1.4. Implications for Public Health and Environmental Policies

The study's implications on international public health are profound. Water pollution is linked to diseases and health conditions, affecting millions globally. By offering real-time surveillance and monitoring capabilities, drones can aid in the early detection of contaminants, allowing for swift action to protect community health and prevent the spread of waterborne diseases.

From an environmental policy standpoint, the data obtained through drone technology can be instrumental in informing policy decisions, crafting effective regulations, and implementing remediation strategies. As international environmental policies evolve to address climate change and pollution, the data provided by drones becomes invaluable for setting benchmarks, tracking progress, and ensuring compliance with environmental standards.

Moreover, the findings from the Otamiri River study can contribute to global knowledge and best practices in water quality management. They can serve as a case study for similar ecological systems, assist in developing international collaborative efforts to improve water quality, and influence the formulation of policies that are both sustainable and adaptable to local contexts while aligning with global environmental goals.

The integration of drone technology in environmental monitoring signifies a transformative step towards proactive and preventive water management practices on an international scale. The study underscores the potential for innovative technology to bridge the gap between local challenges and global solutions in the quest for clean and safe water for all.

1.5. Statement of Problem

Water pollution has become a global issue of concern due to its profound effects on aquatic ecosystems and the health of human populations. Otamiri River, a major water source for the inhabitants of Imo State, Nigeria, has been compromised because of anthropogenic activities and sand mining along its banks. The pollution and contamination have not only endangered the river but also the lives of the people who depend on it and marine life. There is a need to establish the extent of pollution along Otamiri River and its distribution relative to the river course. Therefore, this research seeks assess the quality of water along selected reach of the Otamiri River using a drone technology and correlate it with the presence of contaminants.

1.6. Objectives of Study

The aim of this study is to assess the water quality of Otamiri River along selected reach using drone technology.

The specific objectives are:

- To determine the physicochemical and bacteriological qualities of Otamiri River water and sediment using standard laboratory methods.
- To acquire high-resolution images and data of Otamiri River at a distance using drone technology for Water.
- To obtain satellite images of Otamiri river at a distance reach as data for water as for water quality assessment.
- To develop and apply image processing and analysis techniques to extract water quality parameters from drone data.
- To compare and validate the results obtained from drone technology with those obtained from laboratory analysis.
- To model the impact/effect of distance/reach on the water quality of Otamiri river.

1.7. Justification of Study

The study is important for several reasons:

- Firstly, it will provide information on the sources of pollutants in Otamiri River.
- Secondly, it will help to assess the level and distribution of contamination along the river course.
- Thirdly, the study will determine the self-purification index of Otamiri River which is an indicator of its ecological health.
- Fourthly, the research will provide a spatial representation of the river in high resolution using aerial imagery that will serve as a benchmark for future environmental monitoring.
- Finally, the study will provide a basis for policymakers and stakeholders to make informed decisions on how to address the pollution problems in Otamiri River.

1.8. Scope of Study

This study is focused on modelling flow parameters along Otamiri River using drone technology. The study will investigate the distribution of contaminants and correlate them with the distance along the river course. The study will also collect water and soil samples at various locations along the river and subject them to laboratory tests to determine their levels of contamination.

2. Literature Review

2.1. Review of Past Work

The environment could be defined as the combination of external or extrinsic conditions that affect, either directly or indirectly, the growth and development of organisms and the wellbeing and activities of man (NNPC,1995). Environment impacts of oil discharge may occur because of obstruction, debris discharges and physical interruption. According to Sharma et al environmental pollution has adverse effects on plant growth, and these may range from morphological abbreviation, reduction in biomass to stomata abnormalities [1]. Water pollution is a global challenge that affects both aquatic ecosystems and the health of human populations. Industrialization, agricultural activities, and anthropogenic activities have contributed to the pollution of water sources such as rivers and lakes.

Otamiri River is a major river in Nigeria that has been compromised because of anthropogenic activities and industrialization. Several studies have been conducted to assess the quality of Otamiri River water. This literature review will examine past studies on the pollution of Otamiri River, its physicochemical parameters, and the use of drone technology in modelling flow parameter of Otamiri River. All over the world there has been a lot of effort to analyse the effect of pollution in the environment where it occurs. Most of these studies were done during actual spill events while others were while monitoring studies on non-spill state of pollution of the environment. There has been quite a lot of impressive literature on the oil spill, which would be cited.

2.2. Theme 1: Environmental and Public Health Impact of Water Pollution

2.2.1. The Environment and its Relationship to Pollution and Public Health

The environment refers to the natural world or the conditions and influences under which any organism or community exists. This broad definition encompasses not only the physical and chemical conditions that organisms live in but also includes the complex interactions between all living and non-living components [2]. When the natural balance of this system is disrupted by pollutants, it can lead to a range of adverse effects. Pollution is the introduction of contaminants into the natural environment that can cause instability, disorder, harm, or discomfort to the ecosystem i.e., physical systems or living organisms [3]. Public health is intrinsically linked to the environment; clean water, air, and soil are fundamental to the health of communities [4].

2.2.2. General Effects of Environmental Pollution on Plant Growth

Environmental pollution has a profound impact on plant growth, as plants are particularly sensitive to changes in their surroundings. According to Sharma et al, pollutants can cause a range of morphological and physiological changes in plants, including reduced growth rates, altered water and nutrient uptake, and impaired photosynthesis [1]. These changes not only affect the health of individual plants but also have broader implications for ecosystem services such as carbon sequestration and soil stabilization, with potential knock-on effects on food security and livelihoods [5].

2.2.3. Water Pollution as a Global Challenge

Water pollution is an issue of global concern, affecting both developed and developing nations. Industrial waste, agricultural runoff, and inadequate sanitation contribute to the degradation of water bodies, leading to eutrophication, hypoxia, and the loss of biodiversity [6]. Aquatic ecosystems are particularly vulnerable, as they often serve as sinks for pollutants. This can lead to the accumulation of toxins in aquatic organisms, which can be transferred up the food chain, affecting human health [7].

2.2.4. Otamiri River as a Case Study

The Otamiri River in Imo State, Nigeria, exemplifies the challenges of water pollution. Rapid industrialization and urban expansion have led to increased discharge of pollutants into the river, adversely affecting water quality [8]. Studies have detected elevated levels of heavy metals and other contaminants, making the water unsafe for human consumption, and posing significant risks to aquatic life [9]. The use of drone technology to assess the water quality of Otamiri River represents a novel approach to monitoring, offering the potential for real-time, high-resolution data collection to inform management and remediation efforts [10].

2.3. Theme 2: Sources and Effects of Otamiri River Pollution

2.3.1. Sources of Water Pollution Affecting the Otamiri River

The Otamiri River has become a repository for a variety of pollutants due to rapid industrialization, urbanization, and intensified agricultural activities within its catchment area. Industries along the river's banks discharge a range of contaminants, including organic and inorganic waste, into the water body. Urbanization further contributes to the river's pollution through the release of untreated sewage and urban runoff, which carries pollutants from streets and buildings directly into the river. Additionally, agricultural activities contribute to the river's deteriorating water quality through the runoff of pesticides and fertilizers [11].

2.3.2. Impact of Pollution on Otamiri River

Studies focused on the Otamiri River have highlighted the presence of heavy metals in the water, which is a cause for concern due to their toxic nature and tendency to bioaccumulate. reported elevated levels of lead, copper, and zinc in the river, primarily resulting from industrial effluents and inadequate wastewater treatment [12]. further underscored the unsuitability of the river water for human consumption due to the contamination from agricultural and domestic wastes [13]. These pollutants have not only compromised the quality of the water but have also affected the health of the local communities relying on the river for domestic and agricultural purposes.

2.4. Theme 3: River Health and Self-Purification Capacity

2.4.1. Self-Purification Index (SPI) as an Indicator of River Health

The Self-Purification Index (SPI) is a crucial measure of a river's ability to naturally remove pollutants without human intervention. It involves a combination of physical, chemical, and biological processes that break down and assimilate pollutants, thereby restoring the river to a state of equilibrium. A high SPI indicates a healthy river ecosystem with robust self-purification capabilities, while a low SPI points to a stressed and potentially unhealthy river environment [14].

2.4.2. Otamiri River's Moderate Self-Purification Capability

Ludwig et al conducted a comprehensive study on the self-purification potential of the Otamiri River [14]. The findings revealed that the river possesses a moderate self-purification capability, which is however being overwhelmed by the scale and intensity of pollution. The study noted that human activities such as indiscriminate dumping of waste significantly hamper the river's self-purification processes. This has resulted in a decline in water quality and has compromised the river's resilience to pollution. The study emphasized the need for stringent regulatory policies and active enforcement to reduce pollution levels and protect the river's health.

2.5. Theme 4: Advancements in Monitoring Techniques – Focus on Drone Technology

2.5.1. Emergence of Drone Technology in Environmental Monitoring

Drone technology has significantly advanced the capabilities of environmental monitoring, offering a versatile and efficient approach to data collection. Bortoni et al discuss how drones, equipped with various sensors, can capture high-resolution imagery, and provide data for analysing water quality parameters, sediment transport, and river morphology [15]. Drones offer a unique vantage point for environmental scientists, enabling them to survey large and inaccessible areas with relative ease and at a lower cost compared to traditional methods.

2.5.2. Application of Drone Technology in Assessing Otamiri River's Condition

Recent studies have leveraged drone technology to monitor the Otamiri River's water quality and ecosystem health. utilized drones to assess the river's physicochemical parameters, finding elevated levels of total dissolved solids and electrical conductivity [16]. Nwachukwu et al applied drone-collected data alongside water quality index (WQI) and multivariate statistical techniques to conclude that the water was unfit for drinking and certain agricultural uses [17]. Similarly, Ugwumba et al used the Canadian Council of Ministers of the Environment water quality index (CCME-WQI) and found the river water quality had deteriorated [18]. Maduako et al., contributed to these findings by using drones to assess the river's heavy metal pollution levels, determining that they exceeded international standards [19].

2.6. Theme 5: Ecological Health and Biodiversity

2.6.1. Impact of Pollution on the Biodiversity and Ecological Health of Otamiri River

The ecological health and biodiversity of the Otamiri River are under threat from ongoing pollution. Studies such as Okike et al have shown a decline in fish species diversity and abundance, indicating a broader ecological imbalance [20]. Nwachukwu et al used the macroinvertebrate community index to gauge the river's health, demonstrating significant negative impacts from activities such as farming and the discharge of untreated wastewater [21]. Ajima et al reported a reduction in the abundance and diversity of benthic macroinvertebrates, key indicators of aquatic health, due to industrial and domestic pollution [22].

2.6.2. Wider Ecological Effects of Pollution on Otamiri River

The industrial effluents and microplastics present in the Otamiri River have wider ecological implications, affecting not only the river's immediate environment but also the surrounding ecosystems. evaluated the impact of industrial effluent discharge, finding significant changes in the physio-chemical properties of the river and a subsequent decline in macroinvertebrate populations [23]. Acha-Ngwodo et al focused on microplastic contamination, revealing a concerning presence in both the river water and sediment [24].

2.7. Theme 6: Impact on Local Livelihoods and Agricultural Practices

2.7.1. Relationship Between Pollution, Agricultural Practices, and Local Livelihoods

Pollution's intersection with agricultural practices significantly affects local livelihoods, particularly in areas dependent on water bodies like the Otamiri River for irrigation and fishing. Ofoegbu et al discuss how pollutants from industrial and urban areas, alongside agricultural runoff containing pesticides and fertilizers, degrade water quality and soil health, leading to lower agricultural yields and impacting food supply [25]. This degradation can force communities to alter their traditional farming practices, affecting their economic stability and lifestyle.

2.7.2. Implications for Food Security and Agriculture

The pollution of water sources crucial for irrigation poses a risk to food security, especially in agrarian societies. Ahirwar et al highlight how advancements in technology, such as the use of drones, can help in monitoring crop health, optimizing irrigation, and managing soil quality [26]. These innovations can mitigate some effects of pollution on agriculture, but they also emphasize the need for sustainable farming practices to prevent further degradation of vital water resources like the Otamiri River.

2.8. Theme 7: Technological Innovations in Environmental Surveillance

2.8.1. Potential of Robotic and Drone Technologies in Environmental Surveillance

The role of robotic and drone technologies in environmental surveillance, particularly in oil spill detection and monitoring, is becoming increasingly prominent. Ejofodomi and Ofualagba explored the feasibility of robotic surveillance to detect oil spills early and prevent extensive environmental damage [27]. Such technologies enable continuous monitoring and rapid response to environmental threats, providing an invaluable tool for managing and protecting ecosystems like the Otamiri River.

2.8.2. Dynamic Path Planning and Real-Time Monitoring

These technological tools are not only used for static surveillance but are also equipped for dynamic path planning, allowing for the adjustment of monitoring routes in real-time based on environmental data inputs. This capability ensures comprehensive coverage and detailed data collection, facilitating better-informed decisions for environmental management and policymaking.

2.9. Types of Drones and Their Uses in Water Quality Assessment

2.9.1. Understanding UAV and UAS Terminology

In the context of agricultural and environmental monitoring, drones, or UAVs (Unmanned Aerial Vehicles), and their encompassing systems, UAS (Unmanned Aerial Systems), play an instrumental role. UAS not only include the aerial vehicle but also the associated ground-based controller and the system of communications between the two [28]. The practical uses of UAVs in environmental studies are increasingly recognized, particularly in water quality assessment where the on-demand, high-resolution data collection capabilities of drones are invaluable [29].

2.9.2. Rotary Drones for Precision Monitoring

Rotary drones, identified by their multiple rotors like the commonly known quadcopters, offer excellent manoeuvrability and stability which are essential for precision monitoring in environmental studies [30]. Their ability to hover and perform vertical take-offs and landings makes them particularly useful for detailed spot checks along the Otamiri River, allowing for the collection of water samples and close-up imagery of specific points of interest where water quality may be compromised.

2.9.3. Application to Otamiri River

The features of rotary drones can be directly applied to the study of Otamiri River's water quality. The manoeuvrability of rotary drones is beneficial for navigating the river's varied landscapes and for monitoring in regions where traditional boat-based methods may be impeded by vegetation or obstacles. Furthermore, the ability to hover allows for the deployment of sensors or samplers in a precise manner, which is critical for gathering accurate water quality data [31].

2.9.4. Fixed-Wing Drones for Broad-Scale Surveys

Fixed-wing drones, resembling airplanes, are characterized by their efficiency over long distances and their extended flight times compared to rotary drones. These drones are especially suited for broad-scale surveys of the Otamiri River, providing a comprehensive overview of water quality across a large area. This capability is particularly useful for identifying patterns of pollution dispersal and for understanding the broader environmental impact along the river's course [32].

2.10. Selection and Suitability for Otamiri River

For the Otamiri River, the selection of the drone type should be aligned with the specific objectives of the water quality study. If the goal is to obtain a detailed analysis of pollution at specific locations, rotary drones would be the preferred choice. Conversely, if the study aims to assess the overall health of the river system, fixed-wing drones would provide the necessary range and efficiency. In some cases, a hybrid approach using both types of drones could offer a comprehensive assessment of the river's water quality.

2.11. Integration with Data Collection Goals

Integrating the capabilities of UAVs with the data collection goals for the Otamiri River study will enhance the efficiency and accuracy of environmental monitoring. By employing rotary drones for targeted analysis and fixed-wing drones for longitudinal surveys, researchers can compile a robust dataset that reflects both the micro and macro perspectives of water quality and river health [33].

2.12. Remote Sensing and its Application in Water Quality Assessment of Otamiri River

2.12.1. Remote Sensing Systems Overview

Remote Sensing (RS) systems are indispensable in environmental monitoring, providing critical data for the assessment and management of water resources. These systems use sensors to detect and classify objects on Earth based on the radiation that is reflected or emitted by the objects [34]. The RS technology has evolved to include both microwave and optical sensing, each with unique capabilities suitable for various environmental applications, including water quality monitoring.

2.12.2. Microwave and Optical Remote Sensing Technologies

Microwave remote sensing operates using wavelengths that can penetrate atmospheric conditions such as cloud cover and rain, offering an all-weather, day-and-night capability for monitoring [35]. This feature is particularly useful for consistent data collection in regions with frequent cloud cover, such as the Otamiri River area. Active microwave sensors, such as Synthetic Aperture Radar (SAR), emit their energy and measure the return signal, which provides valuable information on surface roughness and moisture content, factors that can indirectly influence water quality. Optical RS, on the other hand, relies on sunlight and measures the solar energy reflected by Earth's surfaces. These sensors, including multispectral and hyperspectral imagers, are well-suited for detecting specific water quality parameters like turbidity, chlorophyll concentration, and waterborne pollutants [36]. The high spectral resolution of hyperspectral sensors allows for the discrimination of subtle differences in water composition, which is crucial for identifying and monitoring several types of pollutants.

2.12.3. Application in Otamiri River's Water Quality Monitoring

In the context of the Otamiri River, RS technologies, especially those deployed on drones, have the potential to significantly enhance the monitoring of water quality. Drones equipped with hyperspectral cameras can capture detailed images that reveal the river's condition across numerous spectral bands, enabling the detection of a wide range of pollutants [37]. The application of drone-based RS aligns with the objectives of this study, which seeks to monitor the spatial distribution of pollutants and the ecological impact on the river.

2.12.4. Advantages Over Traditional Methods

The use of drones equipped with RS sensors offers several advantages over traditional water quality monitoring methods. Drones can access remote or difficult-to-navigate areas along the Otamiri River without the need for human operators to be present, reducing risk and increasing the frequency and consistency of data collection [38]. Additionally, the real-time data acquisition capability of drones allows for immediate analysis and decision-making, a critical component in managing pollution events and mitigating their impact on the river's ecosystem and surrounding communities.

2.13. Microwave Remote Sensing

Microwaves are the portion of the electromagnetic spectrum with a wavelength between 1000 µm and 1 m that fall within regions of electromagnetic radiation that are almost unimpeded by the atmosphere. Microwave RS is categorized as active, also known as a non-optical sensor, and passive remote, also called an optical sensor. Optical sensors depend on the energy of the sun, unlike non-optical sensors, which produce their energy. Although most studies have measured WQPs using optical RS, there is an opportunity to measure these parameters from the microwave region of the electromagnetic spectrum. Passive microwave sensors detect the emitted energy within their field of view. Active microwave sensors are those sensors that provide their source of radiation to illuminate their target. They are grouped as imaging and non-imaging with a generic form of imaging active microwave sensors being RADAR; non-imaging active microwave sensors include scatter meters and altimeters.

Active microwave sensors send pulses of electromagnetic radiation, particularly microwave radiation. The sensor then records the energy that is scattered back or reflected. Properties of the reflected energy received at the antenna of the sensor depend on its distance from the antenna, target properties, and the wavelength of the signal received. Some examples of active sensors include Radio Detection and Ranging (for example Synthetic Aperture Radar (SAR)) and Light Detection and Ranging (LIDAR). These sensors are used in managing disasters, precision, agriculture, and exploring crime. The SAR is a well-developed non-optical microwave sensor that operates by recording the amount of energy reflected after interacting with the Earth. Microwave sensors have been used to effectively monitor and solve environmental issues in different applications. They have been used in the study of crops, forest cover, snow ice, soil moisture, hydrological processes such as floods and rainfall measurements, water surface pollution, the productivity of natural and agricultural ecosystems, and surface temperature detection of anomalies, among others. An example of a rainfall sensor is the Tropical Rainfall Measuring Mission (TRMM). These sensors have moderate spatial resolution compared to visible and infrared satellite sensors and present an effective means of measuring rainfall, unlike conventional methods. Conventional methods of measuring rainfall such as a network of rain gauges suffer major limitations due to inappropriate spatial coverage for the capturing of spatial variations in the rainfall. The energy recorded by the passive microwave RS can be emitted, reflected, or transmitted from the surface. Passive microwave sensors are therefore mostly categorized by low spatial resolution.

Passive microwave radiometers and active SAR are commonly used for the RS of soil moisture and snow water equivalent (SWE). Studies have explored the usefulness of microwave signals for the determination of the surface soil layer. Microwave bands of wavelength ranging from 0.3 to 30 cm are noted to be effective in soil moisture measurement. The microwave sensor however has a major drawback in soil estimation, which is the poor surface penetration of its signals through forest canopies and vegetation covering the soil surface. There are known satellite microwaves including the Soil Moisture and Ocean Salinity (SMOS) by the ESA and Soil Moisture Active Passive by the National Aeronautics and Space Administration (NASA) that have been explored in studies.

2.14. Optical Remote Sensing

Optical RS sensors are passive sensors that make use of the sun's energy. The USGS Landsat, NASA'S MODIS, and the ESA's Sentinel-2 among many others are some optical remote sensors that have been used by several scientists including water researchers for monitoring and managing water resources. This research focuses on passive RS sensors. Passive sensors can be either airborne or spaceborne sensors based on the platforms launched. Images from these sensors can be multispectral or hyperspectral based on the spectral and spatial resolutions as described in the subsequent subsection.

2.15. Spectral Imaging

Spectral imaging is the acquisition of several digital images at a different and well-defined number of optical wavelengths. The passive optical remote sensors are categorized as multispectral or hyperspectral images based on the spectral resolution of the sensors used. Multi and hyperspectral RS images have been used in several studies including water and land observation monitoring.

Hyperspectral and multispectral satellite missions offer the opportunity for the detection of species-specific spectral features. This functionality of the sensors was postulated as far back as the 1990s and is a reality today. Multispectral systems collect data in 3–10 spectral bands in a single observation from the visible and the near-infrared range of the electromagnetic spectrum. The spectral bands of multispectral bands range from 0.4 to 0.7 µm for red-green-blue, and infrared wavelengths within the range of 0.7–10 µm, or more for near, middle, and far infrared. The use of multispectral images is, however, restrictive because the spectral resolution of the images influences the quality and quantity of the information they can provide.

Several multispectral sensors have been successfully used in the estimation of several WQPs. These include Landsat sensors, which have been used for the estimation of TSM, COD, and TP.

There have, however, been advances in sensor development through the development of hyperspectral sensor technologies to overcome the limitations of multispectral sensor systems over the past two decades. Hyperspectral systems can collect and store several hundred spectral bands in a single acquisition producing much more detailed spectral data and high spectral resolutions in the third dimension. They have been widely applied in medical imaging, processing, food safety testing, and agricultural yield. Hyperspectral RS applications offer an effective mechanism for frequent, synoptic water quality monitoring over a large spatial extent. They have been used in several studies including studies to distinguish between cyanobacterial and algal blooms in inland waters. Several hyperspectral sensors have been developed and have been applied in several studies. Some of the hyperspectral satellite missions include NASA's Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE), Germany's Environmental Mapping and Analysis Program (Nmap), ESA's Fluorescence Explorer

(FLEX), Italy's PRecursore IperSpettrale della Missione Applicativa (PRISMA), and India's Hyperspectral Imaging Satellite (HySIS). Other miniature hyperspectral sensors used for image acquisitions and monitoring missions include Norway's HySpex VNIR, US' Micro- and Nano-Hyperspec, and Germany's Fire- flEY, which can be installed on manned or unmanned airborne platforms such as Unmanned Aerial Vehicle (UAVs), airplanes, or helicopters. There are different hyperspectral cameras for image acquisition. These include push broom, whiskbroom, and snapshot cameras. The principle used by each hyperspectral sensor is a function of its ability to obtain the whole picture referred to as a snapshot at one time, one point of the picture known as whiskbroom, or one line of the picture called push broom.

Hyperspectral sensors collect 200 or more bands, enabling the construction of a continuous reflectance spectrum for all the pixels in the scene. Hyperspectral RS has been applied in a variety of water resource studies including flood detection, water quality monitoring, wetland mapping, estimation of bathymetry, land-use and vegetation classification, and evapotranspiration, among others. Despite the emergence of hyperspectral images, multispectral sensors have been the preferred sensors for the mapping and monitoring of WQPs including salinity and TSS due to the low cost of image acquisition.

2.16. Platforms: Satellites to Complementary Drones

Most recent techniques using one sensor, or a combination of sensors, are done remotely using satellites systems. Radar satellites supply a choice of resolutions and polarizations. Serious efforts have been made to replace airborne remote sensing with satellite remote sensing. However, satellites face the limitations of overpass frequency and low spatial resolution, and the long time needed for processing the dataset, potentially disrupting oil spill contingency planning. This limitation has been improved using satellite constellations. A combination of satellite and airborne sensors is used in many countries in northern Europe for oil spill surveillance. The strategic planning is based on satellite imagery that supplies a synoptic view of the oil spill, while airborne sensors are used for short-term or tactical responses. Contrarily to visible and radar sensors, due to the high atmospheric absorption and scattering, many sensors including the infrared and the fluoro-sensors are not suitable to be run on a space-borne platform.

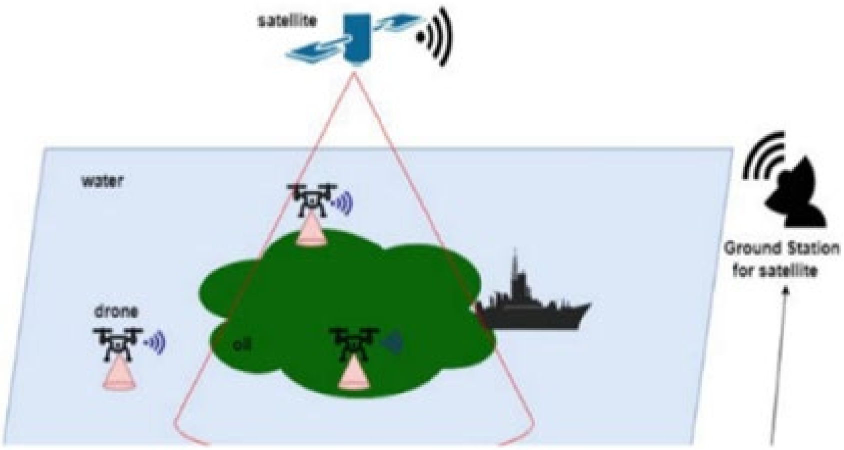

Figure 1: Satellite Based Drone

Despite all the effort done using space-borne platforms, only 25% of the pollution cases are detected by satellite systems. For a quick response and rapid intervention, the European Maritime Safety Agency (EMSA) has proposed using drones as complementary systems in satellite maritime surveillance. Aerial surveillance could be improved significantly through the introduction of drones because it is a quick assessment tool for oil spill accidents. In addition, drone-based tools will be particularly valuable as it supplies high spectral resolution, at a low cost.

2.16.1. Features for Good Monitoring

Once a spill occurs, the oil will spread quickly on the water surface to form oil layers such as slicks, films, and sheens. To alleviate the severity of oil spills and promptly react to such incidents, it is crucial to have oil-spill monitoring systems that enable an effective contingency plan. ("Recent Advances in Oil-Spill Monitoring Using Drone-Based Radar Remote ...") A rapid response time and a quick intervention allow dictating the best actions to deal with oil spills. Therefore, monitoring systems must perform several functionalities and supply valuable information to have the damage. According to Saleem et al., in crude oil detection, the following processes are paramount:

2.17. A Review of Dynamic Drone Device

A dynamic drone is a flying robot that can be remotely controlled or fly autonomously using software-controlled flight plans in its embedded systems. ("Drones have come a long way since their early days") UAV drones are equipped with different ultramodern technology such as infrared cameras, GPS, and laser. These features are good at surveillance and can help detect oil spillage. Using drones for in Agriculture can increase the accuracy of field data and save time as well. Drones not only send 2D view of earth but also can collect point clouds for 3D for physical and manufactured objects easily and rapidly. Obtaining precise and right data on land and water bodies are a pre-requisite for making effective and prompt economic and strategic plans in a densely populated country such as Nigeria. Therefore, use of Drones, now has become an important part of national planning and development schemes for the country.

Figure 2: A Dynamic Drone Device

2.17.1. Working Principle of Drone and Flow Pattern

The subject of Fluid dynamics plays a significant role in the design and development of planes and drones. This consists of the working principle of the aerodynamics of planes. Enough upward force is needed to lift the vehicle against gravity which is named Lift. A force created to move the vehicle or body in motion is called thrust. These forces can be studied using the kinematic laws of fluid flows. When air flows over an aerofoil and pressure, viscous and drag force act on the profiles. Force is directly proportional to the velocity of air at the inlet. The flow pattern around the cross-section of the aerofoil or propeller is shown below. "High fluid pressure at the bottom and low pressure at the top of the propeller causes an upward force which is called a lift." (“Working Principle and Components of Drone - Flow Engineering”) This force manages lifting the weight of an aero-plane or drone.

The amount of lift force depends on the angle of inclination of the aerofoil or propeller. Based on the principle of conservation of energy in fluid flow (Bernoulli’s principle, the sum of all forms of energy in a fluid is constant along the streamline. When air flows over an aerofoil or wing, its velocity increases at the top part. But the pressure of air decreases. In contrast, the air velocity decreases, and pressure increase at the bottom side of the blade. The next pressure difference across the aerofoil results in an upward force which is called a lift.

2.17.2 Major Components of a Dynamic Drone

According to Jiang et al., a dynamic drone is made up of various parts. These parts are important during the assembly stage in dynamic drone development. They include:

- **The Frame:** It should have sufficient strength to hold the propeller momentum and added weight for motors and cameras. It should be Sturdy and less aerodynamic resistance.
- **Propellers:** The speed and load lifting ability of a drone depends on shape, size, and number of propellors. The long propellors create huge thrust to carry heavy loads at a low speed (RPM) and less sensitive to change the speed of rotation. Short propellors carry fewer loads. They change rotation speeds quickly and require a high speed for more thrust.
- **Motor:** Both motors brushless and brushed type can be used for drones. A brushed motor is less expensive and useful for small-sized drones. Brushless type motors are powerful and energy very efficient. But they need Electronic Speed Controller (ESC) to control their speed. These brushless motors are widely used for racing freestyle drones, traffic surveys and aerial photography drones.
- **ESC (Electronic Speed Controller):** ESC is used to connect the battery to the electric motor for the power supply. It converts the signal from the flight controller to the revolution per minted (RPM) of motor. ESC is provided to each y motor of the drone.
- **Flight Controller (FC):** It is the computer processor which manages balance and telecommunication controls using different transmitter. Sensors are in this unit for the accelerometer, barometer, magnetometer, gyro meter and GPS. The distance measurement can be conducted by an ultrasound sensor.

Others such as the Radio Transmitter sends the radio signal to ESC to pilot to control motor speed, the Radio Receiver receives the signal from the pilot. This device is attached to the quadcopter and the Battery (High-power ability, Lithium Polymer (LiPo)) is used for most dynamic drones.

Figure 3: Basic Components of a Drone Device

2.17.3 Development of a Dynamic Drone

The working principle of drones is like the flying of aeroplanes. The vertical lift force is created due to pressure difference across the rotating blades. ("Working Principle and Components of Drone - Flow Engineering") The drag and gravity forces act against its vertical motions. By controlling the speed and directions of different rotors we can control the motion of the drone or UAV. Drones consist of mechanical, electrical, and electronic components all of which perform a strategic function on the drone. The Payload of drone, Number, and speed of propellors, Aerodynamics of propellors, spacing between the propellors, lift coefficient of drone, the thrust generated by the drone decide the aerodynamic design of the drone. CFD modelling will help to perfect the aerodynamics and applications of drone.

Additionally, diverse types of drones, including fixed-wing, rotary-wing, and flapping-wing systems, can be developed. Furthermore, various environments where drones can be deployed are considered, such as aerial, underwater, marine, and space. Modelling, analysis, and discussions on the bioinspiration and biomimicry side of drones are also appreciated to better understand the locomotion of biological systems and their effectiveness. ("Drone Design and Development - A section of Drones - MDPI"). To reach best efficiency and endurance, aerodynamic, structural, fluid–structure interaction modelling should be performed analytically, numerically, or experimentally during development. The primary stages of development include the modelling of the drone to give it a definitive design, the assembly of its various parts and the configuration of the drone. During the configuration, the drone is programmed to do specific jobs including getting a 3D image of agricultural lands which can be especially useful in surveillance during oil spillage monitoring.

Figure 2: Development of A Drone Device

2.18. Theoretical Framework

2.18.1 Sustainable Livelihood Theory

This theory was used here to support each other in parts in which there is a gap that would promote the achievement of an approach to management and detection of oil spillage in Nigeria. The Brundtland Commission proposed the concept of sustainable livelihoods for the first time in its 1986 World Commission on Environment and Development report. An international conference in 1992 called for sustainable livelihoods to be adopted as an overall aim in the fight against poverty. Skills, activities, and resources necessary for making a living are included in a sustainable way of life according to Knutsson. It is also important to support or increase one's ability and assets today and, in the future, without damaging the natural resource base, for a lifestyle to be considered sustainable. As told by Morse et al., social, health, and educational aid are the primary building blocks of this strategy. There is a lack of water and grazing land, as well as security issues, which makes it difficult for residents to access their possessions. An international framework for sustainable livelihoods, represented in Figure 2, was employed in this study as a beginning point for the research. The asset portfolio, which is a sign of a person's basic means of subsistence; vulnerability context and policy; institutions and procedures; and the loop connecting a person's methods for subsistence with his or her actual results, according to the Department for International Development.

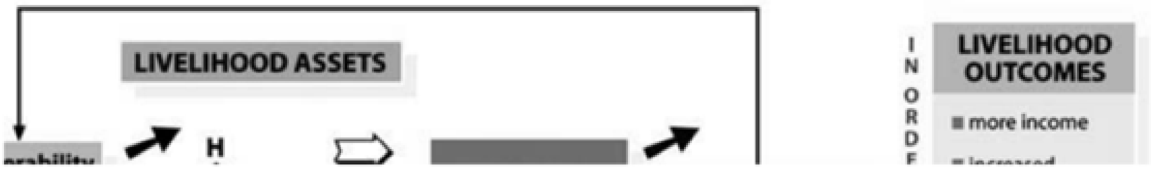

Figure 5: Sustainable Livelihood Framework (Source: DFID, 2008).

For this research, the Sustainable Livelihoods approach is a good fit because it clearly demonstrates the impact of various oil-related activities on specific livelihoods promoting activities like pastoralism or small-scale farming as well as other physical and social infrastructures in the oil drilling fields. There is a significant rate of residents giving up their traditional sources of income to work in the oil industry. Considering the oil industry's cyclical nature, the subject of the long-term viability of the local economy should constantly be on the table. Investment in infrastructure, water supplies, and urban growth have all resulted from oil and gas exploration because of corporate social responsibility from the investors. However, these studies failed to explore the sustainability principles of the first developments which come with these kinds of initiatives, a problem which this study investigated under the idea of sustainable livelihoods. An economic crisis could occur if local communities as well as investors do not have adequate policies in place to strengthen their capacity and educate them on the importance of diversifying their sources of income. People participation and engagement, empowerment, and sustainability in resource and structure use are all part of the sustainable livelihoods approach's essential normative concepts for addressing community difficulties.

People-centred sustainable livelihood strategy, says Carney, means that the focus should be on the livelihoods of poor people rather than the resources or services they utilize. It should empower the people and give them a voice in their own lives. This strategy also should be responsive and participative to encourage the active participation of individuals in identifying and addressing their own problems. Her decisive point is to emphasize the importance of incorporating economic, social, and ecological sustainability into all aspects of the project. Ecologically sustainable management in the context of oil and gas exploration is one of the goals of this study, which aims to push the agenda outlined above among the oil field communities. In Nigeria's extractive oil industry, procedures must be put in place to achieve a balance between oil and gas exploration, management of people' livelihoods, and ecology.

2.19. Research Gap

The extensive body of literature reviewed elucidates the multifaceted impacts of pollution on the Otamiri River's ecosystem, the health of its biodiversity, and the livelihoods of the communities that depend on it. Notably, advancements in drone technology for environmental monitoring have been identified as pivotal in assessing and addressing the river's water quality issues. The innovative application of drones, as discussed in the works of Bortoni et al., Ohaeri et al, and others, provides high-resolution, real-time data that can revolutionize the way water quality is monitored and managed [39,40]. This technology enables the capturing of comprehensive data across inaccessible areas, offering insights that are crucial for informed decision-making and effective policy implementation.

Identification of Research Gap Despite the advancements and applications of drone technology in environmental monitoring, there remains a significant gap in its deployment for the continuous and systematic assessment of water quality in the Otamiri River. Previous studies, while insightful, have not fully exploited the potential of drones for long-term monitoring and the integration of their data with traditional water quality assessment methods. There is a pressing need for an updated, efficient, and comprehensive approach to water quality monitoring that leverages the capabilities of drone technology to provide a more nuanced understanding of the spatial and temporal variations in the river's condition. This study aims to bridge this gap by developing a drone-assisted monitoring framework that can be integrated with existing management practices to enhance the resilience and sustainability of the Otamiri River and its surrounding ecosystems.

2.19.1. International Studies on Water Quality Assessment Using Drone Technology

Recent research has shown the growing trend of using drone technology for environmental monitoring across various geographic regions. For instance, a study conducted in the United States by utilized drones equipped with multispectral sensors to monitor nutrient runoff into freshwater systems [41]. Similarly, in Europe, a collaborative effort by the Water JPI (Joint Programming Initiative) has been experimenting with drone-based photogrammetry to study river dynamics and water quality [42].

In Asia, Zhou and Wang applied UAV technology to track pollution levels in the Chang Jiang, identifying critical points of industrial discharge [43]. These studies collectively highlight the versatility of drones in capturing spatial variability in water quality, which is often a limitation in traditional sampling methods.

2.19.2. Comparison with Best Practices

Internationally, best practices in drone-based water quality monitoring emphasize standardized protocols for data acquisition and analysis. The work of Garcia-Rodriguez et al., underlines the importance of calibration and validation against ground truth data to ensure accuracy [44]. These best practices can be compared to the methodologies adopted in the Otamiri River study, where similar protocols can be implemented to enhance the reliability of the findings.

2.19.3. International Standards for Water Quality

The World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) have set forth guidelines and standards for water quality that address a range of parameters such as turbidity, chemical composition, and microbiological content [45,46]. The study on Otamiri River should refer to these international standards to contextualize the significance of the findings, especially when considering the health implications and ecosystem impacts.

2.19.4. Relevance to Otamiri River Findings

The literature review should draw parallels between international standards and the specific conditions of the Otamiri River. For example, comparing the levels of contaminants found in Otamiri River to the thresholds set by the WHO can elucidate the severity of pollution and its potential health risks. Furthermore, examining how other studies have approached similar challenges can provide insight into remediation strategies and policymaking.

2.19.5. Technological Innovations in Drone-Based Water Quality Monitoring

Technological advancements have paved the way for more sophisticated sensors and analytical tools for water quality assessment. For instance, a study by Fernandez et al., highlighted the integration of hyperspectral imaging with drones to detect heavy metal concentrations in water bodies in South America [47]. In Australia, researchers have utilized thermal imaging from drones to monitor temperature fluctuations in water as indicators of certain types of pollution [48].

2.19.6. Data Processing and Analysis Techniques

Modern data processing techniques play a crucial role in interpreting the vast amounts of data gathered by drones. Machine learning algorithms have been employed to process drone-captured imagery and predict water quality metrics with high accuracy [49]. These techniques can be adapted to the Otamiri River study to analyse the spatial distribution of pollutants and their dispersion patterns.

2.19.7. Comparative Analysis with Other African Studies:

Drawing comparisons with similar environments, studies conducted on the Nile River and the Lake Victoria basin have utilized drone technology for environmental monitoring and have faced challenges akin to those expected in the Otamiri River study [50]. These studies offer valuable lessons on logistical, technical, and methodological aspects relevant to the Nigerian context.

2.19.8. Integration with Global Environmental Policies

The research findings on the Otamiri River can be aligned with global environmental initiatives such as the United Nations Sustainable Development Goals (SDGs), particularly Goal 6, which focuses on clean water and sanitation [51]. The study can contribute valuable data towards achieving these goals by identifying pollution hotspots and informing targeted clean-up efforts.

2.19.9. Public Health and Environmental Conservation

The implications of water quality on public health can be further discussed by referencing international research on the impact of waterborne diseases and the importance of maintaining ecological biodiversity in freshwater systems [52]. The Otamiri River study can contribute to this global narrative by highlighting the health implications of river pollution and advocating for conservation efforts.

2.20. Cross-Cultural Approaches to Water Quality Management

The cultural context and community practices surrounding water bodies significantly influence the strategies for water quality management. For instance, research by Ochieng et al., in Kenya highlighted how community-based water quality monitoring, combined with drone surveys, led to more engaged conservation practices [53]. Such community-centric approaches may offer insights into engaging local populations around the Otamiri River.

2.20.1. Economic Impact of Water Quality on Development

The economic ramifications of water quality are not limited to public health but also extend to development sectors such as agriculture, fisheries, and tourism. A study by in India demonstrated how water quality directly affects the livelihoods of communities dependent on riverine ecosystems [54]. Similar economic assessments can be conducted for the Otamiri River to underscore the importance of maintaining high water quality standards.

2.20.2 Climate Change and Its Impact on Water Quality

Global climate patterns have a profound effect on water quality dynamics, with increased weather variability often leading to more frequent pollution events. Research on the Mekong Delta by Tran et al revealed how climate-induced changes affect river systems [55]. Incorporating climate change variables into the Otamiri River study can align it with global environmental research trends.

2.20.3 Policy Implications and International Collaboration

The Otamiri River study can inform not only local but also national and international policy frameworks. The European Water Framework Directive (WFD) provides a policy model that promotes integrated river basin management, which may have parallels to the Nigerian context [56]. International collaboration, such as sharing best practices and data exchange, could enhance the study's relevance and application.

2.20.4 Utilizing International Water Quality Indices

Standardized water quality indices, like the Water Quality Index (WQI) used by the United States Environmental Protection Agency (EPA), can serve as benchmarks for comparison and evaluation. Integrating such indices into the study's methodology could allow for a standardized assessment of the Otamiri River's water quality [57].

2.20.5 Technological Advancements in Water Quality Monitoring

Advancements in technology have revolutionized the methods of water quality monitoring. A study Zhang, et al., by in China used satellite-based remote sensing in conjunction with drone technology to monitor large river systems, demonstrating the scalability of these technologies [58]. Similar innovative approaches can be applied to the Otamiri River study to enhance the accuracy and comprehensiveness of water quality assessments.

2.20.6 Impact of Urbanization on River Systems

Urbanization significantly impacts river systems, often leading to increased pollution and ecological degradation. Research by Santos et al., in Brazil showed how urban sprawl affects water bodies, providing valuable insights into managing river systems in rapidly urbanizing regions [59]. These findings can be relevant to the Otamiri River, particularly given the urban context of Imo State.

2.20.7 Role of Community Engagement in Water Quality Management

Community engagement plays a critical role in effective water quality management. A study by Johnson & Wilson in the United States highlighted the success of community-led initiatives in monitoring and improving water quality [60]. Incorporating community-based approaches in the Otamiri River study can lead to more sustainable and locally driven solutions.

2.20.8 Global Environmental Health and Safety Standards

International standards and guidelines set by organizations like the World Health Organization (WHO) and the International Standards Organization (ISO) offer frameworks for assessing and managing water quality. The Otamiri River study can reference these standards to contextualize its findings within a global framework [61,62].

2.20.9 Best Practices in Drone Technology for Environmental Monitoring

Best practices in drone technology for environmental monitoring are continually evolving. A review by Thompson et al., provides an overview of the latest developments in drone-based environmental monitoring, including water quality assessment [63]. These practices can guide the methodologies employed in the Otamiri River study.

2.21. Sustainable Water Resource Management

Sustainable water resource management is critical in maintaining ecological balance and supporting human activities. A study by Martinez et al., in Spain highlights how sustainable practices can be integrated into river management, including pollution control and ecosystem restoration [64]. These practices can provide valuable guidelines for managing the Otamiri River sustainably.

2.21.1 Drones and Artificial Intelligence in Water Quality Monitoring

The integration of artificial intelligence (AI) with drone technology is an innovative area in water quality monitoring. Research by Lee & Kim demonstrated how AI algorithms can process drone-captured imagery to identify pollution sources and assess water quality parameters efficiently [65]. Implementing AI in the Otamiri River study could significantly enhance data analysis and interpretation.

2.21.2 Global Warming and Its Impact on Water Quality

Global warming poses a significant threat to water quality, altering hydrological cycles and affecting pollution dynamics. Studies on the impact of global warming on river systems, such as the work by Singh et al., on the Ganges River, offer insights into potential future challenges for the Otamiri River [66].

2.21.3 Collaborative International Efforts in Water Quality Monitoring

Collaborative efforts, such as those under the United Nations Environment Programme emphasize the importance of international cooperation in addressing water quality issues [67]. The Otamiri River study can contribute to these efforts by sharing data and insights with global initiatives.

2.21.4 Water Quality and Public Health:

The relationship between water quality and public health is a critical area of research. The study by O'Reilly et al on the association between waterborne diseases and river pollution provides a context for understanding the health implications of the Otamiri River's water quality [68]. The relationship between water quality and public health is a critical area of study. Research by Singh et al, examines the direct impact of polluted river water on the health of nearby communities, emphasizing the importance of maintaining high water quality standards [69]. Applying these insights to the Otamiri River can highlight the potential health implications of its current water quality status.

2.21.5 Innovations in Water Quality Data Analytics

Innovative data analytics techniques are reshaping how water quality is monitored and analysed. A study by Gupta and Kumar on the application of big data analytics in river water quality assessment offers insights into how large datasets from diverse sources, including drones, can be effectively utilized [70]. Applying these techniques to the Otamiri River study could significantly enhance the understanding and management of its water quality.

2.21.6 Water Quality Governance and Policy Frameworks

Effective governance and robust policy frameworks are crucial for sustainable water quality management. Research by Nkonya et al, explores how policy interventions and governance mechanisms can improve river water quality in sub-Saharan Africa [71]. Insights from this research could inform policy recommendations for the Otamiri River based on the study's findings.

2.21.7. Impact of Agricultural Practices on River Water Quality

Agricultural activities significantly influence river water quality. A comparative study by Rodriguez et al. on the impact of different agricultural practices on river ecosystems in Europe and Asia highlights the need to consider agricultural runoff in water quality assessments [72]. This aspect is particularly relevant for the Otamiri River, given the agricultural activities in its catchment area.

2.21.8. Role of Citizen Science in Water Quality Monitoring

Citizen science initiatives in water quality monitoring have gained popularity, provided valuable data, and engaged local communities. A study by Fischer and Newman demonstrates the potential of citizen science in complementing traditional monitoring methods [73]. Engaging local communities around the Otamiri River in such initiatives could enhance data collection and foster environmental stewardship.

2.21.9. Climate Change Adaptation Strategies for Water Quality

Adapting to climate change is critical for maintaining water quality. Research by Thompson and White on climate change adaptation strategies for water resources emphasizes the need to consider climate impacts in water quality studies [74]. This perspective is vital for future-proofing the Otamiri River's water quality management strategies.

2.21.10. Remote Sensing and GIS in Water Quality Assessment

The integration of remote sensing and Geographic Information Systems (GIS) in water quality assessment is becoming increasingly prevalent. A study by Wei et al, on the use of remote sensing and GIS for tracking water pollution in large river basins illustrates how these tools can enhance spatial analysis and environmental monitoring [75]. This approach could be highly beneficial for comprehensive mapping and analysis of the Otamiri River.

2.22. Ecosystem Services and River Health:

Understanding the relationship between ecosystem services and river health is crucial for sustainable water resource management. Research by Johnson and Williams examines how rivers provide essential services and the impact of pollution on these services [76]. This perspective can offer a holistic view of the Otamiri River's ecological significance and the implications of water quality degradation.

2.22.1 International Case Studies on Drone-Assisted Water Monitoring

Comparative analyses of international case studies on drone-assisted water monitoring can provide valuable lessons and insights. For instance, a study by Sanchez et al., on the application of drone technology in the Amazon Basin shows how drones can be used effectively in diverse and challenging environments, offering parallels to the Otamiri River context [77].

2.22.2 Public Policy and Stakeholder Engagement in Water Management

Public policy and stakeholder engagement are pivotal in effective water management. A study by Patel and Kumar explores successful models of stakeholder involvement in river management projects, highlighting the importance of community participation and multi-stakeholder approaches [78]. These insights can inform strategies for involving local communities and policymakers in the Otamiri River study.

2.22.3 Advanced Analytical Techniques in Water Quality Research

The use of advanced analytical techniques, such as machine learning and statistical modelling, is transforming water quality research. Research by Zhang and Li demonstrates how machine learning algorithms can predict water quality parameters with high accuracy [79]. Incorporating such advanced techniques can enhance the predictive analysis of the Otamiri River study.

2.22.4 Socio-Economic Impacts of Water Quality

Examining the socio-economic impacts of water quality on communities is essential. A study by Kim and Park in South Korea explored the economic costs associated with river pollution, including impacts on health, agriculture, and tourism [80]. Understanding these aspects in the context of the Otamiri River can provide insights into the broader implications of water quality on local economies and livelihoods.

2.22.5 Biological Indicators in River Health Assessment

The use of biological indicators for assessing river health is an evolving field. Research by Thompson et al, highlights the effectiveness of using aquatic flora and fauna as indicators of water quality [81]. Applying such biological assessments to the Otamiri River could complement physical and chemical analyses, offering a more comprehensive view of the river's ecological status.

2.22.6 Drone Regulations and Ethical Considerations

As drone technology becomes more prevalent in environmental research, understanding the regulatory and ethical considerations is crucial. A study by Patel and Singh reviews the legal frameworks governing drone usage in environmental monitoring, emphasizing the importance of adhering to regulations and ethical guidelines [82]. This perspective is critical for the responsible use of drones in the Otamiri River study.

2.22.7 Global Climate Change and River Systems

The impacts of global climate change on river systems are a major concern. Research by Johnson and Lee investigates how climate change affects river flow patterns, water quality, and aquatic ecosystems [83]. These findings can inform the Otamiri River study, particularly in modelling future scenarios and adaptation strategies.

2.22.8 Water Quality Education and Awareness

Education and awareness programs play a significant role in water quality management. A study by Zhang and Wong on the effectiveness of educational initiatives in promoting water conservation and pollution prevention shows the potential of these programs in fostering sustainable water use practices [84]. Implementing similar initiatives in the Otamiri River region could enhance community involvement and awareness.

2.22.9 Technological Advancements in Water Quality Monitoring

Exploring innovative technological advancements in water quality monitoring is crucial. A study by Martinez and Fernandez investigates the latest sensor technologies for real-time water quality monitoring [85]. These advancements can significantly enhance the accuracy and timeliness of data collection for the Otamiri River study, providing a more dynamic understanding of water quality changes.

2.23. Sustainable Water Management Practices

Investigating sustainable water management practices is key to addressing water quality issues. A study by Garcia and Lopez focuses on integrated water resource management strategies that include pollution prevention, conservation, and stakeholder involvement [86]. These practices could be relevant for developing sustainable solutions for the Otamiri River.

2.23.1 Global Environmental Policies on Water Quality

Understanding global environmental policies related to water quality can provide a broader context for the study. Research by Garcia and Lopez on the influence of international environmental agreements on national water policies could offer insights into how Nigeria's water policies align with global standards and practices [87].

2.23.2 Community Involvement in Water Quality Monitoring

The role of community involvement in water quality monitoring is increasingly recognized. A study by Ortiz and Gonzalez explores community-based monitoring programs and their effectiveness in enhancing local engagement and improving water quality [88]. Such approaches could be beneficial for the Otamiri River study, fostering a sense of ownership and responsibility among local communities.

3. Materials and Methods

3.1. Materials

3.1.1 Materials Selection

- **Drone:** A drone will be used to collect data on water quality parameters such as temperature, pH, dissolved oxygen, and turbidity. The drone will be equipped with sensors for measuring these parameters.
- **Memory Card:** A memory card will be attached to the drone to store the data collected during the flight.
- **Software:** Software such as ArcGIS and Python will be used for data processing and analysis.
- **Traditional Water Sampling Equipment:** Traditional water sampling equipment such as water sampling bottles, thermometers, pH meters, and turbidity meters will be used to collect water samples for validation of the drone data.
- **Laboratory Equipment:** Laboratory equipment such as spectrophotometers, pH meters, and turbidimeters will be used for the analysis of the water samples collected using traditional water sampling methods.
- **GPS:** A GPS device will be used to record the coordinates of the sampling locations and the drone flight paths.
- **Safety Equipment:** Safety equipment such as life jackets, helmets, and first aid kits will be provided for the field team.
- **Communication Equipment:** Communication equipment such as walkie-talkies and mobile phones will be used for communication between the field team and the laboratory.

3.1.2. Study Area

One of the major rivers in Imo State, Nigeria is the Otamiri River. The river flows to the Atlantic Ocean at Ozuzu in Etche, in Rivers State, after passing through Nekede, Ihiagwa, Eziobodo, OlokwuUmuisi, Mgbirichi, and Umuagwo all the way from Egbu past Owerri. The kilometers (19 miles) long from its source to where it meets the Uramiriukwa River at Emeabiam. With an average annual rainfall of 2,250 to 2,500 millimetres (89 to 98 miles), the Otamiri watershed has a surface area of around 10,000 square kilometers (3,900 square miles). The 9.2 km (5.7 mi) long Nworie River, which originates in Owerri, joins the Otamiri at Nekede.

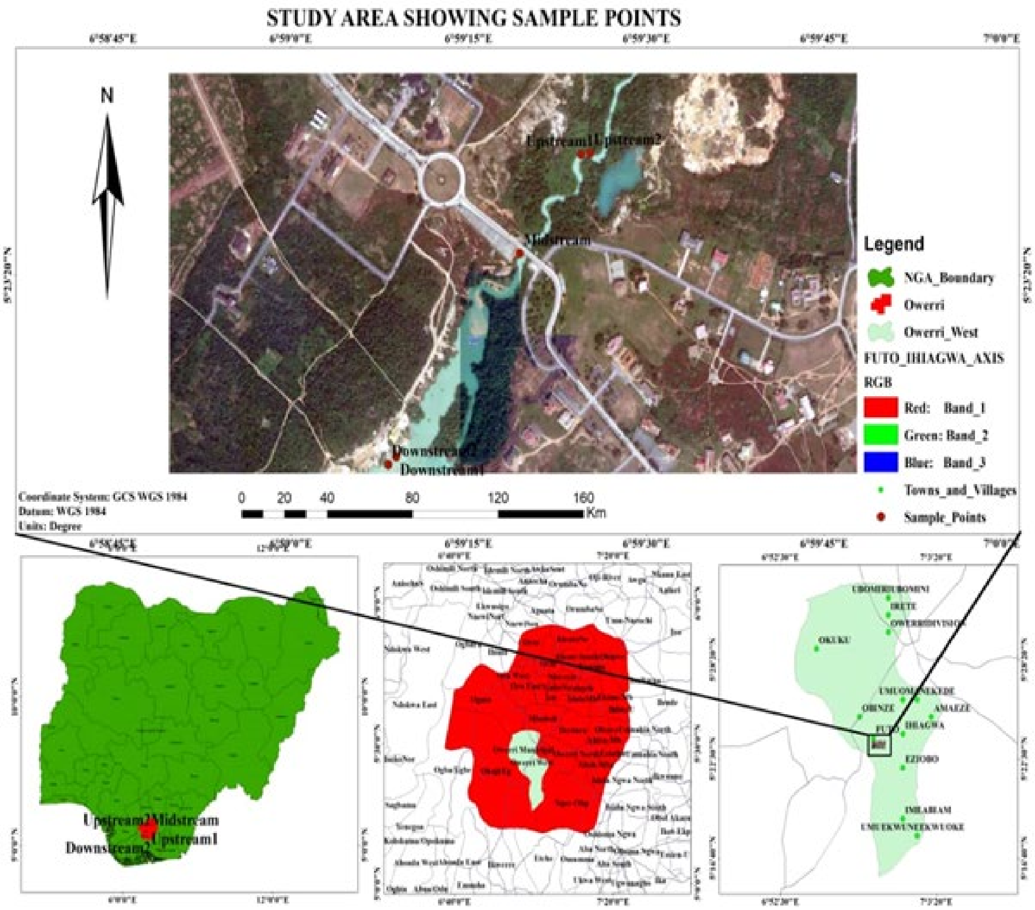

Figure 6: Map of the Study Area

3.2 Method

3.2.1. Collection of Water Samples

Water samples will be collected at the 0-15 and15-30cm depths from 5 sampling points and a control point located outside the contaminated-impacted area.

3.2.2 Laboratory Procedures

The laboratory procedures to be used for the analysis of the water samples collected during the assessment of water quality of Otamiri River using drone technology will include the following:

1. Temperature: The temperature of the water samples will be measured using a thermometer. The thermometer will be calibrated before use. The temperature will be recorded in degrees Celsius.

2. pH: The pH of the water samples will be measured using a pH meter. The pH meter will be calibrated before use. The pH will be recorded on a logarithmic scale.

3. Dissolved oxygen: The dissolved oxygen content of the water samples will be measured using the Winkler method. The Winkler method involves adding reagents to the water sample to precipitate the dissolved oxygen as manganese dioxide. The manganese dioxide is then titrated with a standardized solution of sodium thiosulfate.

4. Turbidity: The turbidity of the water samples will be measured using a turbidimeter. The turbidimeter will be calibrated before use. The turbidity will be recorded in nephelometric turbidity units (NTU).

5. Total suspended solids (TSS): The TSS of the water samples will be measured by filtering a known volume of the water sample through a pre-weighed filter paper. The filter paper will be dried and then re-weighed. The difference between the initial and final weights will give the TSS of the water sample.

6. Chemical oxygen demand (COD): The COD of the water samples will be measured using the open reflux method. The open reflux method involves digesting the water sample with a mixture of potassium dichromate and sulfuric acid. The residual potassium dichromate will be titrated with a standardized solution of ferrous ammonium sulfate.

7. Biological oxygen demand (BOD): The BOD of the water samples will be measured using the standard BOD method. The BOD method involves incubating the water sample in a BOD bottle for five days at a constant temperature. The amount of oxygen consumed by the microorganisms in the water sample during the incubation period will be calculated.

8. Color: This will be determined using the color chat method.

The laboratory procedures will be conducted following standard methods recommended by the American Public Health Association (APHA), the United States Environmental Protection Agency (USEPA), and the National Environmental Standards and Regulations Enforcement Agency (NESREA) in Nigeria.

3.2.3. Statistical Analysis

Descriptive statistics were used to present mean, standard error, minimum and maximum values as well as range of data. The Pearson correlation will be used to explore the factors that affected the water quality. The one-way analysis variance (ANOVA) will be used to test homogeneity in mean variance of factors while the post hoc means plot will be used to detect structure of group means. Variations plots will be used to elucidate spatial variations.

3.2.4. Float Method of Measuring River Velocity

3.2.4.1. Equipment Needed

- A floating object (e.g., a brightly coloured ball, a piece of wood, or a specifically designed float)
- A stopwatch or timer
- Measuring tape or a pre-measured stretch of riverbank
- Notepad and pen for recording data

3.2.4.2. Procedure

- **Selection of the Float:** Choose an object that floats well and is visible from a distance. The float should have minimal submersion to reduce the effect of undercurrents and should not be too large to avoid being affected by wind.
- **Measuring the Course:** Identify a straight section of the river with uniform flow. Using the measuring tape, measure a known distance along the riverbank. This stretch is where the velocity will be measured. Common distances range from 10 to 30 meters, depending on the river size and flow conditions.
- **Starting Point and Endpoint:** Clearly mark the start and end points of the measured section. These points should be easily visible from where you will observe the float (5meters marked out).
- **Release of the Float:** Place the float in the river upstream of the starting point, allowing it sufficient time to reach the average velocity of the river before it crosses the starting point.
- **Timing the Float**: As the float crosses the starting point, start the stopwatch. Stop timing when the float crosses the end point. It is crucial to be as accurate as possible with timing to ensure reliable data.
- **Repeat Measurements:** To account for variations in flow and any potential errors, repeat the measurement several times. Use the same float and the same stretch of the river for consistency.
- **Recording Data:** Note down the times for each trial, along with any observations about river conditions, weather, and potential disturbances like wind or obstacles.

3.3. Calculations

- **Average Time:** Calculate the average time taken for the float to travel the measured distance across all trials.
- **Velocity Calculation:** Divide the measured distance by the average time to obtain the average velocity of the river in that section.

Velocity (m/s)=Distance (m)/Average Time (s)

3.4. Considerations

- **Accuracy:** The float method provides an approximation of surface velocity, which may be different from the average velocity throughout the river's depth and width.
- **Surface Flow:** This method measures the velocity of the surface flow, which is faster than the flow near the riverbed due to frictional forces.
- **Environmental Conditions:** Wind, waves, and other environmental factors can affect the float's movement and, consequently, the accuracy of the measurements [89-93].

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