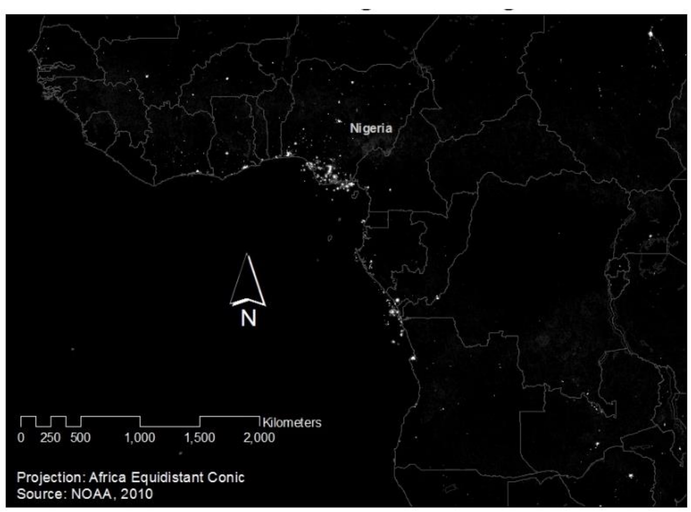
Lights from Nigeria: Reductions in Gas and Oil Flaring from Pipelines



by Mark Chesney

presented to Dr. Gordon McCord

Graduate School of International Relations and Pacific Studies, UC San Diego

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Abstract

The lights at night recorded by satellite imagery are due primarily to city lights and secondarily to the flaring of natural gas. In this report, the flaring is measured across time, with the hypothesis that the areas relatively closer to the constructed fuel pipeline experience a diminishing in earth night lights. The reasoning is that this diminishing is due to natural gas being shipped out of the vicinity via the pipeline, as an alternative to igniting them. To run the experiment, the time and place chosen was Nigeria with its pipeline system from 2010 to 2011. The result was a linear relationship to be found between the light detected and the distance of the flaring from the pipeline locations. At the end of this report the limitations and assumptions of this study are discussed.

Background

There is increasing use in the social sciences of earth photography taken from satellites at night. It is perhaps most commonly used as a proxy for economic activity, an indication of tremendous energy consumption and development in cities and/or ports. However, a significant portion of these lights are emanated from the flaring of natural gas. A byproduct of oil extraction, natural gas is captured and stored or shipped when possible and profitable. Otherwise, it is burned off, in order to convert methane gases into CO_2, which are less harmful to earth's atmosphere. Various spatial factors can influence the cost of natural gas capturing and shipping, such as the existence of costly transport infrastructure, or the proximity or remoteness of gas reserves to a viable market. Ideally this flaring may present itself as an economic opportunity, when natural gas can be liquified and stored into tankers or shipped via pipelines to processing plants. Although the exact pricing structure of natural gas infrastructure is complex, nonetheless gas flaring can be studied from light at night imagery to reveal and confirm information on pipeline construction. .

In these satellite images, gas flaring is the second largest source of lights from earth, after the use of lights to help people see at night. In 2000, about 1% of Earth's land area fell into polygons whose primarily night lights were gas flares. This had accounted for 3% of all of Earth's lights that year.[1]

High resolution satellite photographs have been collected over the past two decades, and this data is available from the National Oceanic and Atmospheric Administration (NOAA). There have been six satellites, each one spanning several years. Though the intra-satellite variance is attenuated properly enough to allow for accurate cross-year comparisons of light imagery, the inter-satellite variance is quite large. This makes it rather difficult to compare night light images across a wide span of years, since the photography of more than one satellite is required.[2]

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[1] (Henderson, Storeygard and Weil)
[2] (National Oceanic and Atmospheric Administration)

Table 1 below shows some time trends with gas flare volume (measured in billions of cubic meters). It is worth noting the general downward trend in the two leading nations, with Russia's vast size undoubtedly driving the global trend. Nigeria was selected for this study due to its rich data content, and a cursory method to distinguish gas flaring apart from city lights is confirmed in the *Data* section below. Nigerian pipeline maps located around its southern coast were also available, which was necessary to investigate the role played by geospatial distance from pipeline to observed flaring. Figure 1 below also visualizes night lights over West Africa.

Estimated flared volume from satellite data					
Volume (bcm)	**2007**	**2008**	**2009**	**2010**	**2011**
Russia	52.3	42	46.6	35.6	37.4
Nigeria	16.3	15.5	14.9	15	14.6
Iran	10.7	10.8	10.9	11.3	11.4
Iraq	6.7	7.1	8.1	9	9.4
USA	2.2	2.4	3.3	4.6	7.1
Global	154	146	147	138	140

Table 1: Top five gas flaring countries. Flaring is measured in billions of cubic meters (bcm). Source: World Bank (primary source: NOAA)

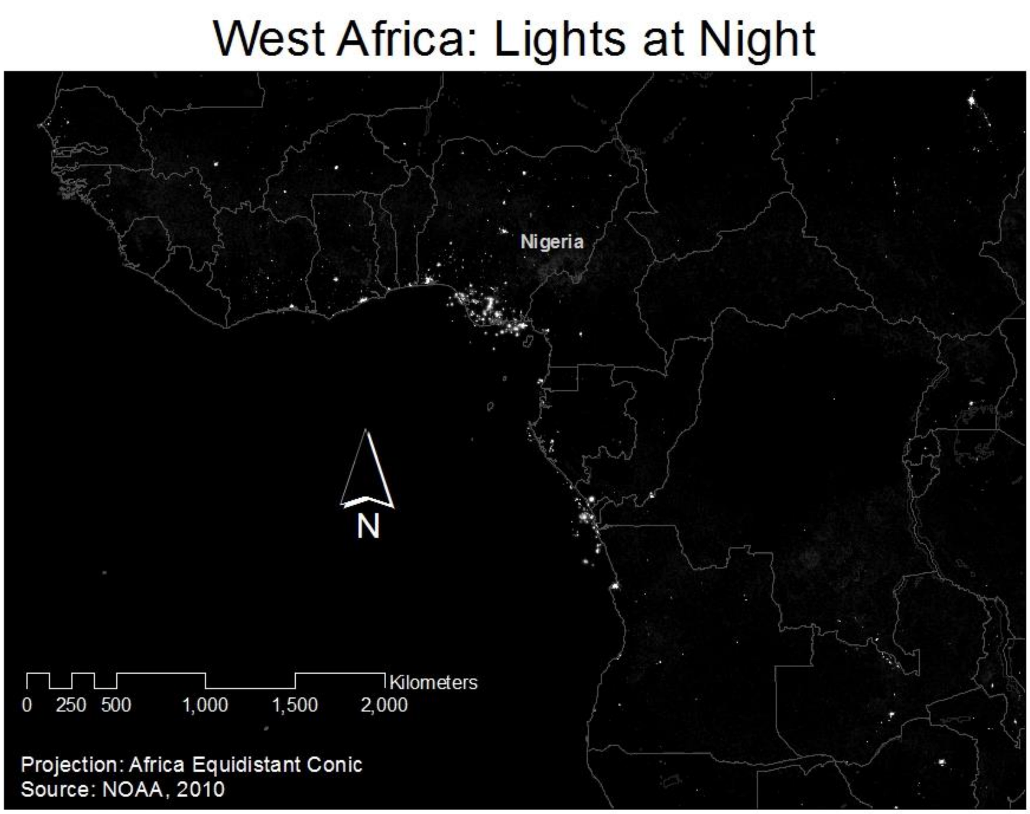

Figure 1: Satellite imagery showed many non-urban lights at night in West Africa . Nigeria, with large amounts of oil and natural gas, was a host to particularly many of these lights.

Data

There were various sources of data used to construct this analysis:

- Earth lights at night: Satellite-captured night data from NOAA is calculated from the average visible band of cloud-free light detections multiplied by the percent frequency of light detection. This resulting digital value is normalized for day to day variations of lighting. This is used to infer gas flaring volumes from the lights at night.[3]
- Gas flaring shapefiles: NOAA also is the source of polygon shapefiles that were used as masks to contain areas of flaring activity, both within the country's borders as well as offshore.[4]
- Nigeria pipeline maps: A 2008 map of land and offshore pipelines in Nigeria for both oil and natural gas was georeferenced into a polyline file.[5]
- Administrative province-level boundaries: these were used for improved georeferencing in Nigeria.[6]

The regions of Nigeria's flaring is shown here in Figure 2.

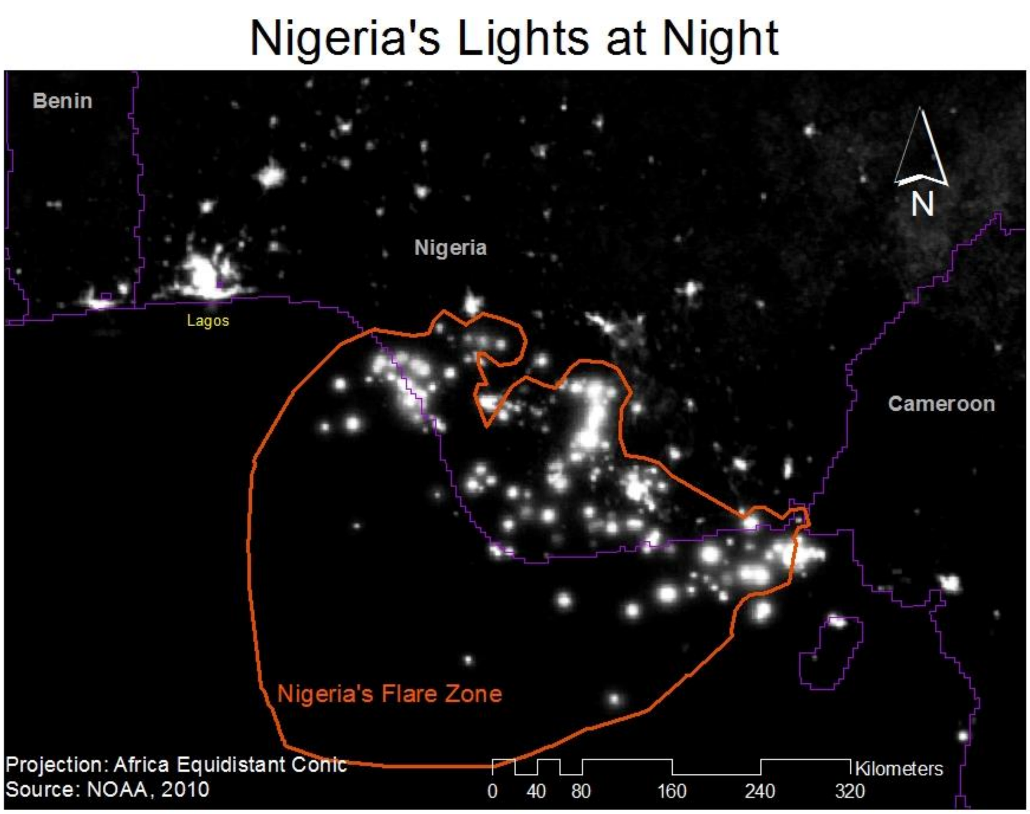

Figure 2: An up-close look at night at light data within Nigeria and its waters. Source: NOAA.

[3] (National Oceanic and Atmospheric Administration)
[4] Ibid.
[5] (Information Technology Associates)
[6] (Global Administrative Areas)

Given that the vast majority of lights come from the urban built environment, a cursory method of detecting regions of large lighted areas is through use of the *urban extents* raster, as shown in Figure 3. By using *urban extents* to identify city night lights, the light that remains is for the large part due to flaring. Smaller specks of light will show up outside of major urban areas. Error can be attributed to the timing of the year of creation of *urban extents*, which was 2004. This can tend to bias downward the 2010 urban extents, under the assumption that urban areas increased between these two years; this should bias upwards the night time flaring estimates.

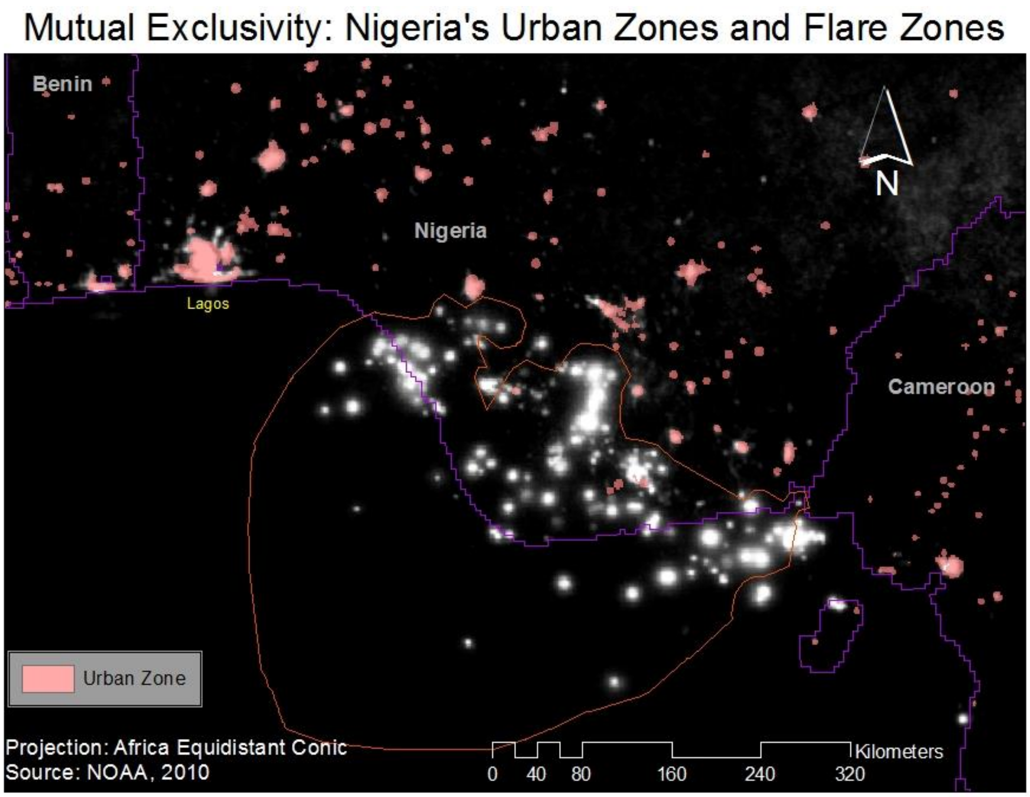

Figure 3: Upon visual inspection, virtually none of the night lights in the identified gas flaring region can be attributed to city lights.

Methodology

This procedure can be broken into georeferencing the pipeline, tracing it out, buffering, calculating Euclidean distance, differencing two rasters, creating a fishnet, performing zonal statistics, then running an OLS regression.

A map that specifies the location of a constructed pipeline on and off Nigeria's coast was georeferenced into a GIS polyline shapefile. This map was provided by Information Technology Associates. To ensure accuracy and minimized spatial distortions, the software map was converted to the projection coordinate system (PCS) of the imported print map, Lambert

Conformal Conic Projection. All further shapefiles and rasters followed this PCS convention (until buffering and Euclidean were performed; these tools rely on an equidistant projection).

A handful of major cities served as control points, although intersections of administrative (national and province level) boundaries were effective in connecting exact locations between the imported picture map and the software map. About 20 points were used in all, with a distribution focused more on the southern Nigerian shore. This was done so that geospatial accuracy near the delta regions in the Gulf of Guinea would not be compromised.

After georeferencing, a polyline shapefile was drawn and superimposed over the length of the completed pipeline. The length of the pipeline that is planned or under construction was not traced out, under the assumption that these pipelines were not in operation in the 2010-2011 time frame. Furthermore, two separate polylines were drawn for natural gas pipelines and oil pipelines. These were merged together to produce one larger polyline file. Originally the notion was that significant reductions in gas flaring was occurring near gas pipelines. Upon visual inspection, however, it became apparent that plentiful flaring occurred within the vicinity of the oil pipeline as well. Hence this decision to merge the two types of pipelines together. (As mentioned in the discussion section, it will be nontrivial to distinguish between the natural gas and oil pipelines, to measure an effective difference between the two.)

A buffer was created and centered on the pipelines, reaching 35-kilometer out. This was a distance arbitrarily determined to enclose a large portion of the flaring. This polygon served as a mask to contain an enclosed boundary for various spatial analysis tools. See Figure 4. City lights were shadowed out for visual emphasis on flaring.

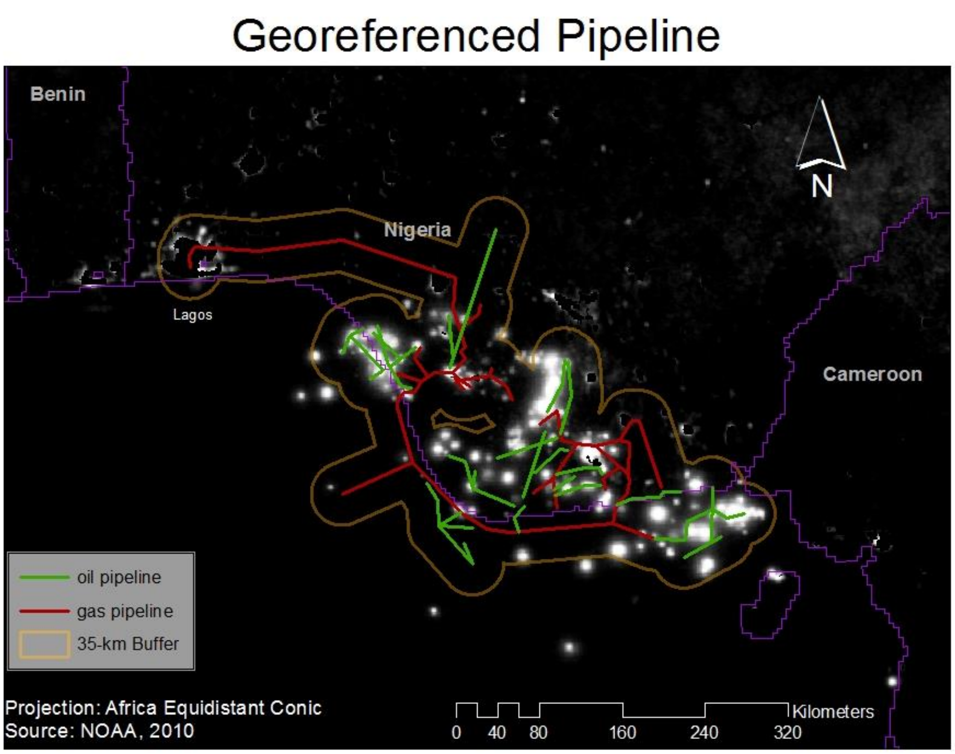

Figure 4: Most flaring falls within the 35-km buffer centered on the oil and gas pipelines.

To capture in raster format the spatial distribution of distances from any section of pipeline, a Euclidean distance calculation was performed, which was also centered on the pipeline. Figure 5 shows this Euclidean distance raster. By obtaining this distance an independent variable could then be created for the OLS regression to follow.

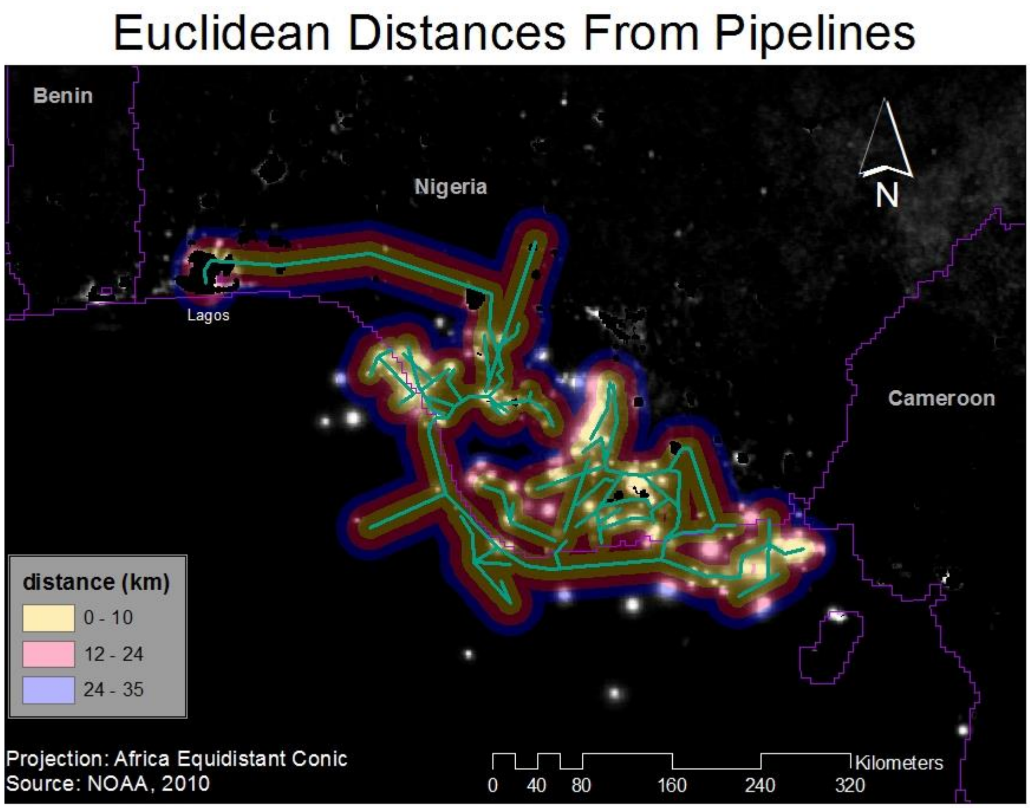

Figure 5: A Euclidean distance was calculated so that raster cells in the buffer zone, especially those containing flaring light, would possess this distance.

All satellite data displayed in maps thus far have been the 2010 starting point night lights. A difference in rasters of 2011 lights minus 2010 lights was stored and mapped in Figure 6. This difference raster points toward potential support for the hypothesis of decreases in night lights near the pipelines.

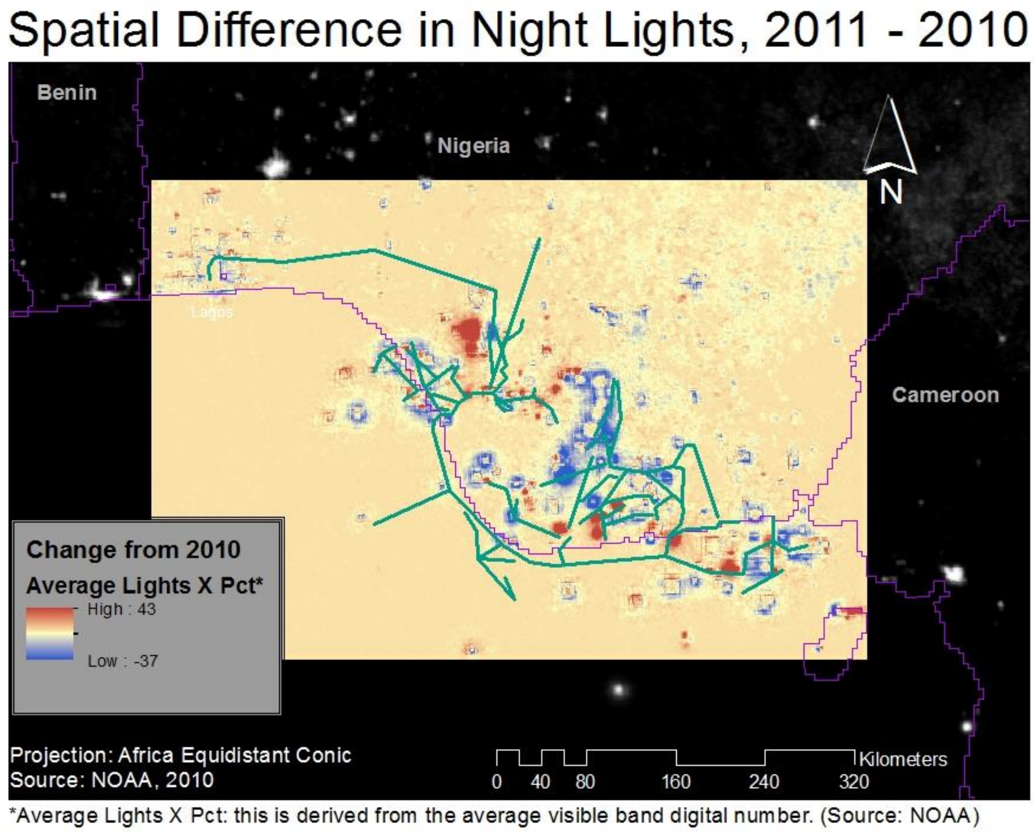

Figure 6: The blue regions indicate a "cooling" or reduction in night lights from 2010 to 2011. Red indicates a "warming" or increase.

OLS Regression

In order to run an OLS regression, a fishnet layer was then constructed to produce a grid of 5-km by 5-km zones that fully circumscribe the 35-km buffer zone around the pipeline. *Zonal Statistics As Table* was performed to capture the mean value of the difference raster (in Figure 6) and store these into the gridded observational units.

On these gridded units of analysis, the light difference was regressed on Euclidean distance from the pipeline. The model would be illustrated in this form:

$$(light_{2011} - light_{2010}) = \beta_0 + \beta_{Eucl\_dist} Eucl\_dist + \epsilon$$

Results

The two coefficients were $\beta_0 = 0.0012\ (t = 7.3), \beta_1 = -41.9\ (t = -15.8)$. The full regression table appears as Table 1.

Source	SS	df	MS
Model	455874.141	1	455874.141
Residual	31311772.8	3701	8460.35472
Total	31767647	3702	8581.21204

Number of obs	= 3703
F(1, 3701)	= 53.88
Prob > F	= 0.0000
R-squared	= 0.0144
Adj R-squared	= 0.0141
Root MSE	= 91.98

nitelit~2010	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
eucl_mean	.001212	.0001651	7.34	0.000	.0008883	.0015357
_cons	-41.87215	2.644763	-15.83	0.000	-47.05748	-36.68681

Table 1: output of bivariate model: regression of light difference on Euclidean distance from pipeline.

Interpretation

What this regression indicates is that there is reason to reject the regression's null hypothesis. To restate that null hypothesis: the distance from detected flaring to the pipeline will have no statistically significant correlation to the change in satellite-observed lighting between 2010 and 2011. In other words, this model suggests that the construction of this pipeline in Nigeria showed a statistically significant correlation to the reduction of gas flaring that was detected across one year's time.

Discussion

Despite positive findings to support the experiment's original hypothesis, there are a number of limitations and assumptions that should be taken into account to measure the validity of this analysis. These are the selection of control points, distinction between natural gas pipelines versus oil pipelines, the buffer selection, the chronological accuracy of the pipeline maps, and controls for the OLS regression.

In the process of georeferencing the printed Nigerian pipeline map, there is room for error in the selection of control points. Considering that the accuracy of the transformation of the map to another coordinate system improves with more points selected, there can always be improvement by adding more points, especially far away from the region of interest to get a sufficient spread. However, a visual confirmation performed would suggest that this is not likely a large source of error.

As mentioned prior, it will be worthwhile to distinguish the effect on change in lights of Euclidean distance from the natural gas pipelines separately from the oil pipelines. This is because of the way that these two very different fuels are handled, extracted, and shipped. For simplicity these two polyline files were merged; it would be interesting to see how the analysis could change by performing separate regressions (and thus separate buffers, distance calculations, etc.)

The question to set a 35-km buffer, or any buffer at all, was the subject of debate at the time of writing this document. If no masking limitation was set, and the full processing extent was used (say, one to match the visual extent), it would be worthwhile to see whether the regression relationship would change significantly. Nonetheless, the buffer was done under the assumption that distances very far away from pipelines would not affect the testing of the hypothesis, positively nor negatively.

There were assumptions that had to be made with the lack of exact information on the pipelines. One assumption was made by not tracing out the length of the pipeline that is planned or under construction, believing these to be non-operational. If these were not the case, there would be a bias in the results. The other assumption is that the constructed pipelines which were used are still serving a treatment effect, either by being a relatively new structure or by some other recent breakthrough in extractions of oil and natural gas. If this is incorrect, and the rate of extraction has reached a solid state, then this brings down the value of the hypothesis and experiment altogether.

There is worthwhile discussion over the limited explanatory variables in the OLS regression, which the largest shortcoming of the model. It will be an improved model if more controls are captured, such as urban extents (which was never controlled for in the model but just visually blocked out), terrain, and weather data, just to name a few from a potentially long list.

The value of the analysis would be deeply improved if these calculations were repeated for future years of data. NOAA does have data on 2012 and 2013 available; further analysis can be pursued here to further confirm or reject the trend that is studied here for 2010 and 2011.

Continuation of Research

This procedure can be extended and improved upon to other regions where gas flaring is occurring, as well as where pipelines have been constructed. Original plans for this analysis were to study flaring in North Dakota's Bakken formation, until it became evident that this young and newly discovered natural resource area did not have constructed pipeline infrastructure to transport the natural gas there. From the night time map of Figure 1, much of the lights in Sub Saharan Africa are attributed to flaring in Angola; thus, further investigation into Angola's pipeline projects can be conducted as well. Obviously any location where both gas flaring is observed and pipeline maps can be georeferenced can serve as an opportunity to strengthen or challenge the hypothetical model put forth in this research. These techniques can be used to provide opportunities for insight into the losses of natural gas to flaring.

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