Evaluation of Remotely Sensed Thermal Fluxes in Monitori Woodland Carbon: The Case of Liwale and Kilwa in Tanzan

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Background

A functional, cost-effective, and comprehensive system for measurement, reporting and verification (MRV) of forest carbon on a regular basis is important for sustainable forest management. Optical remote sensing datasets are critical for the development of such a system. The datasets are free, and have a wall-to-wall and repetitive coverage. Their use in estimating woodland above-ground carbon (AGC) is limited because of their perceived limitations of cloud contamination and saturation of the vegetation indices derived from the data. The indices, which quantify the magnitude of vegetation greenness as a measure of the vegetation density are commonly used to quantify biomass with optical satellite imagery. This study resolves the saturation problem by developing a Forest Biomass Index (FoBI). The index models the magnitude of latent and sensible heat fluxes in woodlands. The study proposes that this magnitude relates significantly to the amount of woodland biomass and carbon (Figure 1) than that of greenness does. It is therefore a better proxy for estimating AGC. The study applies an image processing chain that also eliminates the cloud contamination. By the solving these two problems, AGC estimates can be made accurately, affordably, comprehensively, and repetitively using free satellite imagery.

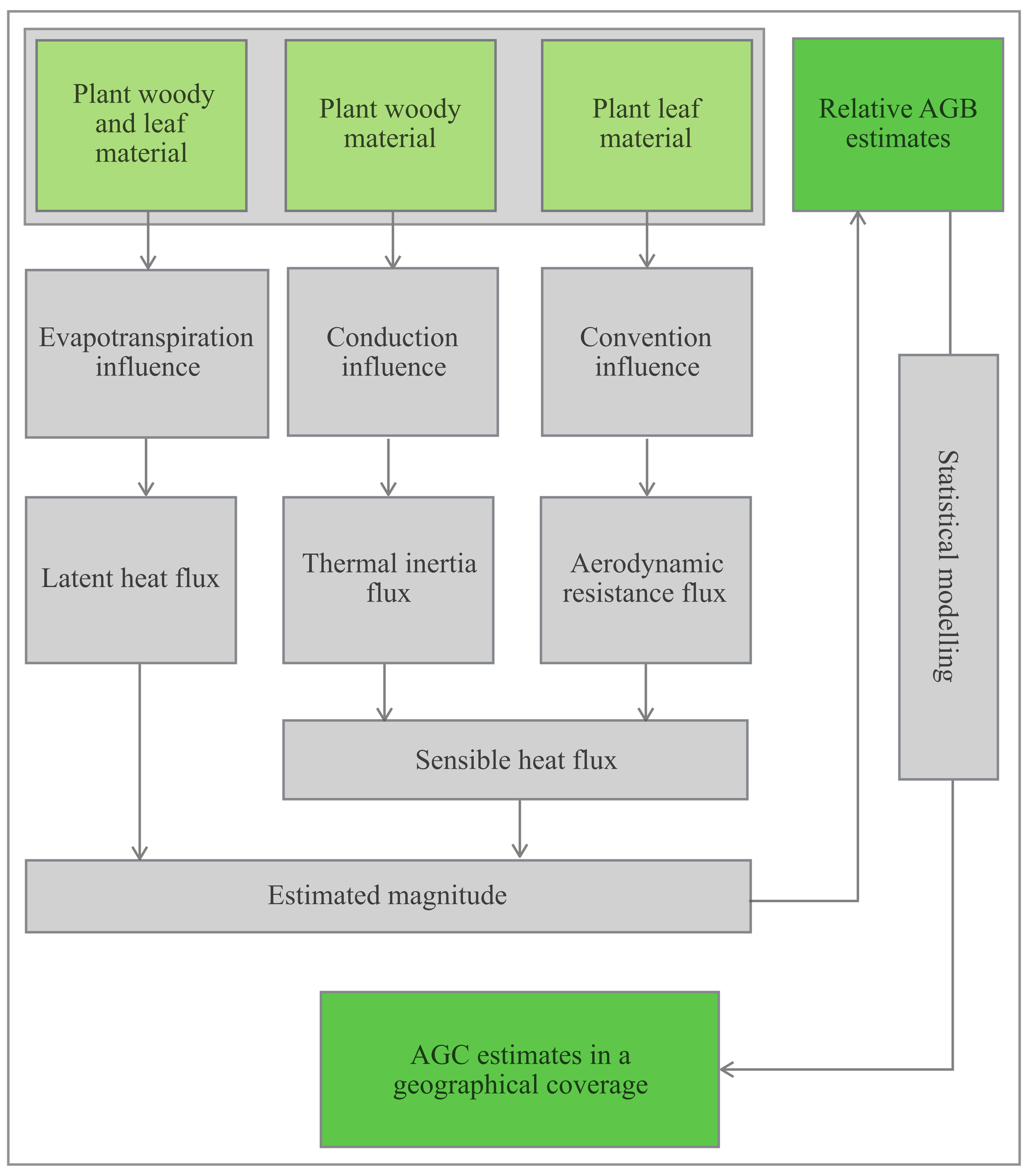

Figure 1. A framework for relating the thermal fluxes and their magnitude with woodland AGB and C.

Modelling Thermal Fluxes: The VIT Theory

Figure 2. Shows the vegetation index-surface temperature (VIT) trapezoid. It enables the interpretation of the magnitude of the latent and sensible heat fluxes by pairing surface temperature (Ts) and vegetation greenness in form of Normalised Differential Vegetation Index (NDVI).

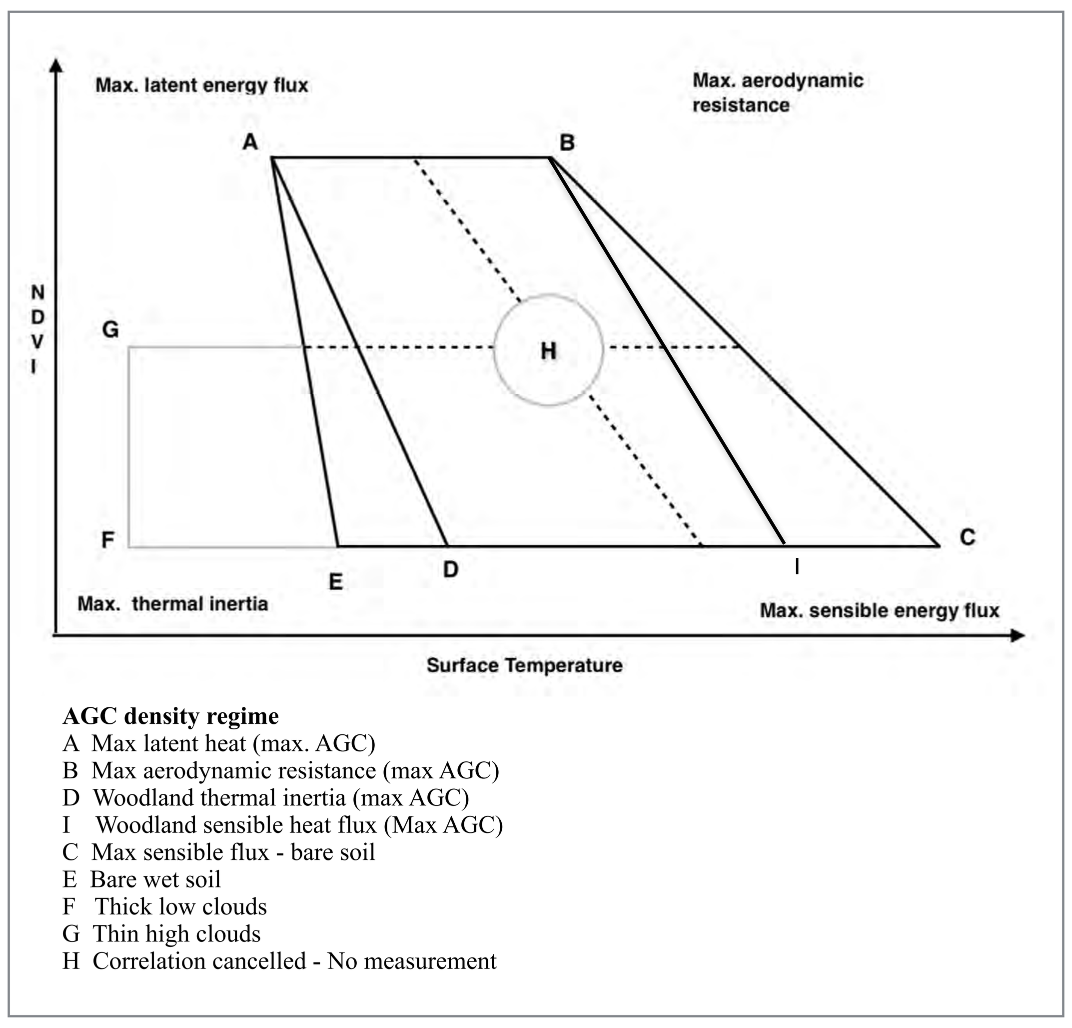

Figure 2. Pairing remotely sensed Ts and NDVI to interpret the magnitude of the woodland latent and sensible heat fluxes.

Methodology

1. The study area

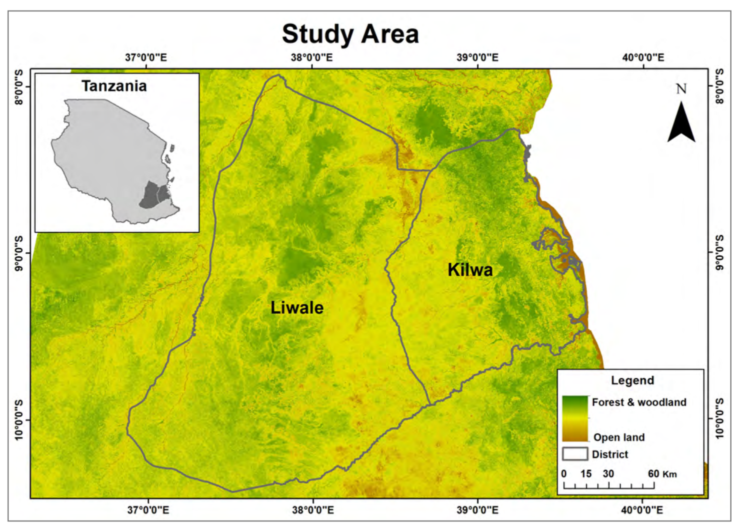

Fig. 3. Liwale and Kilwa are districts in Lindi region located between 7°56′41′′ and 10°25′56′′ S, and 36°51′52′′ and 39°39′59′′. They cover 49,277 km².

2. Deriving the Ts and NDVI Layers

Landsat images are calibrated, and Ts is derived from thermal infrared image bands (Figure 4). NDVI is calculated from reflected red and near-infrared bands. The layers are spatially filtered at predetermined kernel sizes.

Cloud cover is eliminated in the image processing chain using the maximum value composite (MVC) method.

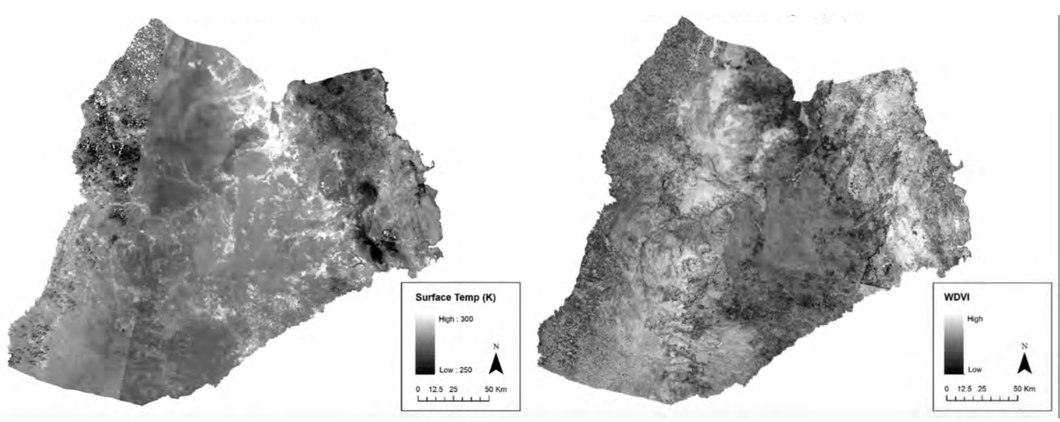

Figure. 4 Surface temperature (Ts) and Normalised Difference vegetation Index (NDVI) layers

3. Methodological workflow

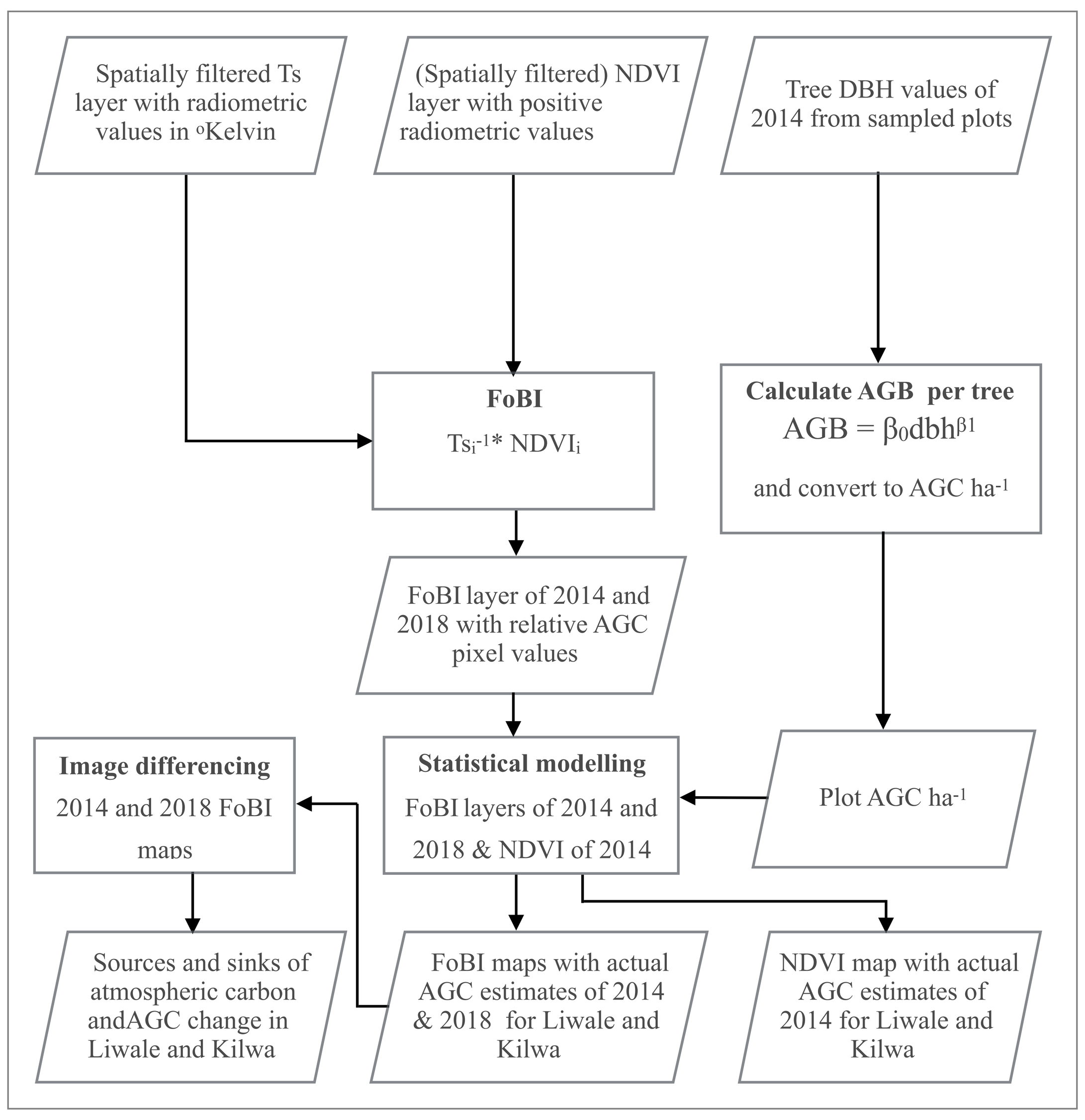

Figure 5: Workflow for estimation of AGB and C using FoBI

4. Deriving FoBI Maps

Ts and NDVI were paired using the equation 1:

$$FoBI = (Ts_i^{-1} * NDVI_i) \qquad (1)$$

FoBI is the forest biomass index, Ts_i^{-1} is inverse surface temperature in location i, and $NDVI_i$ is the negatively-adjusted NDVI value at location i.

5. Statistical modelling

The maps were statistically modelled with plot-based AGC estimates using ordinary least squares (OLS) with cubic polynomial transformation for spatial prediction and estimation of AGC in Liwale and Kilwa for the years 2014 and 2018. The performance of the FoBI maps was benchmarked against the performance of NDVI in estimating AGC. The accuracy of NDVI is commonly accepted in estimation of AGC in conventional biomass mapping studies.

6. Change analysis

Change was determined using equation 2:

$$I_d(x,y)=I_i(x,y)-I_2(x,y) \qquad (2)$$

Where where I_d is the difference image, I_1 and I_2 are the FoBI maps of 2014 and 2018 statistically modelled to estimate actual AGC of the study area in the two years.

Results

1. Cloud removal

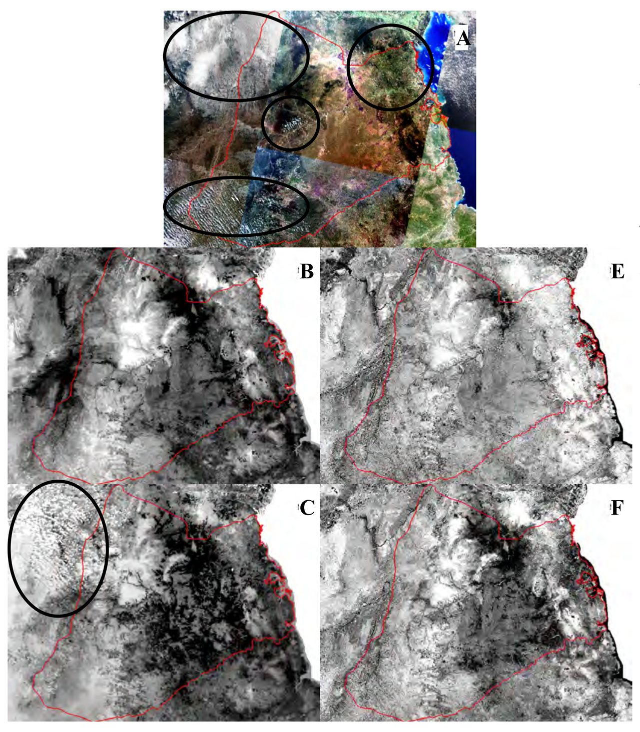

Figure 6. Cloud-free image composites of Ts (B&C) and NDVI (E&F) composited using the MVC method.

2. Statistical modelling

Table 1. Parameter estimates of a cubic polynomial AGC model used with FoBI and that of quadratic with NDVI ($p < 0.001$) as predictors (n = 200 for all 2014 maps, 130 for 2018 map). The FoBI-plot AGC models (bold) have better overall performance than those of NDVI-plot AGC counterparts.

Variables	Parameter Estimates				R	R²	P - value	RMSE (C t/ ha)	% RMSE
	Intercept (α)	Slope (β₁)	Slope (β₂)	Slope (β₃)					
Wet FoBI (2014), Plot AGC (2014)	22.31	0.00	-613.37	2923.04	0.73	0.53	0.00	11.99	34.62
Dry FoBI, (2014), Plot AGC (2014)	-15.31	404.9	-1386.0	2053.21	0.66	0.43	0.00	12.77	36.85
Annual FoBI, (2014), Plot AGC (2014)	-47.01	415.61	-923.51	805.41	0.72	**0.52**	0.00	**12.05**	34.41
Annual FoBI (2018), Plot AGC (2014)	-49.17	794.9	-2505.6	2604.2	0.76	**0.58**	0.00	**7.54**	21.30
Wet NDVI (2014), Plot AGC (2014)	744.21	-2270	1782.19	-	0.66	0.43	0.00	13.18	37.24
Dry NDVI (2014), Plot AGC (2014)	254.51	-770.	644.88	-	0.61	0.37	0.00	13.48	38.67
Annual NDVI (2014), Plot AGC (2014)	107.21	-411.1	427.32	-	0.66	0.44	0.00	13.05	36.53

3. AGC Estimates in 2014 and 2018

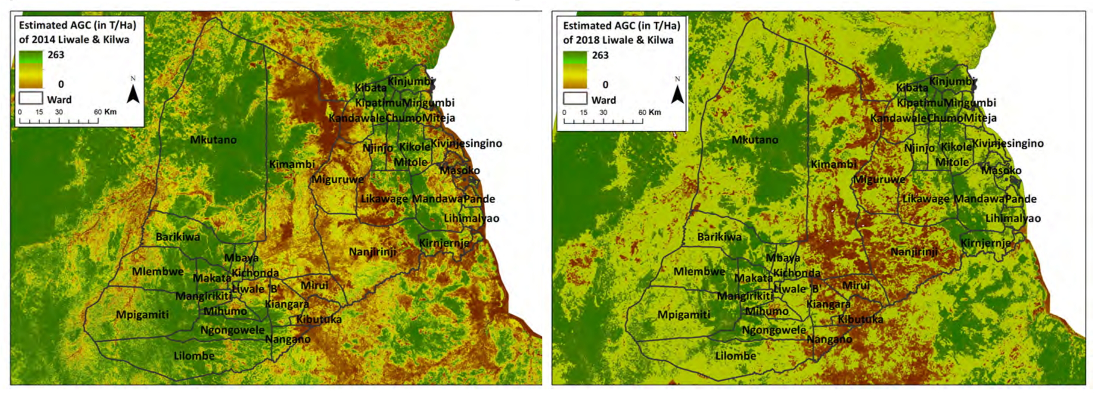

Figure 7. Above-ground carbon (t ha⁻¹) distribution in the wards of Liwale and Kilwa in 2014 and 2018. The total AGC in the study area was 220.4 Mt. In 2014 and 213.3 in 2018.

4. AGC change, 2014-18

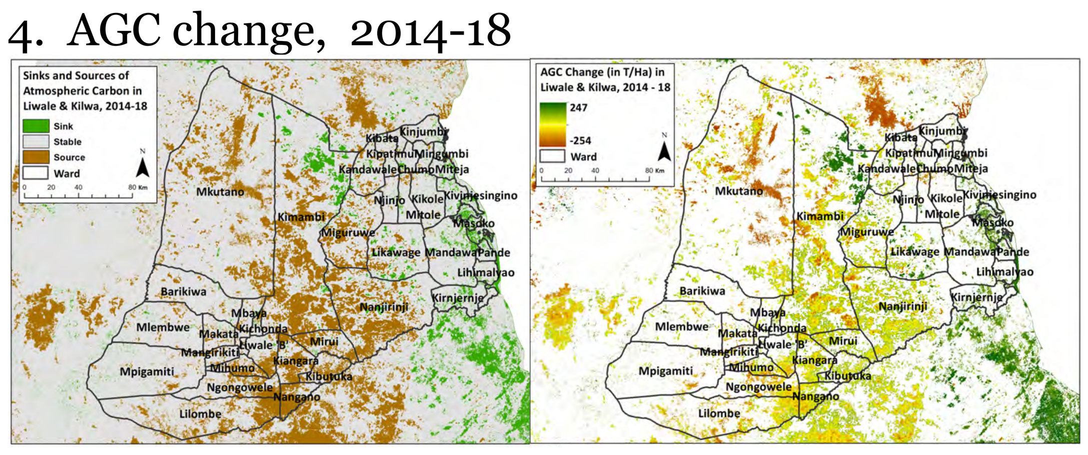

Figure 8. The sinks and sources of AGC in the wards of Liwale and Kilwa (left) and actual AGC change between 2014 and 2018. The total change area was 11,368 km² (23% of the study area). The absolute net AGC change was 6.6 Mt (3% of total averaged AGC in 2014 and 2018).

Conclusions

a. FoBI has better model performance and twice the range of estimation than using NDVI as an estimator of AGC in woodland conditions.

b. FoBI's extended range of AGC estimation indicates the saturation problem with optical remote sensing has been resolved. Cloud contamination is also eliminated as part of image processing chain. With these limitations purged, optical imagery can be readily used as part of a cost effective and functional MRV system.

c. AGC change between 2014 and 2018 is not significant and AGC stocks in Liwale and Kilwa are generally stable.

Acknowledgement

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