Mapping Dumpsites in Freetown Sierra Leone using Open-source satellite data

Report by

Ronald Ssembajwe |GIS/RS Specialist | Makerere University | +256-706-469640 | ronaldnazirite@gmail.com

This study adopted freely existing relatively high-resolution optical satellite images from Copernicus sentinel 2-L2A and L1C for the period 2018-2023. Among the quality control measures used is the use of a cloud filter of <15%. Images were preprocessed for Area Of Interest (AOI) and timeseries extraction as well. The Top of the Atmosphere (TOA) reflectance bands were then stacked into multiple varying composite image files (GeoTiff format) for training a Deep learning Convolutional Neural Network (CNN) for detecting dumpsites in Freetown, Sierra Leone.

Sentinel data can be accessed via Google Earth Engine or via Copernicus Browser. All the analysis was done in QGIS3.14 and MATLAB2023b software on an Intel i5 7th gen computer, with 32 GB RAM. The code employed was written according to the principles of research transparency and reproducibility and relied heavily on Matlab's Mapping and Computer Vision Toolboxes.

The figure below shows the study area (Freetown, RGB image) and location of the two major Dumpsites in Freetown.

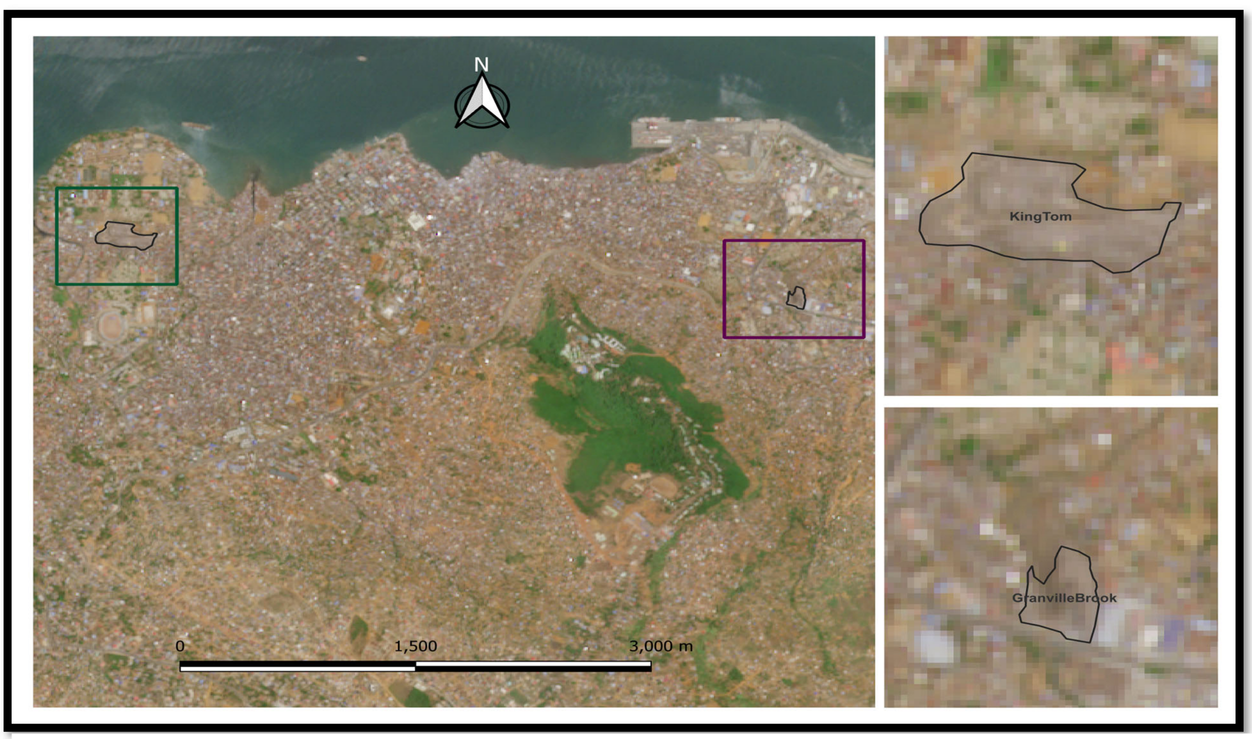

Figure 1. Aerial view (RGB-Image) of the Northern stretch of Freetown, Sierra Leone showing location of the Two main Dumpsites; Kingtom and Granville Brook. (Image source: Copernicus, Sentinel 2- L2A).

While below is analysis of the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI). The two indices have predominantly been used in vegetation and agricultural application, while in this study, we demonstrate their possible use in dumpsite monitoring. For example, the continued increase in NDMI could be a proxy for inferring wet dumping activity over a given dumpsite.

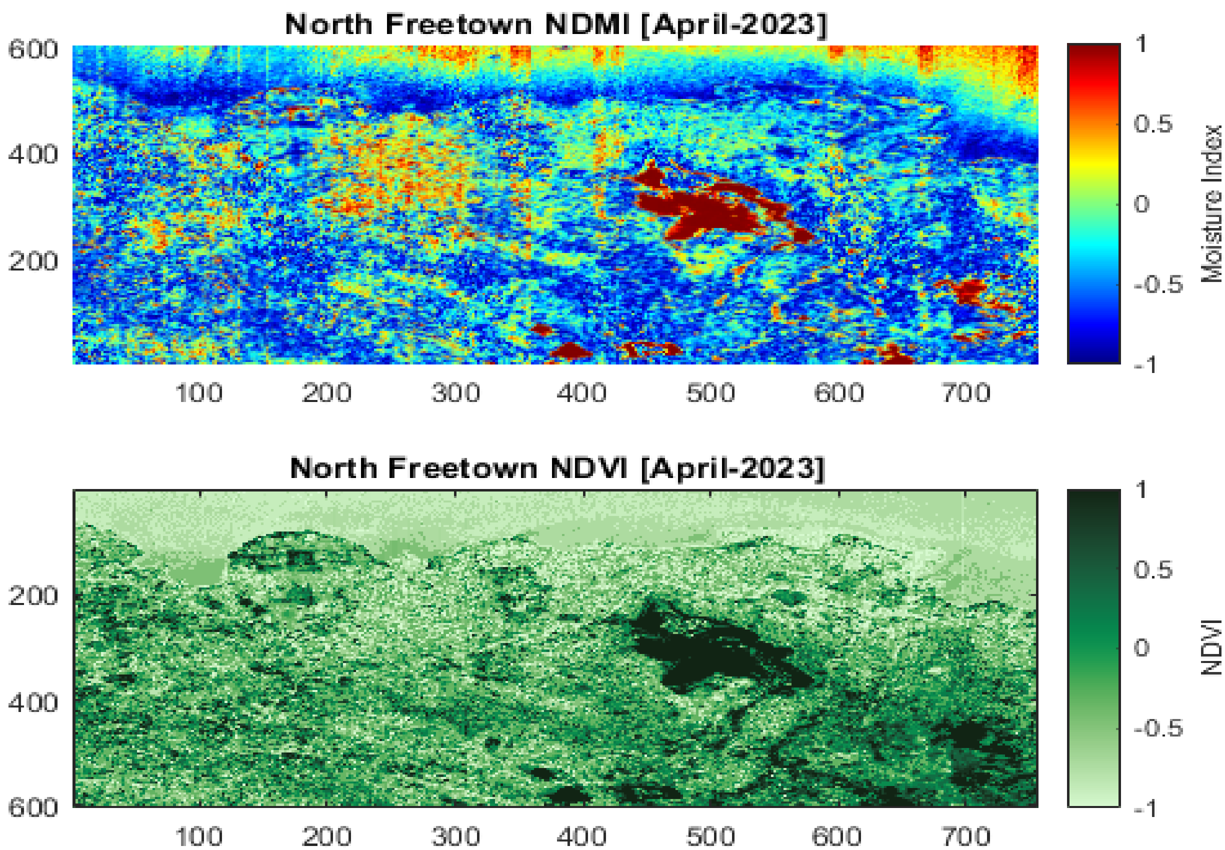

Figure 2. Vegetation conditions over the Northern Freetown in April 2023

Deep learning for dumpsite Detection

One of the major hypotheses of this project was the possibility of monitoring illegal dumping through the use of remote sensing and machine learning techniques to detect dumbing sites. As such, our goal was to train a deep learning model using exiting opensource satellite data.

As stated earlier, sentinel 2-L2A images were adopted and used to train a deep learning CNN for dumpsite detection in Freetown, Sierra Leone. To be specific, a true color composite and an all-band composite were the two considered composites for this specific CNN model development activity. Sentinel 2 has a total of 12 bands at varying spatial resolution but mainly the highest are 10m resolutions.

A CNN deep learning model was trained and deployed as explained by Devesa & Brust, (2021) using Matlab programming language although the a similar approach is possible in other existing opensource programming languages such as Python, Julia or R programming language.

Two training classes namely; Dumpsite and Non-Target were used in labeling, pixel extraction and training the CNN image segmentation model over Kingtom AOI. A small AOI was necessary to avoid bulky input data that would slow the model training process. Figures (3-5) below generally show the AOI RGB, labeled training image and the model training progress. The blurry appearance of the images is due to the relatively spatial resolution of sentinel 2 and small size of Kingtom dumpsite.

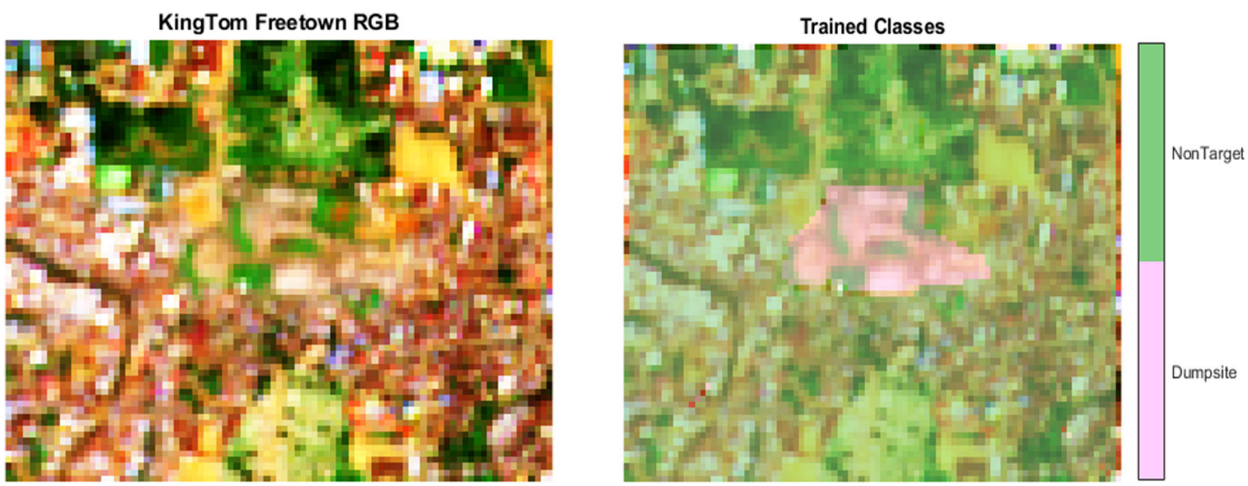

Figure 3. Area of interest (Left-RGB image) and Trained classes for deep-learning image segmentation for identification of Dumpsites in Freetown, Sierra Leone.

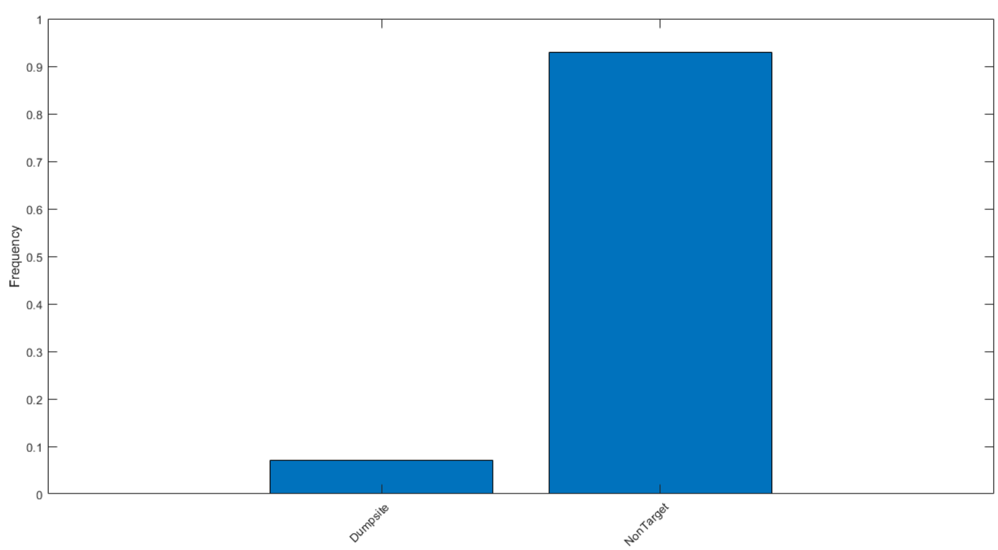

Figure 4. Frequency distribution of Trained class pixels.

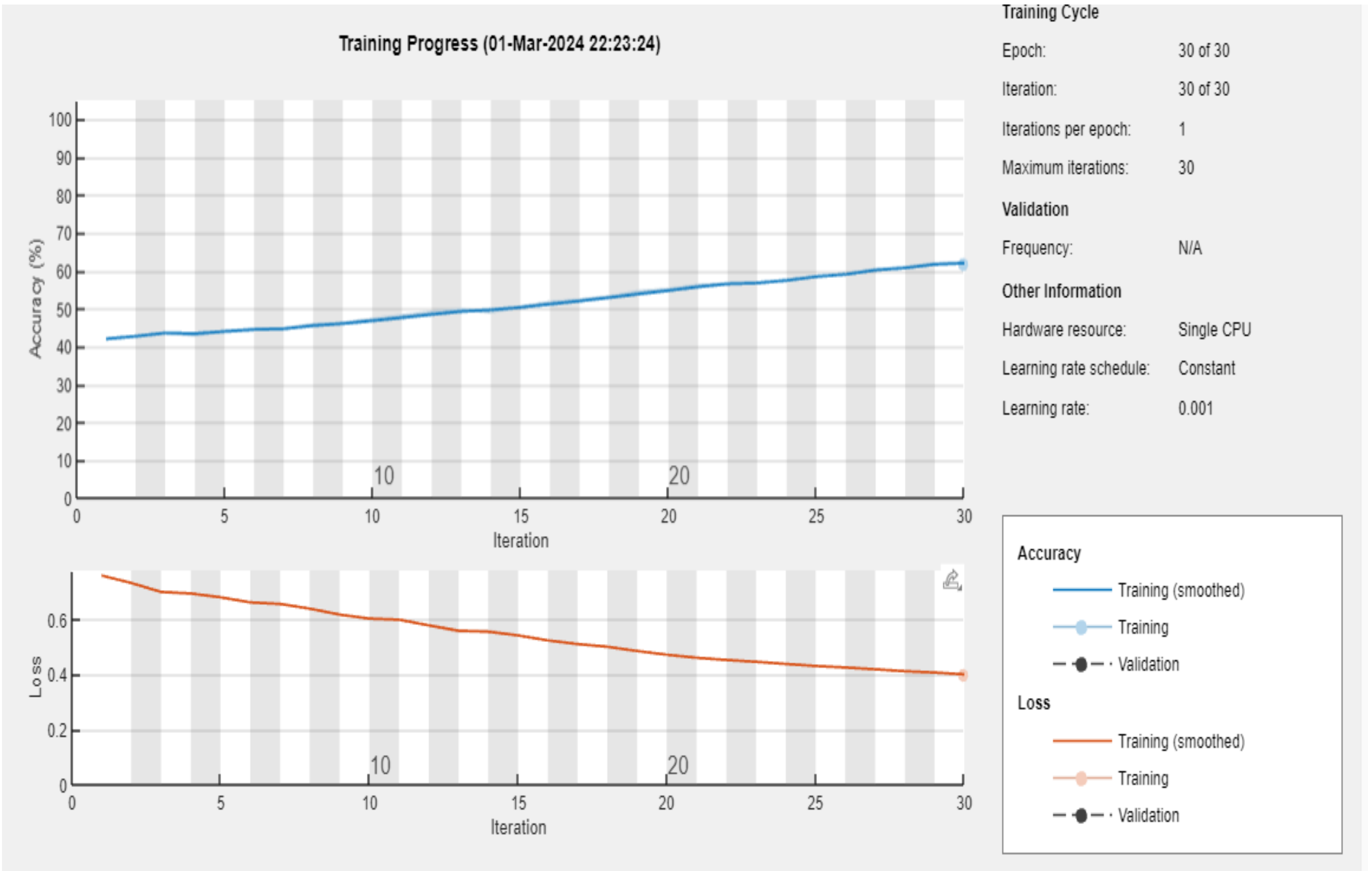

Figure 5. CNN Network Training progress

As shown in figure (5) above, despite the low spectral resolution, the model was able to achieve more than 60% accuracy at a go during training.

The test performance results are visually shown in figure (6) below. Results generally show that the CNN Model had some trouble differentiating Kingtom dumpsite from surrounding land use land cover types. This can be attributed to slummy nature of the largest portion of the Kingtom AOI and input spectral resolution. A better result should be expected upon adoption of a higher spectral resolution composites and heterogenous Dumpsite locations

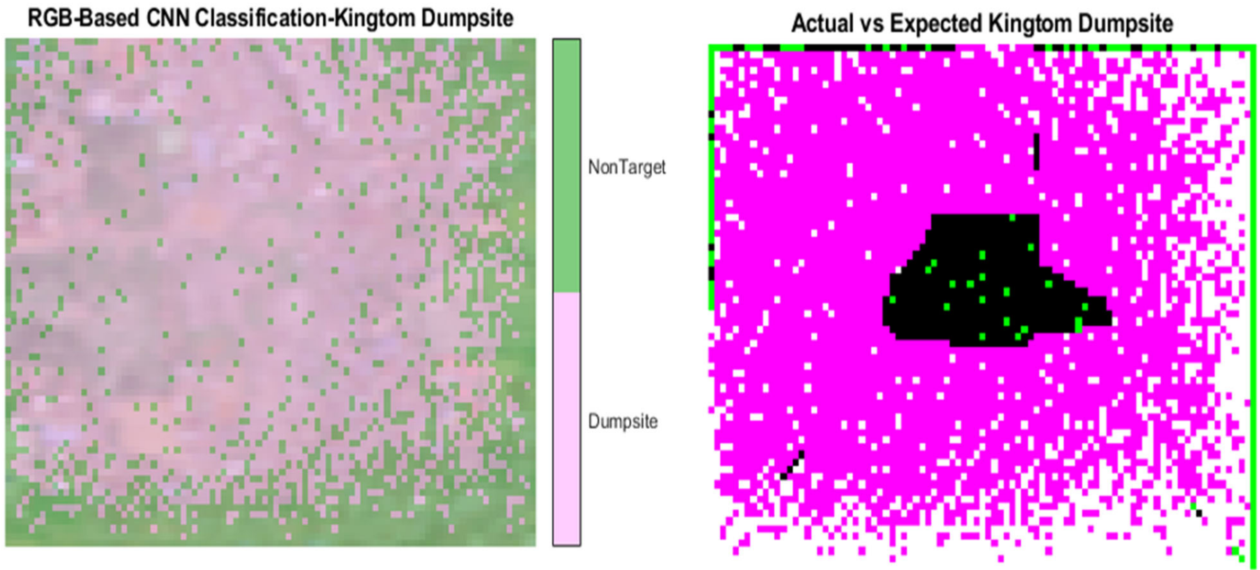

Figure 6. Test performance of trained Deep CNN Network for Kingtom dumpsite detection.

Overlap in the model performance was assessed using Jaccard index computed as the Intersection-over-union (IoU) metric. The results for the individual classes are presented in the table below.

	Classes	IoU
1	Dumpsite	0.0912
2	Non-Target	0.2801

The considerably low IoU for the dumpsite can be attributed to the high entropy of the land dumpsite and its surrounding.

Nevertheless, the model's overall test performance shows promising results given the relatively low spatial and spectral resolution of the adopted sentinel 2 images that do not host methane or dumpsite specific channels as shown in the table below

Metric	Global Accuracy	Mean Accuracy	Mean IoU	Weighted IoU	Mean BFscore
Score	0.3355	0.6215	0.1899	0.2732	0.187

Moreover, the considered Kingtom Dumpsite use-case is not a specialty dumpsite as it is a collections of various waste materials and vegetation cover which would confuse any algorithm.

Nonetheless, the adoption of multi spectral composites for image training greatly increased the model's accuracy by up to 21.4%.

NDVI-Moisture Index Relationship as a proxy of Dumpsite Detection.

Studies on illegal status and evolution of dumpsites have highlighted the role of vegetation-based indices in site monitoring. As such, we adopted the area average time series of NDVI and NDMI for Kingtom Dumpsite as a proxy for monitoring temporal status of Dumpsites. The two indices normally have a strong positive linear relationship. With this in mind, any alterations in this relationship would generally imply a system that is not independent. As such, three metrics such as correlation coefficients, homogeneity using double mass curves and Man-Kendall trend tests were used to scientific construct s shown in figure 7 below.

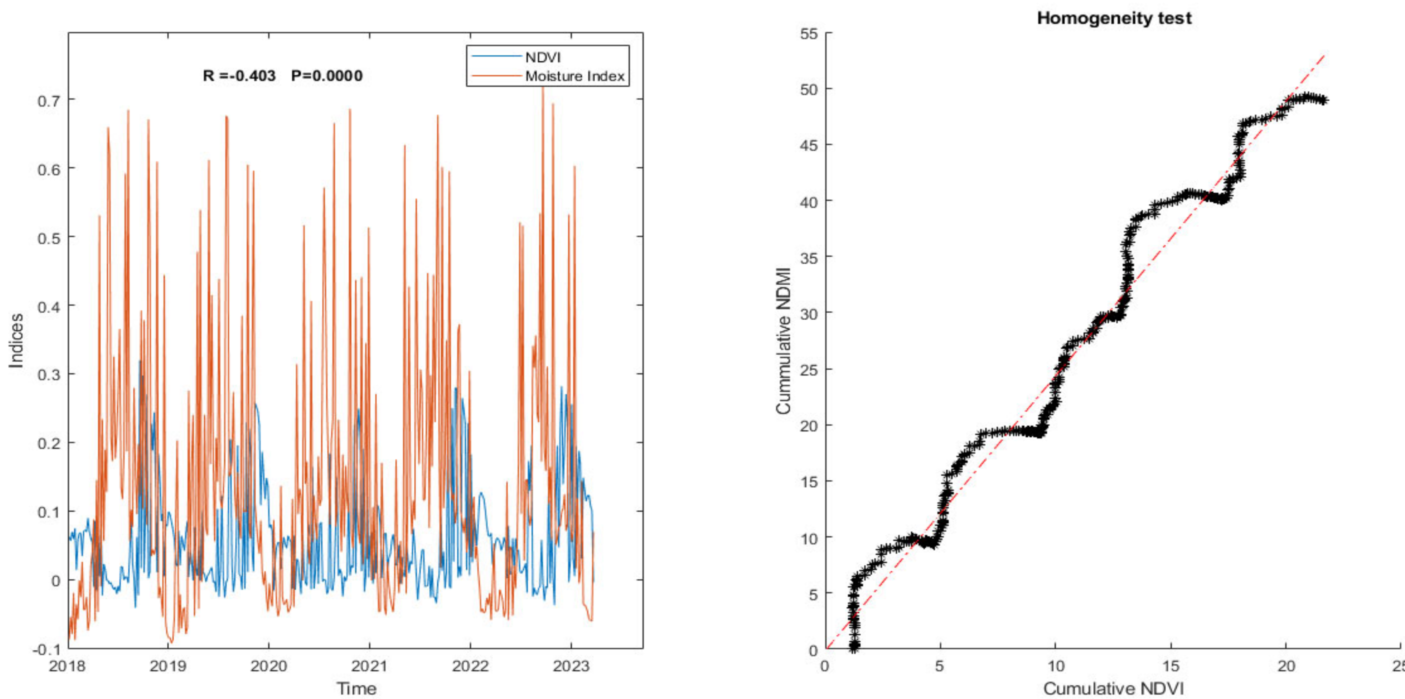

Figure 7. Comparison of KingTom Dumpsite NDVI and NDMI between Feb 2018 and Feb 2023

A strong significant negative correlation was observed between NDVI and NDMI over the Kingtom dumpsite for a five-year period. In a normal environment where the soils are left bare, the absence of water stress implies vegetation sprouting. However, for a dumpsite, presence of other mixture of dangerous substances in form of chemical waste damages both crop cover and soils leading to low NDVI values as is the case in his NDVI-NDMI relationship. This is further supported by the homogeneity display in the double mass curve.

Furthermore, the observed trends in NDMI at 0.95 confidence level over the Kingtom dumpsite further shows the potential of vegetation-based indices to monitor dampness of dumpsites over time a proxy for monitoring leakage in dumping sites.

Conclusion.

In this project, using a suit of opensource optical satellite images from Copernicus along with image processing, deep learning and statistical techniques have been successfully explored for their ability to detect dumpsite and or monitor pollution in these sites.

A case study of Kingtom dumpsite in Freetown, Sierra Leone has been considered. Results show huge potential of Dumpsite detection and or pollution monitoring in Freetown using remote sensing and deep learning techniques of up to 62% accuracy. This accuracy can however be improved with the use of hyperspectral images with high spatial resolutions.

For specific remote monitoring and hotspot analysis of methane, we recommend direct use of spectral data with methane's absorption-reflection channels especially 1.65µm which are at the time of this research not readily available at small dumpsite resolutions. However, with the launch of MethaneSAT high resolution direct methane analyses are expected to be easier.

Acknowledgement

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