ASSESSMENT OF RIVER-GROUNDWATER INTERACTIONS IN THE BAROTSE FLOODPLAIN, WESTERN PROVINCE, ZAMBIA

PRESENTED BY

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2018270109

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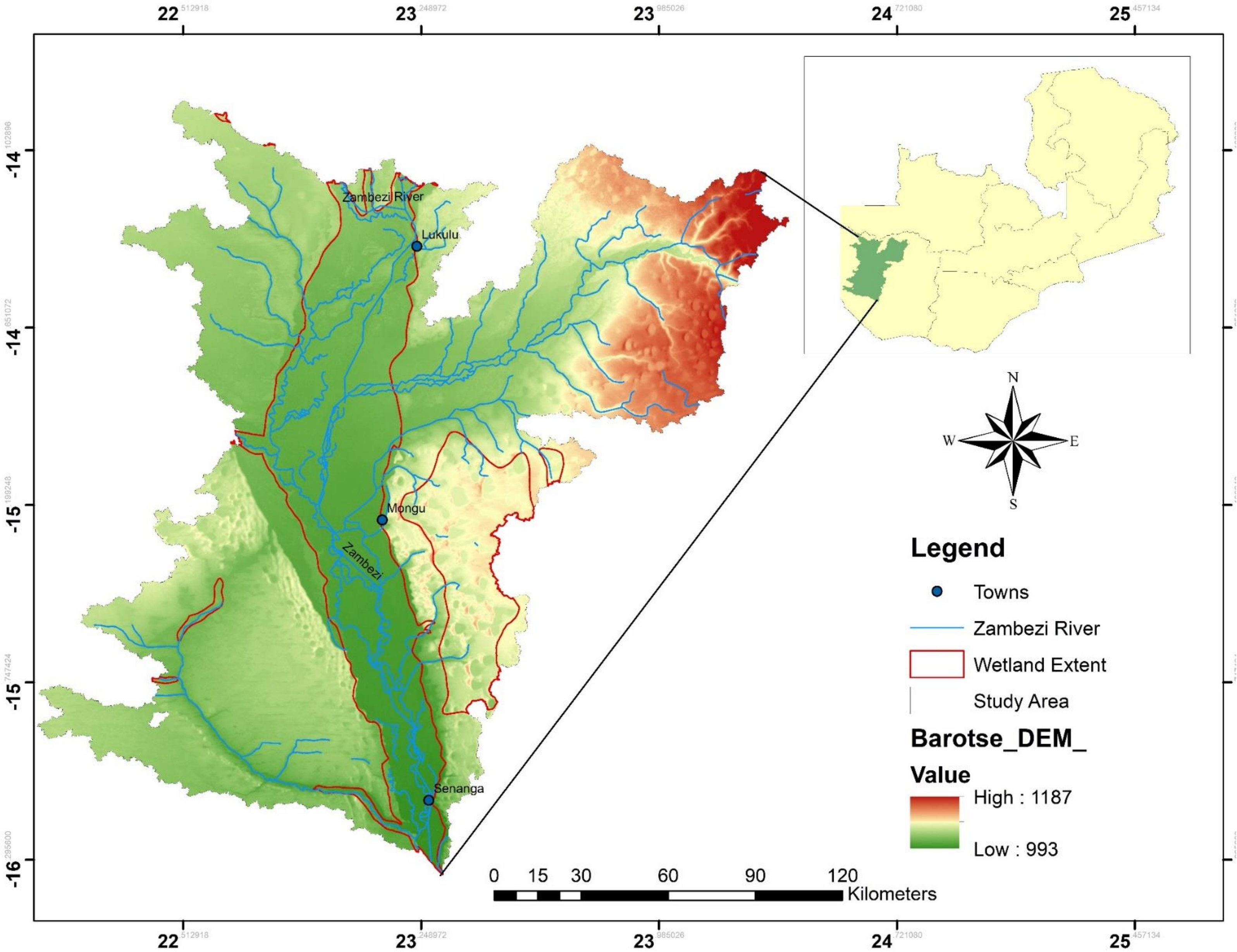
PRESENTATION LAYOUT

- **Introduction**
- **Study area**
- **Objectives**
- **Significance of the Study**
- **Research design**
- **Methodology**
- **Results**
- **conclusion**

INTRODUCTION

- Rivers are a major component of the water cycle, and they also shape landscapes, transport mass, energy and provide ecosystem services.
- There interactions between ground and surface water is a key element in understanding the resilient of floodplains to hydrological changes, especially with the advent of climate change and variability that has affected many aquatic ecosystems
- Conjunctive evaluation of ground and surface water in floodplains is critical for integrated water resources management.
- Efforts to protect wetlands are in place but the effective assessment and monitoring of wetland ecosystems is undermined by poor in-situ monitoring networks and data gaps.

STUDY AREA



- The study area is delineated by the wetland and stretches from Lukulu in the North via Mongu to Senanga in the South.
- The actual size of the wetland is unknown but the total inundatable area is estimated at around 7700 km^2
- The Zambezi is the main river with the Luanginga, Lungwebungu and Kabompo as the major tributaries.
- Livelihood depend on fishing from the Zambezi River, small scale farming and cattle rearing.

OBJECTIVES

Main Objective:

To evaluate river-groundwater interactions in the Barotse Floodplain

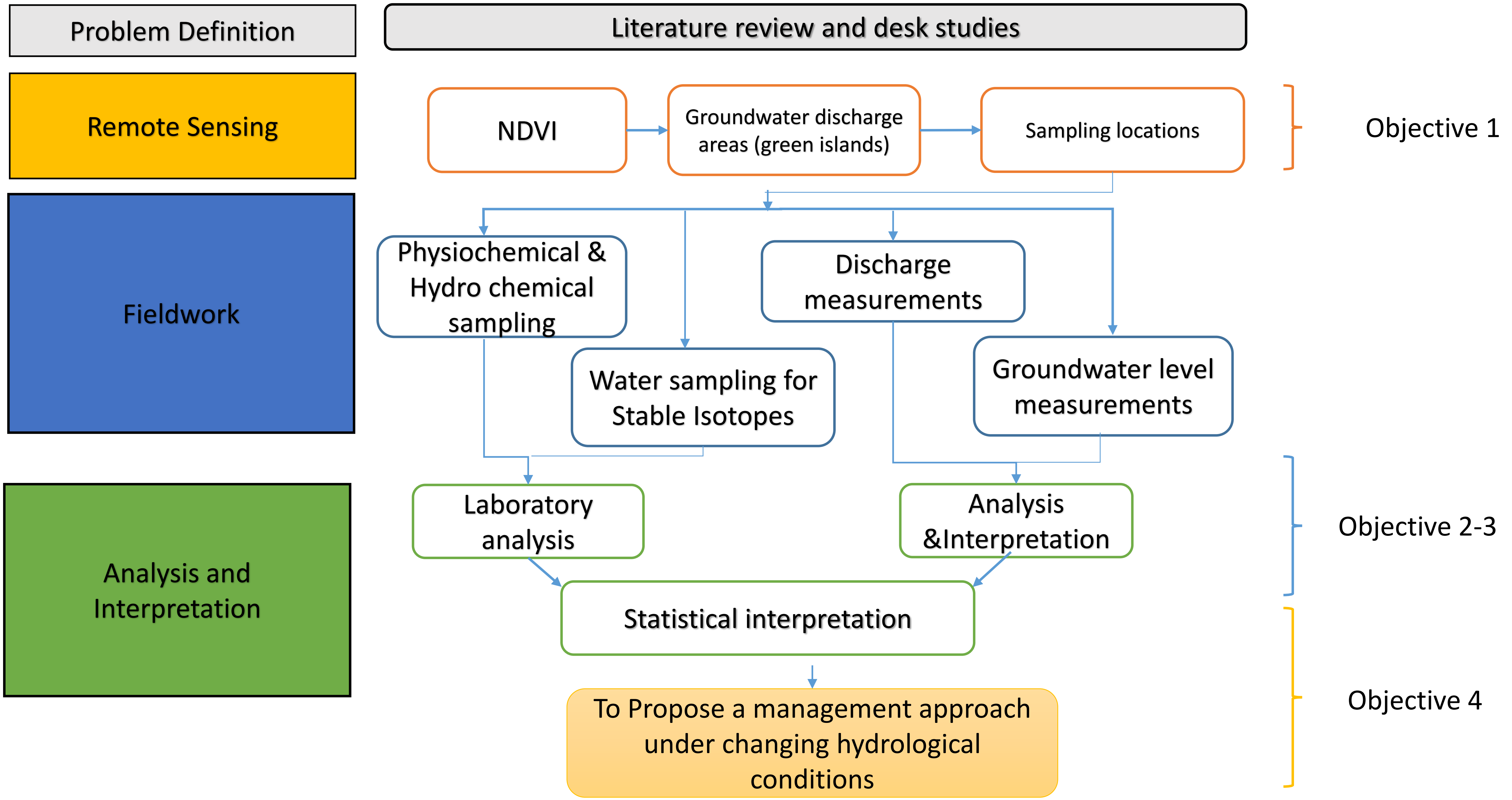
Specific objectives:

- To identify areas of groundwater, diffuse/discharge to the floodplain region.
- To determine the connectivity between the river system and underlying aquifer system
- To evaluate the influence of groundwater discharge to the floodplain’s hydrochemistry (if any).
- To Propose a management approach under changing hydrological conditions

SIGNIFICANCE OF THE STUDY

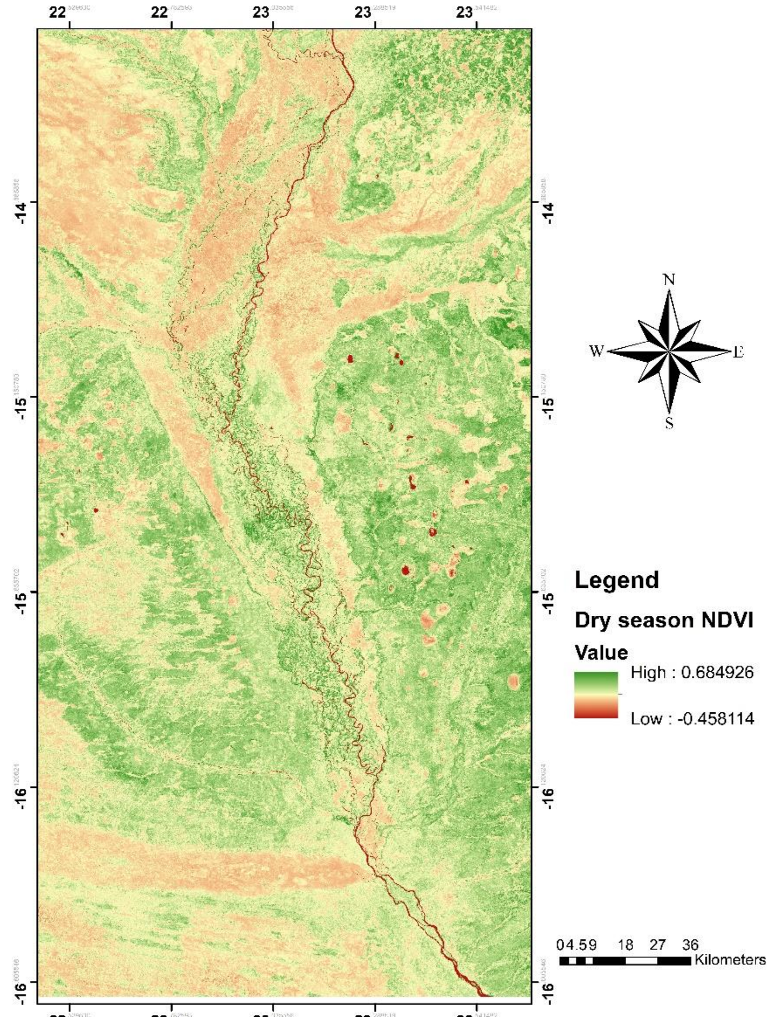
- The interaction between river and groundwater is a vital aspect of the wetland hydrology. As development of land and water resources increases, it is apparent that development of either of these resources affects the quantity and quality of the other.
- Effective land and water management requires a clear understanding of the linkages between groundwater and surface water as it applies to any given hydrologic setting.
- Increase the understanding of river-groundwater interaction that will contribute to developing effective water resource management in monitoring and conservation strategies of the floodplain

RESEARCH DESIGN



METHODOLOGY

- Remote Sensing
- Google earth engine(Sentinel-2)



- High spatial resolution
- Free
- Capture the NDVI across seasons
- Data set starts from September 2015
- In the Script:
- Filtered according to date.
- Set boundaries according to study area.
- Masked cloudy images.
- Radiometric correction Top of Atmosphere.
- Computed NDVI using

$$= \frac{NIR - Red}{NIR + Red}$$

- Extract NDVI band and create NDVI median composite image
- Exported the image to drive as a GeoTIFF
- ArcGIS added Palette for better visualization

- Point selected. Time series in GGE export as .csv file.
- To get the trend, seasonality, radomness (additive time series using fpp and forcast module using R studio)

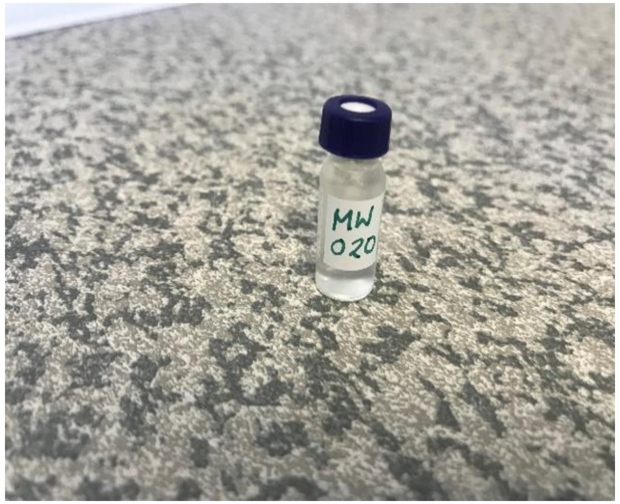
Field data collection

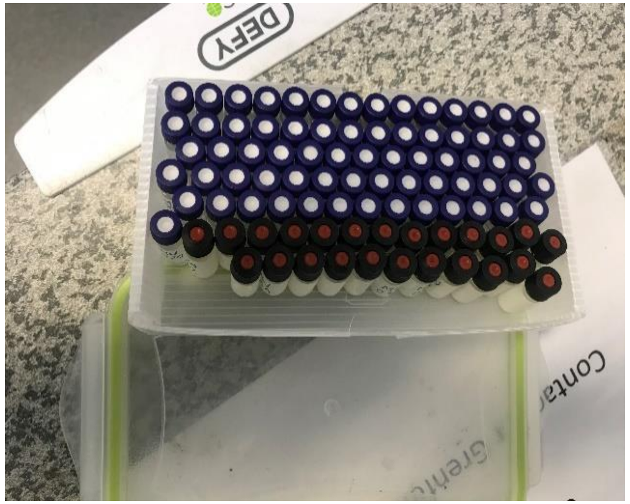
- Water samples were collected
- Insitu physiochemical parameters measured using a multi-meter.

Groundwater levels were measured using a Dip meter

River discharge was measured using an ADCP meter
This was done to verify the flow measurements from ZRA

LAB ANALYSIS





- Water samples to be tested for stable isotopes were repackaged in 10 ml vials
- Stored in a cooler box with ice-packs
- Transported to Ithemba LABS Johannesburg
- The equipment used was Los Gatos Research (LGR) Liquid Water Isotope Analyzer.
- The instrument is used to measure Oxygen and Hydrogen isotope in water
- The stable isotope composition of water is determined by Isotope Ratio Mass Spectrometry (IRMS)

Analysis using R-Statistical Package

Base flow Separation

- Used EcoHydRology Library
- Input data was the River Discharge from ZRA
- Filter parameters: The value recommended by Nathan and McMahon (1990) is 0.925, (0.9-0.95)
- The number of times you want the filter to pass over your data. 1-3

Statistical Test

- Shapiro Wilk Normality test
  W-value (0-1)
- P-value = confidence interval (0.05)
- Pearson correlation test
  (assumes parametric data)
- Spearman correlation test
  (assumes non-parametric data)

NDVI Decomposition

- Utilized fpp and forcast Libraries
- Apply Detrend to the NDVI time series from GEE
- Set monthly data as time series
- In order of seasonality n=12
- Applied a detrend to the matrix
- Plotted:

✓ seasonality

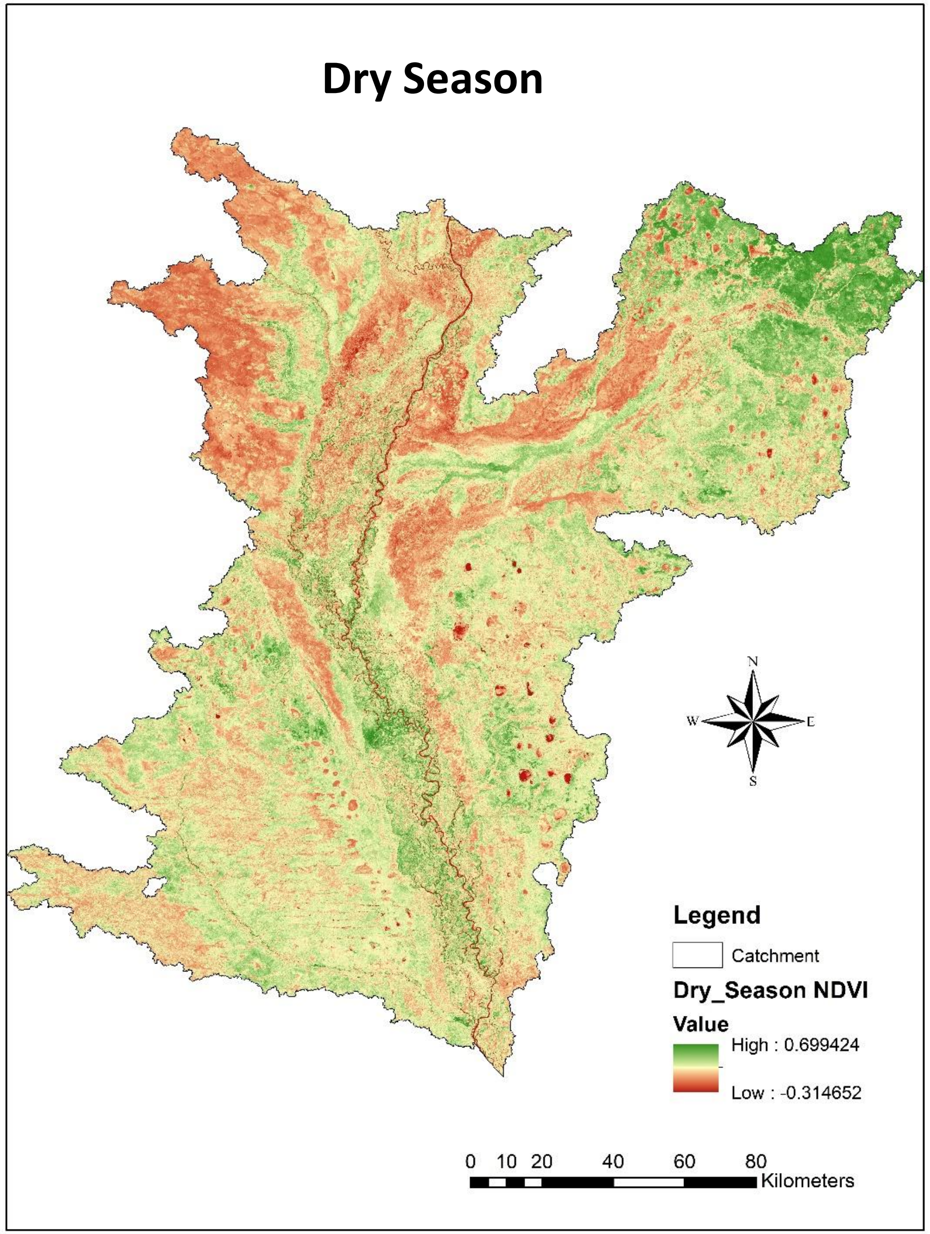
✓ Random data

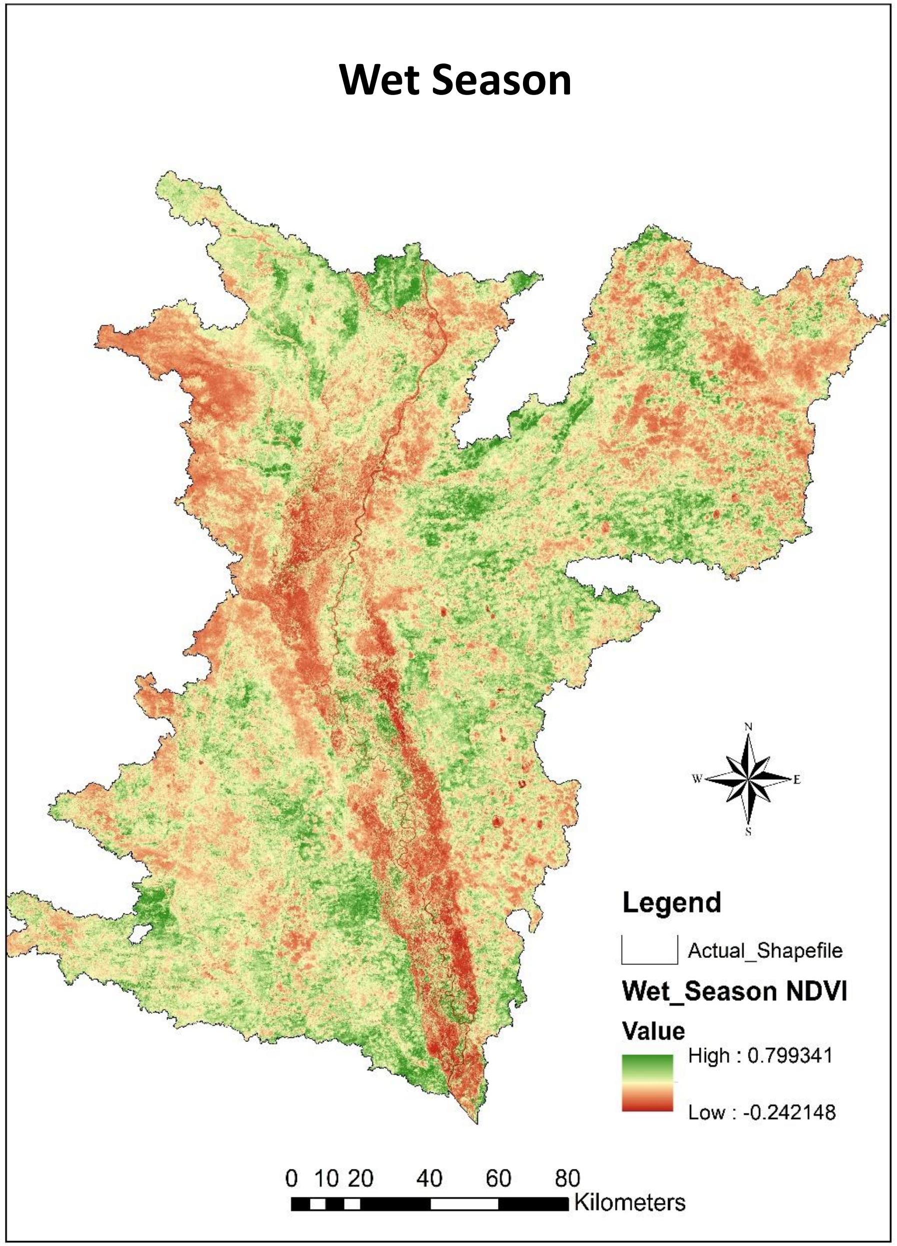
- Recomposer beer used to extract an additive time series

ATS=NDVI + seasonality + random

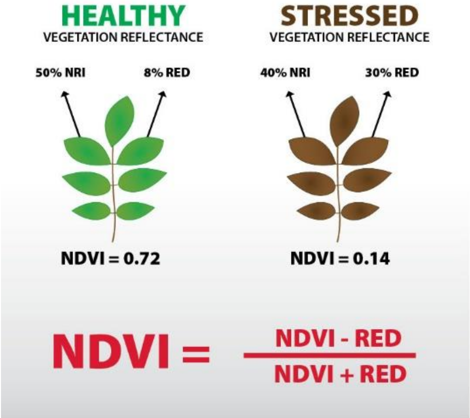
- Produced a trend line

RESULTS

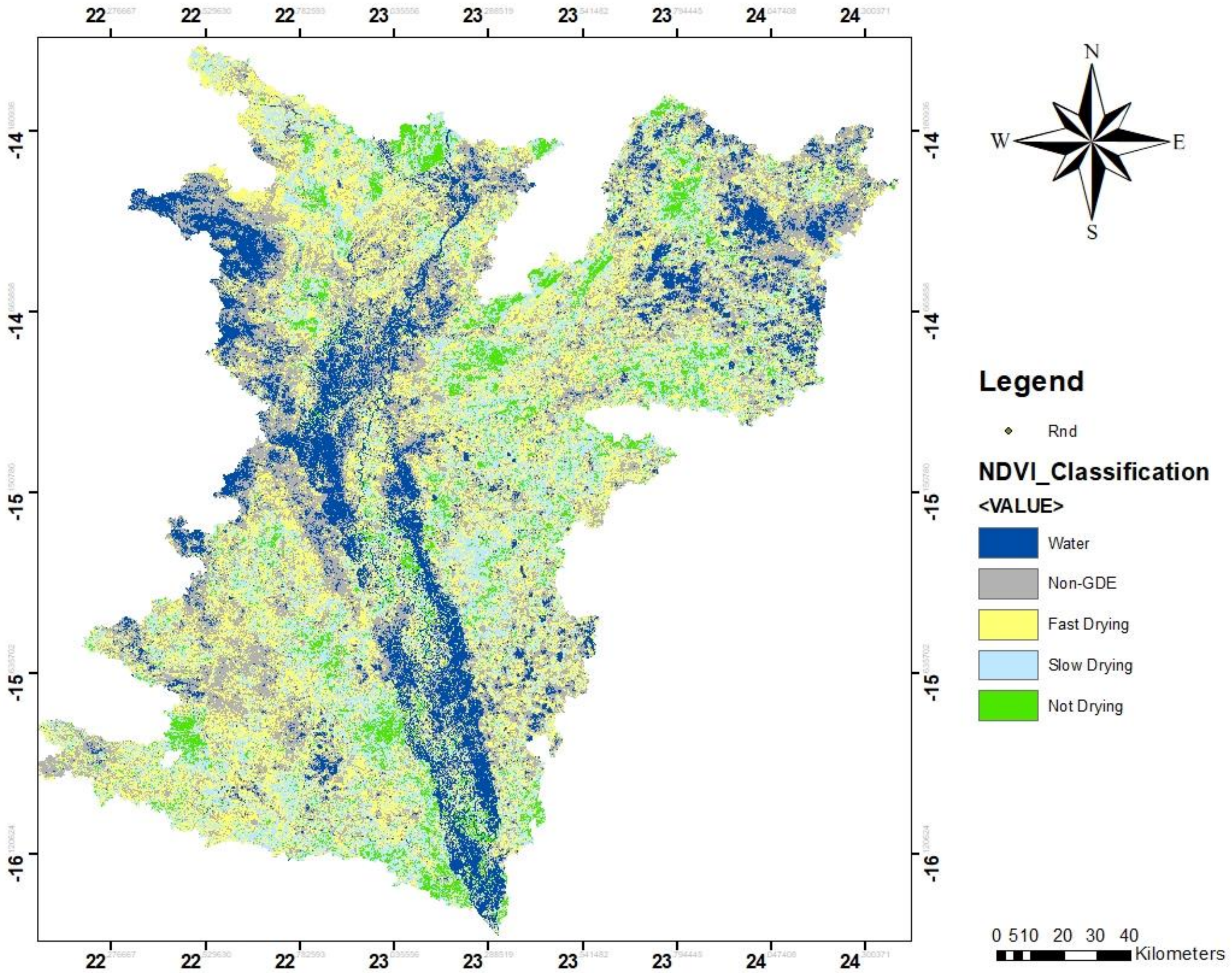




- Healthy vegetation showed the highest NDVI values while
- Bareland and Flooded areas showed the least NDVI vales
- During the dry season areas with healthy vegetation were assumes to be tapping from groundwater



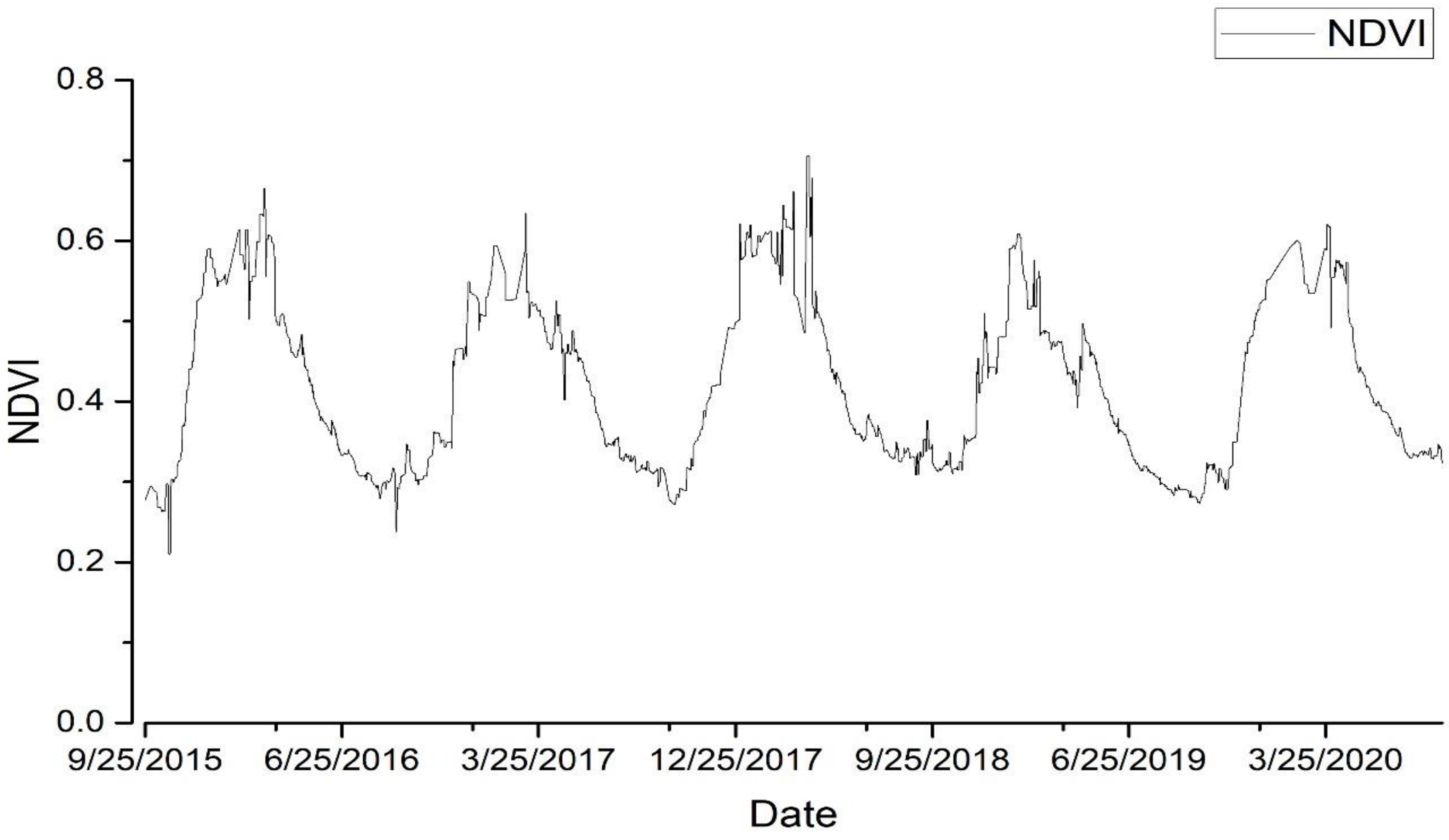
NDVI Difference map

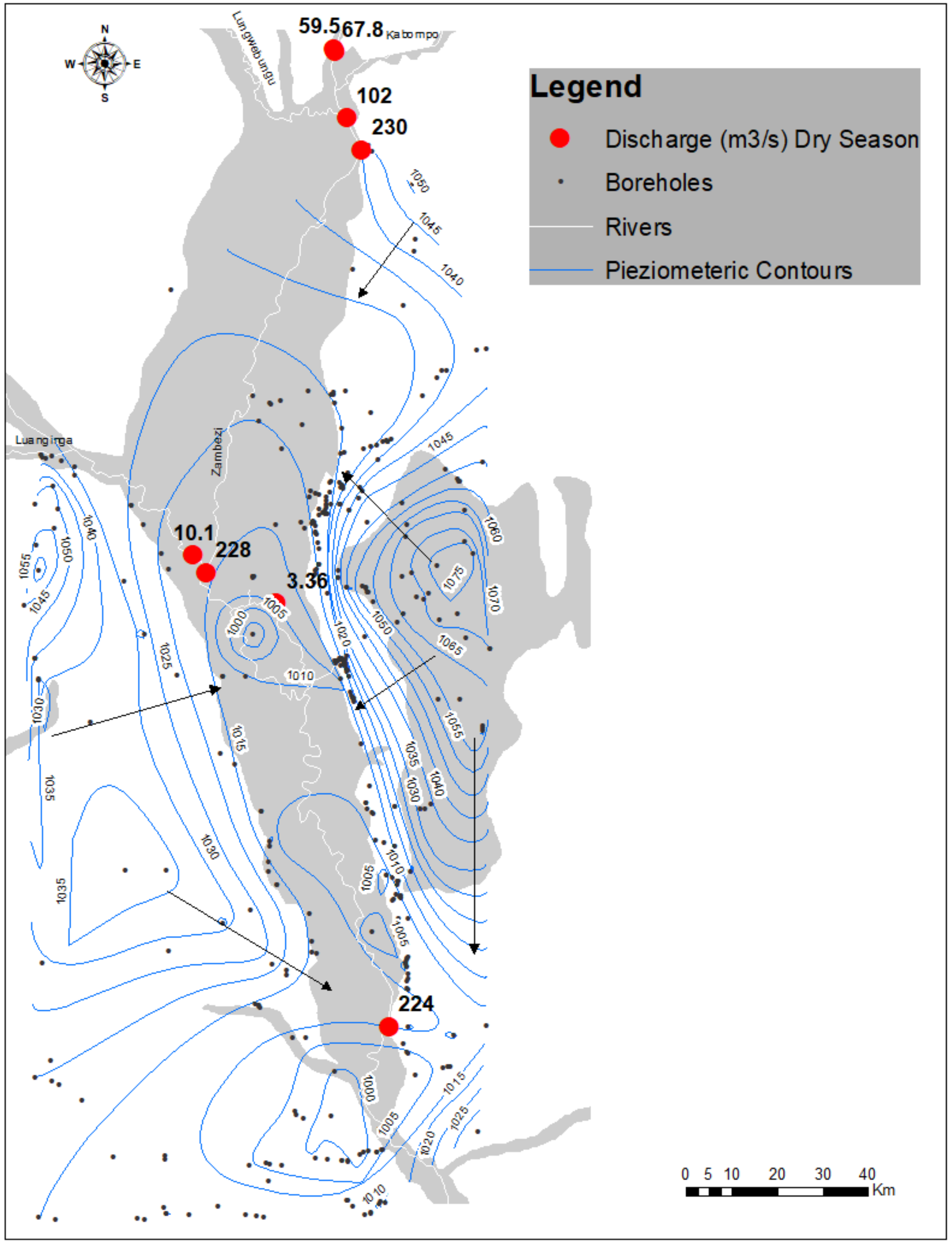


Class	NDVI values
• Water:	Less than 0
• Non-GDE:	0 - 0.1
• Fast Drying:	0.1 - 0.2
• Slow drying:	0.2-0.4
• Non Drying:	Greater than 4

- Validation of the classification
- Using a Kappa Coefficient: 65.7%
- Overall coefficient: 74.6%

NDVI over a 5 year period from 2015 to 2020

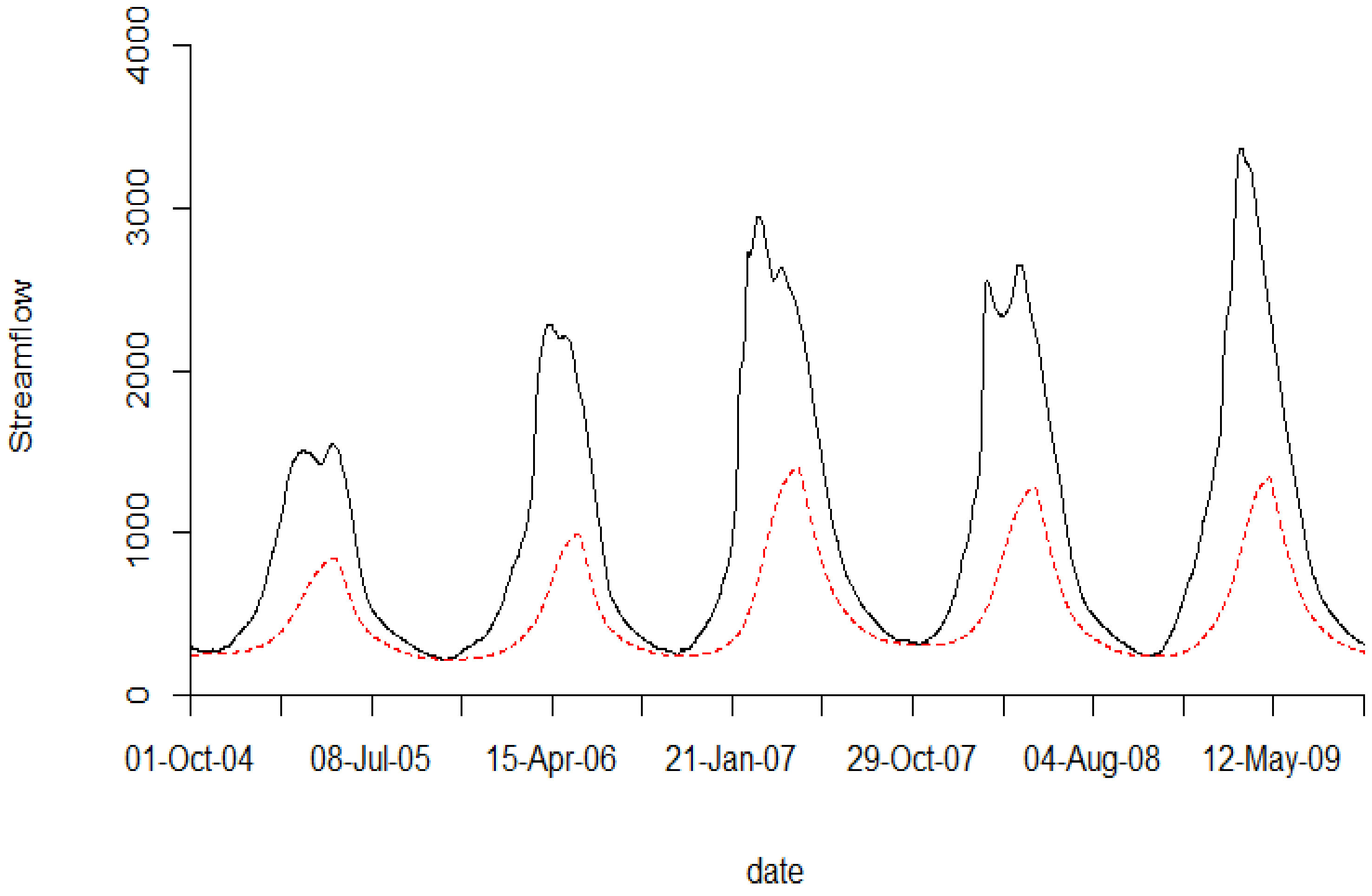




Groundwater flow direction

- Piezometric head contours
- Upstream hydraulic gradients are relatively gentle (Infiltration zone) compared to the downstream (discharge zone).
- Overall groundwater flow is towards the floodplain
- Surface flows reduce downstream

Base flow



Base flow (m^3/s)	Quick flow (m^3/s)
Min. : 218.3	Min. : 0.00
1st Qu.: 266.8	1st Qu.: 79.15
Median : 356.1	Median : 282.97
Mean : 500.0	Mean : 536.93
3rd Qu.: 655.8	3rd Qu.: 829.90
Max. :1401.7	Max. :2501.21

$$Base\ flow\ contribution = \frac{Mean\ Baseflow}{Mean\ flow}$$

$$= \frac{500}{1036.93} * 100$$

= 48.2 %

Hydrochemistry of the major elements in water on the Barotse Floodplain

	DRY		WET		Zambezi	River
Elements	Surface Water	Groundwater	Surface water	Groundwater	Dry	Wet
HCO3	105.4133	172.0152	39.3	90.08889	97.15	26.87
Ca	17.14286	22.51515	20.5	14.96774	14.75	29
K	1.857143	7.30303	12.9	9.483871	1.5	1
Mg	5.785714	4.272727	4.9	5.322581	6	4.6
Na	6.071429	42.27273	9.7	6.258065	4.25	3
SO4	5.533333	24.9697	8.6	26.32258	5.25	3.33

Both River and groundwater had similar ionic signatures
Dry season: Na >Ca>K>Mg
Wet season: Ca>Na>K>Mg

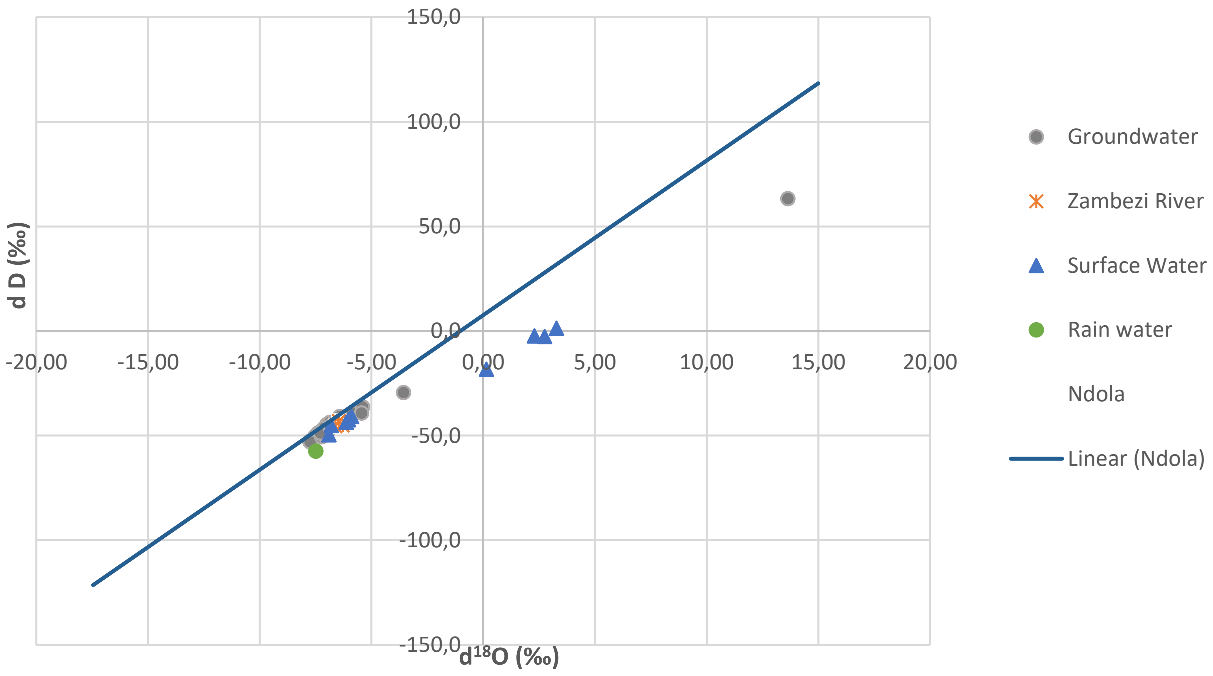
	Zambezi River	
Surface water	0.829	Correlation Coefficient
	0.028	P Value
	20	Number of Samples
Groundwater	0.675	Correlation Coefficient
	0.037	P Value
	20	Number of Samples

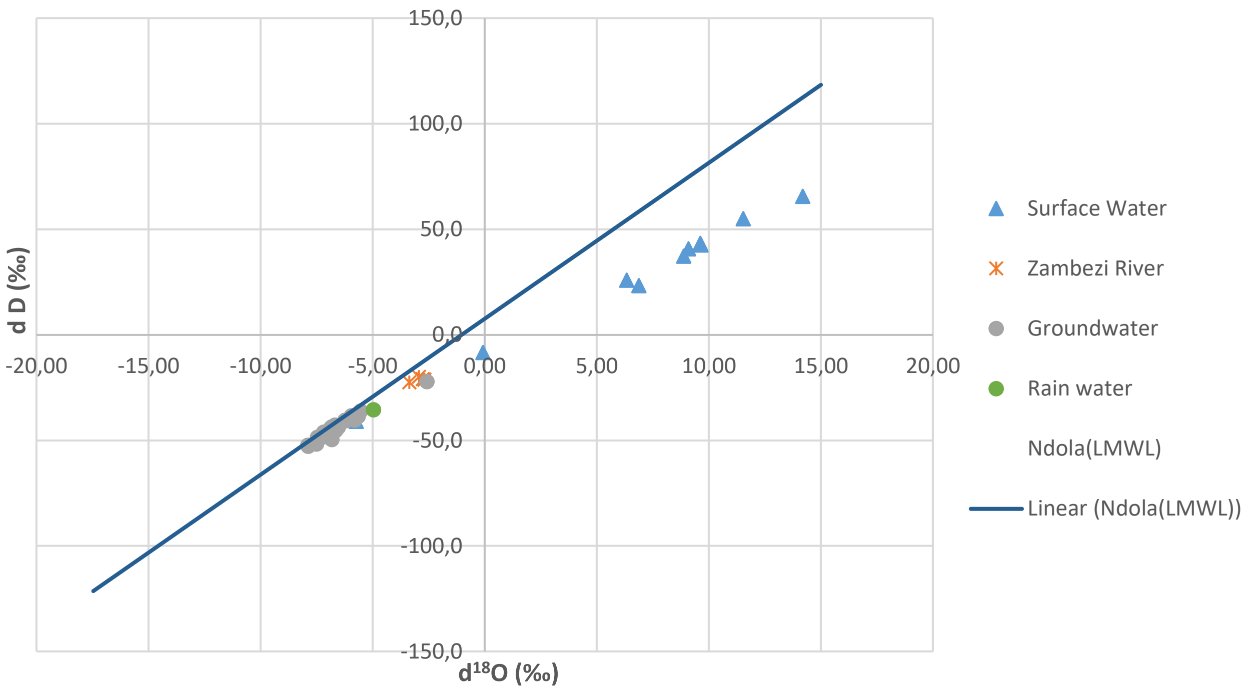
Electrical conductivity

Location	Groundwater		Zambezi River	
	Wet	Dry	Wet	Dry
Upstream	396.992	373.341	92.3	194
Midstream	159.056	344.833	69.1	134.3
Downstream	74.575	66.4	63.2	113.9

- Groundwater has a higher electrical conductivity than surface water.
- There is also a reduction in electrical conductivity from upstream to downstream in both the wet and dry season in the Barotse Floodplain.
- Conductivity is primarily influenced by abiotic factors therefore the reduction in conductivity maybe due to the reduced concentration in total dissolved solids downstream of the Barotse Floodplain

Stable Isotopes





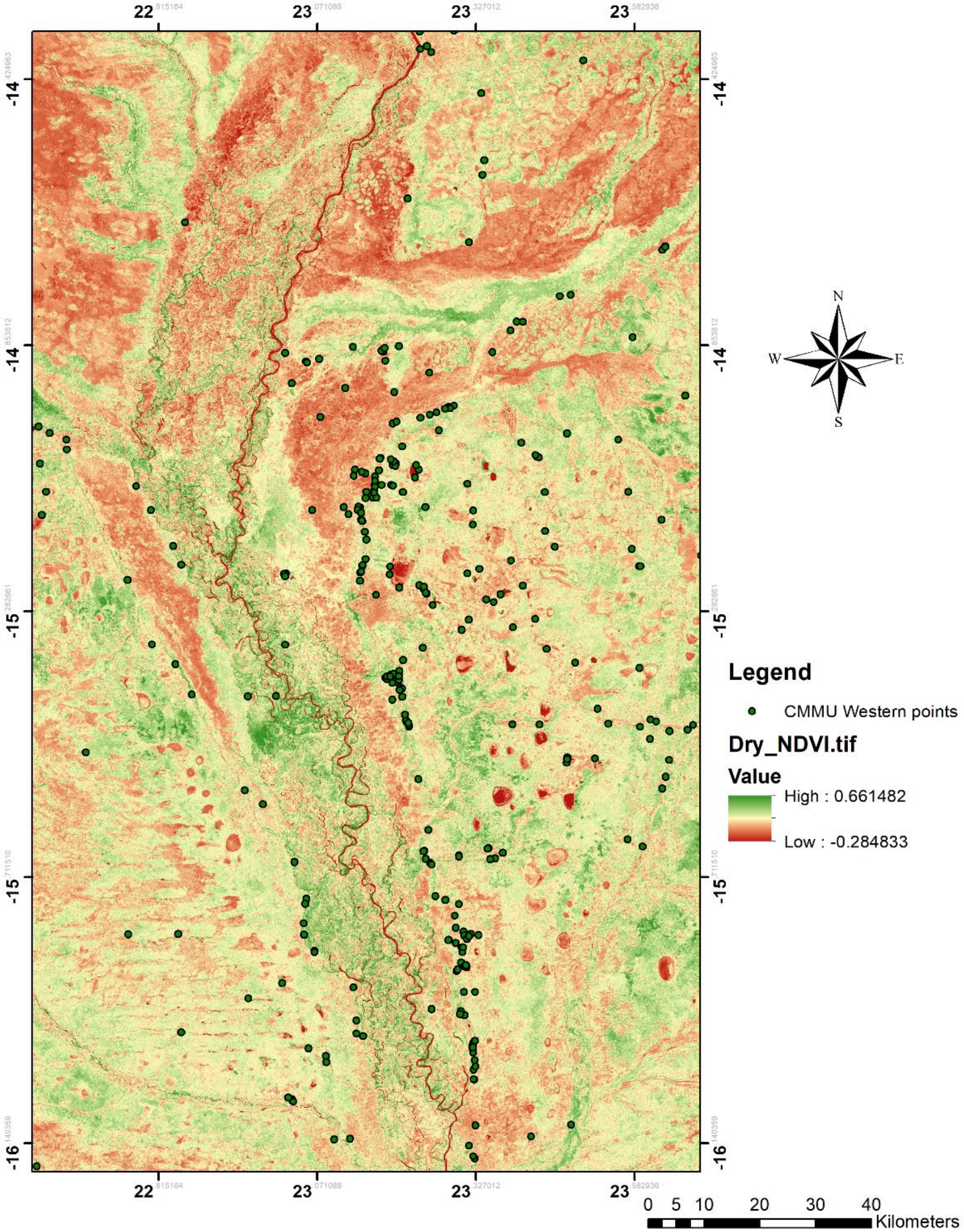
- Dry season Isotope data

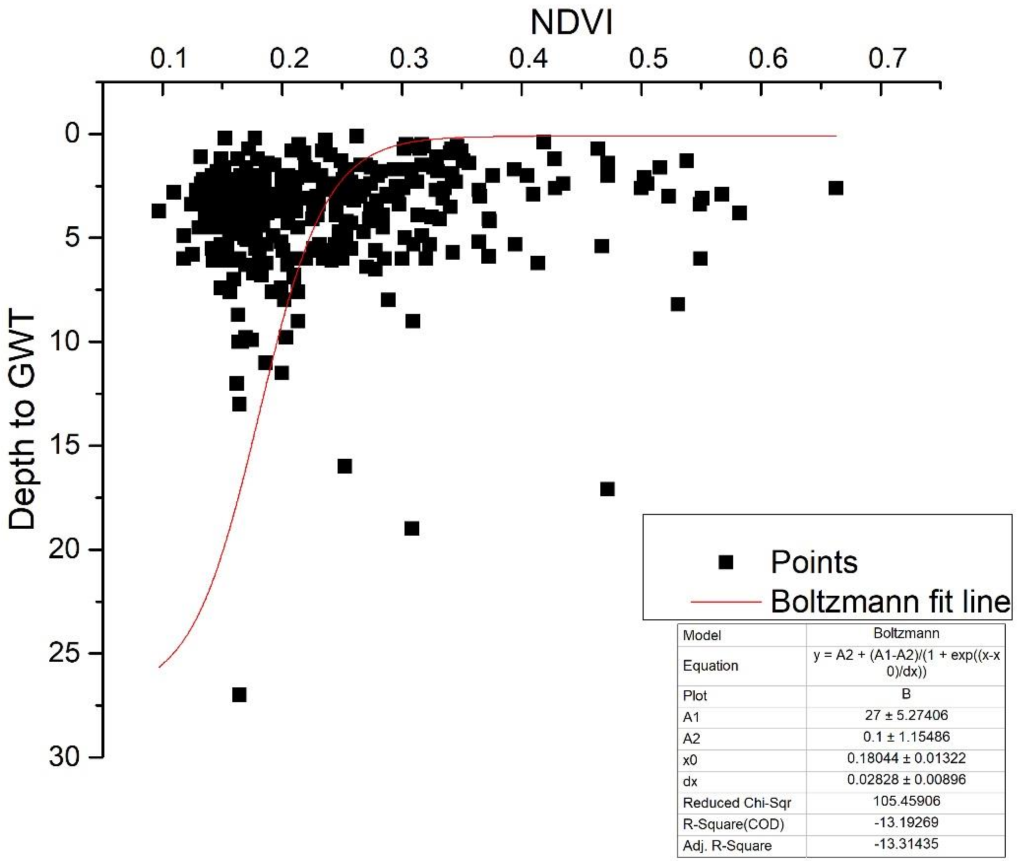
- Plotted against the LMWL
- $y = 7.6311x + 9.1439$
- GMWL: $Y=8x+10$

- Wet season Isotope data

- River water and groundwater both plot in the depleted zone of the LMWL
- High local infiltration
- Not affected by evaporation

Spatial Relationship between NDVI and Depth to groundwater table

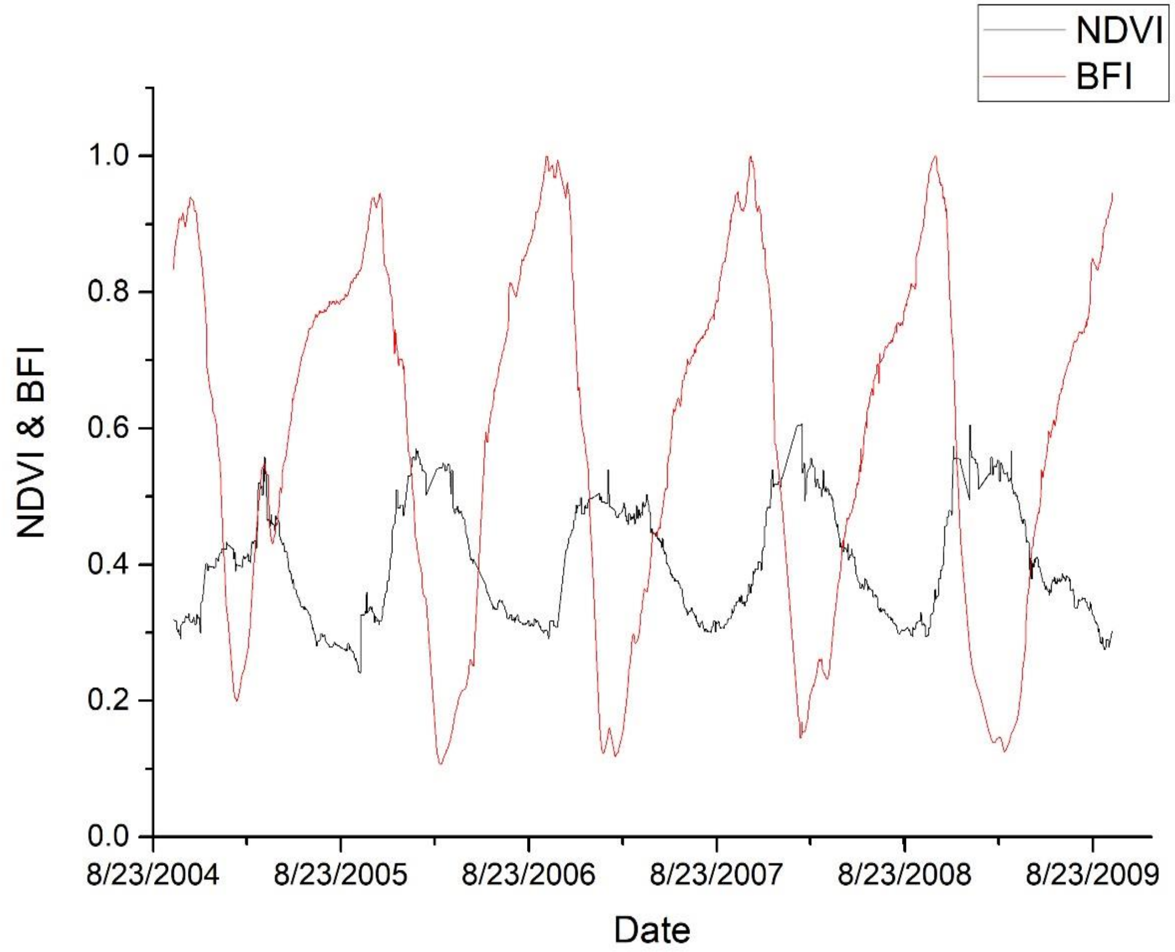




Model	Boltzmann
Equation	y = A2 + (A1-A2)/(1 + exp((x-x0)/dx))
Plot	B
A1	27 ± 5.27406
A2	0.1 ± 1.15486
x0	0.18044 ± 0.01322
dx	0.02828 ± 0.00896
Reduced Chi-Sqr	105.45906
R-Square(COD)	-13.19269
Adj. R-Square	-13.31435

$$GWT = 27 / (1+\exp(NDVI - 0.18)/0.028))$$

Statistical Correlations



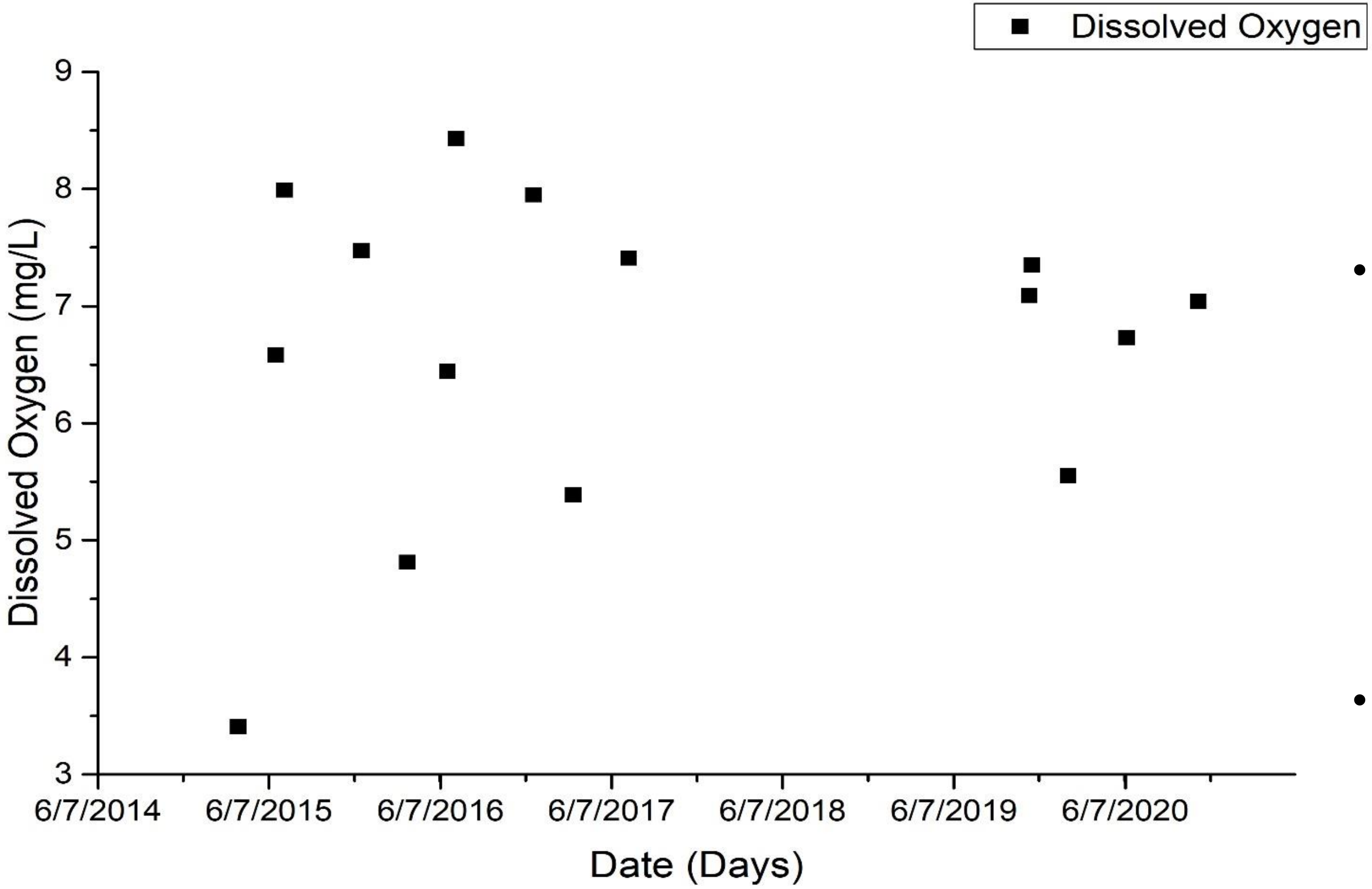
Shapiro Wilk Normality test

NDVI:	W-Statistic 0.939	=	P < 0.001	Failed
BFI:	W-Statistic 0.929	=	P < 0.001	Failed

Inverse correlation

	Base flow index	
NDVI	-0.759	Correlation coefficient
	0.0000002	P value
	1642	Sample size

Dissolved Oxygen



	DO
BFI	0.952 0.000000200 17

- From the various Physiochemical parameters measured, Dissolved oxygen was used in the determination of the significance of groundwater to the Floodplain because it is not affected by abiotic conditions.

- The concentration in dissolved oxygen increases during the dry season

- And decreases in the rainy (wet) season

CONCLUSION

- The green islands concept was applied using NDVI to map the surface expressions of groundwater through the identification of perennial green vegetation
- Hydrograph separation method using digital filtering and stable water isotopes to determine the connectivity and evaluate the influence of this connectivity
- Groundwater flow using piezometric head contours and major ion chemistry show that the nature of interaction is such that groundwater discharges into the Zambezi river
- The isotope data reveals that there is high local infiltration from precipitation into the groundwater aquifer
- At the pick of baseflow contribution to the river flow the dissolved oxygen concentration was at its highest. Therefore, the increased baseflow in the dry season provides increased dissolved oxygen concentration in the Zambezi River that is used by biota for the sustainability of the ecosystem.

Thank you for Listening