# Improving remote survey of gas flaring in the Niger Delta region of Nigeria with Landsat imagery

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## Summary

Pollution from oil exploration in the Niger Delta greatly endangers the natural ecosystem. Gas flaring is a key agent of environmental pollution in the region. Efforts to evaluate the impact of flaring on the surrounding environment are hampered by lack of official information on flare locations and volumes. This paper describes an objective method of flare detection based on the combination of the infrared bands of Landsat satellite imagery. The method was validated through comparison with manually interpreted aerial photographs; it represents a robust approach for flare detection and monitoring and facilitates our ongoing work assessing the environmental impacts of flares.

**Keywords:** Gas Flaring, Environmental Pollution, Thermal Bands

## 1.0 Introduction

Decades of oil and gas exploration in Nigeria have brought huge financial benefits but also severe environmental problems that have impacted upon the region's fragile biodiversity. Various environmental issues such as agricultural land and mangrove degradation, biodiversity loss, water and air quality degradation (Chukwuezi, 2006, Ugochukwu, 2008), have strongly been associated with oil and gas exploration activities in the region. Gas flaring has been identified as a key pollution source in the region. There are strong indications that flaring may cause widespread environmental degradation (air pollution, greenhouse gas emission, heat stress, acid rain, and soil bacteria reduction) (NLNG, 2008; Zabbey, 2004). However, there is little auditable evidence of the magnitude of impacts due to the inherent difficulty in obtaining reliable information about flaring from relevant agencies. This lack of information has greatly hindered empirical assessment of the impact of flaring on the environment, and most research in this area has largely been speculative. Remote sensing offers a potential solution to this through the detection and subsequent mapping of flare locations.

Fire detection from satellites is based on the capability of sensors to detect signals produced by fire from space. Although numerous studies have been conducted on satellite fire detection, most have focused on forest/biomass fires and volcanoes. Only a few (Muirhead and Cracknell, 1984, Elvidge *et al*., 2007, 2009a, 2009b) have focussed on anthropogenic flares. Fire detection from space is based on Planck's function (the temperature of a blackbody determines the characteristics of spectral radiation it emits). Images from sensors such as AVHRR, MODIS, and GOES, with mid-infrared bands have mostly been used for forest fire detection (Prins and Menzel, 1992, Kaufman *et al*., 1998, Li *et al*., 2000; Ichoku *et al*., 2003, Justice *et al*., 2006). Although it has been suggested (Elvidge *et al*., 2007, 2009a, 2009b, Cracknell and Mansor, 1992) that Landsat products could be used to detect high temperature events (flare, underground coal fire etc), few researchers have focused on this. Previous attempts to detect gas flares from satellite images (Muirhead and Cracknell, 1984, Elvidge *et al*., 2009a) have relied upon visual techniques of identification, with obvious limitations. The present research aims to develop a spectral algorithm that may be universally and objectively applied for accurate identification of flares.

## 2.0 Methodology

### 2.1 Data

The main data used in this research were Landsat thermal infrared, shortwave, and near-infrared imagery obtained from USGS (http://glovis.usgs.gov/). The Landsat data were intercalibrated to minimise radiometric and atmospheric differences between scenes and years. Aerial photographs and high resolution satellite images were obtained from Google Earth, and a political map of Nigeria delineating state boundaries, was obtained from the Department of Geoinformatics and Surveying, University of Nigeria, Nsukka.

### 2.2 Methods

#### 2.2.1 Preliminary investigation

The flare detection capabilities of all Landsat bands were investigated through interactive examination of the bands. Many different band combinations and sequences were tested. The infrared bands (6, 7, and 4) were found to exhibit the greatest potential for detecting flares (Figure 1). Pixels with high DN values were further examined and different thresholds tested, to determine optimal threshold values for flare detection.

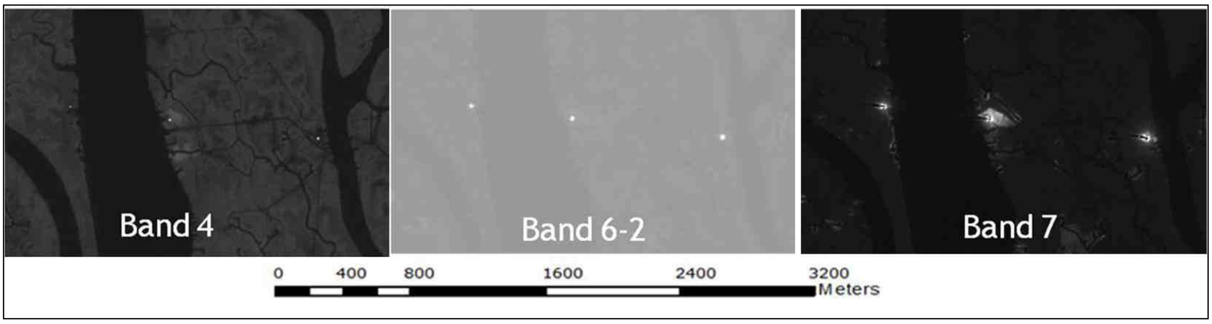


*Figure 1: Flare detectability of Landsat bands*

#### 2.2.2 Spectral algorithm for flare identification

Three criteria were established as optimal for accurate flare detection. The first criterion focuses on identifying locations with high shortwave infrared emissions. Pixels in band 7 with values greater than the optimum threshold were selected as high emission events. To minimise the effects of spatial offsets between bands, a spatial buffering of 300m radius was applied on selected pixels. The second criterion identifies high temperature events through the thermal band – band 6 (Pixel value > optimum threshold = high thermal infrared pixel). The pixels identified at this stage were overlaid with those identified at the first stage to eliminate most of the ‘false alarms’ (high shortwave infrared emission events without high thermal infrared components and vice versa). The third criterion identifies high near infrared events from band 4 (Pixel value > optimum threshold = high near infrared pixel). The final stage involves the overlay with the previous result (overlay of high thermal infrared pixel and high thermal infrared pixel) with the high near infrared pixels. The algorithm (Figure 2) was consequently applied on mosaics of six Landsat scenes covering the entire study area.

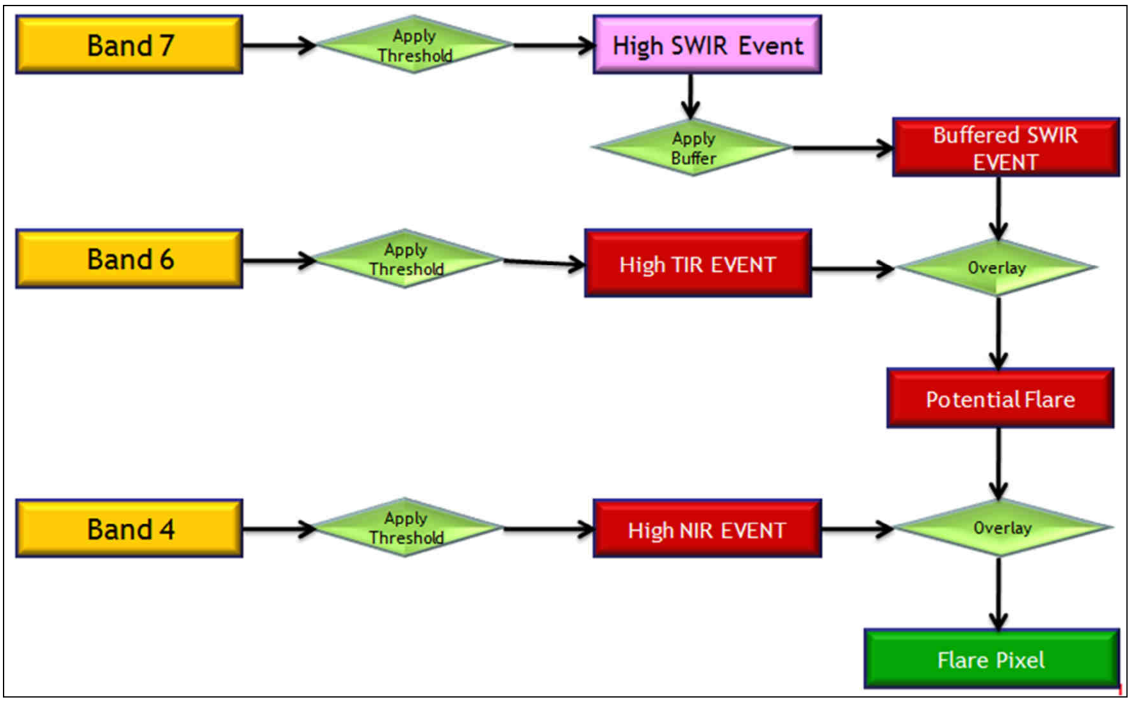


*Figure 2: Flare detection algorithm (SWIR – Shortwave infrared, TIR – Thermal infrared, NIR –Near infrared)*

### 2.2.3 Validation

Flaring activity can be observed on high resolution Google Earth imagery, with physical structures such as buildings, flare pits, and flare stacks clearly recognisable (Figure 3). These data can therefore be used to validate outputs from the flare detection model. The images are displayed with acquisition dates which can be closely linked to corresponding Landsat images. Google Earth imagery was therefore used to confirm flare presence in the absence of ground-truth data. Immediate ground-truthing was not feasible at the time of this study due to logistical and safety issues associated with fieldwork in this politically volatile region. This alternative method for collecting reference data using Google Earth has been employed effectively by other researchers (Elvidge *et al*., 2009b).


*Figure 3: Identifying flares with GeoEye in Google Earth*

## 3. 0 Results

The validation process revealed that the flare detection algorithm had a sensitivity of 71% and the resulting map of flares is presented in Figure 4. The spatial distribution of these flares corresponds closely with known areas of oil and gas production within states. From the result it is obvious that environmental impacts associated with flaring will be concentrated in certain regions.

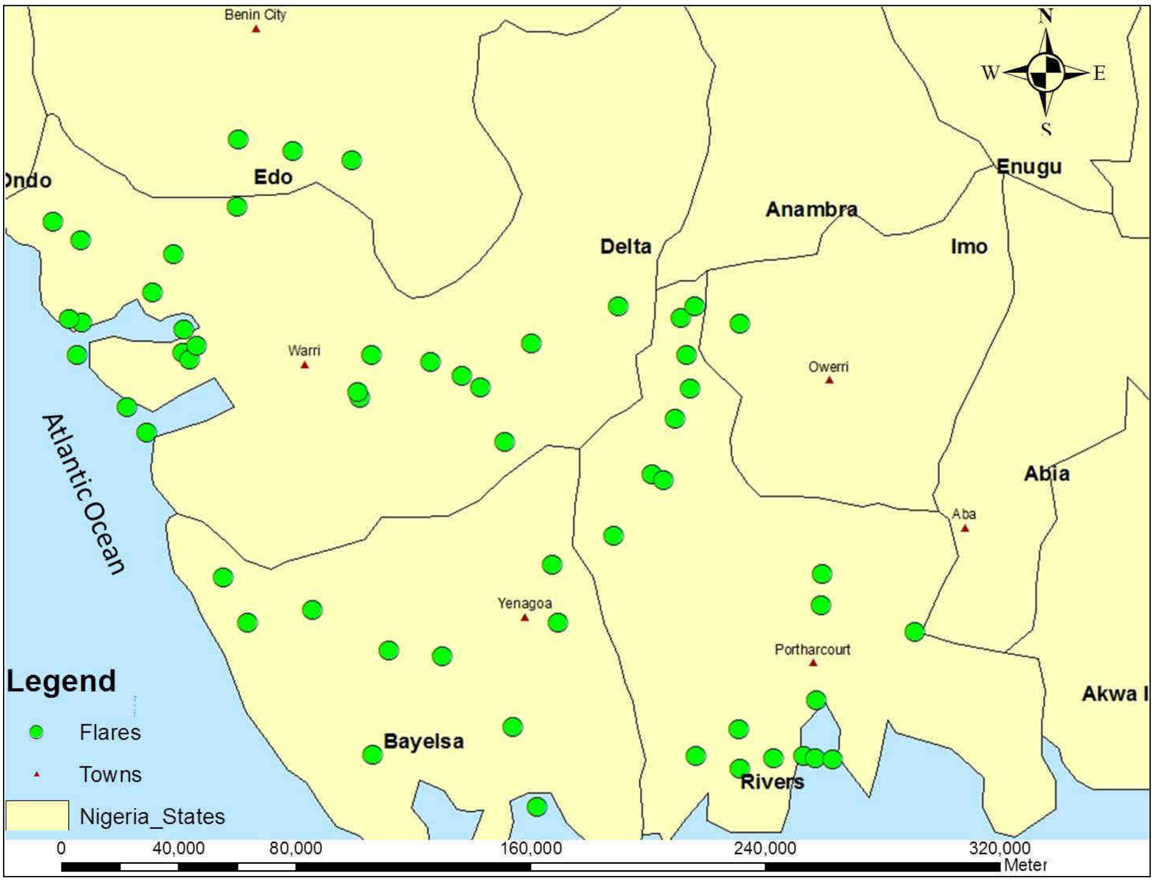


*Figure 4: Result obtained from the initial method*

In order to provide some context, the results obtained using this method were compared against those obtained from an analysis of night time DMSP-OLS images (Elvidge et al., 2009) for the region. The DMSP-OLS is specifically designed to use highly sensitive detectors for the identification of natural and anthropogenic fires and lights, among other features, and due to night time observations it is not encumbered by errors arising from solar glints. It was found that most of the locations identified by the DMSP method were also identified by the current Landsat-based method; however some of the locations identified as flares by the DMSP-OLS techniques were found not to contain flares, based on manual interpretation of aerial photography. These 'false alarms' were also correctly identified as non-flares by the current Landsat method and some additional flares that were missed by the DMSP technique were identified. Hence, this initial intercomparison with the DMSP-OLS method indicates that the higher spatial resolution and multispectral capabilities of Landsat are proving advantageous for flare detection.

## 4.0 Conclusion

The research is highly relevant as it potentially provides an objective, accurate, reliable and cost-effective means of flare detection and monitoring over time. It pioneers the use of Landsat infrared bands for flare detection and is expected to be of considerable value in improving global estimates of flaring volume, and modelling its impacts on the environment. Results obtained have demonstrated the viability of using Landsat images to detect flares.

Our ongoing work is attempting to improve the "flare-detectability" of the technique, which will be followed by the testing of the robustness of the technique in other flaring locations (Russia, Algeria, Venezuela and Angola). Further work will be carried out to develop a flare volume estimation algorithm, through the fusion of outputs from the Landsat-based algorithm with information from MODIS, AVHRR, MSG/SEVIRI and DMSP. Temporal persistence analysis (expected to also improve the accuracy of the technique) will also be carried out to monitor flaring activity in the region over an extended time period, leading to the development of a flaring history model and quantification of the associated environmental impacts.


### Acknowledgement

I wish to thank the U.S. Department of the Interior. U.S. Geological Survey for granting access to Landsat imagery as well as the Department of Geoinformatics and Surveying University of Nigeria Enugu Campus, for allowing the use of their political map of Nigeria in this research.


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