NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) EVALUATION OF GAS FLARING ON VEGETATION-A 1991-2013 CASE STUDY OF AWOBA FLOWSTATION, SOUTHERN NIGERIA.

BY

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LSC1806590

AN UNDERGRADUATE PROJECT SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, NIGERIA; IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF BACHELOR OF SCIENCE (B.Sc) DEGREE IN ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY.

APRIL, 2024

CERTIFICATION

This is to certify that this research titled “**Normalized Difference Vegetation Index (NDVI) Evaluation of Gas Flaring On Vegetation- A 1991-2013 Case Study of Awoba Flow station, Southern Nigeria**” was carried out by **“OMOREGBEE GIFT ELOGHOSA”**and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City; in partial fulfillment of the requirements for the award of Bachelor of Science (B.Sc) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of Bachelor of Science degree in Environmental Management and Toxicology.

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DECLARATION

I "**OMOREGBEE GIFT ELOGHOSA**" declare that "**Normalized Difference Vegetation Index (NDVI) Evaluation of Gas Flaring On Vegetation- A 1991-2013 Case Study of Awoba Flowstation, Southern Nigeria**" is my own work and that all sources that I have used or quoted have been acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other University.

……………………………………….. …………………………

OMOREGBEE GIFT ELOGHOSA **Date**

DEDICATION

I dedicate this Project Report to the Almighty God for His endless favor, protection, grace, blessing and mercy upon my life throughout this period. Also, I want to dedicate this work to my family, for their financial and moral support and encouragement which helped make this possible.

ACKNOWLEDGEMENTS

My profound and sincere gratitude goes to the Almighty God, the Sole of my existence and the main reason for the success of this project work. He made this possible even when things seemed to be going out of place.

I wholeheartedly appreciate my highly esteemed supervisor Dr. C.F Amaechi for his unrelenting efforts, commitment and assiduity to make sure this work was well done and presented in a way its essence would be best communicated. He was indeed the motivation behind this research. I also want to appreciate Dr. Charles for his assistance. To my wonderful and supportive course adviser, Dr. Osayomwanbo Osarenotor thank you for immense support and encouragement, it really meant a lot.

I am grateful to all lecturers and staff of the Department of Environmental Management and Toxicology.

My heartfelt appreciation goes to my ever loving and caring parents Mr. and Mrs. Edosa Omoregbee for their prayers, advice, love and finance given me during this my undergraduate program. To my Siblings, Gladys, Godfrey and Gabriel, thank you so much for believing in me.

To the Oriarewo's family, thank you for your great love and support.

To my friends Sadiku Monsura and Izekor Faith Itohan, thank you for the gift of friendship. To my course mates and fellow project mates, God bless you all.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: METHODOLOGY

CHAPTER FOUR: RESULTS

CHAPTER FIVE: DISCUSSION CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

Gas flaring which is the burning of associated gas from crude oil, is a common practice in Nigeria. The absence of a strong regulatory framework, which could be brought about by a lack of awareness of the effects on the environment, is one of the primary reasons for its continuous usage. This study makes use of Awoba flowstation as a case study to access the impacts of gas flaring on vegetation. The study assessed vegetation health with the use of GIS at marked distances of analyzed years. There have been numerous studies conducted to demonstrate the negative impacts of gas flaring on the environment, but none have attempted to measure the cumulative long-term impact on vegetation. Furthermore, there hasn't been much effort in Nigeria to use GIS to evaluate the effects of gas flaring. The Normalized Difference Vegetation Index (NDVI) a GIS based change detection methodology, was used to examine how the vegetation in the study area changed over time. This was accomplished by gathering four distinct time series of satellite imagery of the research area at specified distances of 1km and 2km, making use of Landsat 4-Thematic Mapper (TM)/1991, Landsat 5-Thematic Mapper (TM)/1999, Landsat 7-Enhanced Thematic Mapper Plus (ETM+)/2003 and Landsat 8-Operational Land Image(OLI)/2013. The results show that gas flaring has a significant role in altering the natural vegetation, with the impact of gas flaring being more pronounced in areas near the flowstation. Furthermore, results from the year 1991 showed that the NDVI values between 1km and 2km did not significantly differ from one another. However, the 1999,2003 and 2013 indicated significant difference in the NDVI values between marked distances. This study emphasizes the need for a safe distance of 2km for human settlement from gas flare stacks. This study recommends that Government should implement policies, such as the polluter pay principle and/or give out incentives to companies so as to reduce gas flaring.

CHAPTER ONE

INTRODUCTION

1.1. Background of Study

The burning of associated gas fields is known as gas flaring. In addition, it can refer to the procedure or act of releasing associated gas into the atmosphere while drilling for crude oil (Nwaogu, 2010; Ubani and Onyejekwe, 2013; Amaechi and Ajokpauwu,2022; Morakinyo, 2023; Abu *et al*. 2023).

Most industrialized nations flare natural gas as a safety precaution for the proper disposal of gas during emergencies or when equipment breaks down. However, flaring is common in underdeveloped nations because of its low cost and lack of the necessary technologies for gas harvesting or re-injection (Edino *et al.,* 2010 World Bank, 2003; Enam, 2015; Lu *et al*., 2020).

Many pollutants are released into the environment during the extraction of oil from natural gas, including carbon dioxide (CO2), methane (CH4), and black carbon, which makes up a sizeable portion of particulate matter(PM). We call this technique "gas faring" (Abu *et al*., 2023; Shabab *et al*., 2023).

The promotion of natural gas flaring may be attributed to several variables, the most common ones being weak governmental rules against flaring and inadequate infrastructure for either locally using or transporting gasses to markets (Elvidge, 2018; Zhang, 2019; Amaechi and Ajokpauwu, 2022).

In the modern energy market, crude oil is a significant participant. Oil-producing nations, like Nigeria, boost their output in order to keep up with the continuing rise in demand (Akpomuvie and Orhioghene, 2011).

According to data gathered by the World Bank's Global Gas Flaring Reduction Partnership (GGFR), as of 2022, the world's flared about 139 billion cubic meters (bcm), of associated gas annually, which was enough to power all of sub-Saharan Africa.

According to reports, the top ten flaring nations produce half of the world's oil and 75% of the world's gas flared (World Bank, 2023). Particularly, flaring has increased recently in Mexico, Libya, and China, whereas the world's top producers of natural gas- Russia, Iraq, Iran, the United States, Venezuela, Algeria, and Nigeria, have seen comparatively constant volumes of flared gas. Together, Russia, Iraq, Iran, the US, Algeria, Venezuela, and Nigeria are responsible for 65% of the world’s gas flaring production, making them important contributors to the issues brought on by gas flaring (World Bank, 2023).

The World Bank (2015) reported that the gas flared in Africa (37 bcm in 2000) could generate 200 TWh of electricity, or roughly 50% of the continent's current power consumption, and more than twice that of Sub-Saharan Africa, excluding the Republic of South Africa.

According to Abua and Ashua (2015), one of the more prolific gas flaring countries on the planet is Nigeria. According to the 2022 Global Gas Flaring Report, Nigeria flared 6.8 billion cubic meters (bcm) of gas in 2022, releasing 19.5 million tonnes of CO2 into the environment. In 2022 this quantity of gas flaring made up 4.7% of the gas flaring worldwide and 9.4% of Nigeria's entire gas output. In 2020, Nigeria came up at number seven on the global ranking of the top ten flaring nations (World Bank, 2023).

Both locally and globally, there is worry about the effects of gas flaring (Asadi and Farahani, 2018). Gas flaring is one of the most challenging energy and environmental concerns the world is currently facing, whether on a regional or global slevel. It is a multi-billion-dollar waste, a regional environmental disaster, and a long-standing worldwide energy and environmental issue (Ismail *et al*., 2012).

Carbon (IV) oxide (CO2), methane (CH4), nitrous oxide (NO2), water vapor, and sulphur dioxide (SO2) are the principal constituents of these flared gases (Atuma *et al*., 2013; World Bank, 2023).

The emissions of greenhouse gases (GHG) that contribute to global warming are largely caused by these flaring gases. If left unchecked, this might worsen the planet's already dire living circumstances and hasten the risk of climate change (Ajugwo, 2013; Ite and Ibok 2013; Akuirene *et al*., 2019; Amaechi and Emejulu, 2021).

Gas flaring, impacts the surrounding areas health and generate environmental issues like acid rain, which affects vegetation, making the soil to become more acidic, hindering the growth of some plants, degrade the soil, and lower agricultural production and prevents any flora from growing in the vicinity of the flare. (Chukuka *et al*., 2018; OGP 2000; Ite and Ibok 2013 Ajugwo, 2013; Amaechi and Emejulu, 2021).

According to research, crops in the Niger Delta experience a retardation in growth as a result of gas flaring, it has also been reported that it specifically impacts the physiochemical characteristics of soil in the area of flare locations and lowers the amount of chlorophyll in nearby plants (Dung *et al*., 2008; Seiyaboh *et al*.,2017; Amaechi and Emejulu, 2021; Amaechi and Ajjkpauwu,2022).

Globally, these effects have drawn the greatest attention and prompt remedial action. While the effects are more noticeable in poor nations like Nigeria, Angola, Libya, and others, where the technology to use this kind of energy has just lately been used slowly (Ismail *et al*.,2012).

Government must work to discourage this behavior in emerging nations by creating a financial, legal, and regulatory framework that encourages the use of gas (World Bank, 2023; Amaechi and Emejulu, 2021).

A significant supply of the active nutrients that the body needs is found in plants. Plants can provide you with fat, protein, carbohydrates, and other minerals and vitamins, depending on species. Some noteworthy plants, such as oil palm and cassava, may be found near residential areas and farms. Livestock, particularly herbivores like goats, cows, grass cutter rabbits, and so on, rely on vegetation as a source of food. Many animal species, particularly those of the wild, rely on vegetation cover as a source of habitat, Plants also stop soil erosion, (Izah *et al*. 2016; Seiyaboh *et al*., 2017).

Plants next to flare stacks have been documented to sustain physical harm as a result of gas flaring (Amadi, 2014).

According to research conducted by (Maduka and Tobin-west, 2017, gas flaring is the main cause of acid rain in Nigeria’s Niger Delta region, which has a negative impact on the fertility of the soil and plants.

There can be other downstream effects from this. Furthermore, gas flaring may change the physiochemical and microbiological properties of soil (Okeke and Okpala, 2014). Gas flaring frequently affects a number of significant soil quality factors, including pH, temperature, soil moisture, and soil microbial population (Ubani and Onyejekwe, 2013).

According to Okeke and Okpala (2014), several soil quality measures exhibited a reduction with distance from the flaring site, such as bulk density and temperature, whereas others, such moisture content, CEC, and organic matter, increased. The authors continued by saying that the gas flaring environment had less soil nutrients than the Niger Delta's Eket and Izombe areas, which served as the control.

The visible and near-infrared bands are subjected to electromagnetic spectrum analysis to create the Normalized Difference Vegetation Index (NDVI) is a numerical indicator. It is used to determine whether or not a target under observation has active, green vegetation (Tian *et al*. 2017). As a tool for estimating agricultural yields, pasture efficiency, and rangeland carrying capacity, among other things, NDVI has found extensive usage in vegetative research. As stated by Basith *et al*., (2010), it is frequently closely connected to other ground characteristics including the percentage of ground cover, the quantity of biomass, surface water, the photosynthetic capacity of the plant, and the leaf area index.

Ratios with values ranging from -1 to 1 are used to represent NDVI data. Aquatic conditions are indicated by negative NDVI readings (values that are close to -1). Elsewhere in rock, sand, or snow, values around zero (-0.1 to 0.1) are typically indicative of desolate regions. Lastly, high values denote temperate and tropical rainforests (values nearing 1), whereas low, positive values (about 0.2 to 0.4) signify shrub and grassland (Tian *et al*., 2017).

Optimizing the analysis of vegetation information using remotely sensed data is the overarching goal of NDVI. The Normalized Difference Vegetation Index (NDVI), according to research, is a helpful tool for differentiating between savannah, dense forest, non-forest, and agricultural sectors. It can also be used to estimate various vegetation properties, such as the Leaf Area Index (LAI) (Tian *et al*., 2017), biomass (Zhu and Liu 2015), chlorophyll concentration in leaves

(Pastor-Guzman *et al*. 2015), plant productivity (Vicente-Serrano *et al*., 2016), fractional vegetation cover (Dutrieux *et al*., 2015), and plant stress (Chavez *et al*., 2016).

A common method for deriving such estimations is to correlate the values of these variables observed on the ground with the remotely sensed NDVI values. The resilience of models connected to the NDVI is directly influenced by its dependability ((Butt. 2018).

1.2. Statement of Problem

Farmers in gas-flaring zones have long complained of low agricultural yields in these areas, citing soil and air pollution as the cause. This contamination affects crop yields by impairing vegetation (Amaechi and Ajokpauwu,2022).

Studies have shown how gas flaring has drastically changed Nigeria's land cover, how it has harmed biodiversity, impacted plants over time, polluted the soil, and had a negative impact on people—particularly those who live close to the flare source. Gas flaring will thus, if it is not reduced, have a major negative impact on the health of the local population living near the gas flaring sites and cause land difficulties (Nwaogu and Onyeze, 2020; Amaechi and Ajokpauwu,2022).

In the Niger Delta, according to a survey research, 77% of people believe that gas flaring has an impact on vegetation and agricultural operations (Adewale and Mustapha, 2015). Residents of the Ebedei village in Delta state, 94.6, 90, 98.75, 50.4, and 5% believe that gas flaring has an impact on foods including potatoes, yam, cassava, okra, and plantains (Ozabor and Obisesan, 2015). In addition, deforestation and acid rain are possible outcomes of gas flaring (Ozabor and Obisesan, 2015). The extraction of crude oil and related gas flaring, according to Ezenwaji *et al*. (2013), has a long history and is a major contributor to acid rain in the Nigerian Niger Delta area.

Acid rain could lead to loss of vegetation and several symptoms in plants that could lead to their death (Amadi, 2014). Some of the notable symptoms include chlorosis, abscission and yellowing of leaves, wilting of the leaf tips and accelerated senescence, root and shoot of plants are also destroyed and microbial community that aid in decompositions processes (Efe, 2011). The impacts of acid rain on vegetation structures and cover is most severe close to gas flaring stack (Efe, 2011).

In addition, minimal study has been done since gas flaring initially started in Nigeria regarding its long-term effects. Ishisone, (2004) claims that one of the main causes of the Nigerian government's absence of an effective gas flaring regulating strategy is the small number of studies conducted as well as the inadequate amount of environmental consciousness of the consequences of nationwide gas flaring. That is why it is still in use. Consequently, in order to accurately calculate the enormous environmental change that gas flaring has created, research assessing the long-term impacts of gas flaring on vegetation cover is crucial.

1.3. Aim and Objectives

Aim:

The aim of this study is to evaluate how gas flaring impacts the condition of health of vegetation around the Awoba flow station.

The specific objectives of this research are:

1. Select years with less than 10% cloud cover to determine vegetation cover to determine accuracy from 1991-2013.

2. Examine the impacts of emissions on the health of vegetation at marked distances.

3. Calculate the vegetation's chlorophyll reflectance index in relation to the gas stack's distance.

4. Determine if there is a significant difference on vegetation health overtime.

1.4. Justification

Research has connected vegetation to the consequences of gas flaring; yet, for a variety of reasons, the government and business community have not been able to considerably limit gas flaring. Therefore, this study's objective is to determine the temporal harshness of the vegetation. Since crude oil was discovered in the Niger Delta region, there hasn't been enough research conducted in Nigeria utilizing Geographic Information Systems (GIS) to assess the \\\impacts of gas flaring on vegetation. In addition, the bulk of research on how gas flaring affects vegetation relies more on public opinions gathered through surveys than on scientific methods (Odjugo and Osemwenkhae, 2009).

Therefore, a more sophisticated scientific tool would be required to fully assess the long-term consequences of gas flaring on the vegetation and land cover in the vicinity of gas flaring.

CHAPTER TWO

LITERATURE REVIEW

2.1. GAS FLARING IN NIGERIA

In the past, the Nigerian Bitumen Corporation, a German firm, began exploring for crude oil in 1908. The rights to exclusive exploration were granted to Shell D'Arcy in 1937. The Second World War interrupted oil prospecting in 1946, but it restarted in 1951 with the drilling of the first oil well at Ihuo in Owerri, Imo state. The initial operational oil well, which was at Oloibiri, Bayelsa state, poured out oil in 1956, marking a breakthrough, and the first oil was exported in 1958 (Obi *et al*., 2021; Ukala, 2010).

Following this, exploratory extensions sliced across other portions of the 75,000 km2 Niger Delta, which was bordered to the south by the Atlantic Ocean. The shoreline extended from the east bank of the Imo River to the west bank of the Benin River (Ololube, *et a*l., 2013). According to geology, the base Akata formation, middle Agbada, and upper Benin formations are all anchored by the Niger Delta basin (Ehirim and Abbey, 2016).

Its enormous quantities of gas and petroleum crude oil, which reach up to 800–1000 scfd (standard cubic feet per day) of gas to oil ratio, attracted attention from all over the world in 1958 when Shell Petroleum Development Corporation (SPDC) reported success (Kaladumo and Ideriah, 2014). Its hydrocarbon development is due to these structural traits, which are typical in an inland tertiary sedimentary basin exhibiting stratigraphic and structural complexity resulting from formational changes. The synsedimentary tectonics and concomitant sediment loading of the Niger Delta were responsible for the structural traits' abundance (Emam, 2016). These provided the area with commercial deposits of natural gas and crude oil. Natural gas is extracted together with the oil, and the refinery needs to separate the two gases first. While natural gas had no known market and no technological means of being used, oil was exported in large quantities. The only choice was to burn it off by flaring, which suggests that the initial oil production in 1956 marked the beginning of gas flaring. Uwem and Enobong, (2017) state that there are two sources of natural gas supply in Nigeria: gas found in solitary wells, also known as non-associated gas, and gas found in conjunction with oil, also known as associated gas. There are about equal amounts of these two sources. While associated gas must be extracted or disposed of on site as an undesired byproduct of oil, non-related gas can be kept underground until required. Associated gas is ineluctably removed together with crude oil. If the amount being disposed of is small enough, venting is a frequent on-site disposal technique; for greater volumes, flaring is used (Ibitoye, 2014).

Gas flaring is the burning of associated gas fields. In addition, it can refer to the procedure or act of releasing associated gas into the atmosphere while drilling for crude oil (Nwaogu, 2010; Ubani and Onyejekwe, 2013; Amaechi and Ajokpauwu,2022; Morakinyo, 2023; Abu *et al*. 2023).

Gas flaring began in Nigeria on August 3, 1956, when crude oil was discovered in commercial quantities at Oloibiri, Ogbia Local Government, Bayelsa State, and it has continued to this day (Obi, *et al*., 2021; Ukala, 2010). The biggest mangrove swamp in Africa (Ogbeibu and Orihabor, 2023) and the second-largest delta in the world (World Bank, 2023) are the regions of Nigeria where this flaring activity is taking place.

Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo, and Rivers are the nine oil-producing states that make up the Niger Delta area (Ikenwa,2024, Ariemu,2023).

Nigeria is one of the world's most active gas flaring nations, according Abua and Ashua (2015). According to the 2022 Global Gas Flaring Report, Nigeria flared 6.8 billion cubic meters (bcm) of gas in 2022, releasing 19.5 million tons of CO2 into the environment. This amount of gas flaring accounted for 9.4% of Nigeria's total gas production in 2022 and 4.7% of gas flaring globally. Nigeria ranked seventh globally among the top ten flaring countries in 2020 (World Bank, 2023).

Nigeria has prohibited gas flaring since 1984, yet despite this, it continues to be one of the top 10 gas-flare nations, with around 7.4 billion cubic meters and 425.9 billion standard cubic feet of gas burned in 2018 and 2019, respectively (Eboh, 2019).

Paradoxically, the Niger Delta area that generates the nation's economic prosperity has seen catastrophic circumstances due to gas flaring, despite reports (Ogwu *et al*., 2021) linking the primary Niger Delta issues to Nigeria's oil and gas sector. If Americans are concerned about the 17.6 million people who live about a mile away from oil or gas wells (Cushing *et al*., 2021), then the Nigerian government is treating the Niger Delta locals unfairly if they use the heat from flare sites to dry their food. According to studies, toxins released into the land, water, and air as a result of incomplete gas flare combustion have harmed fish, crops, flora, people's health, and their socioeconomic way of life, not to mention their homes (Amaechi and Biose, 2016).

The worst are the emission of greenhouse gases and radioactivity forcing (Cushing et al., 2021), which cause drastic, permanent changes in the climate that have recently garnered international attention. Researchers like Ogbe *et al*. (2011), Adekomaya *et al*. (2016), and Ogolo and Onyekonwu (2015) have made clear that there is an urgent need to stop anthropogenic emissions from gas flaring in order to draw awareness to this ecological and climatic injustice on a worldwide scale.

2.2. Reasons for Gas Flaring

2.2.1. **Safety Reasons Flaring**

Gas flaring can be necessary for security concerns. Dealing with very high and variable pressures is a part of the extraction and processing of oil and gas. An explosion during the extraction of crude oil might be caused by a sudden or significant rise in pressure. Although they are uncommon, industrial mishaps with oil and gas can cause devastating, deadly, and persistent fires that are challenging to prevent and manage. By burning any extra gas, gas flaring enables operators to handle big and unpredictable pressure changes and de-pressurize their equipment (Maduka and Tobin-west, 2017; World Bank, 2024).

2.2.2. **Economic and Technical Reasons**

The majority of oil fields are situated in difficult-to-reach locations, and they may not consistently produce large volumes of usable associated gas that the operators can use. This can pose logistical and financial challenges in transporting associated gas to processing and utilization facilities. Moreover, if oil production sites are relatively small and distributed over an extensive area, the cost of collecting and utilizing the associated gas is frequently considered prohibitively high, in which case the associated gas is flared. In other cases, the associated gas can be conserved by re-injecting it back into the reservoir. Even with recent technical advancements, this isn't always possible (Maduka and Tobin-west, 2017; World Bank, 2024).

2.2.3 **Regulatory Reasons**

Nonetheless, a nation's legal framework may provide challenges or outright prohibit businesses from offering related gas for sale. For instance, even though a business has obtained the authorization to extract oil, it could not be the owner of the related gas that is created in the process. In other cases, rules might not outline the commercial handling of related gas. This leads to uncertainty in law on the proper processing of related gas. Furthermore, laws penalizing businesses for flaring gas may not always be successful in stopping the practice, particularly if flaring and paying a fine is a more financially feasible option than collecting the gas and marketing it (Maduka and Tobin-west, 2017; World Bank, 2024).

2.3. EFFECTS OF GAS FLARING

1. Environmental Impacts

Because gas flaring releases a variety of pollutants and greenhouse gasses into the atmosphere, it is unfortunate from an environmental standpoint.

Climate Change: The primary greenhouse gases released by gas flaring are carbon dioxide and methane. Approximately 80% of global warming has been attributed to these two gases combined (Ajugwo, 2013; Anejionu *et al*., 2015). Due to their low capacity to deal with the impacts of climate change, such as a shortage of food and water, the spread of illnesses and pests, and the possibility of floods in coastal regions, third world nations and Africa are particularly affected by it (Giwa *et al*., 2017).

Acid Rain: The main source of acid rain is the production of nitrogen oxides (NO) and sulfur dioxide (SO2), which when combined with atmospheric moisture, generate nitric acid and sulfuric acid, respectively. Because the acidity of the rainwater that results from gas flaring has affected oil-bearing towns and their surroundings, there have been many incidents of damaged roofs. Lakes and streams turn acidic due to acid rain, which also causes harm to plants (Ajugwo, 2013; Amaechi and Ajokpauwu, 2022).

Agriculture: The depletion of soil nutrients is a result of acidification of the soil caused by gas flaring-related composites of chemical compounds, including hydrocarbon, particulate matter, and oxides of nitrogen, carbon, and sulfur (Ajugwo, 2013). Reduced agricultural yields in the Niger Delta have been documented to cause famine (Izah and Ohimain, 2015). According to Ismail and Umukoro (2012), gas flaring also frequently has a negative impact on bacterial spectrum alteration and ecology.

Pollution: Black soot from gas flaring accumulates on rooftops and is carried into the soil by rain, polluting the surrounding area (Ishisone, 2014). One form of noise pollution is the roaring caused by gas flaring operations. In Nigeria, there have also been documented occurrences of thermal pollution as a result of the high heat and temperatures brought on by the flared gas (Ismail and Umukoro, 2012).

2. Effect on Health

Ismail and Umukoro (2012) claim that flaring releases approximately 250 known pollutants, including metals like mercury and carcinogens like benzene. Numerous blood-related illnesses, including acute leukemia, are brought on by benzene exposure. According to Ismail and Umukoro (2012), gas flaring raises the health hazards for the communities around it, increasing the likelihood of cancer, respiratory ailments, early deaths, and asthma attacks. According to Ajugwo (2013), flare has been linked to neurological, reproductive, and developmental repercussions as well as lung damage, skin issues, abnormalities in children, and other negative health implications (Korppoo, 2018; Maduka and Tobin-west, 2017).

3. **The effects on the economy**

In addition to the negative effects gas flaring has on public health and the environment, the country loses billions of dollars' worth of gas that is physically burned off every day in the atmosphere (Amaechi and Emejulu, 2021). A large portion of this may be transformed for home usage and electrical production. By doing this, the nation's electrical production may be increased to match demand. Oil spills and gas flaring have cost Nigeria enormous sums of money in lost income (Effiong and Etowa, 2012). Despite the fact that oil accounts for more than 65% of government revenue (Arowolo and Adaja, 2011), it has been estimated that gas flaring costs the government $2.5 billion yearly in lost revenue.

Plate 2.1: Gas flaring in Nigeria (buzzNigeria.com,2018).

2.4. GAS FLARING AND ITS EFFECTS ON THE VEGETATION HEALTH ON THE NIGER-DELTA AREAS OF NIGERIA.

One of the main sources of the active nutrients that the body needs is plants. Depending on the species, they can provide you with fat, protein, carbs, along with additional minerals and vitamins.

For livestock, particularly herbivorous animals like goats, cows, grass cutter rabbits, etc., vegetation serves as a food source. For many species of animals that do not burrow, vegetation cover provides a supply of habitat (Seiyaboh and Izah, 2017). There are several ecological responsibilities that vegetation performs. For example, vegetation inhibits soil erosion (Izah *et al*., 2016). Cassava and oil palm are two prominent types of vegetation that may be found near farms and residential areas in the Niger Delta region. These are the two main types of plants that are found around gas flaring locations in the Niger Delta and are consumed as food (Ohimain *et al*.,2014). Many plant species are likely to be impacted by gas flaring, particularly in terms of growth and production (Ozabor and Obisean, 2013). For example, it has been found that when distance from where the flares decreases, gas flaring causes cassava to become shorter and weigh less while increasing the amount of amino acids and total sugar it contains (Lawson et al., 2016). The scientists went on to say that these declines were also connected with drops in the tubers' ascorbic acid (vitamin C) and starch contents. According to a poll conducted in the Niger Delta, 77% of locals believe that gas flaring has an impact on the area's flora and agricultural practices (Adewole and Mustapha, 2015). According to residents of the Ebedei village in Delta State, gas flaring has an impact on foods such potatoes, yam, cassava, okra, and plantains (Ozabor and Obisean, 2013).

Gas flaring can also cause deforestation and acid rain (Ozabor and Obisean, 2013). According to Ezenwaji *et al*. (2013), extraction of crude oil and related gas flaring is a major cause of acid rain in the Niger Delta area of Nigeria. Acid rain could lead to loss of vegetation (Amadi,2017) and several symptoms in plants that could lead to their death. Some of the notable symptoms include chlorosis, abscission and yellowing of leaves, wilting of the leaf tips and accelerated senescence, root and shoot of plants are also destroyed and microbial community that aid in decompositions processes (Efe,2011). The impacts of acid rain on vegetation structures and cover is most severe close to gas flaring stack (Seiyaboh and Izah,2017). Acid rain result in the decline in productivity and growth of some major food crops such as cassava, sweet potatoes, maize, melon, plantain, and cash crop like rubber (Efe,2011). The effects in the growth and productivity of crops could also be an indication that the soil fertility have been impacted upon. This may lead to loss of vital soil nutrients that encourage the growth of plants. Plants are known to have pharmacological and bioactive composition (Epidi *et al*., 2016). The composition of the bioactive constitutes play a significant role in determining their medicinal properties. In one case, Ifemeje (2015), stated gas flaring might alter the anti-nutrient compositions (alkaloid, phytate, oxalate, Saponin, tannin and cyanogenic glycosides) in some common vegetables used for food usage such as scent leaf, bitter leaf, water leaf and fluted pumpkin leaf. Ujowundu *et al*. (2013) also reported effects in phytochemical (alkaloid, tannin, cyanogenic glycoside, phytate), proximate composition (moisture, ash, protein and carbohydrate), micronutrients (calcium, sodium, magnesium, potassium and phosphorus) and vitamins (riboflavin, vitamin E and C) in African breadfruit and Bambara groundnuts grew close to gas flaring stack. Anacletus *et al*., (2014) also noted that gas flaring may have an impact on the trace metal (zinc, iron, lead, cadmium, and zinc) and phytochemical (alkaloids, flavonoids, saponins, and tannins) components of fluted pumpkin.

Plants adjacent to flare stacks have been known to sustain physical harm as a result of gas flaring (Amadi, 2014). There may be additional downstream effects from this. Furthermore, as noted by Okeke and Okpala (2014), gas flaring may change the physiochemical and microbiological aspects of soil quality. Gas flaring frequently affects a few significant soil quality parameters, including pH, temperature, soil moisture, and soil microbial population (Ubani and Onyejekwe, 2013). According to Okeke and Okpala (2014), several soil quality measures from flaring sites like bulk density and temperature increased with proximity from the flare point, whereas others like CEC, organic matter, moisture content, etc. declined. The authors also claimed that, in comparison to the control in the Niger Delta regions of Eket and Izombe, soil nutrients were reduced in the gas flaring environment. Variation in the properties of the soil, particularly those linked to nutrients, may have an indirect impact on crop yield. Because microbes are special, variations in the characteristics of the soil may affect the variety and density of microbes. Microbes are often crucial to the biogeochemical and nutritional cycles. According to a survey conducted by Olisemauche and Avwerosuoghene (2015), residents of Okpai, Ndokwa East Local Government Area, Delta State, believe that gas flaring is affecting the soil's fertility and production for food crops including yam, cassava, and plantain.

2.5. GEOGRAPHIC INFORMATION SYSTEM (GIS)

An effective tool for analyzing, visualizing, and comprehending intricate interactions in the actual world is a Geographic Information System (GIS), which integrates spatial data (location information) with attribute data (descriptive information) (Fotheringham *et al*., 2015). Software, attribute data, and geographical data make up its three main parts. While attribute data define qualities related to specific places, spatial data reflect the actual locations on Earth's surface. These data layers may be stored, modified, analyzed, and visualized using GIS software (Longley *et al*., 2015; Kumar *et al*., 2019). GPS, surveys, satellite imaging, and remote sensing are just a few of the sources of data that are integrated by GIS. Building thorough and educational geographic databases is made possible by this integration (Burrough and McDonnell, 2015). The capability of GIS to do geographical analysis is one of its primary advantages. In order to provide answers, provide forecasts, and resolve challenging geographical issues, this entails applying mathematical and statistical methods to spatial data (Fotheringham *et al*., 2015). Numerous disciplines, including as urban planning, epidemiology, transportation, natural resource management, and emergency response, use GIS. From disease outbreaks to patterns of land use, it has been employed to map and evaluate everything (Kemp, 2016). GIS facilitates decision-making by offering modeling, scenario analysis, and visualization capabilities. Based on geographical data, it assists analysts, planners, and policymakers in making well-informed decisions. Technology developments and the widespread adoption of open-source GIS software have increased GIS accessibility for a wider range of users. Because of its democratization, GIS is now accessible to people and organizations with different degrees of knowledge (Cromley and McLafferty, 2011).

A good GIS adheres to business principles and an implementation strategy that are specifically tailored to the models and operational procedures of each firm (Jia *et al*., 2017). It has been demonstrated that GIS is an effective tool for data distribution, analysis, presentation, and integration. As a result, when developing policies for integrated management, remote sensing, GPS, and GIS have become standard tools (Zhang and Griffith, 2000).

GIS is the right instrument needed to adequately evaluate the effects of gas flaring on the Niger Delta's flora and land cover, given the spatial character of many environmental consequences. Therefore, the goal of this study is to evaluate the long-term effects of gas flaring on the surrounding flora and land cover using GIS (Amaechi and Ajokpauwu,2022).

2.6. LANDSAT 4, 5, 7 AND 8

2.6.1. LANDSAT 4

Landsat 4 was launched from Vandenberg Air Force Base in California on July 16, 1982 on a Delta 3920 rocket. The sensors onboard the satellite collected data until late 1993, and the satellite was decommissioned on June 15, 2001. Landsat 4 was built and launched by NASA. NOAA initially oversaw the operations of the satellite but was eventually contracted out to the Earth Observation Satellite Company (EOSAT) in 1984. Despite numerous operations transfers, USGS EROS has remained responsible for the record and data keeping of the Landsat program.

Although the satellite was set in a lower orbit than Landsat 1-3, it had a higher field of view to retain the same swath width as its predecessors of 185 km (115 mi). The lower altitude results in a different swathing pattern.

With an updated design from the previous three missions, the satellite carried the MSS as well as the new TM instruments. It did not carry the Return Beam Vidicon (RBV) sensor (USGS,2024).

Landsat 4 Instruments

Landsat 4 carried the Multispectral Scanner (MSS) and the new Thematic Mapper (TM) sensors. Landsat 4's first light image captured eastern Lake Erie, and the cities of Toledo, Detroit, and Windsor on July 25, 1982. Although the Landsat program had been collecting images of the Earth since 1972, this was the first time that the data could be depicted as a natural color image due to the new Thematic Mapper sensor onboard Landsat 4.

Multispectral Scanner (MSS)

The MSS sensor on Landsat 4 was identical to Landsat 1, 2 and 3.

- Four spectral bands:
  - Band 4 Visible Green (0.5 to 0.6 µm)
  - Band 5 Visible Red (0.6 to 0.7 µm)
  - Band 6 Near-Infrared (0.7 to 0.8 µm)
  - Band 7 Near-Infrared (0.8 to 1.1 µm)

Thematic Mapper (TM)

The TM's improved spectral and spatial resolution allowed the instrument to see the ground in greater detail and included a thermal band.

- Added the mid-range infrared to the data
- Seven spectral bands, including a thermal band:
  - Band 1 Visible Blue (0.45 - 0.52 µm) 30 m
  - Band 2 Visible Green (0.52 - 0.60 µm) 30 m
  - Band 3 Visible Red (0.63 - 0.69 µm) 30 m
  - Band 4 Near-Infrared (0.76 - 0.90 µm) 30 m
  - Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m
  - Band 6 Thermal (10.40 - 12.50 µm) 120 m
  - Band 7 Mid-Infrared (IR) (2.08 - 2.35 µm) 30 m

Plate 2.2: Image of Landsat 4 (USGS,2024).

2.6.2. LANDSAT 5.

Similar to Landsat 4, Landsat 5 was developed by NASA and launched on March 1, 1984, from Vandenberg Air Force Base in California. It carried the Multispectral Scanner (MSS) and Thematic Mapper (TM) equipment. Before it was retired on June 5, 2013, Landsat 5 provided Earth imaging data for over 29 years, setting a Guinness World Record for "Longest Operating Earth Observation Satellite." This satellite clearly surpassed its three-year design period (USGS,2024).

Landsat 5 Instruments

The Multispectral Scanner (MSS) and Thematic Mapper (TM) sensors were carried by Landsat 5. collections of MSS data over the US halted in 1992, while collections worldwide concluded in 1999. The MSS instrument was brought back online in November 2011 following the failure of the TM sensor. More than fifteen thousand MSS scenes were gathered between June 2012 and January 2013. Northern Minnesota, the Apostle Islands of Wisconsin, and an ice Lake Superior are seen in one of the earliest unclouded Landsat 5 photos.

Five days after launch, on March 6, 1984, the Thematic Mapper (TM) picture was captured. It is displayed as a false hue composite utilizing the near infrared, red, and green bands (bands 4, 3, 2).

Multispectral Scanner (MSS)

- Four bands in the spectrum (matching those of Landsat 1 and 2):
    - Band 4 Visible Green (0.5 to 0.6 µm) — powered off due to high current in August 1995
    - Band 5 Visible Red (0.6 to 0.7 µm)
    - Band 6 Near-Infrared (0.7 to 0.8 µm)
    - Band 7 Near-Infrared (0.8 to 1.1 µm)

Thematic Mapper (TM)

- Added the data's mid-range infrared.
- There are seven spectral bands, one of which is thermal:
    - Band 1 Visible Blue (0.45 - 0.52 µm) 30 m
    - Band 2 Visible Green (0.52 - 0.60 µm) 30 m
    - Band 3 Visible Red (0.63 - 0.69 µm) 30 m
    - Band 4 Near-Infrared (0.76 - 0.90 µm) 30 m
    - Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m
    - Band 6 Thermal (10.40 - 12.50 µm) 120 m
    - Band 7 Mid-Infrared (2.08 - 2.35 µm) 30 m

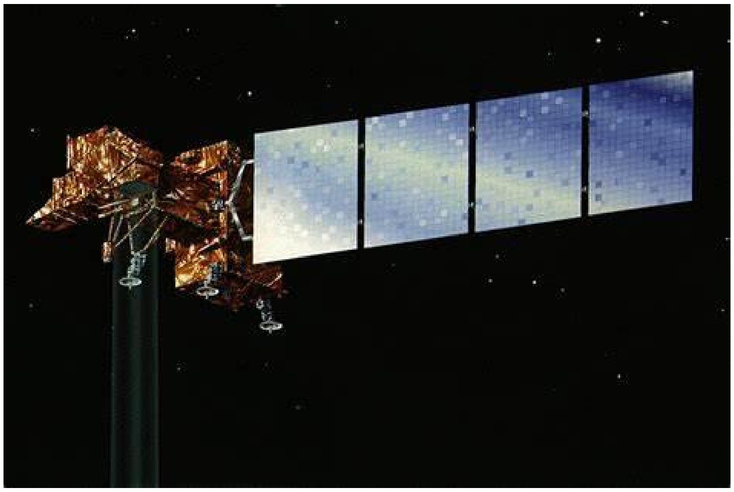


Plate 2.3: Image of Landsat 5 (USGS,2024).

2.6.3. LANDSAT 7

Landsat 7 was launched from Vandenberg Air Force Base in California on April 15, 1999 on a Delta II rocket. The satellite carries the Enhanced Thematic Mapper Plus (ETM+) sensor. This instrument was improved from previous instrumentation designs. The primary features on Landsat 7 include a panchromatic band with 15-meter spatial resolution, an onboard full aperture solar calibrator, five percent absolute radiometric calibration, and a thermal infrared channel with a four-fold improvement in spatial resolution over Thematic Mapper (TM). Since June 2003, the sensor has acquired and delivered data with data gaps caused by the Scan Line Corrector (SLC) failure.

In October 2008, USGS made all Landsat 7 data free to the global public; data downloads increased sixty-fold. About four months later, all Landsat data was made available at no cost.

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Instrument

Landsat 7 carries the Enhanced Thematic Mapper Plus (ETM+) sensor, an improved version of the Thematic Mapper instruments that were onboard Landsat 4 and Landsat 5. Landsat 7 products are delivered as 8-bit images with 256 grey levels. Descriptions of Landsat 7 band designations and comparisons of all Landsat sensors are available.

- The ETM+ contains eight spectral bands, including a pan and thermal band:
    - Band 1 Blue (0.45 - 0.52 µm) 30 m
    - Band 2 Green (0.52 - 0.60 µm) 30 m
    - Band 3 Red (0.63 - 0.69 µm) 30 m
    - Band 4 Near-Infrared (0.77 - 0.90 µm) 30 m
    - Band 5 Short-wave Infrared (1.55 - 1.75 µm) 30 m
    - Band 6 Thermal (10.40 - 12.50 µm) 60 m Low Gain / High Gain
    - Band 7 Mid-Infrared (2.08 - 2.35 µm) 30 m
    - Band 8 Panchromatic (PAN) (0.52 - 0.90 µm) 15 m

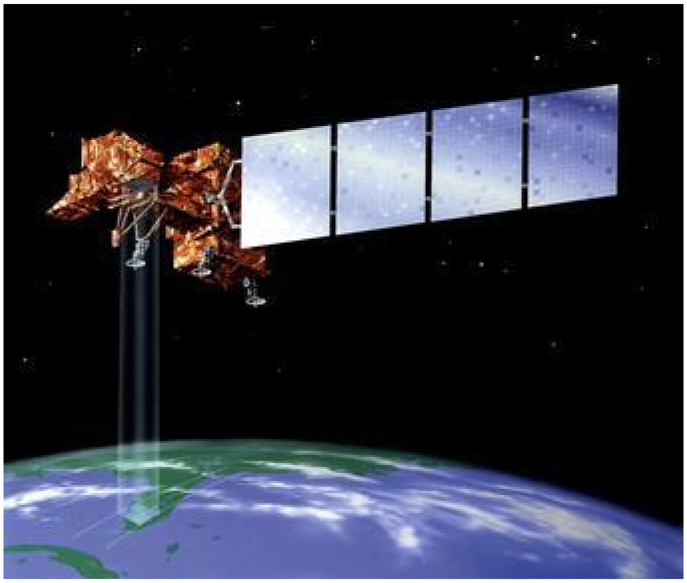


Plate 2.4: Image of Landsat 7 (USGS,2024).

2.6.4. LANDSAT 8

Landsat 8 (formerly the Landsat Data Continuity Mission, or LDCM) was launched on an Atlas-V rocket from Vandenberg Air Force Base, California on February 11, 2013. The satellite carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments.

The OLI measures in the visible, near infrared, and shortwave infrared portions (VNIR, NIR, and SWIR) of the spectrum. The TIRS measures land surface temperature in two thermal bands with a new technology that applies quantum physics to detect heat. Landsat 8 images have 15-meter panchromatic and 30-meter multi-spectral spatial resolutions along a 185 km (115 mi) swath.

Landsat 8 Instruments

Landsat 8 carries two sensors. The Operational Land Imager sensor is built by Ball Aerospace & Technologies Corporation. The Thermal Infrared Sensor is built by NASA Goddard Space Flight Center.

Operational Land Imager (OLI)

- Nine spectral bands, including a pan band:
    - Band 1 Coastal Aerosol (0.43 - 0.45 µm) 30 m
    - Band 2 Blue (0.450 - 0.51 µm) 30 m
    - Band 3 Green (0.53 - 0.59 µm) 30 m
    - Band 4 Red (0.64 - 0.67 µm) 30 m
    - Band 5 Near-Infrared (0.85 - 0.88 µm) 30 m
    - Band 6 SWIR 1(1.57 - 1.65 µm) 30 m

    - Band 7 SWIR 2 (2.11 - 2.29 µm) 30 m
    - Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) 15 m
    - Band 9 Cirrus (1.36 - 1.38 µm) 30 m

OLI captures data with improved radiometric precision over a 12-bit dynamic range, which improves overall signal to noise ratio. This translates into 4096 potential grey levels, compared with only 256 grey levels in Landsat 1-7 8-bit instruments. Improved signal to noise performance enables improved characterization of land cover state and condition.

The 12-bit data are scaled to 16-bit integers and delivered in the Level-1 data products. Products are scaled to 55,000 grey levels, and can be rescaled to the Top of Atmosphere (TOA) reflectance and/or radiance using radiometric rescaling coefficients provided in the product metadata file (MTL file).

Thermal Infrared Sensor (TIRS)

- Two spectral bands:
    - Band 10 TIRS 1 (10.6 - 11.19 µm) 100 m
    - Band 11 TIRS 2 (11.5 - 12.51 µm) 100 m

Plate 2.5: Image of Landsat 8 (USGS,2024).

2.7. NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

The visible and near-infrared bands are subjected to electromagnetic spectrum analysis to create the Normalized Difference Vegetation Index (NDVI), a numerical indicator. According to Tian *et al.* (2017), it is employed to ascertain whether or not an object under observation has verdant, active vegetation. NDVI has been widely used in vegetative research as a technique for assessing several biological parameters, including rangeland carrying capacity, pasture efficiency, and agriculture yields. According to Basith *et al*. (2010), it is often closely related to other ground parameters such as the amount of the plant matter, surface water, the proportion of ground cover, plant photosynthetic capacity, and leaf area index.

To depict NDVI data, ratios with values that range from -1 to 1 are employed. A value around -1 denotes the presence of water. Conversely, readings around +1 indicate lush, green foliage. A near-zero NDVI rating might suggest an urbanized region or even a lack of greenery. (Tian and *et al*., 2017). The main objective of NDVI is to optimize the study of vegetative information utilizing remotely sensed data. The Normalized Difference Vegetation Index (NDVI), according to research, may be used to identify between savannah, thick forest, non-forest, and agricultural sectors. Additionally, it can be used to estimate different vegetation properties, including the following: biomass (Zhu and Liu 2015), productivity of plants (Vicente-Serrano *et al.*, 2016), a fractional cover of vegetation (Dutrieux et al., 2015), plant stress (Chavez *et al.,* 2016), and the Leaf Area Index (LAI) (Tian *et al.,* 2017).

The difference between red (RED) and near-infrared (NIR) reflectance divided by their sum yields the Normalized difference vegetation index (NDVI), as seen below:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

In general, healthy vegetation reflects a significant amount of near-infrared light and absorbs the majority of visible light that strikes it. Weak or unhealthy vegetation reflects less near-infrared light and more visible light. Conversely, in the red and infrared regions of the electromagnetic spectrum, bare soils reflect light (Chavez *et al*., 2016).

2.8. CASE STUDY ON NDVI EVALUATION ON THE EFFECT OF GAS FLARING ON VEGETATION HEALTH.

Using the Normalized Difference Vegetation Index (NDVI), Amaechi and Ajokpauwu performed a study in 2022 to evaluate the impact of gas flaring on the health of the vegetation surrounding the Oben Gas Flow Station in Edo State, Nigeria.

Three years of data were collected: 1987, 2002, and 2019. A 10 km radius around the gas flare stack was mapped out, and NDVI values were created for the vegetation within 2 km, 4 km, 6 km, 8 km, and 10 km of the gas flaring site in order to determine the impact of gas flaring on the vegetation in the vicinity of the Oben gas flow. These were accomplished with the use of ARCGIS 10.3. They obtained satellite photos with less than 10% cloud cover. sThe study used Landsat Research Design to analyze secondary data obtained through the deployment of NDVI technology.

The results of the NDVI analysis of the vegetation surrounding the Oben gas flow revealed variations in the vegetation index in the three years under study (1987, 2002, and 2019). The research findings indicate that in 1987, the vegetation health surrounding the gas stack had the greatest mean and maximum values. The highest NDVI value dropped sharply from 0.66 to 0.27 after fifteen years of use, then rose to 0.5 in 2019. The mean values also showed this. The decline in the temporal evaluation between 1987 and 2002 was ascribed to the impact of gas flaring on the surrounding vegetation of the gas stack.

Gradual increases were seen in the NDVI spatial evaluation from 2 km to 10 km away from the gas stack during the course of the investigated years. This demonstrated that the vegetation surrounding the gas stack suffers as a result of gas flaring. (Dung *et al*., 2008) state that air contaminants such as hydrocarbon, ash, particulate matter, and oxides of nitrogen, carbon, and sulfur are to blame for the crop and vegetation retardation surrounding gas stacks. The investigation also revealed that a significant factor in the decline in the health of the plants surrounding the gas stack is soil pollution and the effects of heating. The findings of this study are consistent with (Dung *et al*., 2008), which states that the impact of gas flares on the surrounding vegetation of a gas stack is spatially gradient. According to Seiyaboh and Leah (2016), gas flaring is the main cause of acid rain in Nigeria's Niger Delta area, which has a negative impact on the fertility of the soil and plants. The NDVI values dramatically decreased in 2002 over all distances examined, then began to rise in 2019. The rise in the average temperature from 27.020C in 1991 to 28.30C in 1997 and back to 27.40C in 2002, as reported by (Amaechi and Biose, 2016), can be linked to the outcome.

Temperature and vegetation health are correlated, according to Adepoja et al. (2019), since rising temperatures and rainfall cause vegetation to deteriorate. The modest rise in the NDVI maximum and mean readings in 2019 can possibly be linked to the drop in output from 2013. Every day, the Niger Delta releases over 1.4 billion cubic feet of gas into the atmosphere. According to Royar (2012), the penalties for flaring related gas grew from US$0.07 per 1000 cubic feet of gas flared in 1998 to US$3.50 in 2008. The study linked the decrease of gas flared, which had an immediate effect on the health of the vegetation, to the increase in penalty fees. The results of this study demonstrate that gas flaring has a detrimental long-term impact on vegetation. At 2 km, the NDVI maximum was 0.49, and at 10 km, it was 0.66. Vegetation health was extremely low in 2002, but it improved slightly in 2019; however, regardless with the increase, the NDVI maximum at 10 km was 0.50. As a result, in order to obtain the NDVI value of 1987 at 2 km in 2019, one had to travel much farther from the gas stack. This may be explained by a drop in the amount of chlorophyll in the surrounding flora in the gas flare region.

Heat is the cause of the reduction of chlorophyll in plants close to flares. Heat is known to reduce the amount of chlorophyll (Lawson *et al*., 2013); gas flares have an impact on photo chlorophyll accumulation as well as the pace at which it converts to chlorophyll in leaves. Lesions and color variation in plants are frequently shown as indications of decreased chlorophyll accumulations.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

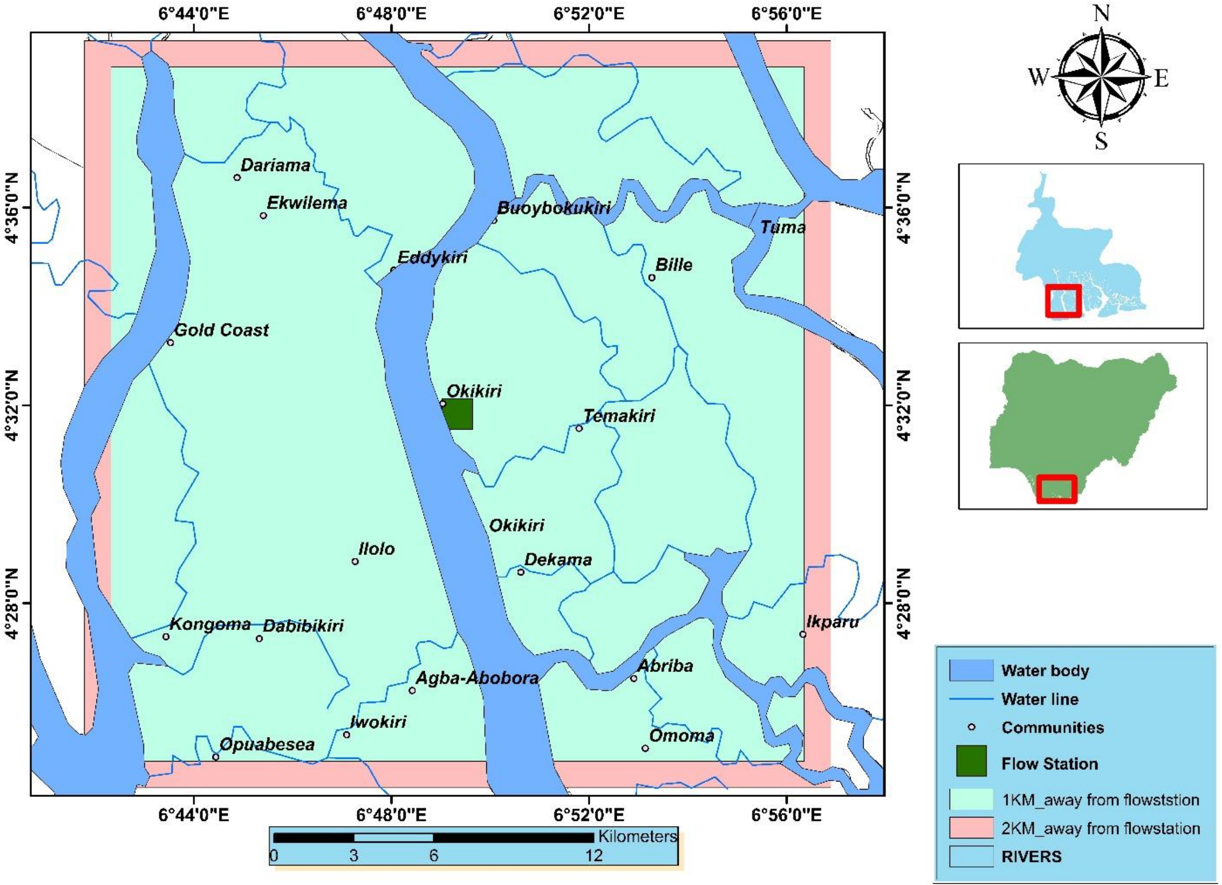


Figure 3.1: Study Area Map showing the study area with the buffered radius with a data frame of Rivers state map indicating the extent of the study area and Nigeria map indicating the extent of Rivers state.

The Awoba flow station, the study station is situated inside the Bille Territory. Bille is a low-lying coastal hamlet in Nigeria’s Niger Delta, a large mangrove forest. The study station (Awoba flow station) lies along 4° 31' 49.90" N, 6° 49' 20.09" E. The station is located in a rural community in Dekama Local Government Area which is located in the southern region of Rivers State.

The first well Awoba-1 which was drilled in 1965 was of structure and was subsequently abandoned. The field was discovered by Awob-002 in 1981. It came on stream in May 1992, producing through the 40,000 bpd capacity Awoba flow station.

The Awoba flow station, also known locally as Bille-2 flow station was commissioned in May 1992, and is part of the OML 24 (Oil Mining Lease 24) asset, it has a 162 square kilometer footprint and is intended to operate in an entirely autonomous, unmanned mode, making use of a pneumatic instrumental logic for fail-safe control and shutdown. The plant is a single train, three-stage, two-phase oil/gas separation station with a capacity of about 40,000 bpd (barrels per day) capacity. The three stages are Extra High Pressure(XHP), High Pressure (HP) and Low Pressure(LP).

3.2. Research Design

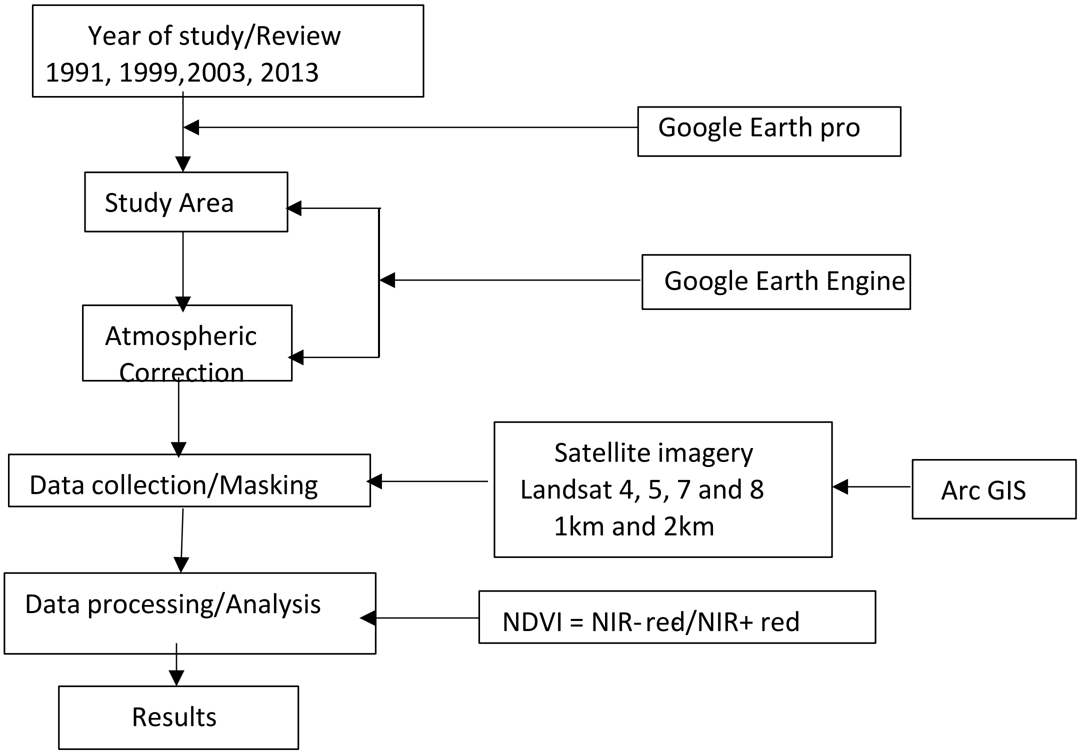


Figure 3.2: Schematic representation of the research design

Data was obtained for the years 1991, 1999,2003and 2013. A radius of 1 and 2km was mapped out from the gas flare stack in order to determine the impact of gas flaring on the surrounding vegetation of Awoba gas flow station. NDVI values were then obtained for the vegetation within these distances. This was achieved using ArcGIS 10.7.1 software. cloud cover of less than 10% was captured in Satellite images.

3.3 Data Type and Data Source

This study relied primarily on secondary data with the use of the data raster data gotten from Landsat 4-Thematic Mapper (TM), Landsat 5-Thematic Mapper (TM), Landsat 7-Enhanced Thematic Mapper Plus (ETM+) and Landsat 8-Operational Land Image(OLI). Secondary data is information obtained directly from the google earth engine using a source script.

3.4. Method of Data Collection

The Google Earth Pro application was used to do a temporal – spatial survey across different places in Nigeria before a suitable study area was selected. After selecting the study area (Awoba flow station) with the aid of the Google Earth Pro. The United States Geological Survey (USGS) provided images for Awoba flow station that were retrieved from Landsat 4, Landsat 5, Landsat 7 and Landsat 8. The information for this study was collected before and after the flow station site got licensed for operation. To collect good quality Landsat imagery, years with cloud cover less than 10% were downloaded (1991, 1999, 2003, and 2013). The Google Earth Engine was used to download raster imagery for the years 1991, 1999, 2003, and 2013. The Google Earth Engine works with a script which generates a raster, after the study area has been selected using a rectangle geometry selector. The NDVI scripts were obtained using the Google Earth Engine. The script for the selected years was allowed to run and then generated NDVI raster datasets for the selected years, which were downloaded to the google drive and then imported into the ArcGIS software for processing.

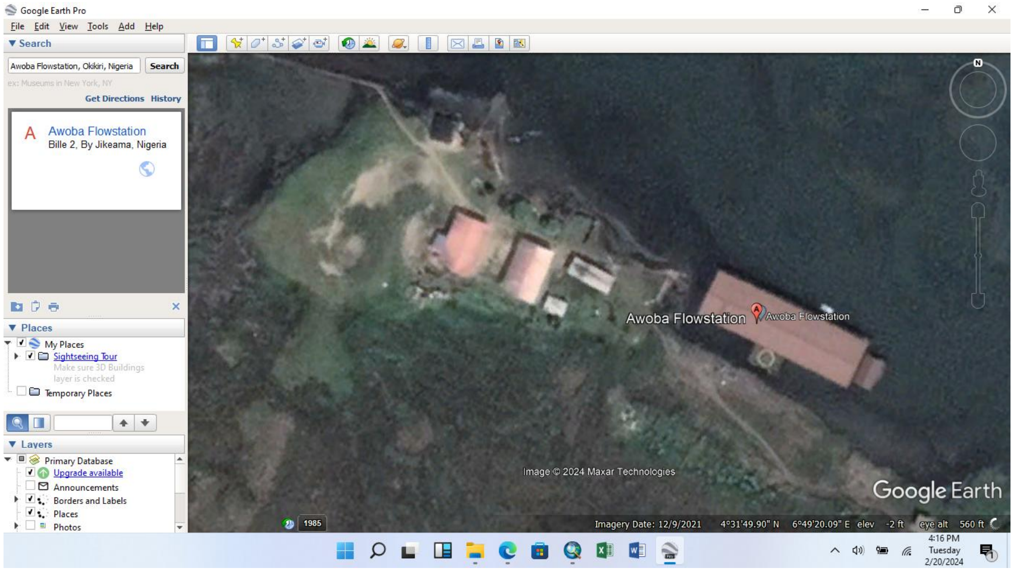
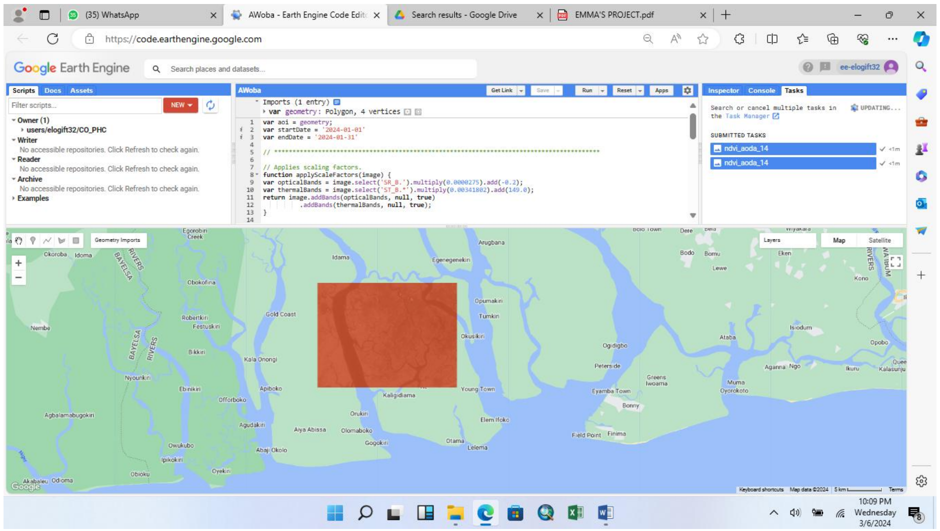
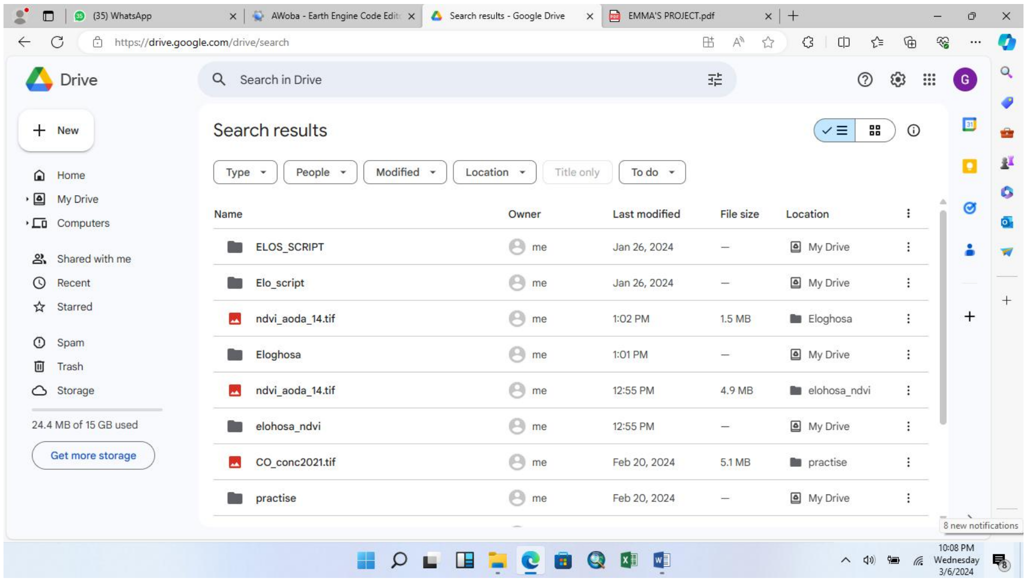


Plate 3.1. Google Earth pro-environment showing the study area.



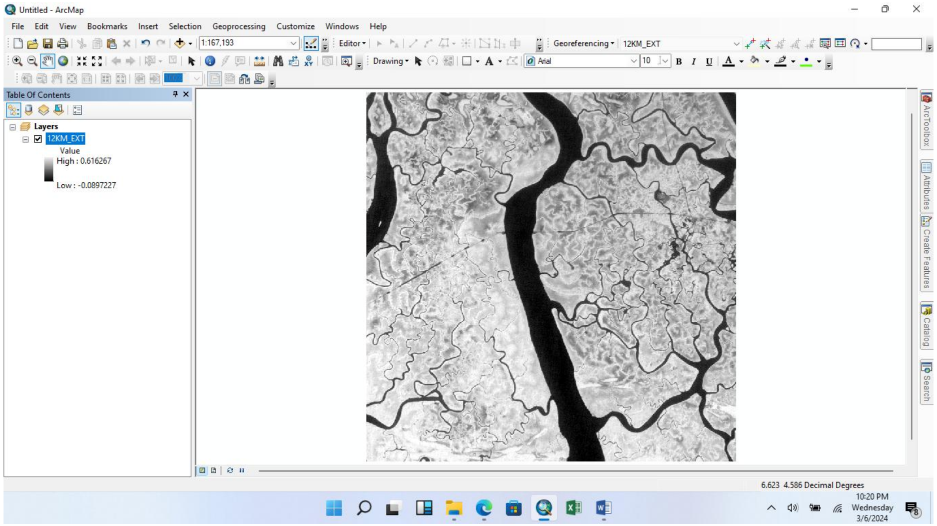
```
Imports (1 entry)
  var geometry: Polygon, 4 vertices
var aoi = geometry;
var startDate = '2024-01-01'
var endDate = '2024-01-31'

// *****************************************************************************************

// Applies scaling factors.
function applyScaleFactors(image) {
var opticalBands = image.select('SR_B.').multiply(0.0000275).add(-0.2);
var thermalBands = image.select('ST_B.*').multiply(0.00341802).add(149.0);
return image.addBands(opticalBands, null, true)
            .addBands(thermalBands, null, true);
}
```

Plate 3.2. Google Earth Engine environment showing script, highlighted geometry and downloaded raster imagery collected from Landsat 4,5,7 and 8.



Name	Owner	Last modified	File size	Location
ELOS_SCRIPT	me	Jan 26, 2024	—	My Drive
Elo_script	me	Jan 26, 2024	—	My Drive
ndvi_aoda_14.tif	me	1:02 PM	1.5 MB	Eloghosa
Eloghosa	me	1:01 PM	—	My Drive
ndvi_aoda_14.tif	me	12:55 PM	4.9 MB	elohosa_ndvi
elohosa_ndvi	me	12:55 PM	—	My Drive
CO_conc2021.tif	me	Feb 20, 2024	5.1 MB	practise
practise	me	Feb 20, 2024	—	My Drive

Plate 3.3. Google drive showing downloaded raster imagery collected from Landsat 4, 5, 7and 8.



Layers
12KM_EXT
Value
High : 0.616267
Low : -0.0897227

Plate 3.4: ArcMap environment showing downloaded raster imagery collected from Landsat 4, 5,7 and 8 before processing.

3.5. Methods of Data Analysis

Table 3.1. Dataset information and their sources

S/N	DATA	SENSOR	BAND	RESOLUTION	SOURCE	DATE	REF SYSTEM
1	Landsat 4	TM	3-4	30m	USGS (online)	01/17/1991	WGS 1984
2	Landsat 5	TM	3-4	30m	USGS (online)	11/29/1999	WGS 1984
3	Landsat 7	ETM+	3-4	30m	USGS (online)	01/8/2003	WGS 1984
4	Landsat 8	OLI	4-5	30m	USGS (online)	01/4/2013	WGS 1984

The data must be arranged and organized for analysis during this step. The software utilized for data processing and analysis was ArcGIS 10.7.1. the steps involved in data processing are listed below:

Projection to GCS WGS 1984: The World Geodetic System (WGS) 1984 Geographic Coordinate System (GCS) was used to project all of the data.

Create a Buffer: To determine how the surrounding vegetation at Awoba gas flowstation is affected by gas flaring, a buffer with a radius of 1and 2km was mapped out away from the gas flow station and NDVI values were generated for vegetation within 1km and 2km away from the gas flaring site. These were achieved using ArcGIS 10.7.1 software.

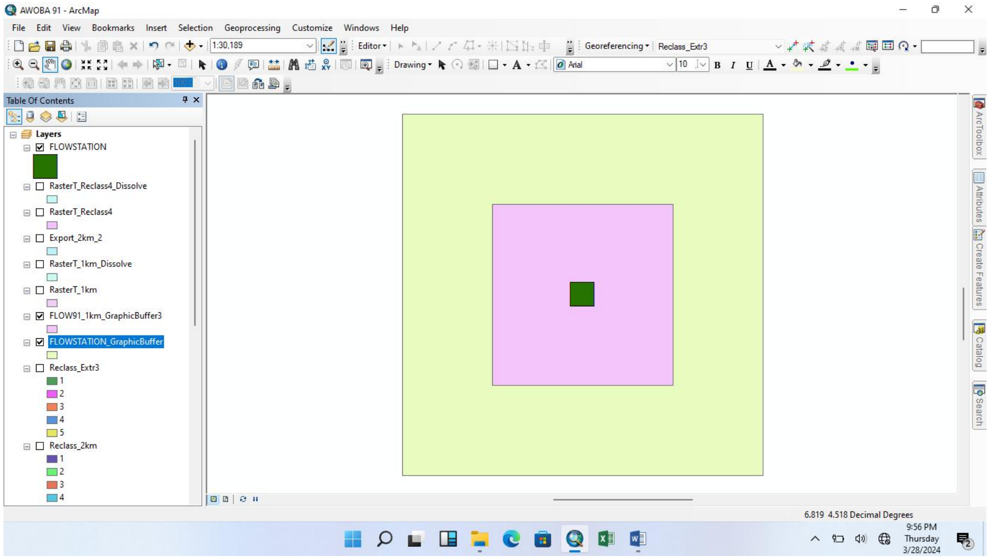


Plate 3.5: ArcMap environment showing the created buffer imagery.

1. **Extraction by Mask:** The processing technique extraction by mask was carried out on the buffered radii, to define the specific region of interest.
2. **Image processing:** Normalized Difference Vegetation Index (NDVI): NDVI is an indicator usually used to assess the spatial distribution of vegetation and their photosynthetic activity (Basith *et al*.,2010). Rouse *et al*., first used it, in 1973 to monitor and distinguish vegetated areas from other land cover types.

   The mathematical algorithm is based on bands 3 [Red (R)] and band 4 [Near Infra-Red (NIR)] for Landsat 4, 5 and 7, while for Landsat 8 bands 4 [Red (R)] and band 5 [Near Infra-Red (NIR)] measurements with the formula below:

   NDVI Equation = (NIR - R) / (NIR + R).

   NDVI for Landsat’s 4, 5 and 7 = (Band 4 - Band 3) / (Band 4 + Band 3)

   NDVI for Landsat 8= (Band 5 - Band 4) / (Band 5 + Band 4)

3. **Visualization:** to give a numerical indicator of the health of the vegetation, high numbers usually denote dense, healthy vegetation, whilst low values can imply sparse vegetation. The buffered radii were visualized for easy interpretation of these values.

4. **Reclassification:** This involves categorizing NDVI values into different classes for easier interpretation. The values were reclassified into 5 classes.

Table 3.2. Table showing the NDVI classification

Class/Feature	**NDVI Range**
Water bodies	-1< -0.999
Barren land	0.043-0.400
Shrub and Grasslands	0.100-0.500
Sparse vegetation	0.200-0.650
Dense vegetation	0.250-<1

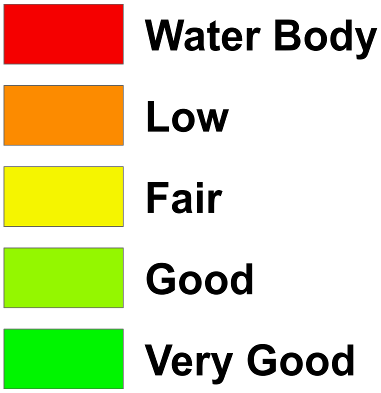


Figure 3.3. NDVI Vegetation Classes.

5. **Raster to Polygon:** The raster dataset is converted to polygon to extract more meaningful information. Polygons represent distinct areas, allowing for a more precise delineation of

vegetation boundaries. This conversion facilitates quantitative analysis, such as calculating vegetation cover or assessing changes in specific region.

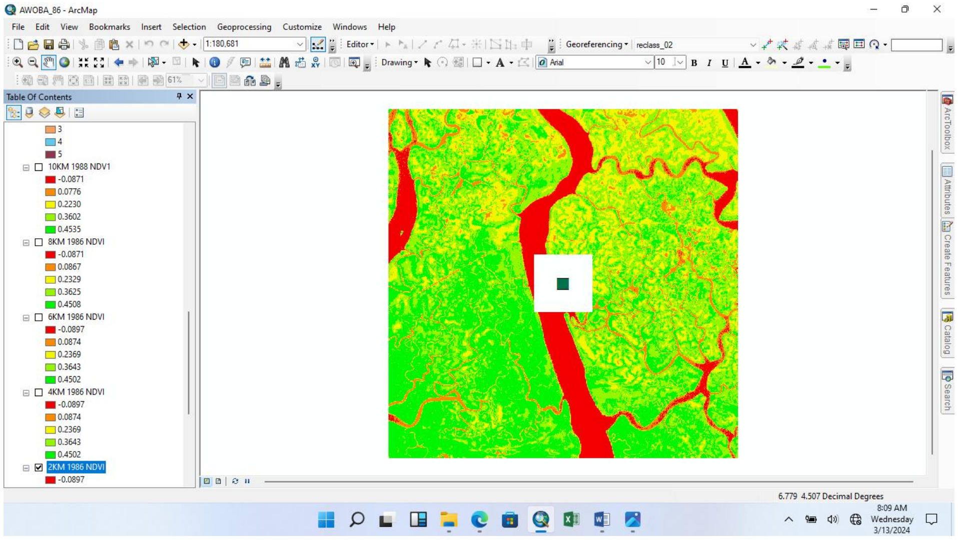


Plate 3.6: ArcMap environment showing downloaded raster imagery collected from Landsat after processing**.**

CHAPTER FOUR

RESULT

4.1. NDVI RESULT FOR 1991

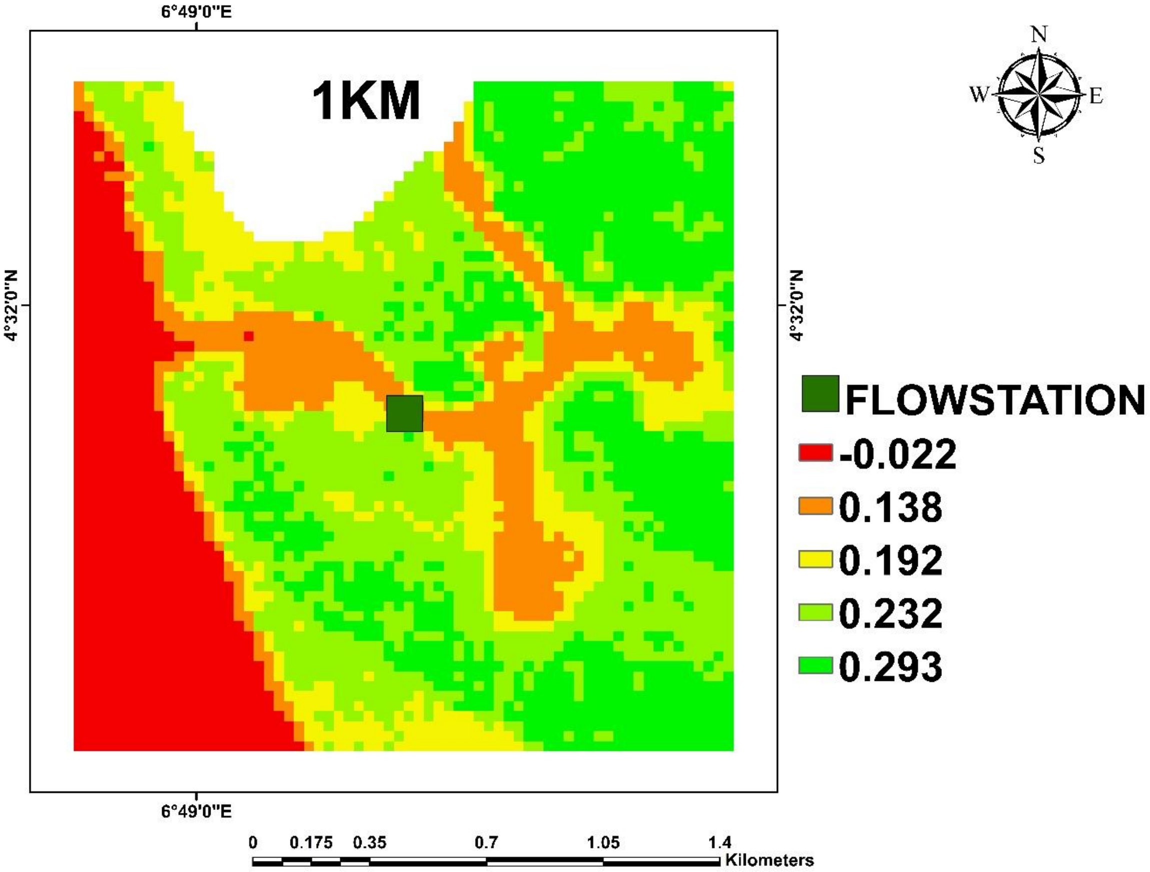


Figure 4.1:1991 Satellite imagery of vegetation at 1km marked distance from flowstation

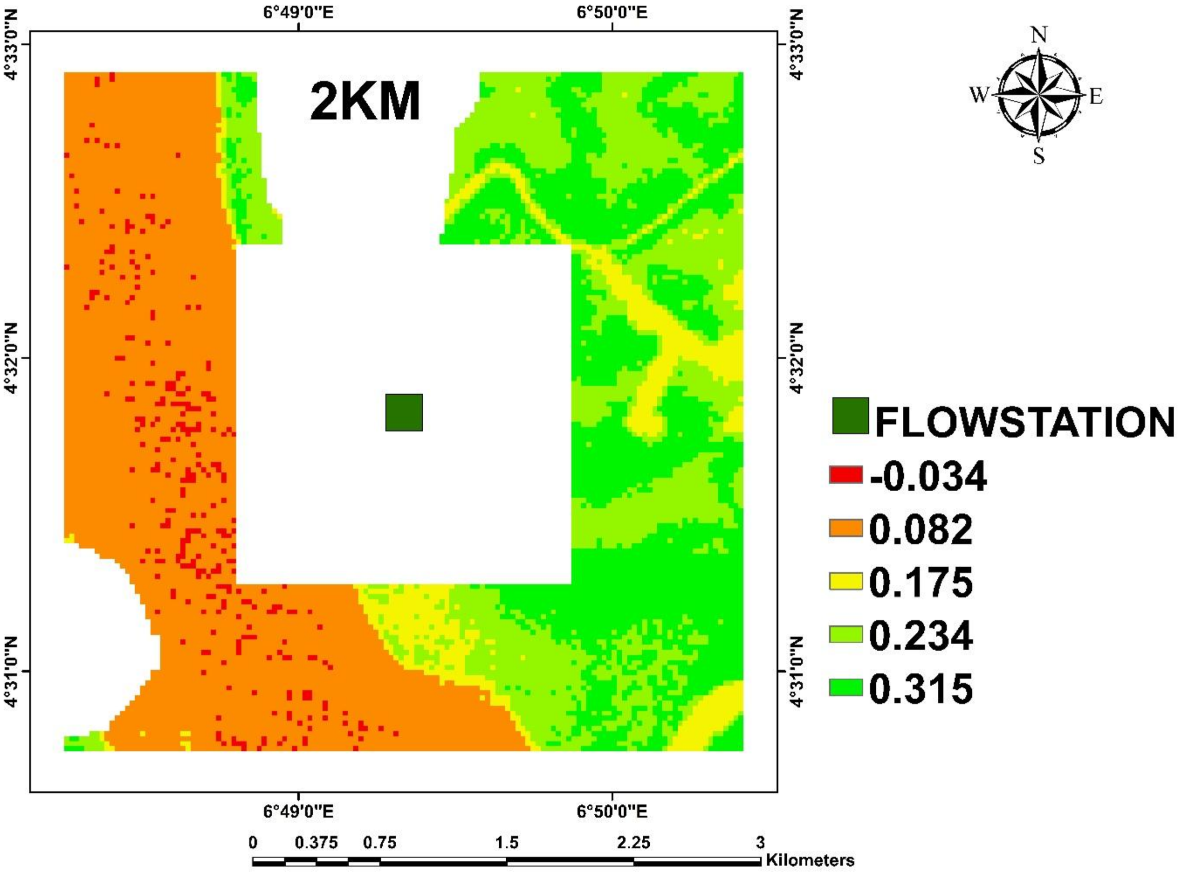


Figure 4.2:1991 Satellite imagery of vegetation at 2km marked distance from flowstation

Table 4.1: A Table showing NDVI values for 1991 at marked distances

Distance	Maximum (NDVI)	Minimum (NDVI)	Mean (NDVI)	Standard Deviation(NDVI)
1km	0.293	-0.156	0.156	0.094
2km	0.315	-0.121	0.121	0.112

4.2. NDVI RESULT FOR 1999

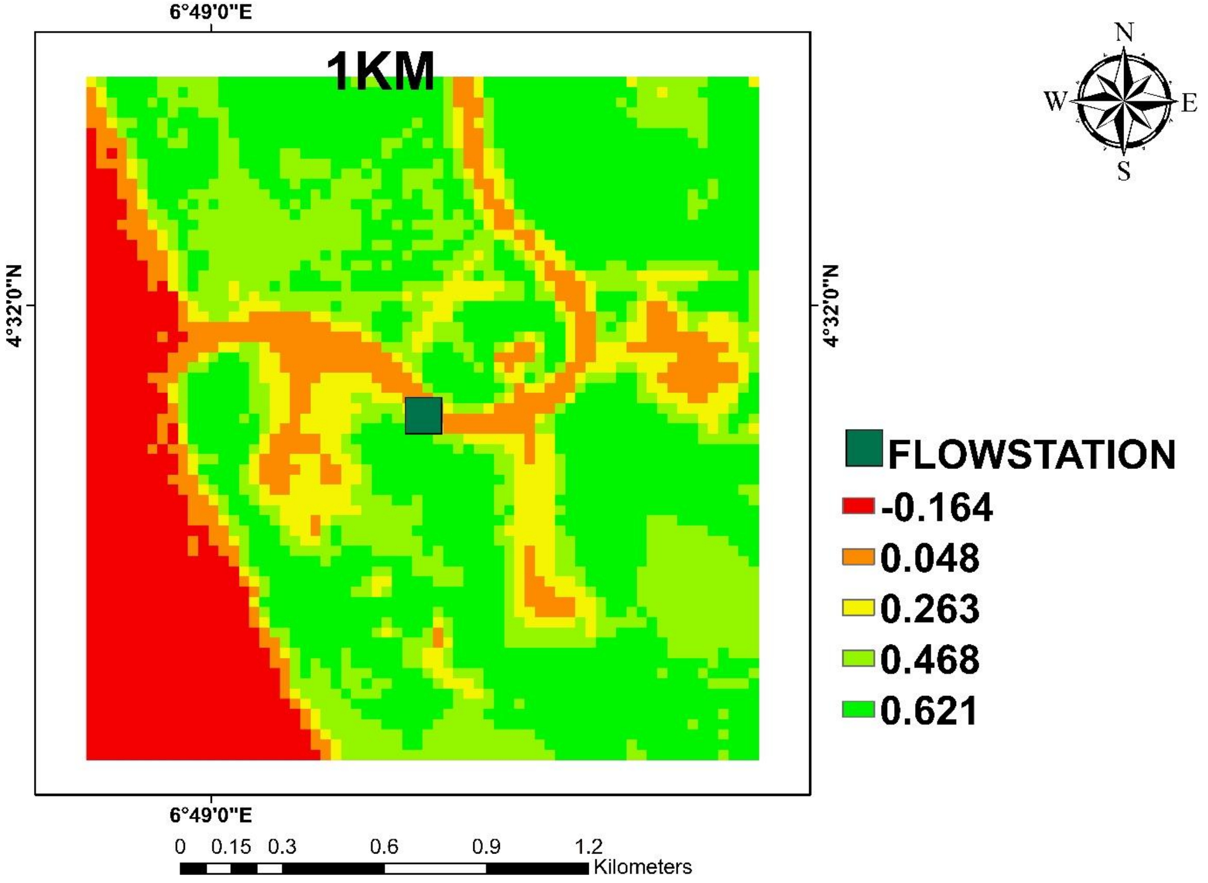


Figure 4.3:1999 Satellite imagery of vegetation at 1km marked distance from flowstation

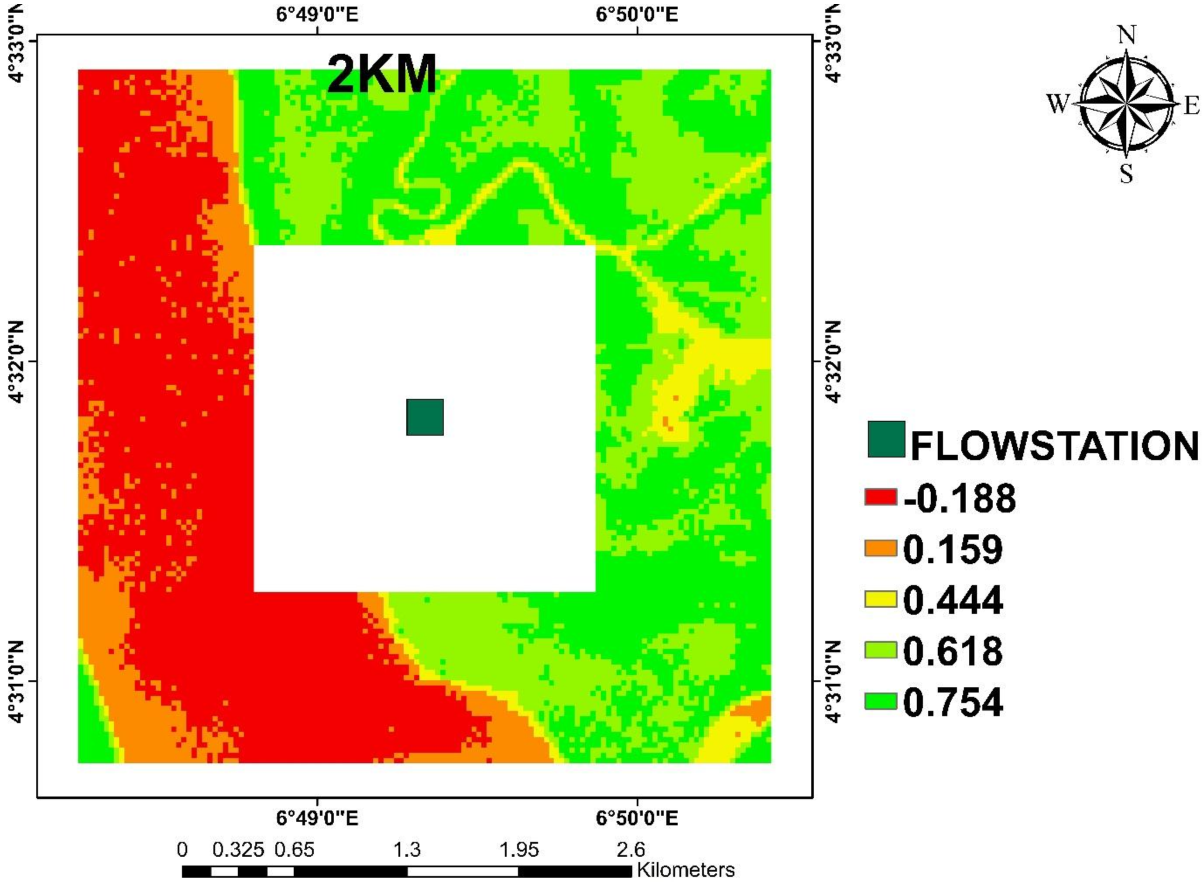


Figure 4.4:1999 Satellite imagery of vegetation at 2km marked distance from flowstation

Table 4.2: A Table showing NDVI values for 1999 at marked distances

Distance	Maximum (NDVI)	Minimum (NDVI)	Mean (NDVI)	Standard Deviation(NDVI)
1km	0.767	-0.164	0.464	0.271
2km	0.767	-0.188	0.353	0.335

4.3. NDVI RESULT FOR 2003.

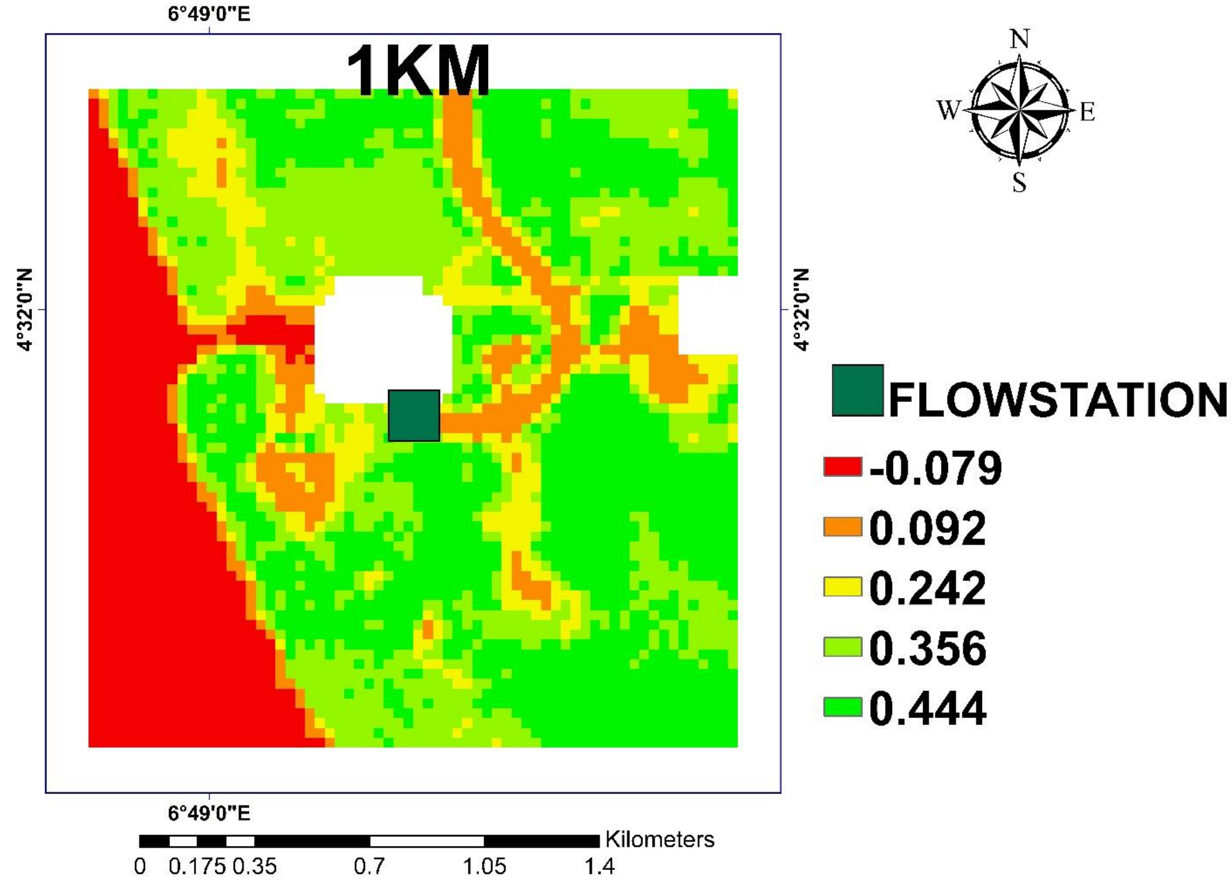


Figure 4.5:2003 Satellite imagery of vegetation at 1km marked distance from flowstation

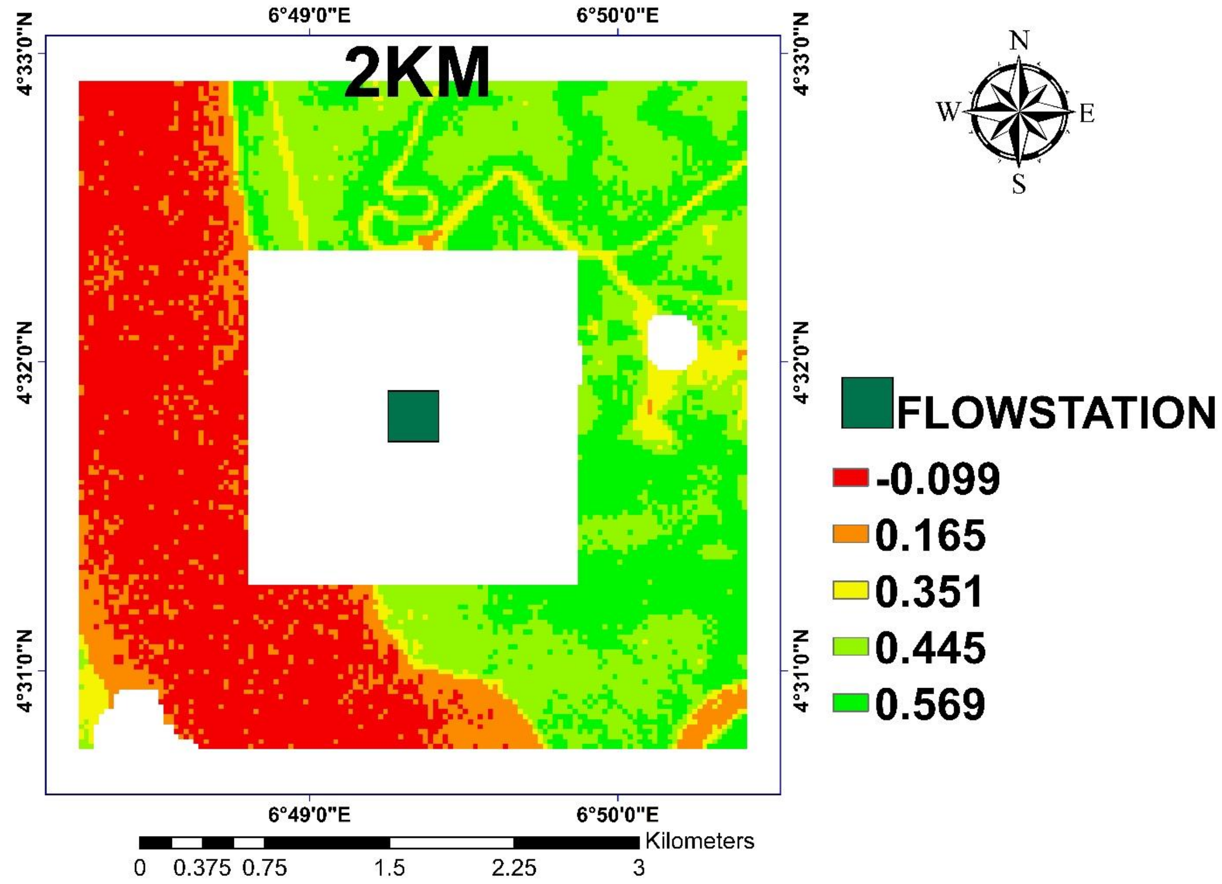


Figure 4.6:2003 Satellite imagery of vegetation at 2km marked distance from flowstation

Table 4.3: A Table showing NDVI values for 2003 at marked distances

Distance	Maximum (NDVI)	Minimum (NDVI)	Mean (NDVI)	Standard Deviation(NDVI)
1km	0.582	-0.079	0.332	0.176
2km	0.332	-0.099	0.264	0.216

4.4. NDVI RESULTS FOR 2013.

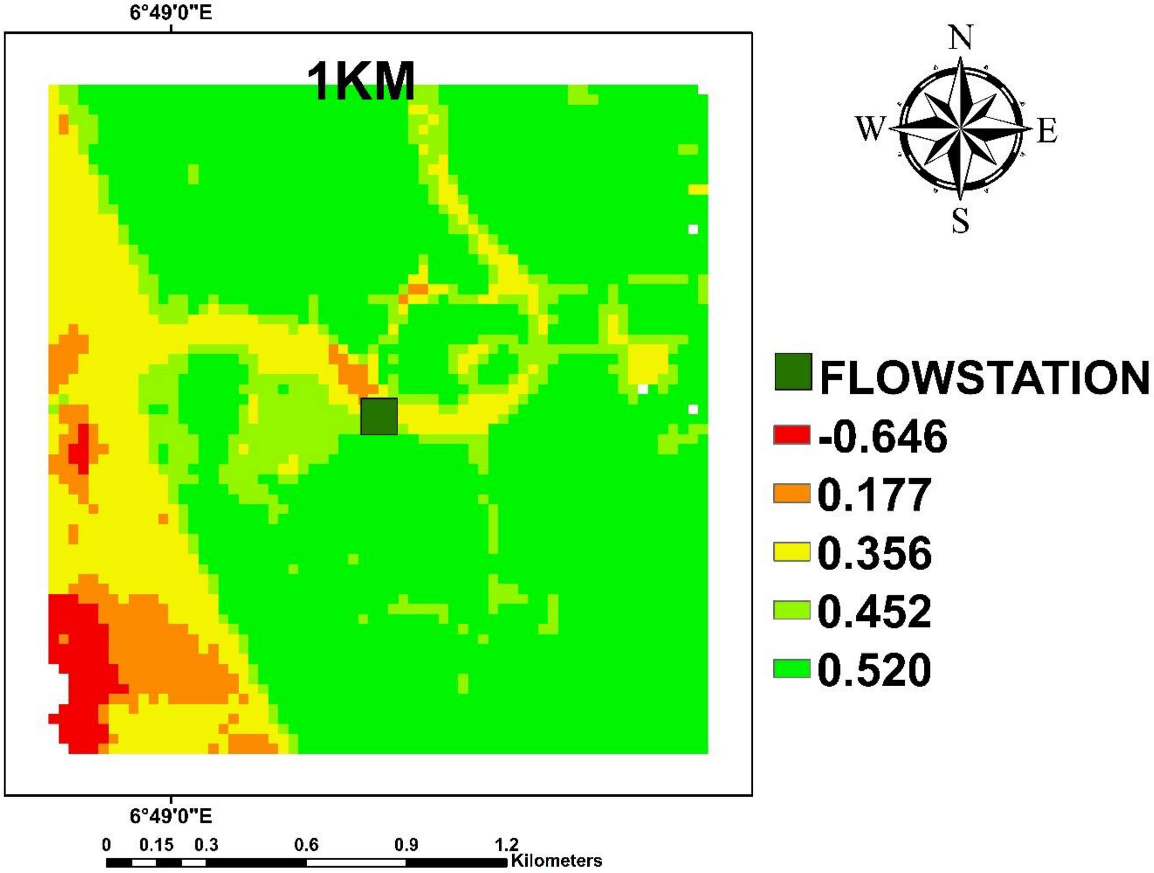


Figure 4.7:2013 Satellite imagery of vegetation at 1km marked distance from flowstation

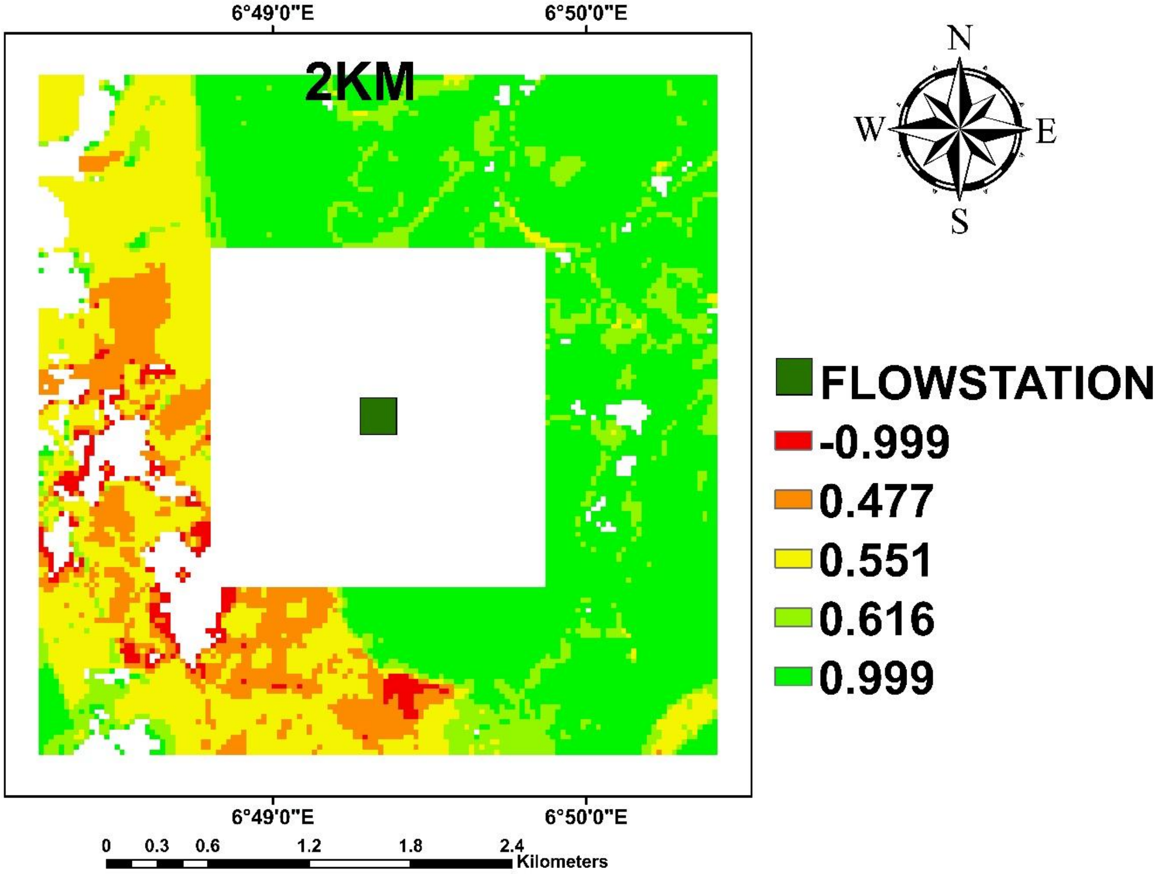


Figure 4.8:2013 Satellite imagery of vegetation at 2km marked distance from flowstation

Table 4.4: A Table showing NDVI values for 2013 at marked distances

Distance	Maximum (NDVI)	Minimum (NDVI)	Mean (NDVI)	Standard Deviation(NDVI)
1km	0.970	-0.973	0.578	0.381
2km	0.999	-0.999	0.397	0.521

4. 5. STATISTICAL ANALYSIS RESULT

The chi-square goodness of fit was used in a Statistical study to find the significant difference between the distances (1km and 2km).

Table 4.5: NDVI Values for Vegetation Cover for 1991, 1999, 2003 and 2013 showing the significant values between the distances covered using chi-square goodness of fit

Distance		1km	2km	p-value	Chi-square values
NDVI Values 1991	Vegetation Characteristics				
	Waterbodies	-0.022	-0.034	$p>0.05$	0.655
	Low	0.138	0.082	$p>0.05$	0.201
	Fair	0.192	0.175	$p>0.05$	0.869
	Good	0.232	0.234	$p>0.05$	0.100
	Very Good	0.293	0.315	$p>0.05$	0.701
NDVI Values 1999					
	Waterbodies	-0.164	-0.188	$p>0.05$	0.100
	Low	0.048	0.159	$p<0.01$	0.016
	Fair	0.263	0.444	$p<0.05$	0.031
	Good	0.468	0.618	$p<0.001$	0.000
	Very Good	0.621	0.754	$p<0.001$	0.000
NDVI Values 2003					
	Waterbodies	-0.079	-0.099	$p>0.05$	0.637
	Low	0.092	0.165	$p<0.001$	0.000
	Fair	0.242	0.351	$p<0.001$	0.000
	Good	0.356	0.445	$p<0.01$	0.002
	Very Good	0.444	0.569	$p<0.001$	0.000
NDVI Values 2013					
	Waterbodies	-0.646	-0.999	$p<0.01$	0.006
	Low	0.177	0.477	$p<0.001$	0.000
	Fair	0.356	0.551	$p<0.05$	0.046
	Good	0.452	0.616	$p<0.01$	0.010
	Very Good	0.520	0.999	$p<0.001$	0.000

Where:

p>0.05- no significant difference

p<0.05 – significant difference,

p<0.01 – high significant difference,

p<0.001 – very high significant difference

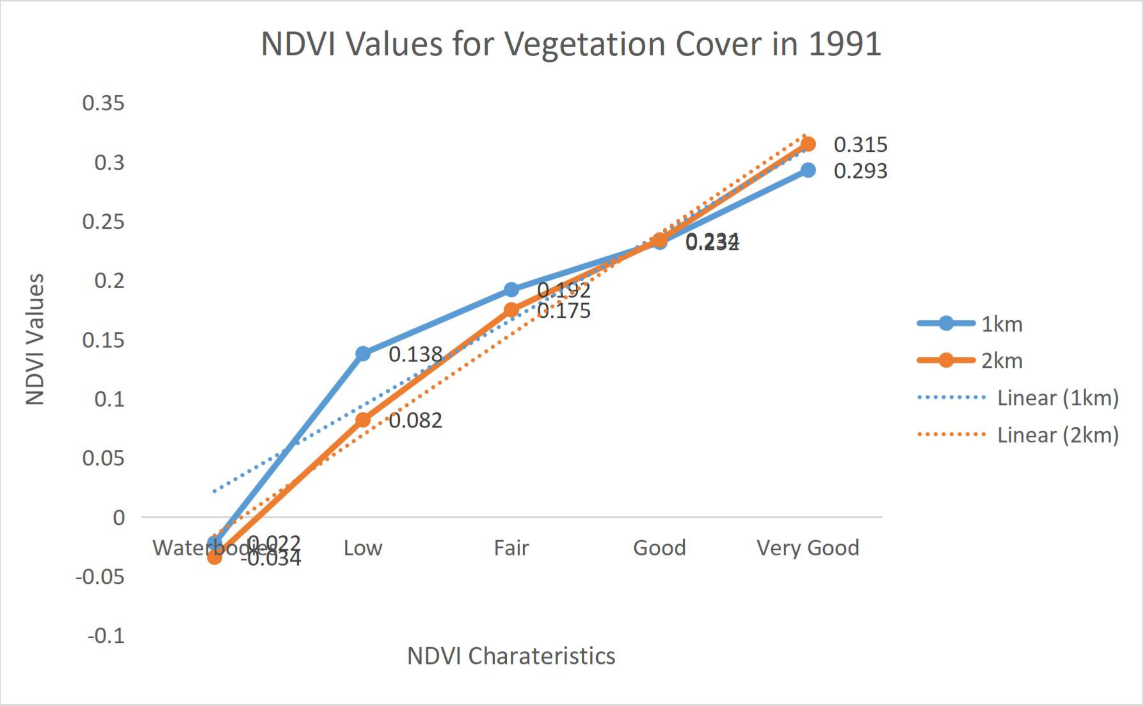


Figure 4.9.: NDVI Values for Vegetation Cover in 1991 between 1km and 2km.

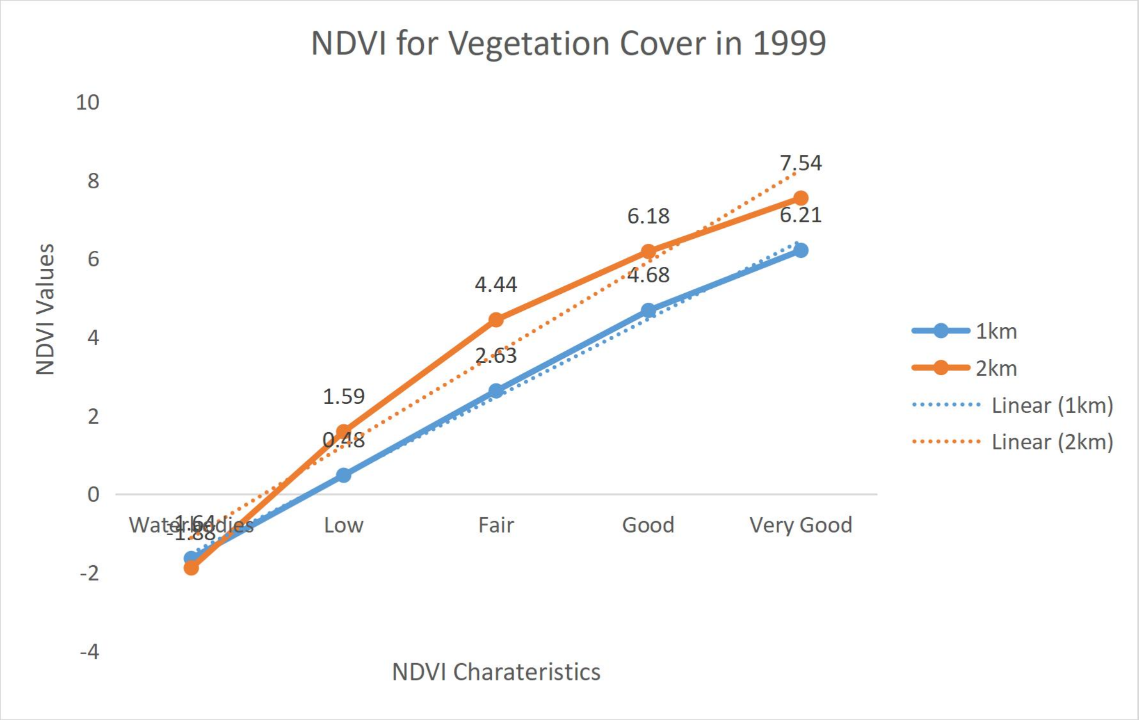


Figure 4.10.: NDVI Values for Vegetation Cover in 1999 between 1km and 2km.

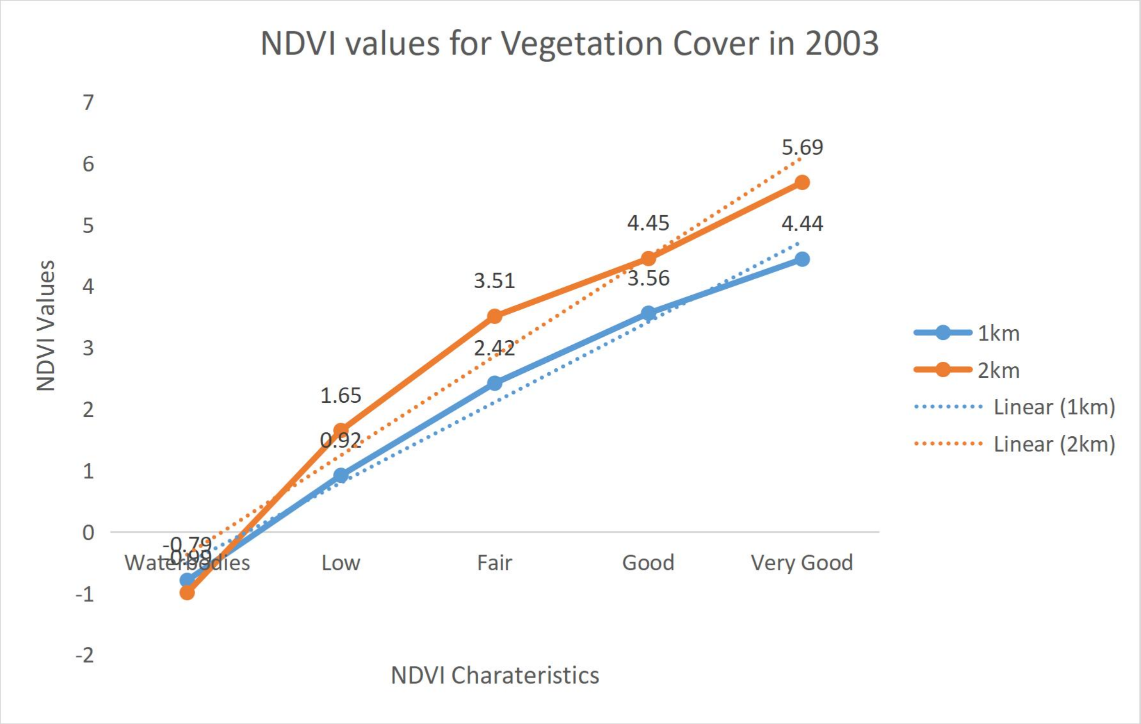


Figure 4.11.: NDVI Values for Vegetation Cover in 2003 between 1km and 2km.

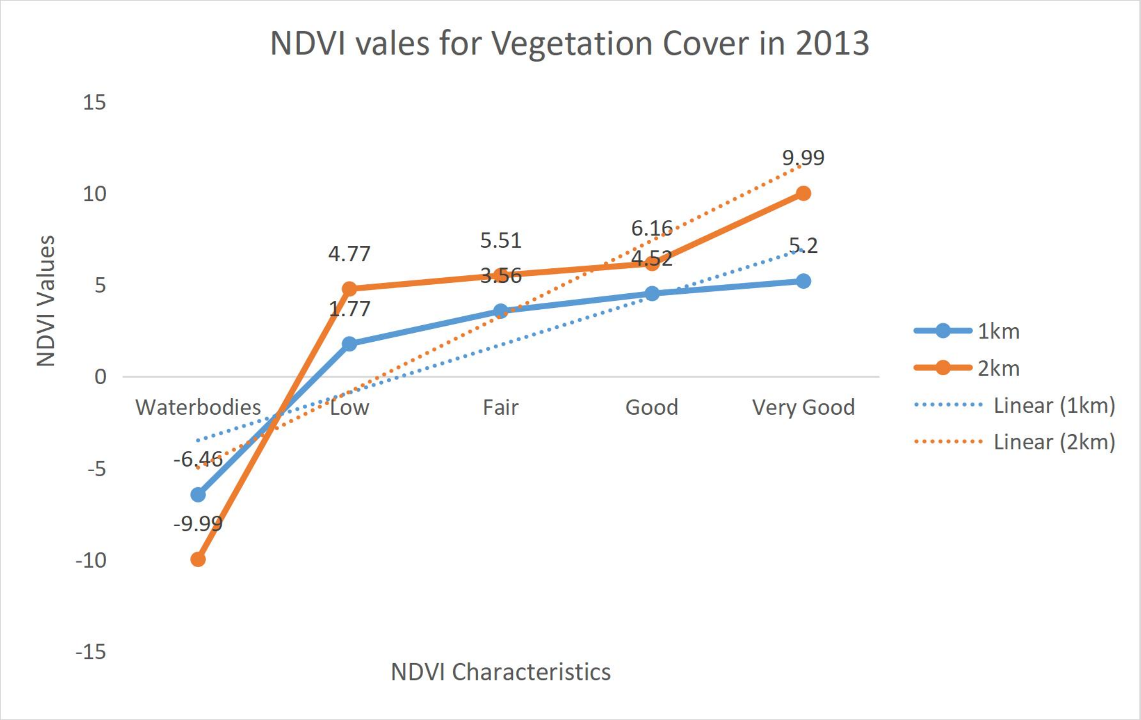


Figure 4.12.: NDVI Values for Vegetation Cover in 2013 between 1km and 2km.

CHAPTER FIVE

5.1. DISCUSSION

The NDVI analysis result for the vegetation health around Awoba flowstation, shows changes in vegetation index across the analyzed years (1991,1999,2003, and 2013). To determine how gas flaring affects the surrounding vegetation at Awoba flowstation, a radius of 1 and 2km was mapped out from the gas flare stack and NDVI values were generated for vegetation within 1km and 2km away from the gas flaring site for each year.

Five (5) classes were assigned to the study area, which are waterbodies, low vegetation health. fair vegetation health, good vegetation health and very good vegetation health.

For the year 1991, the NDVI values 1km away from the flowstation, were -0.022 indicating water bodies, 0.138 indicating low vegetation health, 0.192 indicating fair vegetation health, 0.232 indicating good vegetation health and 0.293 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 1991, 1km away from the flowstation are -0.021,0.293 and 0.156 respectively.

For the year 1991, the NDVI values 2km away from the flowstation, were -0.034 indicating water bodies, 0.082 indicating low vegetation health, 0.175 indicating fair vegetation health, 0.234 indicating good vegetation health and 0.315 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 1991, 2km away from the flowstation are -0.034, 0.315 and 0.121 respectively.

For the year 1999, the NDVI values 1km away from the flowstation, were -0.164 indicating water bodies, 0.048 indicating low vegetation health, 0.263 indicating fair vegetation health, 0.468 indicating good vegetation health and 0.621 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 1999, 1km away from the flowstation are -0.164, 0.767 and 0.464 respectively.

For the year 1999, the NDVI values 2km away from the flowstation, were -0.188 indicating water bodies, 0.159 indicating low vegetation health, 0.444 indicating fair vegetation health, 0.618 indicating good vegetation health and 0.755 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 1999, 2km away from the flowstation are -0.188, 0.767 and 0.353 respectively.

For the year 2003, the NDVI values 1km away from the flowstation, were -0.079 indicating water bodies, 0.092 indicating low vegetation health, 0.242 indicating fair vegetation health, 0.356indicating good vegetation health and 0.444 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 2003, 1km away from the flowstation are -0.079, 0.582 and 0.332 respectively.

For the year 2003, the NDVI values 2km away from the flowstation, were -0.099 indicating water bodies, 0.165 indicating low vegetation health, 0.351 indicating fair vegetation health, 0.445 indicating good vegetation health and 0.569 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 2003, 2km away from the flowstation are -0.099, 0.582 and 0.264 respectively.

For the year 2013, the NDVI values 1km away from the flowstation, were -0.646 indicating water bodies, 0.177 indicating low vegetation health, 0.356 indicating fair vegetation health, 0.452 indicating good vegetation health and 0.520 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 2013, 1km away from the flowstation are -0.973, 0.970 and 0.578respectively.

For the year 2013, the NDVI values 2km away from the flowstation, were -0.999 indicating water bodies, 0.477 indicating low vegetation health, 0.551 indicating fair vegetation health, 0.616 indicating good vegetation health and 0.999 indicating very good vegetation health.

The NDVI minimum, maximum and mean values for the year 2013, 2km away from the flowstation are -0.999, 0.999 and 0.397respectively.

The chi-square goodness of fit was used in a Statistical study to find the significant difference between the distances (1km and 2km).

In 1991, the NDVI values for waterbody between 1km and 2km had a p-value of $p>0.05$, which shows no Significant difference between the NDVI values obtained. The NDVI values for low vegetation between 1km and 2km had a p-value of $p>0.05$, which shows no Significant difference between the NDVI values obtained. The NDVI values for fair vegetation between 1km and 2km had a p-value of $p>0.05$, which shows no Significant difference between the NDVI values obtained. The NDVI values for Good vegetation between 1km and 2km had a p-value of $p>0.05$, which shows no Significant difference between the NDVI values obtained. The NDVI values for very Good vegetation between 1km and 2km had a p-value of $p>0.05$, which shows no Significant difference between the NDVI values obtained.

In 1999, the NDVI values for waterbody between 1km and 2km had a p-value of $p>0.05$, which shows no Significant difference between the NDVI values obtained. The NDVI values for low vegetation between 1km and 2km had a p-value of $p<0.01$, which shows High Significant difference between the NDVI values obtained. The NDVI values for fair vegetation between 1km and 2km had a p-value of $p<0.05$, which shows a Significant difference between the NDVI values obtained. The NDVI values for Good vegetation between 1km and 2km had a p-value of $p<0.001$, which shows a very high Significant difference between the NDVI values obtained. The NDVI values for very Good vegetation between 1km and 2km had a p-value of $p<0.001$, which shows a very high Significant difference between the NDVI values obtained.

1n 2003, the NDVI values for waterbody between 1km and 2km had a p-value of $p>0.05$, which shows no Significant difference between the NDVI values obtained. The NDVI values for low vegetation between 1km and 2km had a p-value of $p<0.001$, which shows a very high Significant difference between the NDVI values obtained. The NDVI values for fair between 1km and 2km had a p-value of $p<0.001$, which shows a very high Significant difference between the NDVI values obtained. The NDVI values for Good vegetation between 1km and 2km had a p-value of $p<0.01$, which shows a high Significant difference between the NDVI values obtained. The NDVI values for very Good vegetation between 1km and 2km had a p-value of $p<0.001$, which shows a very high Significant difference between the NDVI values obtained.

In 2013, The NDVI values for waterbody between 1km and 2km had a p-value of $p<0.01$, which shows a high Significant difference between the NDVI values obtained. The NDVI values for low vegetation between 1km and 2km had a p-value of $p<0.001$, which shows a very high Significant difference between the NDVI values obtained. The NDVI values for fair vegetation between 1km and 2km had a p-value of $p<0.05$, which shows a Significant difference between the NDVI values obtained. The NDVI values for Good vegetation between 1km and 2km had a p-value of $p<0.01$, which shows a high Significant difference between the NDVI values obtained. The NDVI values for very Good vegetation between 1km and 2km had a p-value of $p<0.001$, which shows a very high Significant difference between the NDVI values obtained.

From the results, Figure 4.9 shows the NDVI values for vegetation cover in 1991 between 1km and 2km before the flaring of gas in 1992 in Awoba flowstation The NDVI values obtained for vegetation cover were relatively similar in 1991 but had different values. The NDVI values obtained for 1km before gas flaring started were -0.022, 0.138, 0.192, 0.232 and 0.293 while the values obtained for 2km were -0.034, 0.082, 0.175, 0.234 and 0.315 respectively. The trendline indicates that vegetation cover in 1km was relatively similar and higher before the flaring of gas in 1992, having a total sum of 0.833 NDVI value while 2km had a total sum of 0.772 NDVI values in 1991. The trendline for vegetation cover in 1991 was higher in 1km than 2km indicating a higher trendline as shown in the figure 4.9. This shows that the vegetation health in Awoba flowstation in 1991 prior to the operation of the flowstation in 1992, was healthier since it hasn't been affected by gas flaring.

From the results, Figure 4.10. shows the NDVI values for vegetation cover in 1999 between 1km and 2km during flaring of gas in Awoba flowstation The NDVI values obtained for vegetation cover were different in 1999. The NDVI values obtained for 1km during gas flaring were -0.164, 0.048, 0.263, 0.468 and 0.621 while the values obtained for 2km were -0.188, 0.159, 0.444, 0.618 and 0.754 respectively. The trendline indicates that vegetation cover in 2km was relatively higher than the vegetation covers in 1km during flaring of gas in 1999, having a total sum of 1.787 NDVI value while 1km had a total sum of 1.236 NDVI values in 1999. The trendline for vegetation cover in 1999 was higher in 2km than 1km indicating a higher trendline as shown in the figure 4.10. This demonstrate that the flaring of gas is having an effect on the vegetation cover closer to it.

From the results, Figure 4.11. shows the NDVI values for vegetation cover in 2003 between 1km and 2km during flaring of gas in Awoba flowstation The NDVI values obtained for vegetation cover were different in 2003. The NDVI values obtained for 1km during gas flaring were -0.079, 0.092, 0.242, 0.356 and 0.444 while the values obtained for 2km were -0.099, 0.165, 0.351, 0.445 and 0.569 respectively. The trendline indicates that vegetation cover in 2km was relatively higher than the vegetation covers in 1km during flaring of gas in 2003, having a total sum of 1.431 NDVI value while 1km had a total sum of 1.055 NDVI values in 2003. The trendline for vegetation cover in 2003 was higher in 2km than 1km indicating a higher trendline as shown in the figure 4.11. This demonstrates that the flaring of gas is having an effect on the vegetation cover closer to it.

From the results, Figure 4.12. shows the NDVI values for vegetation cover in 2013 between 1km and 2km during flaring of gas in Awoba flowstation The NDVI values obtained for vegetation cover were different in 2013. The NDVI values obtained for 1km during gas flaring were -0.646, 0.177, 0.356, 0.452 and 0.520 while the values obtained for 2km were -0.999, 0.477, 0.551, 0.616 and 0.999 respectively. The trendline indicates that vegetation cover in 2km was relatively higher than the vegetation covers in 1km during flaring of gas in 2013, having a total sum of 1.644 NDVI value while 1km had a total sum of 0.859 NDVI values in 2003. The trendline for vegetation cover in 2003 was higher in 2km than 1km indicating a higher trendline as shown in the figure 4.12. This demonstrate that the flaring of gas is having an effect on the vegetation cover closer to it.

The NDVI spatial assessment across the analyzed years from 1km to 2km from the gas stack shows gradual increase from the gas stack. This further demonstrates the detrimental impact of gas flaring on the surrounding vegetation of the gas stack which agrees with studies by Seiyaboh and Izah, 2017: Amaechi and Ajokpauwu,2022. According to Ajugwo, 2013; Izah and Ohiamain 2015, retardation of vegetation and crop around gas stacks can be attributed to air pollutants like oxides of nitrogen, carbon and sulphur, particulate matter, hydrocarbon and ash. The study also revealed that a significant factor in the decline in the health of the vegetation surrounding the gas stack is soil contamination and the effects of heating. In correlation to (Amadi,2014) with the result of this study, there is a spatial gradient in the effect of gas flares on the vegetation around the gas stack. Seiyaboh and Izah,2017, presented that gas flaring is the main cause of acid rain in Niger Delta region of Nigeria, and that this has a negative impact on soil fertility and vegetation. This can be seen in this study, in the year1991 NDVI values for 1km was higher than that of 2km indicating that vegetation health hasn't been affected by gas flares from Awoba flowstation. But from the years 1997, 2003 and 2013 it can be seen that NDVI values for 1km was lower than that of 2km, indicating the effects of gas flaring.

Also, from the statistical analysis conducted it can be seen that for the year 1991, which was before the operation of the flowstation there wasn't any significant difference ($p>0.05$) between the NDVI values for 1km and 2km. But from the years after operations started in the flowstation 1999, 2003 and 2013 it can be seen that there were significant differences ($p < 0.05$, $p<0.01$, $p<0.001$) between 1km and 2km, indicating the effects of gas flaring on vegetation health at the marked distances.

The trendline for vegetation cover in 1991 was higher in 1km than 2km indicating a higher trendline as shown in the figure 4.9.

The trendline for vegetation cover in 1999, 2003 and 2013 was higher in 2km than 1km indicating a higher trendline as shown in the figure 4.10, 4.11 and 4.12. This shows that the gas flaring is having an effect on the vegetation cover closer to it.

This might be attributed to decrease in chlorophyll content of vegetation in area of gas flare (Amadi,2017; Ubani and Onyejekwe,2013). The decrease in chlorophyll in plants near flares is as a result of heat. Heat is known to decrease chlorophyll (Lawson *et al*.,2013) gas flares affect the accumulation of chlorophyll, photo chlorophyll and the rate of conversion of the latter to chlorophyll in leaves. Lesions-related deformations and color variegation are frequently seen signs of decreased chlorophyll accumulations in plants.

5.2. CONCLUSION

The potential of GIS in assessing changes in the environment over time has been evaluated in this study, it made use of the high spatial resolution of the Landsat data to properly determine the amount of changes brought about by gas flaring over time by detecting different types of vegetation cover as early as 1991. The data from NDVI clearly showed the similarities in NVDI values between the distances 1km and 2km in the study area which indicated vegetation hasn't been affected before the flaring of gas by the flow station. However, significant variations were noted over time in the research data of the same study region. This resulted from studies that showed the vegetation was declining quickly. Further results showed that a significant contributing element to this reduction in the study area's rich vegetation is gas flaring. Variations in NDVI values from results indicated that the amount of gas flared and the timing of the commissioning of gas flaring sites are two additional elements that may influence the extent of the impacts of gas flaring.

Furthermore, the study's findings support the concept that gas flaring played a major role in the study's rich natural forest disappearing.

5.3. RECOMMENDATION

It is highly recommended that the Nigerian Government should:

1. Implement policies, such as the polluter pay principle and/or give out incentives to companies so as to reduce gas flaring.
2. Provide adequate funding to scientific research on gas flaring, to fully assess it impacts on vegetation, biodiversity and the entire ecosystem, and develop ways of mitigation.

3. Train its workers especially those saddle with the responsibility of policy implementation on environmental management systems.

4. Associated gas utilization as it will contribute significantly to the economy of Nigeria in general (Amaechi and Emejulu, 2021).

5. From this study, it shows that NDVI value for very good vegetation health at 1km for 2013 was 0.520 but at 2km for 2013 was 0.999. This study further recommends that human settlement should be beyond 2km from the gas flare stack and further research should be done to determine the recommended safe human settlement distance from the gas stack.

If the recommendations mentioned above are put into practice, more thorough research studies would be conducted, which might help in the formulation of more suitable policies and developmental strategies for the area. This would lead to the reduction of gas flaring as one of the factors responsible for its continues flare is limited studies and low level of environmental awareness of its cost and impacts in the country (Adole, 2011). Since over 75% of the population in the Niger Delta depends on the natural environment for their livelihood (Sterner, 2010), it is absolutely pertinent that government should implement suggested recommendations and work towards zero gas flaring. This would ultimately lead to poverty alleviation and sustainable development for the Niger Delta region and Nigeria as a whole(Adole,2011).

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