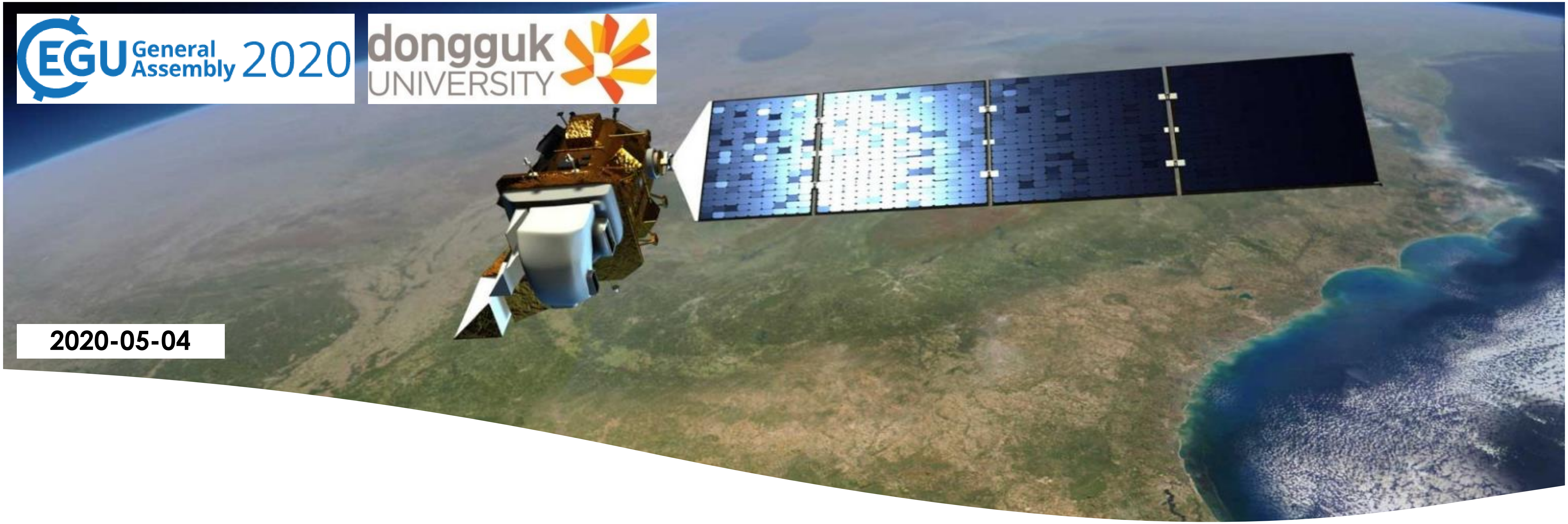

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The Use of Landsat 8 and Sentinel-2 Time Series Data for Monitoring Drought, Chlorophyll-a and Turbidity in Lake Chad

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1. Introduction

- With growing population and human demands, resources needs to be assessed for proper management.
- Poor documentation of these resources renders management difficult. In some parts of Africa, most of its population rely on inland water bodies as its main source of water. However, due to the lack of up to date in-situ measurements these resources are poorly documented hence management and studies becomes very difficult. Also, Carrying out risk assessments and monitoring measures in situ can be very costly and challenging in these areas.
- This makes understanding the issues pertaining to water quantity and quality in these i nland water bodies a priority to nearshore communities who rely on them.
- Under these circumstances, the use of satellite remote sensing products has proven useful to study water bodies in such areas.

2. Study area

Highlighted area represents countries bordering the Lake Chad Basin

2.1 Lake Chad

General Overview

- Lake Chad with ~30million people relying on it as their daily source of water has suffered severe drought throughout recent years. Coupled with lack of up to date data monitoring infrastructure.
- The decrease in water levels led to the emergence of different land surface features within Lake Chad; Vegetation ~55%, Patches of sand dunes ~35%, Marshes ~15%, Open water makes up the remaining 10%.
- The population within the LCB is estimated to reach 80 million by 2030 and with this increase, there is an anticipated rise in demand for water and various economic and livelihood activities linked to it. As such, it is of importance to sustainably manage this natural resource.

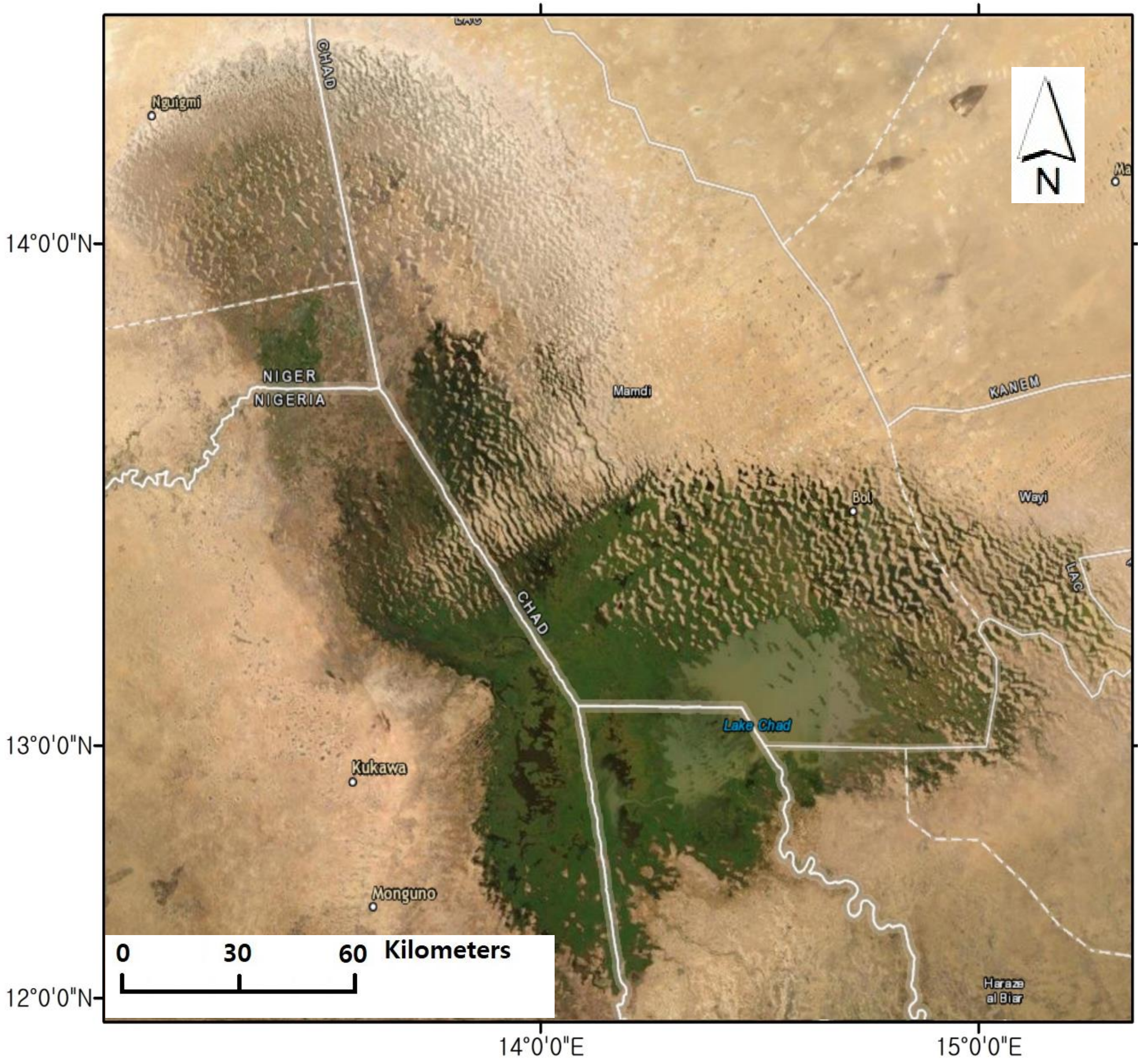


Figure 1. Image represents the focus area in this study.

2.2 Objectives

Farming and animal grazing are the predominant activities among inhabitants in this area. Seasonal drought and Chlorophyll-a (chl-a) variation patterns have the potential to provide vital warning systems for the immediate environment of the lake. This could act as a useful and robust tool for planning and development strategies.

For this presentation, our specific **objectives** are;

- Characterize spatial drought patterns in the immediate environment of Lake Chad during the dry seasons of 1999, 2007, 2010, 2013, 2015 and 2018.
- We used two popular semi-empirical algorithms for estimating chl –a concentrations from OLI/Landsat-8 and MSI/Sentinel-2
- Turbidity studies are ongoing.

3 Materials

Landsat

Bands: Coastal, Blue, Green, Red, NIR,SWIR-1, SWIR-2, (30m)

Temporal resolution. 16 da ys

Data source: https://scihub.copernicus.eu/

Sentinel-2

Bands: Blue, Green, Red, Red-Edge 1-4, NIR, SWIR-1, SWIR-2 (10m, 20m, 30m)

Temporal resolution. 5 days

Data source: https://glovis.usgs.gov

WorldView-3

Bands: Coastal, Blue, Green, Yellow, Red, Red edge, NIR-1, NIR-2 (1.8m)

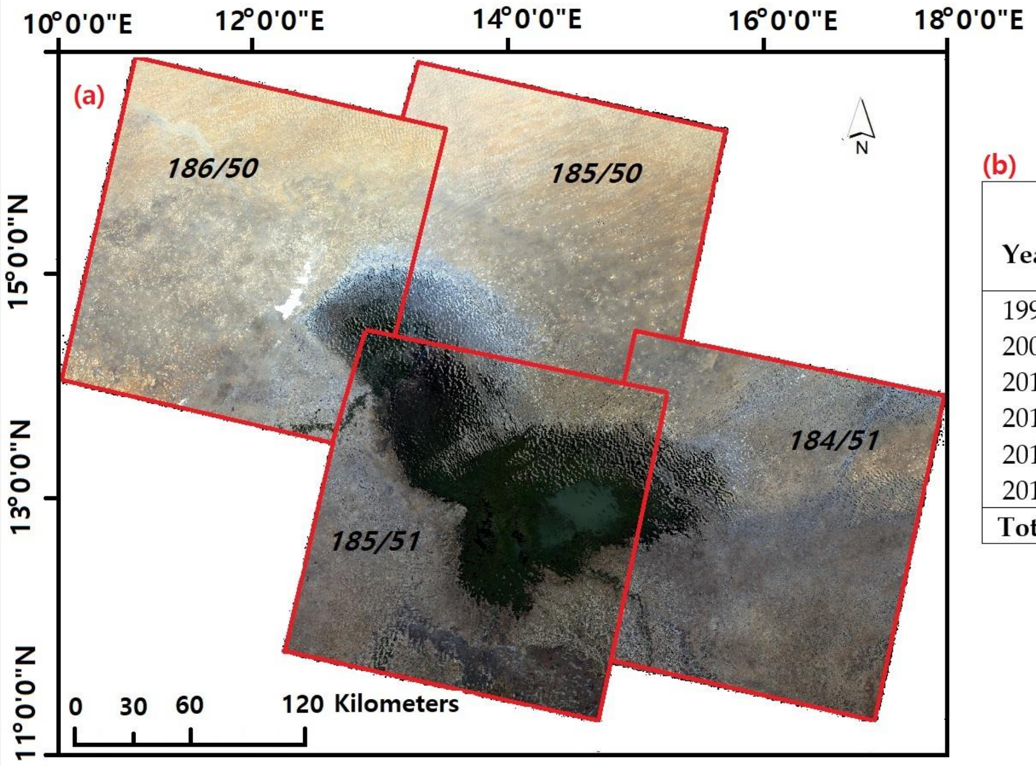
Temporal resolution. 1 days

Data source: www.digitalglobe.com

Acquisition date: 2015/12/22 and 2018/12/09

4. Methods

4.1 Drought Pattern Estimation



(b) Number of images per year per path/row

Year	Path/Row 184/51	185/50	185/51	186/50	Landsat Sensor
1999	1	2	2	2	TM
2007	6	6	8	4	ETM+
2010	3	1	3	2	ETM+
2013	8	7	8	9	ETM+/OLI
2015	9	9	10	9	OLI
2018	5	5	4	3	OLI
Total	**32**	**30**	**35**	**29**	**126 images**

Figure 2. (a) Shows the number of scenes needed to make a "complete" study area.
(b) Shows the number of images per year per path/row used for processing.

Before deriving the drought pattern in this area, the following was carried out;

1. Gap filling for each affected image.
2. Radiometric calibration and atmospheric correction on the images to eliminate errors from sensors, atmospheric scattering, absorption and reflection.
3. Four Landsat scenes (Path/Row: 184/51, 185/50, 185/51 and 186/50) needed to be mosaicked to generate a "complete" region of interest.

4.1 Drought Pattern Estimation

- After preprocessing, both Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) datasets were obtained using Landsat satellite images. Later, the VTCI was produced, identifying drought zones for this area.

- Refer to *Buma et al* for a detailed explanation of the m ethodology.

Table 1. Classification of VTCI values in terms of drought.

Drought	Values
No	0.81 ~ 1
Mild	0.61 ~ 0.81
Moderate	0.41 ~ 0.6
Severe	0.21 ~ 0.4
Extreme	00 ~ 0.2

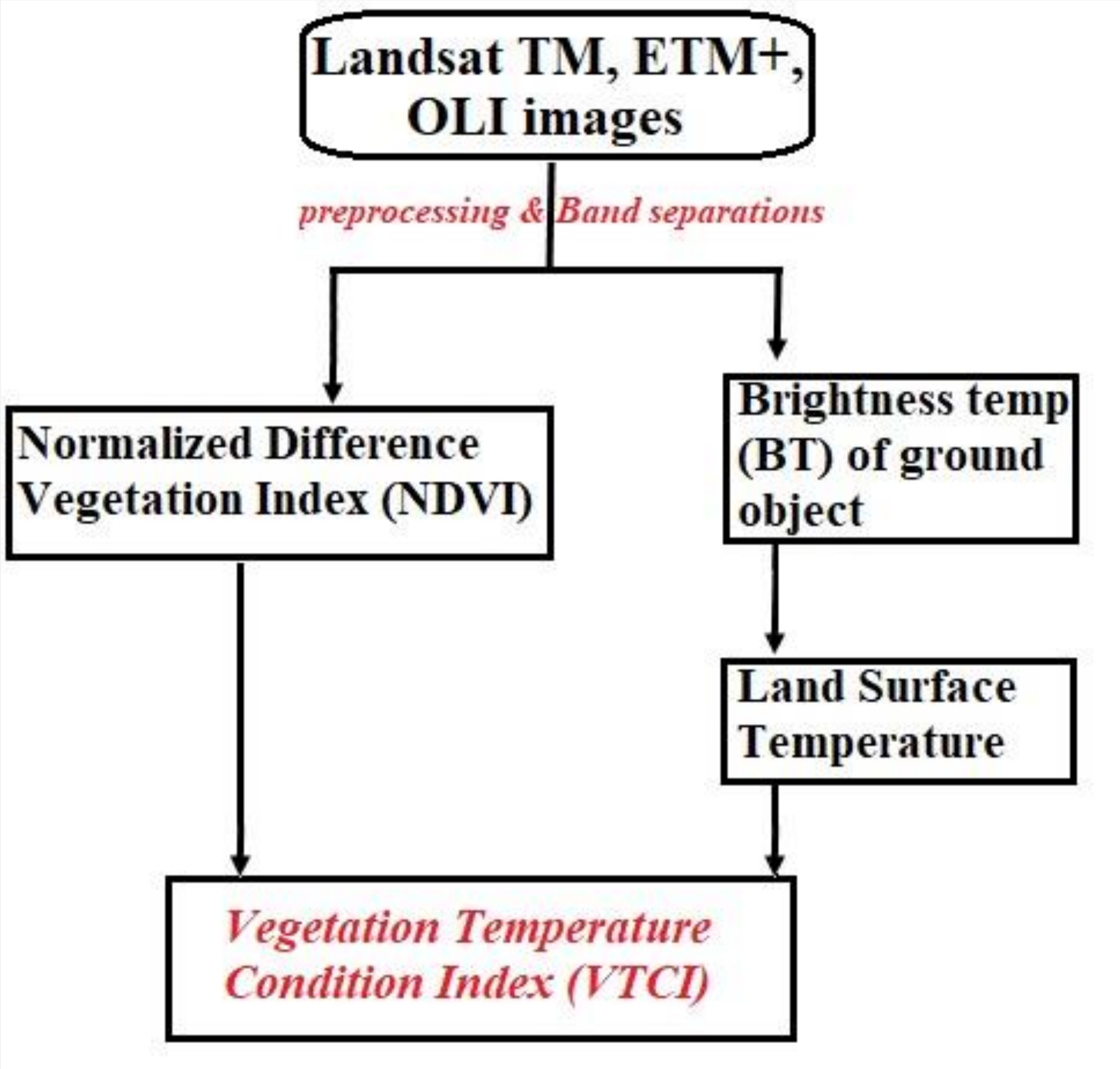


Figure 3. Flow chart of image processing.

Buma et al; Buma, W.G.; Lee, S.I. Multispectral Image-Based Estimation of Drought Patterns and Intensity around Lake Chad, Africa. Remote Sens. ***2019****, 11(21), 2534, doi:10.3390/rs11212534*

4.2 Chlorophyll-a Estimation

Atmospheric correction

- To estimate chl-a from satellite images, we need surface reflectance values from the atmospherically corrected images .
- Surface water-leaving radiance is difficult to determine accurately and often subjected to uncertainties in the sensor's radiometric calibration.
- Also, by using multiple sensors, further complications arises from varying atmospheric and surface conditions.
- In the absence of in situ estimates, it was important to reduce our error sources through carrying out rigorous atmospheric correction. For this purpose, three atmospheric correction algorithms were compared across Landsat 8 and Sentinel-2 images;
  - ELM (empirical line method)
  - FLAASH (Fast Line of-sight Atmospheric Analysis of Hypercubes)
  - QUAC (Quick Atmospheric Correction)
- To compare the performance of different atmospheric correction methods, Worldview-2 atmospherically corrected image was used as reference.

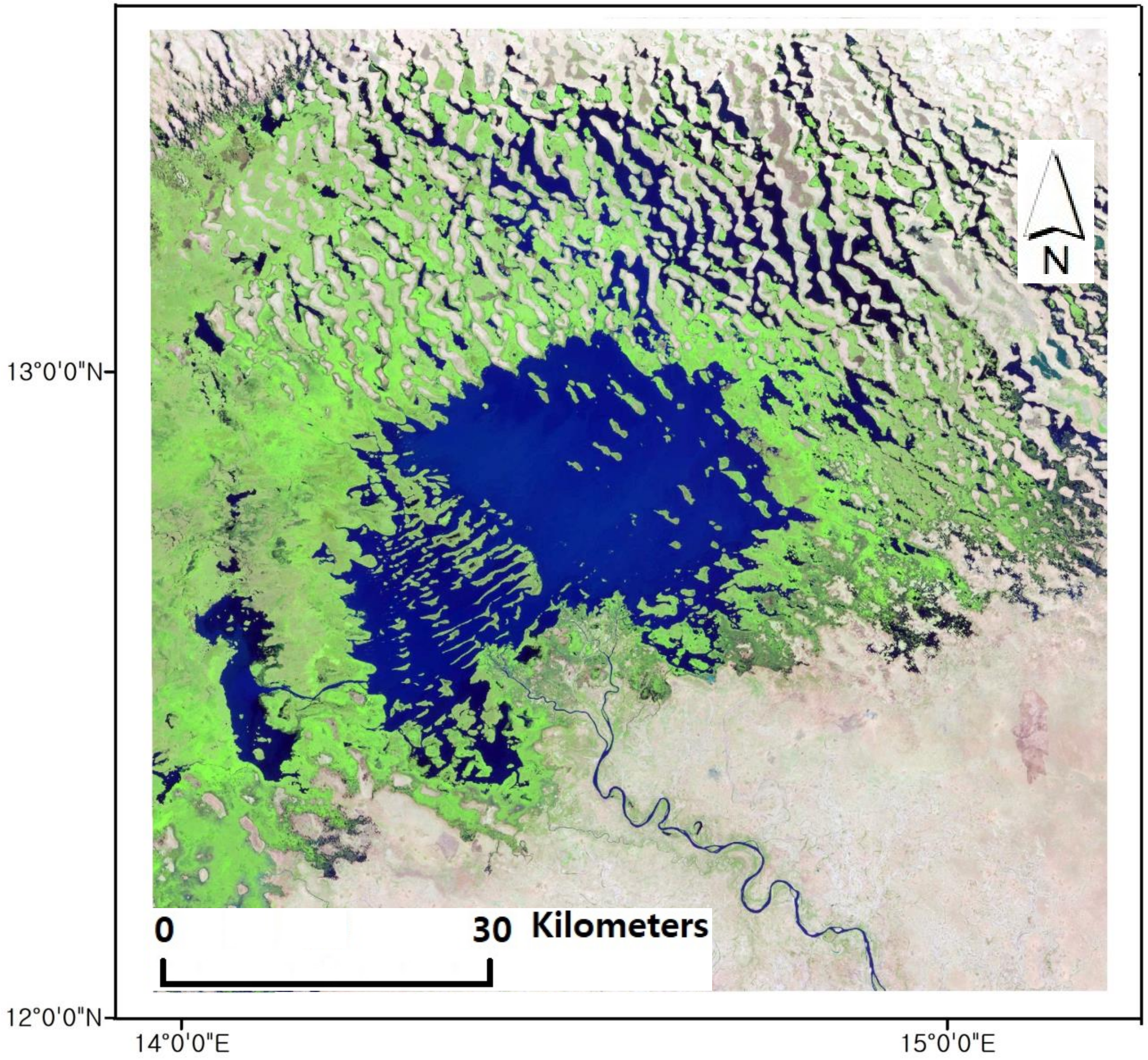


Figure 4. The southern section of the lake with an open pool of water was used for the chl-a concentration estimation.

4.2 Chlorophyll-a Estimation

Atmospheric correction

Sentinel-2A Multispectral Image Data:

Averaged over the nine bands, **EML**, FLAASH, and QUAC atmospheric correction algorithms resulted to an overall average RMS of **15.2%**, 17.1%, and 18.06% respectively.

Landsat 8:

Averaged over the nine Landsat bands, EML, **FLAASH**, and QUAC atmospheric correction algorithms resulted to an overall average RMS% of 12.43%, **11.24**%, and 14.01% respectively.

- ***The chl-a estimation algorithms were extracted using surface reflectance from Sentinel and Landsat images corrected by the EML and FLAASH methods respectively***.

Chl-a estimation algorithm

With numerous water quality satellite reflectance algorithms, we used the Two Bands Algorithm (2BDA) for the Sentinel image and the Florescence Line Height (FLH) for the Landsat image. Both are known to be effective in estimating chl-a in turbid water.

Table 2. Band math for each algorithm used to derive chl-a concentration in Lake Chad.

Mission/Algorithm	Index (wavelength)	Index (Band [B])
Sentinel-2/2BDA	(708/665)	B5/B4
Landsat/FLH	(558) - (658 + (443-658))	(B3) – (B4 +(B1-B4))

5. Results

5.1 Drought Pattern Estimation

- This was achieved by deriving Land Surface Temperature (LST) and vegetation information as indicators for drought monitoring from Landsat images with a spatial resolution of 30 m.
- From figure 5, we see that in 1999, there was very little drought that affected this region followed by a continuous decrease in moisture.
- Between 2007 and 2013 most of the drought events occurred on the northern side of the lake.
- No prevailing extreme drought conditions are observed in the southern section of the lake.
- From 2015 to 2018, there is an improvement in the drought condition.

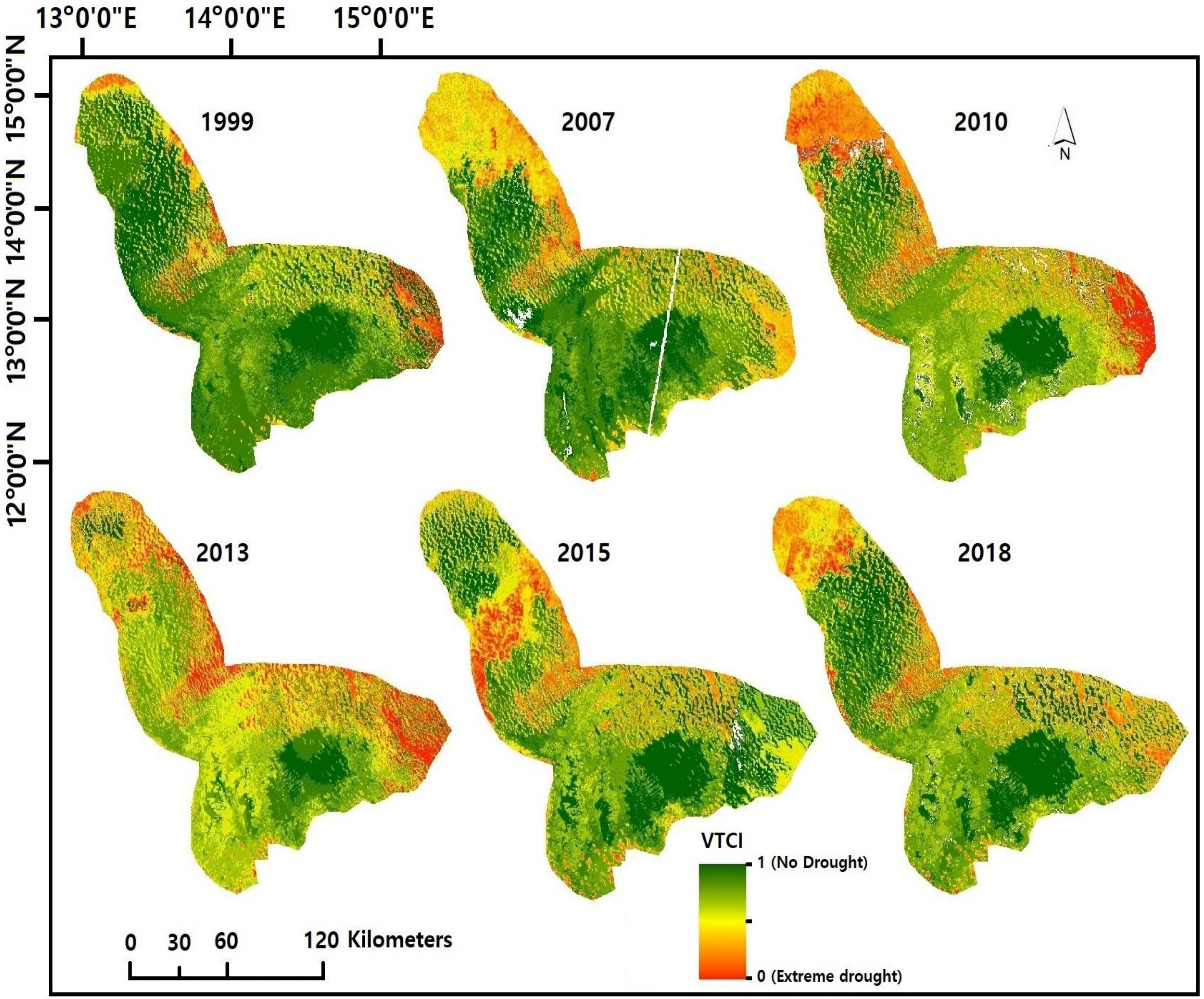


Figure 5. Spatial distribution of averaged VTCI in Lake Chad between 1999 and 2018.

5.1 Drought Pattern Estimation

These variations can be examined with regards to temporal variations in the proportion of each drought category occurring over this area (Figure 10).

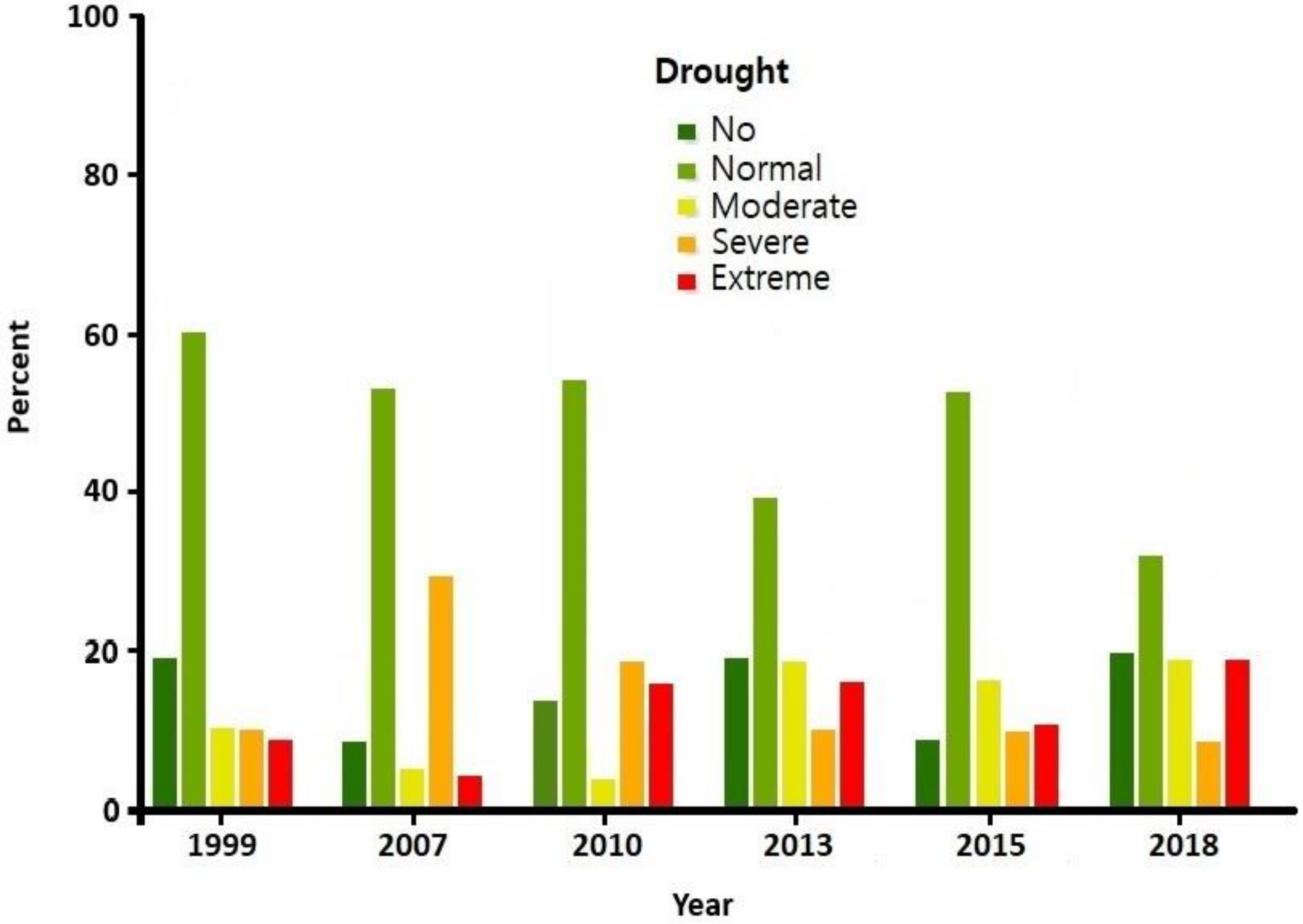


Figure 6. Drought category changes for averaged VTCI in Lake Chad.

5.2 Chlorophyll-a estimation

Figure 7. Sentinel-2 chl-a algorithm (2BDA). Brighter pixels indicates higher chlorophyll-a concentrations.

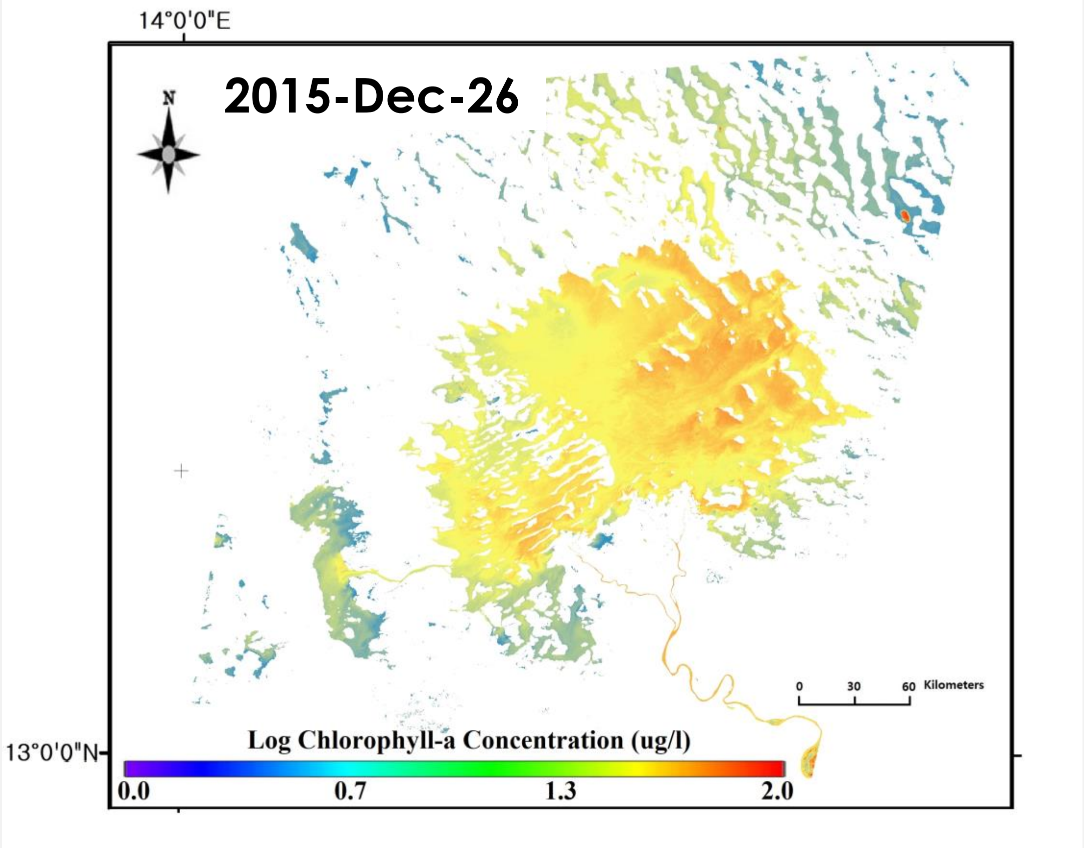
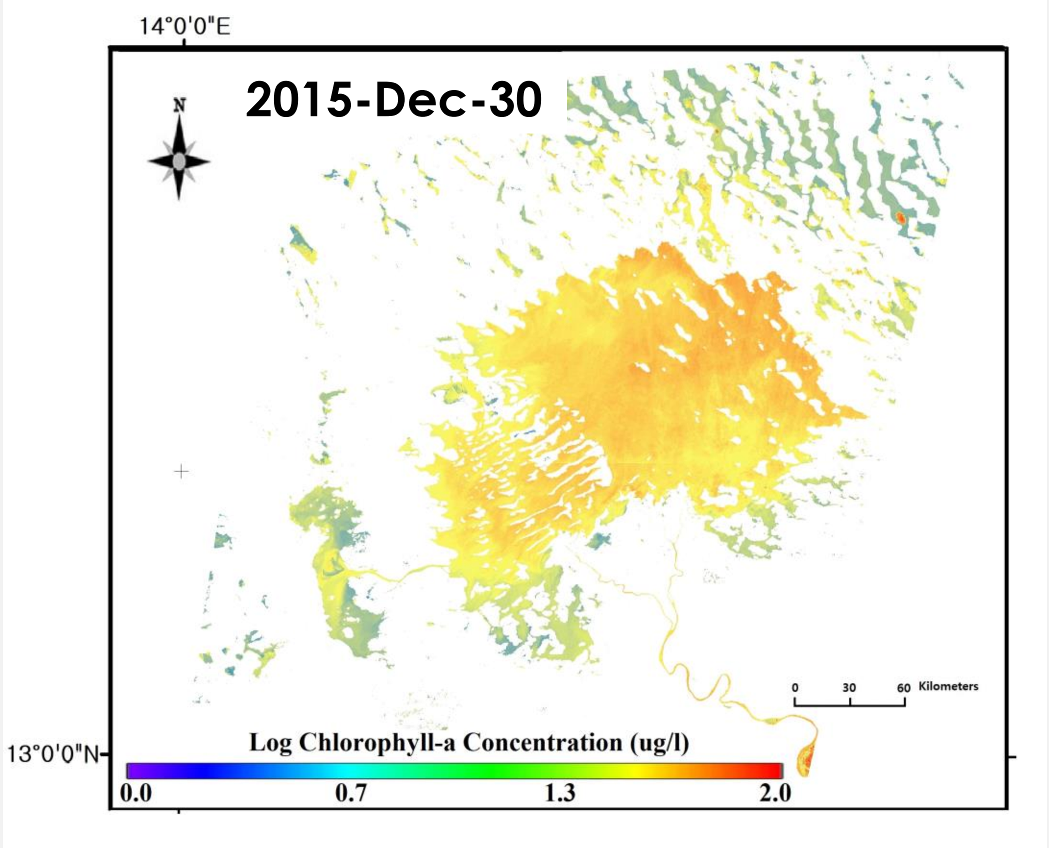


Figure 8. Landsat 8 chl-a algorithm (FLH). Brighter pixels indicates higher chlorophyll-a concentrations.



- Though quite distinctive around the edges, we see a good agreement in the main pool of water (yellow area) between the spatial patterns of image derived chl-a concentration using two different algorithms.
- The three Bands Algorithm (3BDA) and Normalized Difference Chlorophyll Index (NDCI) algorithms are also being tested for this area. After which, a statistical comparison will be carried out against estimates from WorldView-3 to determine which best estimates chl-a concentrations in this area.

6. Conclusions

Conclusions

- We characterized spatial drought patterns around the immediate environment of Lake Chad during the dry seasons of 1999, 2007, 2010, 2013, 2015 and 2018.

- Vegetation Temperature Condition Index was derived from NDVI and LST for a given Landsat products to show examples of identifying extreme events in this area and also to demonstrate the ability of Landsat products to capture and represent spatial and temporal drought estimates.

- Given the absence of in situ data, chlorophyll-a estimation in this area needs sensor inter-comparison and validation exercises for improving the accuracy of chl-a estimations.

- The multispectral images used in this study had some limitations in terms of resolutions where we had the issue of misjudgment between some pixels. Such issues can be addressed through the use of very high resolution images.

- With further result testing and the consistent availability of cloud free multispectral images, a general framework for future drought monitoring and chl-a estimation can be put in place for this area.


THANK YOU