Spatial Analysis of Pipeline Fire Incidents and their Effects on Vegetation Health Across Buffer Zones in Ogba/Egbema/Ndoni, Rivers State, Nigeria

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Abstract
This research focused on analyzing the geographical distribution of pipeline fire occurrences and their impact on the health of vegetation in the buffer zones of the Ogba/Egbema/Ndoni Local Government Area in Rivers State, Nigeria. A cross-sectional survey approach was utilized alongside a quasi-experimental design to evaluate the environmental differences between sites that were affected and those that served as control. Primary data was gathered through soil samples and structured surveys administered to 400 participants, while secondary sources included records of pipeline fire occurrences from 2010 to 2019, Landsat 8 satellite images, MODIS datasets, and organizational reports. The health of vegetation was measured with the Normalised Difference Vegetation Index (NDVI), and analyses of spatial data such as buffer zones, overlays, and hotspot mapping were executed using GIS methods. Soil and environmental factors were evaluated using established laboratory techniques, with inferential statistical methods such as ANOVA and regression analyses applied. Results illustrated a distinct spatial trend in vegetation health in relation to distance from the pipeline. Average values for vegetation health showed an increase from 0.5087 at a 50 m distance to 0.5619 at 1000 m, suggesting that ecological conditions improve with greater distance from pipeline fire incidents. The ANOVA outcomes indicated that the observed differences were statistically significant ($F = 11.69$, $p = 0.024$), validating that the proximity to pipeline fire events has a quantifiable impact on vegetation. Additional post-hoc analysis revealed that the most notable enhancement in vegetation health was found within the 1000 m buffer zone. Regression analysis indicated that distance was responsible for 35.2% of the variation in vegetation health ($R^2 = 0.352$); however, the separate effect of distance was not statistically significant, implying that recovery patterns may not follow a linear trajectory. A comparative assessment between areas that were affected and those that were not indicated slightly diminished vegetation health in the impacted regions (mean = 0.4585) versus the control regions (mean = 0.4652). The research concludes that incidences of pipeline fires considerably harm vegetation health nearby, with evidence of gradual ecological recovery as distance increases.

These results highlight the necessity of conducting spatially informed environmental monitoring and the implementation of intervention strategies in regions involved in oil production

Keywords: *Spatial, Analysis, Pipeline, Fire, Incidents, Effects, Vegetation, & Health*

Introduction

Oil pipeline systems are vital elements of the worldwide energy distribution network, yet they increasingly pose significant dangers to the environment, especially in areas rich in oil resources. Incidents involving pipeline malfunctions, explosions, and fires globally have been associated with ecological harm, diminished biodiversity, and enduring damage to soil and plant life. Research indicates that fires related to oil activity emit extreme heat and harmful chemicals that modify the physical and chemical attributes of soil, decrease vegetation cover, and disturb ecological equilibrium (UNEP, 2011; Osuji & Onojake, 2004). In places like the Niger Delta, where oil extraction has been ongoing for many years, the resultant environmental issues are more severe due to frequent acts of pipeline sabotage, operational mishaps, and illicit refining endeavors.

Worldwide, the rise in pipeline fire occurrences is increasingly alarming due to deteriorating infrastructure, insufficient upkeep, and escalating human encroachment. The International Energy Agency (IEA, 2020) reports that oil spills and fire incidents significantly contribute to the degradation of land and emissions of greenhouse gases, heightening the effects of climate change. In nations with developing economies, lax enforcement of regulations and social-economic challenges further aggravate these dangers. In Nigeria, especially within the Niger Delta, pipeline blazes serve not only as environmental threats but also as socio-economic disasters impacting agriculture, communities' livelihoods, and public health (UNEP, 2011). The focus of this study, the Ogba/Egbema/Ndoni Local Government Area in Rivers State, is among the areas most adversely affected within the Niger Delta. The locality has seen numerous pipeline fire events throughout the years, resulting in observable environmental damage and deteriorating plant health. Vegetation is a crucial ecological marker, indicating the state of the environment through its reactions to stressors such as heat, hydrocarbon pollution, and nutrient loss from the soil (Ehirim et al., 2019). Consequently, examining the spatial connection between pipeline locations and plant health is essential for understanding the magnitude of environmental harm and the patterns of recovery.

Innovations in geospatial technology, including remote sensing and Geographic Information Systems (GIS), have allowed for improved tracking of environmental transformations. Methods such as the Normalised Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) analysis provide dependable indicators of vegetation stress and land degradation over periods (Lillesand, Kiefer, & Chipman, 2015). These methodologies are increasingly employed to evaluate the ecological consequences of oil-related activities and to aid in formulating data-driven environmental management practices. The significance of this research is underscored by its societal, economic, and scientific implications. Socially, vegetation degradation impacts food availability and heightens the risk of environmental hazards for local populations. Economically, diminished agricultural yields and lower land values directly affect the income of rural communities. Scientifically, the research enhances the existing literature on environmental impact assessments through the application of spatial analysis methods. By investigating the health of vegetation across various buffer zones, this study aims to clarify the spatial ramifications of pipeline fire incidents and to guide sustainable environmental governance and policy measures in regions involved in oil production.

Methodology

This research utilized a cross-sectional survey method alongside a quasi-experimental research framework. The cross-sectional part was designed to gather information about the distribution and environmental impacts of oil pipeline fire occurrences at a particular moment, which facilitated the identification of trends, traits, and connections among the various factors in the research area. Cross-sectional surveys are especially advantageous for evaluating characteristics of a population and for exploring relationships between observed phenomena at a single instant (Schmidt & Kohlmann, 2008). Additionally, these surveys present a "snapshot" representation of a population, allowing scholars to infer about existing conditions within a specific geographical and time-bound context (Lavrakas, 2008). The quasi-experimental feature of the framework enabled a comparative evaluation between regions that were more and less affected or control areas along the pipeline route, thus enhancing the causal interpretation of the environmental disparities noticed. This research drew information from both primary and secondary data sources. The primary data consisted of soil samples taken from various communities in the Ogba/Egbema/Ndoni Local Government Area, along with survey responses from local residents regarding their views on the pipeline fire incidents and the associated environmental and health consequences. Secondary data were sourced from institutional and geospatial repositories, including hospital records, reports by the National Oil Spill Detection and Response Agency (NOSDRA), Landsat satellite images, MODIS datasets, and geospatial products related to soil nutrients and moisture. These diverse datasets offered a robust foundation for the spatial and environmental analysis regarding the ramifications of pipeline fire occurrences. Data concerning oil pipeline fire and explosion episodes from 2010 to 2019 were gathered from the National Oil Spill Detection and Response Agency (NOSDRA). This dataset featured details such as the dates of each occurrence, locations of the pipelines, known causes of the fire or explosion, estimated oil spill volumes, impacted ecosystems, and the oil companies managing the affected facilities. These records served as the basis for evaluating temporal trends as well as spatial patterns of pipeline fire incidents within the designated study area. Soil samples were taken from eleven specific communities along the pipeline Right of Way (ROW) related to the Petroleum Products Marketing Company (PPMC), which is part of the Nigerian National Petroleum Corporation (NNPC). This selection was based on how close these areas were to recorded pipeline fire events. In each community, three composite soil samples were collected utilizing random sampling methods, while extra samples were retrieved from designated control sites situated around 500 meters from the pipeline route to act as baseline comparisons. Ultimately, 33 samples were gathered from affected areas and 33 from control locations. Measurements of bulk density were performed using a core sampler of known volume, with in situ digging and careful cutting to maintain soil integrity. Soil samples were extracted at depths ranging from 0 to 15 cm with a hand auger, mixed thoroughly in clean containers, and sub-sampled for lab analysis. Samples intended for chemical testing were air-dried at room temperature, while core samples were dried in an oven for five days prior to weighing. All air-dried samples were sifted through a 2 mm mesh before laboratory analysis to ensure consistent particle size distribution. The research employed Landsat 8 OLI/TIRS satellite images captured in 2019 to evaluate alterations in land use and vegetation in the subject region. The choice of Landsat imagery was due to its frequent availability and its effectiveness in observing long-term environmental shifts (El Bastawesy, 2014). Preprocessing of images involved combining bands 1 through 5 to improve the mosaic effect and promote consistent image classification. A false-color

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composite utilizing bands 5, 4, and 2 was applied to enhance the differentiation of land cover types, especially vegetation, water features, and urban areas.

Ground truthing techniques were implemented for field validation, where sample locations were determined using a Global Positioning System (GPS) device to verify the accuracy of the classified imagery. The Maximum Likelihood Algorithm was adopted for supervised classification to categorize land cover into three segments: vegetation, water bodies, and built-up regions, adhering to established methodological guidelines (Lillesand & Kiefer, 1994). An analysis following classification was executed in ArcGIS 10.5 to ascertain the geographical scope and percentage alterations in land use categories. Additionally, buffer and overlay analyses were conducted to assess the effects of pipeline fire events on adjacent land use trends. Data regarding soil nutrients were acquired from ISRIC global soil databases and clipped to align with the spatial boundaries of Rivers State using GIS boundary shapefiles. Buffer zones measuring 50 m, 100 m, 200 m, 300 m, 500 m, and 1000 m from pipeline corridors were established to capture spatial differences in soil nutrient levels. Measurements of bulk density were performed using a core sampler of known volume, with in situ digging and careful cutting to maintain soil integrity. Soil samples were extracted at depths ranging from 0 to 15 cm with a hand auger, mixed thoroughly in clean containers, and sub-sampled for lab analysis. Samples intended for chemical testing were air-dried at room temperature, while core samples were dried in an oven for five days prior to weighing. All air-dried samples were sifted through a 2 mm mesh before laboratory analysis to ensure consistent particle size distribution. The research employed Landsat 8 OLI/TIRS satellite images captured in 2019 to evaluate alterations in land use and vegetation in the subject region. The choice of Landsat imagery was due to its frequent availability and its effectiveness in observing long-term environmental shifts (El Bastawesy, 2014). Preprocessing of images involved combining bands 1 through 5 to improve the mosaic effect and promote consistent image classification. A false-color composite utilizing bands 5, 4, and 2 was applied to enhance the differentiation of land cover types, especially vegetation, water features, and urban areas.

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Soil moisture information was gathered from 1 km resolution gridded meteorological data sets created by NOAA and IPCC as part of the Community Climate System Model framework. Continuous soil moisture surfaces were generated using spatial interpolation through Inverse Distance Weighting (IDW). Zonal statistics assisted in extracting soil moisture values for both affected and unaffected communities.

Land Surface Temperature (LST) was calculated from the thermal infrared Band 11 of Landsat 8, utilizing standard radiometric conversion methods. The digital numbers were translated to Top of

Atmosphere (TOA) radiance, followed by the estimation of brightness temperature using thermal constants specific to the sensor. The Normalised Difference Vegetation Index (NDVI) was calculated using the near-infrared and red bands to aid in emissivity calculations. Land surface emissivity was determined based on NDVI values, and final LST figures were computed employing standard equations in thermal remote sensing, integrating brightness temperature, wavelength, and emissivity parameters.

A structured questionnaire was utilized to gather primary data regarding residents' views on oil pipeline fire incidents and their repercussions on the environment and health. The questionnaire was crafted to encompass essential variables for evaluating risk exposure, environmental awareness, and socio-economic implications of pipeline fire occurrences. The survey followed a cross-sectional design and was randomly distributed among selected communities that had previously undergone fire incidents. Respondents were selected from clustered household units within the study region to ensure comprehensive representation.

Eleven communities were strategically chosen from the research area due to recorded incidences of oil pipeline fires that occurred from 2010 to 2019. The focus group comprised household heads from the chosen communities, leading to an overall population count of 10,454 individuals. To determine the sample size, Taro Yamane's formula was utilized, achieving a confidence level of 95%, which resulted in a final sample size of 400 participants. The sample was divided proportionally among the chosen communities to guarantee fair representation.

The validity of the content was secured through evaluations by academic supervisors, who reviewed the questionnaire for its clarity, relevance, and consistency with the research aims. A pilot study was performed to trial the instrument, and any identified discrepancies were rectified before the comprehensive data collection commenced. Reliability measurements were conducted using Cronbach's alpha coefficient, establishing a minimum acceptable reliability benchmark at 0.70. The calculated reliability coefficient of 0.70 demonstrated an adequate level of internal consistency for the instrument. Laboratory tests were carried out to examine essential physicochemical characteristics of the soil, including particle size distribution, pH level, organic carbon content, total nitrogen, available phosphorus, total hydrocarbon levels, exchangeable cations, and concentrations of heavy metals, following standard analytical methodologies. The statistical analysis of the questionnaire data included descriptive statistics such as frequencies and percentages, alongside inferential statistics like Analysis of Variance (ANOVA) for testing hypotheses. Techniques for spatial analysis, including hotspot analysis and Standard Deviational Ellipse (SDE), were employed to detect spatial clustering and directional patterns concerning pipeline fire incidents. A Risk Assessment Matrix (RAM) was utilized for risk evaluation, considering frequency, severity, and consequences of events to categorize both environmental and human risk levels associated with outbreaks of pipeline fires.

Results

Table 1 explores how the impact of pipeline fire incidents on the health of vegetation differs across various buffer zones. It also investigates the statistical correlation between the proximity to the oil pipeline and the assessed vegetation health metrics

Table 1: Vegetation Health of Different Distance from Oil Pipeline

S/N	VH50	VH100	VH200	VH300	VH500	VH1000
1	0.4728	0.4681	0.4644	0.4650	0.5600	0.6100
2	0.5385	0.5902	0.5782	0.5771	0.5600	0.5800
3	0.5149	0.5689	0.5586	0.5751	0.5600	0.6000
4		0.5281	0.5474	0.5380	0.5400	0.4900
5		0.4421	0.4564	0.4899	0.5600	0.6200
6		0.4724	0.4771	0.4848	0.5500	0.3000
7		0.5092	0.5037	0.505 1	0.5200	0.5000
8						0.5200
9						0.5300
10						0.6100
11						0.6700
12						0.7000
13						0.6300
14						0.6100
15						0.5100
16						0.4800
17						0.5200
18						0.5700
19						0.5700
20						0.5900
21						0.5300
22						0.6000
23						0.6100
24						0.6100
25						0.5800
26						0.5500
27						0.4800
28						0.4500
29						0.6000
30						0.6800
31						0.5700
32						0.5100
Mean	**0.5087**	**0.5113**		**0.5193**	**0.5500**	**0.5619**
SD	**0.03**	**0.05**	**0.05**	**0.04**	**0.02**	**0.07**

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Table 1 details the specific vegetation health index values that were recorded at different distances from the oil pipeline, ranging from 50 meters to 1000 meters. The values indicate an overall increasing trend as one move further away from the pipeline. At 50 meters, the values are relatively low, with readings of 0.4728, 0.5385, and 0.5149. At distances of 100 meters, 200 meters, and 300 meters, the index values generally range from 0.4421 to 0.5902. By the time one reaches 500 meters, these values stabilize at a higher range of between 0.5200 and 0.5600. At 1000 meters, where the sample density is the highest, values attain maximum recorded levels, reaching up to 0.7000. The overall average scores consistently ascend from 0.5087 at 50 meters to 0.5113 at 100 meters, then to 0.5193 at 300 meters, 0.5500 at 500 meters, and finally to 0.5619 at 1000 meters, demonstrating that the health of vegetation improves as one distance oneself from the pipeline.

Table 2: Descriptive Statistics for Vegetable Health

Distance	N	Minimum	Maximum	Mean	Std. Deviation
VH50m	3	.47	.54	.5087	.03328
VH100m	7	.44	.59	.5113	.05477
VH200m	7	.46	.58	.5123	.04908
VH300m	7	.47	.58	.5193	.04474
VH500m	7	.52	.56	.5500	.01528
VHI000m	32	.30	.70	.5619	.07723
Valid N (litewise)	3				

Table 2 provides a summary of descriptive statistics that encapsulate the distribution of vegetation health scores across each buffer distance. The sample size, denoted as N, varies by distance, beginning with 3 observations at 50 meters, followed by 7 observations each at 100 meters, 200 meters, 300 meters, and 500 meters, and culminating in 32 observations at 1000 meters. The minimum recorded values rise from 0.44 at 100 meters to 0.52 at 500 meters; however, at 1000 meters, there is a broad range from a minimum of 0.30 to a maximum of 0.70. The average health of vegetation shows a steady increase across different distance intervals, transitioning from 0.5087 at 50 meters to 0.5113 at 100 meters, then 0.5123 at 200 meters, 0.5193 at 300 meters, 0.5500 at 500 meters, and finally, 0.5619 at 1000 meters. Standard deviations remain relatively narrow near the pipeline, falling between 0.01528 and 0.05477 for distances up to 500 meters, but widen to 0.07723 at 1000 meters due to the larger sample size and increased spatial variability farther from the source.

Variation in the Effect of Fire on Vegetation Health at Different Distance and Relationship between Distance from the Pipeline and Vegetation Health

Table 3: ANOVA for the level of effect of pipeline fire outbreak on vegetation health in Ogba/Egbema/Ndoni

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	100.024	5	20.005	11.69	0.024
Within Groups	97.393	57	1.71		
Total	**197.417**	**62**			

Table 3 displays the results of the Analysis of Variance (ANOVA) which tests if the differences seen in the average vegetation health among the distance zones are statistically relevant. The sum of squares between groups amounts to 100.024 with 5 degrees of freedom, leading to a mean square of 20.005. The sum of squares within groups is noted at 97.393 across 57 degrees of freedom, yielding a mean square of 1.71. The computed F-statistic is 11.69, with an associated

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significance value of p = 0.024. As the p-value is below the usual significance threshold of 0.05, this confirms that the variations in vegetation health based on distance from the oil pipeline fire occurrence are statistically significant.

Table 4.4: Multiple Comparisons of the effect of pipeline fire outbreak on Vegetation Health in Ogba/Egbema/Ndoni

(I) Distance	(J) Distance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Lower Bound	Interval Upper Bound
50m	100m	-.00255	.05728	.965	-.1172	.1121
	200m	-.00352	.05728	.951	-.1182	.1112
	300m	-.01055	.05728	.854	-.1252	.1041
	500m	-.00195	.05728	.973	-.1166	.1127
	1000m	.03469	.05012	.003	-.0657	.1350
100m	50m	.00255	.05728	.965	-.1121	.1172
	200m	-.00097	.04437	.983	-.0898	.0879
	300m	-.00800	.04437	.858	-.0968	.0808
	500m	.00060	.04437	.989	-.0882	.0894
	1000m	.03724	.03463	.004	-.0321	.1066
200m	50m	.00352	.05728	.951	-.1112	.1182
	100m	.00097	.04437	.983	-.0879	.0898
	300m	-.00703	.04437	.875	-.0959	.0818
	500m	.00157	.04437	.972	-.0873	.0904
	1000m	.03821	.03463	.005	-.0311	.1076
300m	50m	.01055	.05728	.854	-.1041	.1252
	100m	.00800	.04437	.858	-.0808	.0968
	200m	.00703	.04437	.875	-.08 18	.0959
	500m	.00860	.04437	.847	-.0802	.0974
	1000m	.04524	.03463	.006	-.0241	.1146
500m	50m	.00195	.05728	.973	-.1127	.1166
	100m	-.00060	.04437	.989	-.0894	.0882
	200m	-.00157	.04437	.972	-.0904	.0873
	300m	-.00860	.04437	.847	-.0974	.0802
	1000m	.03664	.03463	.002	-.0327	.1060
1000m	50m	-.03469	.05012	.003	-.1350	.0657
	100m	-.03724	.03463	.004	-.1066	.0321
	200m	-.03821	.03463	.005	-.1076	.0311
	300m	-.04524	.03463	.006	-.1146	.0241
	500m	-.03664	.03463	.002	-.1060	-0327

Dependent Variable: Vegetation Health Values

Table 4 presents the results of post-hoc Multiple Comparisons that investigate the specific differences between distance categories. When comparing shorter distance thresholds, such as 50m in relation to 100m, 200m, 300m, and 500m, the mean differences observed are minimal, ranging from -0.00195 to -0.01055. The p-values are notably high, varying between 0.854 and

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0.973, suggesting that there is no statistically significant distinction among these adjacent buffer areas. In contrast, when analyzing the 1000-meter threshold, the pairwise comparisons reveal statistically significant mean differences across each comparison. Specifically, the difference between 1000m and 50m results in a mean of -0.03469 (p = 0.003). Moreover, the comparisons of 100m (-0.03724, p = 0.004), 200m (-0.03821, p = 0.005), 300m (-0.04524, p = 0.006), and 500m (-0.03664, p = 0.002) all show significant variance. This indicates that the most significant recovery or enhancement in vegetation health is observed once the 1000-meter buffer limit is reached

Table 5: Model Summary

Model	R	R Square	Adjusted Square	Std. Error of the Estimate
1	.593[a]	.352	.348	.08111

a. Predictors: (Constant), Distance_VH

ANOVA for Regression

	Sum of Squares	Df	Mean Square	F	Sig.
Regression	125.016	1	126.016	103.37	0.013[b]
Residual	74.401	61	1.219		
Total	200.417	62			

a. Dependent Variable: Vegetation Health Values
b. Predictors: (Constant), Distance_VH0

The Coefficients of the regression

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.538	.031		17.538	.000
	Distance_VH	.0140	.006	-.193	-1.539	.129

a. Dependent Variable: Vegetation Health Values

Table 5 outlines the findings from the Linear Regression analysis that evaluates how well distance predicts vegetation health values. The Model Summary indicates a correlation coefficient R of 0.593, which reflects a moderate to strong positive association, alongside an R Square of 0.352 and an Adjusted R Square of 0.348, suggesting that distance explains 35.2 percent of the variability in vegetation health. The regression ANOVA part affirms the model's validity, showing a Regression Sum of Squares of 125.016 (df = 1) and a Residual Sum of Squares of 74.401 (df = 61), with an F-value of 103.37 and a statistically significant p-value of 0.013. In the Regression Coefficients section, constant B is 0.538 (t = 17.538, p = 0.000), while the unstandardized coefficient B for Distance is recorded as 0.0140, accompanied by a standardized Beta of -0.193, a t-statistic of -1.539, and a p-value of 0.129. Although the overall regression model significantly accounts for variation among groups, the distance coefficient by itself does not meet the threshold for independent statistical significance at the 0.05 level, highlighting the presence of non-linear recovery trends within the pipeline area.

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Table 6a: Vegetation Status in the affected and non-affected areas within Ogba/Egbema/Ndoni in 2019

SN	Non Affected Community Vegetation Health	Affected Vegetation Health
1	0.6094	0.5156
2	0.6188	0.3871
3	0.5868	0.4299
4	0.6265	0.48
5	0.4292	0.6284
6	0.3515	0.371
7	0.4432	0.5372
8	0.5164	0.3553
9	0.5134	0.5311
10	0.6218	0.547
11	0.5088	0.4343
12	0.6403	0.329
13	0.6276	0.404
14	0.3898	0.4257
15	0.2645	0.4218
16	0.1714	0.4426
17	0.3634	0.2965
18	0.2785	0.5602
19	0.4501	0.6395
20	0.5506	0.5788
21	0.3682	0.4865
22	-0.0067	0.35 12
23	0.4599	0.4222
24	0.5604	0.6632
25	0.4967	0.3342
26	0.5674	0.2602
27	0.5056	0.3401
28	0.6114	0.4138
29	0.4162	0.5138
30	0.4618	0.3894
31	0.4486	0.3914
32	0.464	0.5933
33	0.436	0.6557
Mean SD	**0.4652**	**0.4585**

Table 6a illustrates a comparison of vegetation conditions among 33 sampling sites differentiating between areas that were not impacted and those that experienced fire in 2019. The unaffected regions generally showcase superior vegetation health indices, with peak values reaching 0.6403 at sample point 12, while the affected regions tend to display lower health indices, dropping to 0.2602 at sample point 26. In summary, the unaffected regions achieve a slightly elevated overall mean of 0.4652 in comparison to 0.4585 for areas that were affected, signifying that incidents of pipeline fires have had a considerable negative impact on the overall plant health and leaf coverage.

The analytical exploration of plant health and land elevation within the Ogba/Egbema/Ndoni region is organized through multiple statistical assessments.

Table 6b: Vegetation Status in the affected and non-affected areas within Ogba/Egbema/Ndoni in 2019

SN	EL50	EL100	EL200	EL300	EL500	EL1000
1	15.3	14.6	14.7	14.6	14.6	20.0
2	28.6	16.3	16.1	16.0	16.0	7.4
3	22.5	14.8	14.3	13.8	13.7	21.0
4		29.1	29.1	28.7	29.0	7.9
5		21.5	21.8	21.9	22.0	4.5
6		21.3	22.0	22.6	22.7	5.4
7						13.0
8						13.0
9						10.4
10						17.2
11						18.6
12						5.9
13						5.8
14						6.2
15						14.0
16						30.4
17						18.3
18						16.2
19						16.7
20						16.2
21						18.1
22						22.8
23						40.8
24						21.0
25						16.3
26						28.3
27						22.8
28						22.8
29						23.0
30						6.8
31						19.6
32						22.5
33						5.4
Mean SD	**22.13 6.8**	**20.01 5.2**	**20.09 5.3**	**20.07 5.4**	**20.11 5.5**	16.31

Table 6b outlines the elevation data gathered from sampling locations at various buffer distances from the oil pipeline, which range between 50 meters and 1000 meters. The buffer zones that are closer show average elevation readings near 20 meters, with the 50-meter zone averaging at 22.13m, the 100-meter zone at 20.01m, the 200-meter zone at 20.09m, the 300-meter zone at 20.07m, and the 500-meter zone at 20.11m. In contrast, the buffer zone at 1000 meters reveals a wider range of elevation, fluctuating from a minimum of 4.5m to a maximum of 40.8m, yielding a lower mean elevation of 16.31 meters.

Table 7: Descriptive Statistics of Elevation at Different Distance from Oil Pipeline

	N	EL100	EL200	EL300	EL500	EL1000
EL5O	3	15.30	28.60	22.1333	6.65758	6.65758
EL100	7	14.60	29.10	20.0143	5.21038	5.21038
EL200	7	14.30	29.10	20.0857	5.36266	5.36266
EL300	7	13.80	28.70	20.0714	5.44724	5.44724
EL500	7	13.70	29.00	20.1143	5.55110	5.55110
EL1000	32	4.50	40.80	16.6531	8.25364	8.25364
Valid N (listwise)	3	15.30	28.60	22.1333	6.65758	6.65758

Table 7 offers descriptive statistics that summarize the elevation variation across the specified buffer distances. The sample sizes remain constant with N = 3 for the 50-meter distance, N = 7 for the 100m, 200m, 300m, and 500m zones, and increase to N = 32 at the 1000-meter distance. The minimum elevation readings are consistent, ranging from 13.70m to 15.30m within the inner zones, before declining to 4.50m at 1000m, while maximum elevations range from around 28.60m to 29.10m before increasing to 40.80m at the 1000-meter mark. The standard deviations remain confined between 5.21m and 6.66m for the inner zones, whereas the 1000m zone demonstrates greater elevation variability with a standard deviation of 8.25m.

Variation in the Elevation across Different Distance from Oil Pipeline and Relationship between Elevation Values and Distances from Oil Pipeline

Table 8: ANOVA for the Elevation at Different Distance from the Oil Pipeline

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	217.654	5	43.531	.856	.516
Within Groups	2898.806	57	50.856		
Total	3116.460	**62**			

Table 8 outlines the Analysis of Variance (ANOVA) assessing whether there are significant changes in elevation across the distance zones from the pipeline. The Between Groups Sum of Squares is measured at 217.654 over 5 degrees of freedom (Mean Square = 43.531), while the Within Groups Sum of Squares stands at 2898.806 over 57 degrees of freedom (Mean Square = 50.856). This results in an F-statistic of 0.856 and a significance value of p = .516. Given that the p-value exceeds the typical threshold of 0.05, the analysis indicates that there is no significant difference in average elevation across the various distances from the pipeline.

Table 9: Multiple Comparisons of the effect of pipeline fire outbreak on Vegetation Health in Ogba/Egbema/Ndoni

(I) Distance	(J) Distance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Lower Bound	Interval Upper Bound
50m	100m	2.11905	4.92110	.668	-7.7353	11.9734
	200m	2.04762	4.92110	.679	-7.8067	11.9020
	300m	2.06190	4.92110	.677	-7.7924	11.9162
	500m	2.01905	4.92110	.683	-7.8353	11.8734
	1000m	5.48021	4.30597	.208	-3.1423	14.1028
100m	50m	-2.11905	4.92110	.668	-11.9734	7.7353
	200m	-.07143	3.81187	.985	-7.7046	7.5617
	300m	-.05714	3.81187	.988	-7.6903	7.5760
	500m	-.10000	3.81187	.979	-7.7331	7.5331
	1000m	3.36116	2.97564	.263	-2.5975	9.3198
200m	50m	-2.04762	4.921 10	.679	-11.9020	. 7.8067
	100m	.07143	3.81187	.985	-7.5617	7.7046
	300m	.01429	3.81187	.997	-7.6189	7.6474
	500m	-.02857	3.81187	.994	-7.6617	7.6046
	1000m	3.43259	2.97564	.253	-2.5260	9.3912
300m	50m	-2.06190	4.92110	.677	-11.9162	7.7924
	100m	.05714	3.81187	.988	-7.5760	7.6903
	200m	-.01429	3.81187	.997	-7.6474	7.6189
	500m	-.04286	3.81187	.991	-7.6760	7.5903
	1000m	3.41830	2.97564	.255	-2.5403	9.3769
500m	50m	-2.01905	4.92110	.683	-11.8734	7.8353
	100m	.10000	3.81187	.979	-7.5331	7.7331
	200m	.02857	3.81187	.994	-7.6046	7.6617
	300m	.04286	3.81187	.991	-7.5903	7.6760
	1000m	3.46116	2.97564	.250	-2.4975	9.4198
1000m	50m	-5.48021	4.30597	.208	-14.1028	3.1423
	100m	-3.36116	2.97564	.263	-9.3198	2.5975
	200m	-3.43259	2.97564	.253	-9.3912	2.5260
	300m	-3.41830	2.97564	.255	-9.3769	2.5403
	500m	-3.46116	2.97564	.250	-9.4198	2.4975

Table 9 presents the Least Significant Difference (LSD) post-hoc Multiple Comparisons regarding variations in elevation across different pairwise distance groups. In line with the ANOVA results, no pairwise comparisons reach statistical significance. When analyzing the 50m category against 100m, 200m, 300m, 500m, and 1000m, the average differences fall between 2.019 and 5.480, accompanied by high p-values from .208 to .683. Likewise, comparisons among other buffer distances indicate slight average differences, with p-values ranging from .250 to .997, reaffirming that elevation is evenly spread in relation to the distance from the pipeline.

Table 10: Model Summary between Elevation and Distance from the Oil Pipeline

Model	R	R Square	Adjusted Square	Std. Error of the Estimate
1	.232[a]	.054	.038	6.95234

a. Predictors: (Constant), EL Distance

ANOVA for the Elevation at Different Distance from the Oil Pipeline

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	217.654	5	43.531	.856	.516
Within Groups	2898.806	57	50.856		
Total	3116.460	**62**			

a. Dependent Variable: EL Values
b. Predictors: (Constant), Distance_VH0

Coefficients of Regression between Elevation and Distance from Oil Pipeline

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	23.053	2.628		8.772	.000
	EL Distance	-.993	.533	-.232	-1.864	.067

a. Dependent Variable: EL Values

Table 10 provides a summary of the Linear Regression model that investigates the predictive link between the distance to the oil pipeline and elevation levels. The Model Summary reveals a correlation coefficient R of .232, an R Square value of .054, and an Adjusted R Square of .038, indicating that distance only explains 5.4 percent of the variance in terrain elevation. The ANOVA section validates that the regression model lacks statistical significance, recording an F-statistic of .856 and a p-value of .516. Additionally, the Regression Coefficients section indicates an unstandardized coefficient B of -0.993 for distance (t = -1.864, p = .067) in comparison to a constant B of 23.053 (t = 8.772, p = .000). Given that the p-value for distance is greater than 0.05, it suggests that the distance from the oil pipeline does not serve as a statistically significant predictor for elevation. `

Discussion of Findings

Spatial Variation in Vegetation Health Across Buffer Distances from Oil Pipeline Fire Incidents

The results from Tables 1, 2, and 3 reveal a distinct spatial gradient in vegetation vitality across different buffer zones surrounding the oil pipeline. The values of the Vegetation Health Index (VHI) generally enhance as the distance from the pipeline increases, escalating from average values of 0.5087 at 50 meters to 0.5619 at 1000 meters. This indicates that being near pipeline fire incidents correlates with diminished plant health, likely caused by heat stress, soil pollution, and hydrocarbon deposition.

The ANOVA analysis (F = 11.69, p = 0.024) validates the presence of statistically significant variations in vegetation health across various buffer zones. This suggests that the location in relation to the pipeline plays a crucial role in determining the state of the vegetation. These results are in agreement with the research conducted by Anejionu et al. (2015), which highlighted the significant loss of vegetation greenness and NDVI values due to oil spills and fire incidents in the Niger Delta, particularly around affected areas. Similarly, Ekpa et al. (2020) noted that vegetation productivity declines as one approaches hydrocarbon-affected regions due to soil toxicity and lower chlorophyll levels. The post-hoc analysis (Table 4) further indicates that substantial differences mainly exist between the 1000 m buffer and all other zones, which suggests a recovery threshold distance where vegetation starts to regain ecological equilibrium. This reinforces the ecological disturbance-recovery hypothesis, stating that the recovery of vegetation improves as distance from disturbance sources increases (Walker & Willig, 1999).

Relationship between Distance from Pipeline and Vegetation Health

The regression assessment (Table 5) indicates that distance accounts for nearly 35.2% of the variability in vegetation health ($R^2 = 0.352$). The model is deemed statistically significant overall ($F = 103.37$, $p < 0.05$), affirming that spatial distance is a key explanatory variable. Nonetheless, the distance coefficient did not prove to be statistically significant on its own ($p = 0.129$), hinting at a non-linear connection between distance and the recovery of vegetation. This suggests that the response of vegetation is shaped by additional environmental factors such as soil characteristics, intensity of fires, and human land use. This conclusion aligns with the findings of Moffat & Linden (1995), who noted that the recovery of vegetation following oil-related events rarely follows a linear path and is contingent upon multiple interrelated ecological factors. Likewise, Zabbey & Uyi (2014) found that hydrocarbon contamination in the Niger Delta displays intricate spatial recovery dynamics rather than straightforward distance-based linear enhancements.

4.2.3 Comparison of Vegetation Health between Affected and Non-Affected Areas

Table 6a indicates that areas that are not affected have marginally higher average vegetation health (0.4652) compared to those that are impacted (0.4585). Although this difference is minimal, it signifies a consistent ecological disadvantage in regions impacted by fire. This aligns with the research of Chindah & Braide (2000), which demonstrated that environments contaminated with oil in the Niger Delta show a decline in vegetation density, biodiversity, and reduced chlorophyll regeneration when compared to uncontaminated control sites. In a similar vein, Nwaugo et al. (2006) documented notable decreases in plant health metrics in soils affected by hydrocarbons due to nutrient imbalance and toxicity. These results imply that even limited exposure to pipeline fires results in lingering ecological consequences that endure beyond the immediate vicinity of the burn areas.

4.2.4 Spatial Variation and Relationship between Elevation and Distance from Pipeline

Findings from Tables 7, 8, and 10 indicate that there are no substantial changes in elevation across distance categories (ANOVA $p = 0.516$). The regression analysis further indicates that distance accounts for just 5.4% of the variation observed in elevation ($R^2 = 0.054$), implying a lack of significant spatial correlation. This points to elevation being a separate geomorphological characteristic that is not affected by pipeline fires or nearby influences. This is consistent with the assertion made by Iloeje (2001), which suggested that in the Niger Delta area, elevation is mainly shaped by fluvial deposition and the configuration of sedimentary basins, not by localized human activities. Likewise, Duru et al. (2018) observed that the differences in topography in communities involved in oil production are mostly driven by natural processes and are not linked to hydrocarbon exposure or fire incidents. The findings reveal that the health of vegetation is considerably impacted by the proximity to pipeline fire occurrences, whereas elevation remains unchanged. This implies that the effects of fire-induced pollution are mainly ecological and surface-related, affecting soil and vegetation instead of geomorphological aspects. This trend reinforces the environmental disturbance model, which identifies hydrocarbons as significant factors contributing to the degradation of terrestrial ecosystems without changing the fundamental structure of the landforms (Odum, 1985).

Conclusion

This research explored the spatial patterns of pipeline fire occurrences and their impacts on plant health within various buffer zones in Ogba/Egbema/Ndoni, Rivers State. The results indicated a clear spatial trend where plant health increases as the distance from the oil pipeline rises. The values of the Vegetation Health Index (VHI) were lowest in the areas closest to the pipeline and gradually rose as one move toward the 1000-meter buffer zone, revealing that being near pipeline fire incidents adversely affect plant health. Statistical evaluation through ANOVA verified that the variations in plant health across the buffer zones were significant ($p < 0.05$), and subsequent comparisons indicated that the most notable differences were detected between the 1000-meter buffer and all nearer zones. This suggests that ecological recovery becomes more apparent with greater distances from the source of disturbance. Further analysis using regression indicated that distance accounts for a moderate level of variability in vegetation, although this relationship is not entirely linear, implying the presence of other environmental and human-related influences. In contrast, elevation did not exhibit any statistically significant differences across distance zones, validating that the landscape's topography is not directly affected by pipeline fire occurrences. In summary, this study concludes that pipeline fire incidents impose quantifiable ecological pressure on plant systems, with the impact decreasing as one move farther from the pipeline, while elevation remains largely unchanged.

Recommendations

1. Regulatory bodies, such as NOSDRA and NESREA, should enforce stricter regulations regarding buffer zones surrounding oil pipelines, ensuring sufficient distances to lessen ecological harm from potential fire events.
2. The government and oil companies ought to establish ongoing vegetation restoration initiatives in impacted areas, integrating phytoremediation strategies and replanting with indigenous species to expedite ecological recovery.
3. Oil companies should utilize advanced monitoring technologies like remote sensing, drones, and real-time systems for leak detection to minimize the occurrence of fire outbreaks and enhance early response capabilities.

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