JIGJIGA UNIVERSITY

Institute of Pastoral and Agro-pastoral Studies(IPADS)

Assessment and Development Forage Biomass Estimation System using high resolution satellite image :case of Harshin,SRS,Ethiopia

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Content of presentation

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1. Background and justification

- Livestock is a backbone of most of African countries; Ethiopia ranks 1st in Africa and 10th in the world in terms of livestock number.
- The country is the least in terms of quality of livestock production; less understanding and management about the quality and quantity of animal feed (forage),
- Most of the present livestock-feed assessment methods in the country are either based on the traditional experience (cuts and weights’) or low-resolution satellite images
- Overall, there is poor characterization of rangelands in terms of palatability, quantity, spatial variation of productivity and their actual stocking capacity.

Background cont'd

- The advances in remote sensing and GIS technology provide some convenient techniques for biomass (animal forage) estimation with more accuracy than traditional systems.
- Such methods can strongly assist the government & decision makers to properly allocate resources and plan rangeland resources.
- It enables them to be aware of the magnitude of the problem ahead of time and to take proactive measure in pastoralist areas (in case where there is drought or shortage of animal forage).
- To the best of our knowledge, high-resolution remote sensing data(10m) has not been used to estimate animal forage in Ethiopia.

Background cont'd

- The result can also be used as Early Warning System (EWS) for decision to make early preparation and take proactive measures.
- This is particularly helpful to estimate the balance between available and needed forage amount during drought (low rainfall) years.
- Livestock insurance companies are the one who are expected to make use of such information to prioritize zones, woredas and kebeles during disasters and severe shortage of animal feed.
- Dryland restoration –prioritizing project/programs implementation

2. Objectives of the research

General objective: **Assess and** develop forage biomass estimation system using satellite image that can be used to derive reliable, cost-effective, timely, and repeatable information on animal feed (particularly grass and herbaceous forage)

The specific objectives are to:

i) Estimate carrying capacity and stocking rate of rangeland.

ii) develop an operational forage biomass forecasting methods based on Sentinel-2 remote sensing data.

iii) validate the models at Harshin district

3. Material and methods

3.1 The study area

The study was done at Harshin district (about 130km from Jijiga): the ground truth data of forage biomass and spectral data which is needed for the model development was collected from this district.

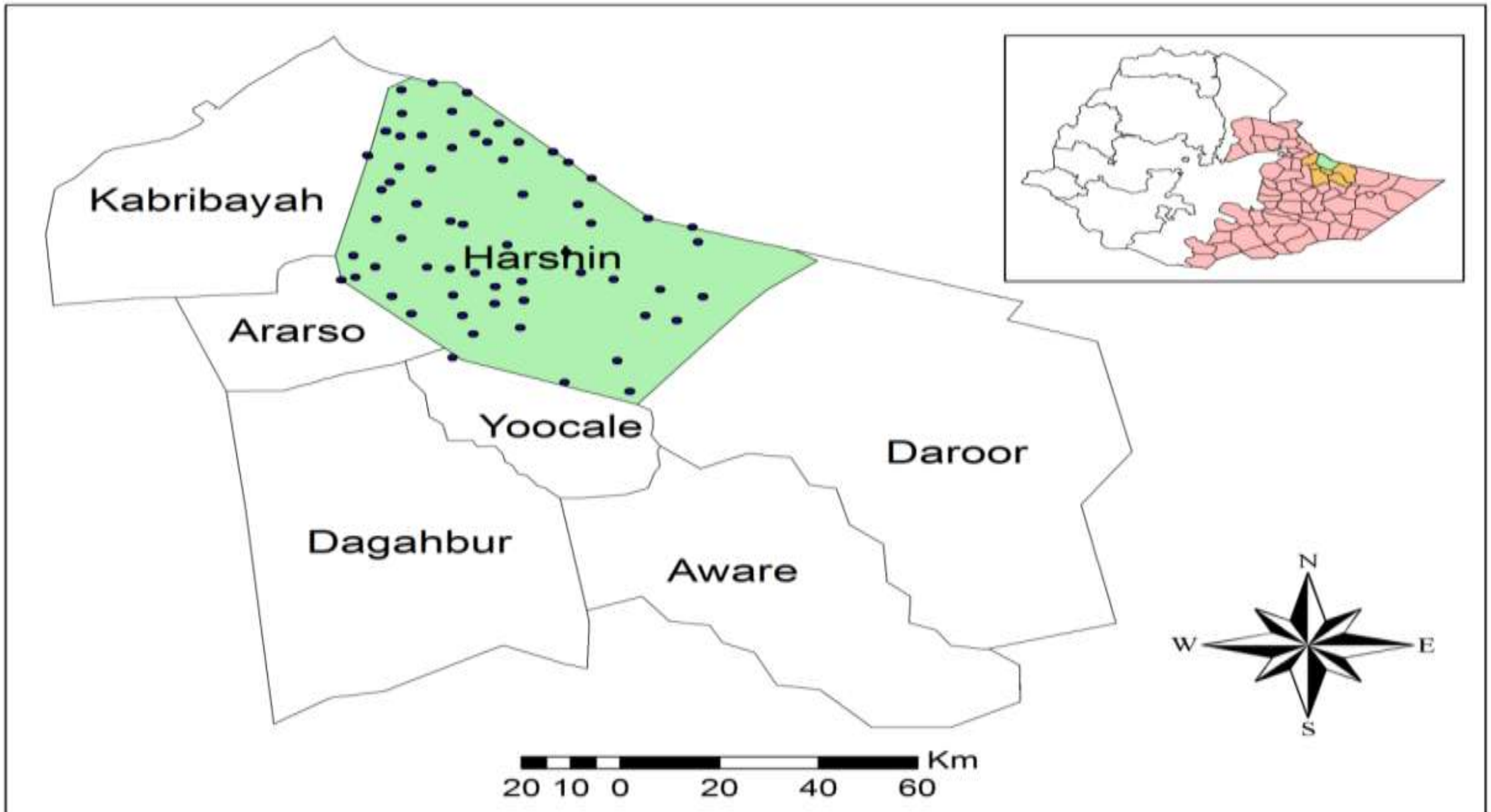


Fig1. Location map of the study area: Harshin and its neighboring districts, Eastern Somali region,

Study area cont'd

- There is high scarcity of water than any other resources
- The recurrent occurrence of drought is one of the most difficult challenges of the pastoralist

Figure 3. Traditional water reservoirs in the region (*birkads and ponds*).

Study area cont'd

- Infrastructure and social services are generally low across the district
- All roads in the district are only seasonal (dry weather roads) that are often difficult to drive under wet conditions

Figure 6. Typical road style in the district: there is no normally constructed gravel or asphalt road

3.2 Types of data and method of collection

- We used three types of data in this specific study: field measured forage biomass data, satellite imagery and socioeconomic data
- We conducted a preliminary field survey (May 15 to 20, 2018) and selected plots to measure above ground biomass (AGB) of grass in Harshin district.
- A total of 55 plots with different forage productivity were selected and geo-marked with GPS for further investigation, monitoring and productivity measurement.
- To be considered for the study, a given plot should have a spatial coverage of at least 0.5 ha to conform to the pixel size of most of the freely available satellite images without being affected by reflection from nearby features or land cover.
- We downloaded satellite images (acquired on 23 May 2018 by Sentinel-2 sensors) and processed to develop spectral model of forage biomass.
- Sentinel-2 data are acquired on 13 spectral bands in the Visible and Near-Infrared (VNIR) and Shortwave Infrared (SWIR) regions
- Of the 13 spectral bands, four (B2, B3, B4 and B8) with 10-m resolution were used for the model development.

Data analysis

The rangeland productivity (biomass) and livestock data were analyzed by means of Microsoft Excel program to generate descriptive statistics.

we used ERDAS 2010 and ArcGIS (version 10.2.2) software to analyze remote sensing data, prepare land use and cover map and calculate the vegetation indexes (NDVI and EVI).

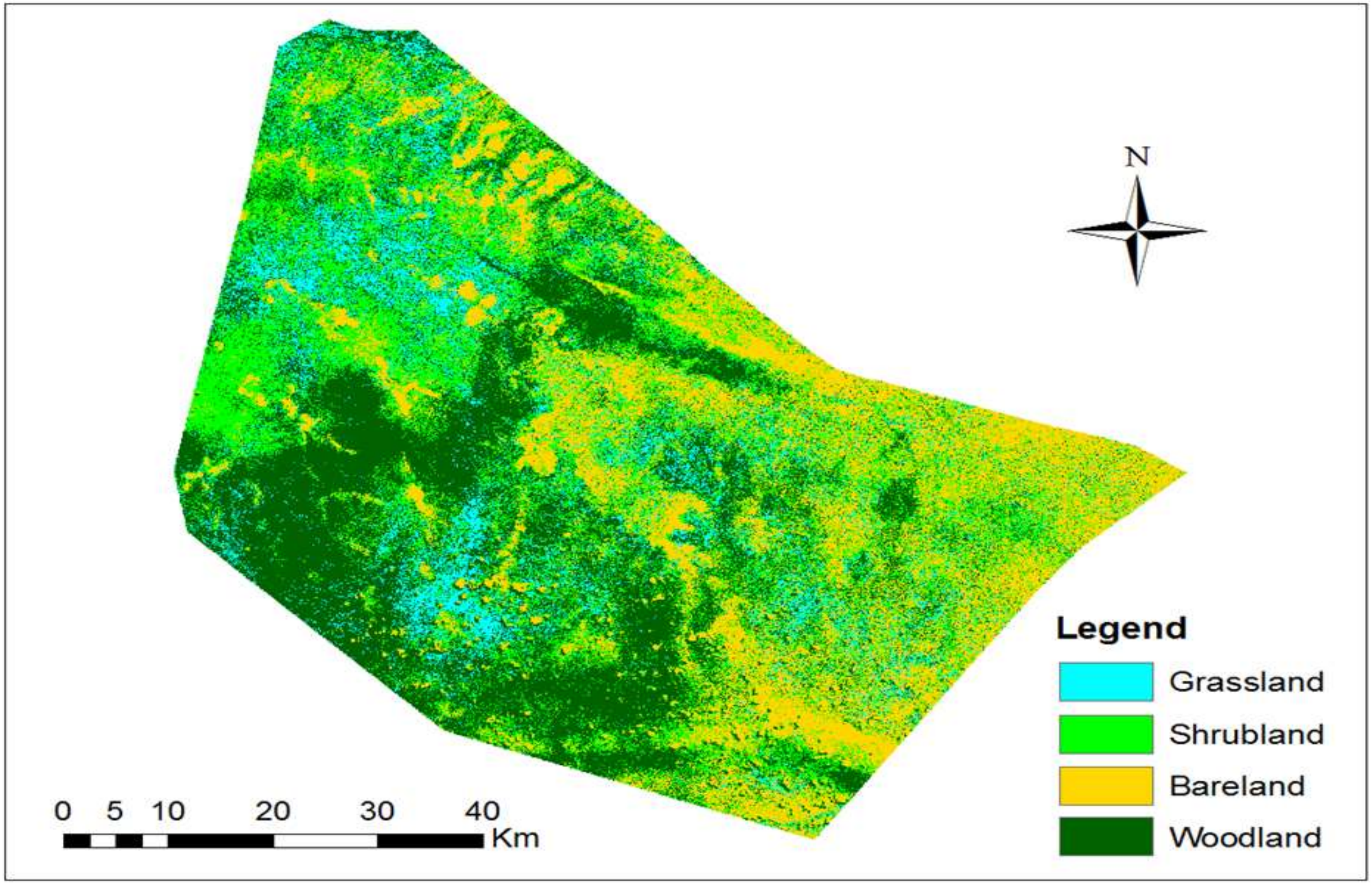
Field photos




4. Results1: rangeland productivity and carrying capacity

4.1Current land use/cover types of the district

The dominant LULC in the study area, include, Woodland (35.5%), Shrubs (28.3%); grass lands (10.6%) and bareland (25.5%)



4.1Current LULC cont'd

Land-cover types	Area coverage		Operational Land-use	Brief description of each land cover
	Hectare	Per cent		
Grassland	51015.8	10.6	Grazing to animals (shoats and cattle)	All areas covered mainly by different grass species, which is used as a natural pasture. And also other small sized herbaceous plants. Usually tree, shrub and bush are found in a very scattered manner.
Shrubland	136438.7	28.3	Browsing to mainly goats and camels	Land covered with sparse woody acacia plants mixed with shrubs, bushes, and grasses. Bush and shrubs are dominants species.
Woodland	170910.7	35.5	Browsing to animals (mainly camels); source of fuel (charcoal and fire wood)	Land with woody species cover >20% (height ranges 5–20m)and mostly dominated by acacia
Bareland	122902.3	25.5	Barren land with no economic value	Areas mainly with no vegetation cover and to some extent very scattered Acacia tree or non-vegetated areas, or areas, very little vegetation cover and may rock is exposed to surface.
Total	481267.5	100.0		

4.2 Grazing livestock population of the district

- Pastoralism is the dominant form of survival in the district (70% of the population).
- Pastoralists rear all types of livestock such as camel (browse), cattle and shoats (graze) in the district.
- The total livestock of the district is about 1,174,459; (48.82%) are sheep, (34.03%) are goat, (11.41%) are camel, (4.14%) are cattle and (1.48%) are donkey

4.3 Grazing pattern and practices

- There is a recent development of informal protection of communal grazing lands (area closure) in the area (since 2000).
- The new system is bringing a good result to secure grass to animals especially in drought years.
- It is widely accepted by the community and rapidly expanding in the district (as a form of drought adapting mechanism).
- Despite its acceptance and positive results, the regional government was opposing this activity and prohibiting them (fearing shortage of communal grazing lands).

Grazing pattern cont'd

- The pastoralists still continue the practice; to avoid confrontation with government they often use croplands as a buffer than the traditional wood and shrubs fences.

Fig 6. Popular method of area closures: wood and shrub method (left); cropland as a buffer (right)

Grazing pattern cont'd

- Sentinel-2 image (June, 2018): Spatial distribution of area closure (Privatization of grazing lands).
- Before this period, the grazing areas within the districts were entirely communally owned.

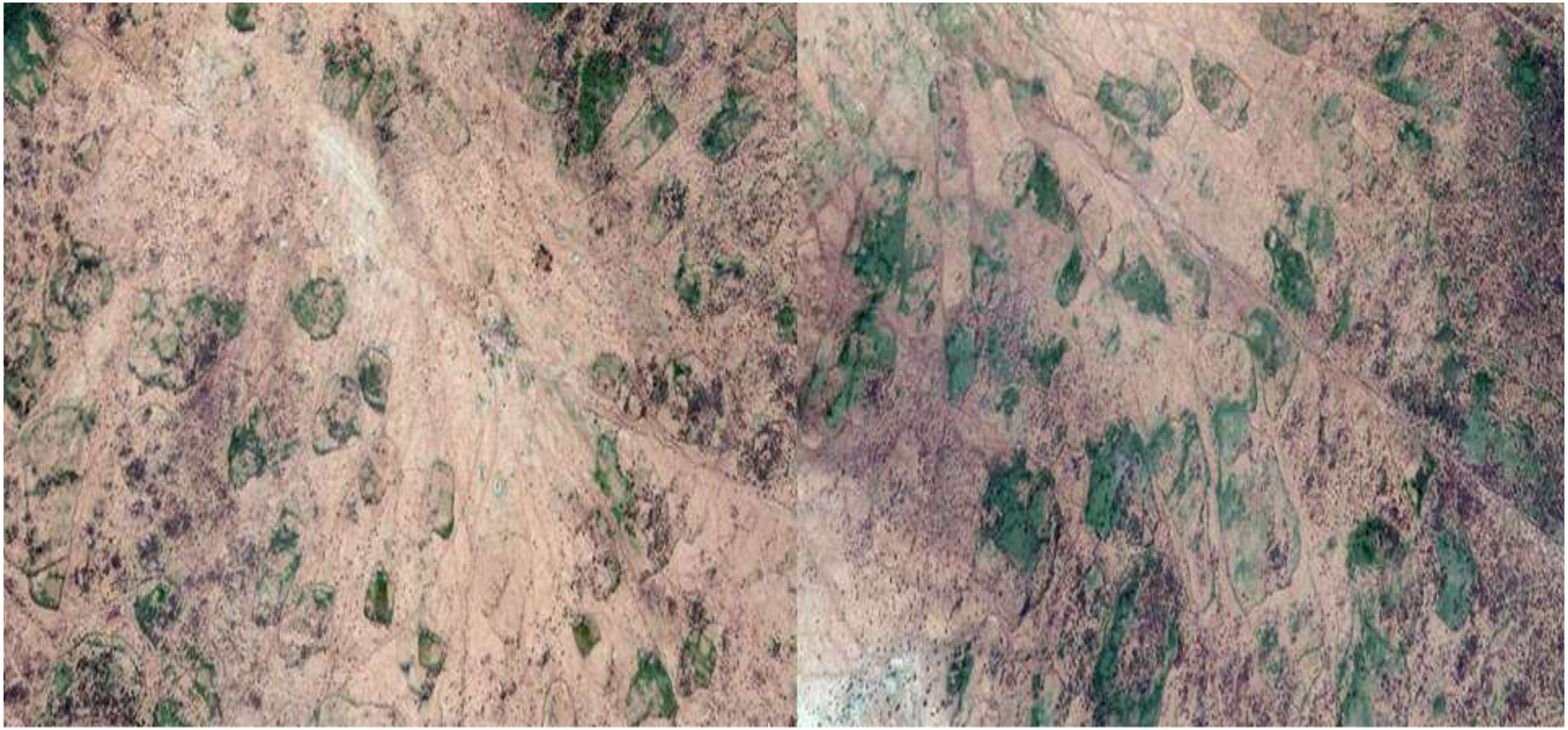


Fig 7. Wider practice of area closure as can be seen from Sentinel image (June, 2018).

4.4 Productivity of rangelands

- We measured above ground biomass (AGB) of grass at the end of the growth period to estimate range land productivity and its carrying capacity (CC)
- The measurement was conducted at 55 different plots which have different productivity (low, medium and high).
- The minimum and maximum forage produced were 105 kg/ha and 2310 kg/ha; the average productivity of the district is 742.6 kg/ha.
- The biomass measurements from the plots were categorized into 3 levels of productivity: high (>1000kg/ha); medium (500 to 1000 kg/ha) and low (<500 kg/ha).
- The height of grasses ranges between (0.4 to 1 meter) and has significant variation among the different species

Productivity of rangelands cont'd

- Typical representative of different productivity: low, medium to high.
- The AGB measurement is comprised of the different productivity.

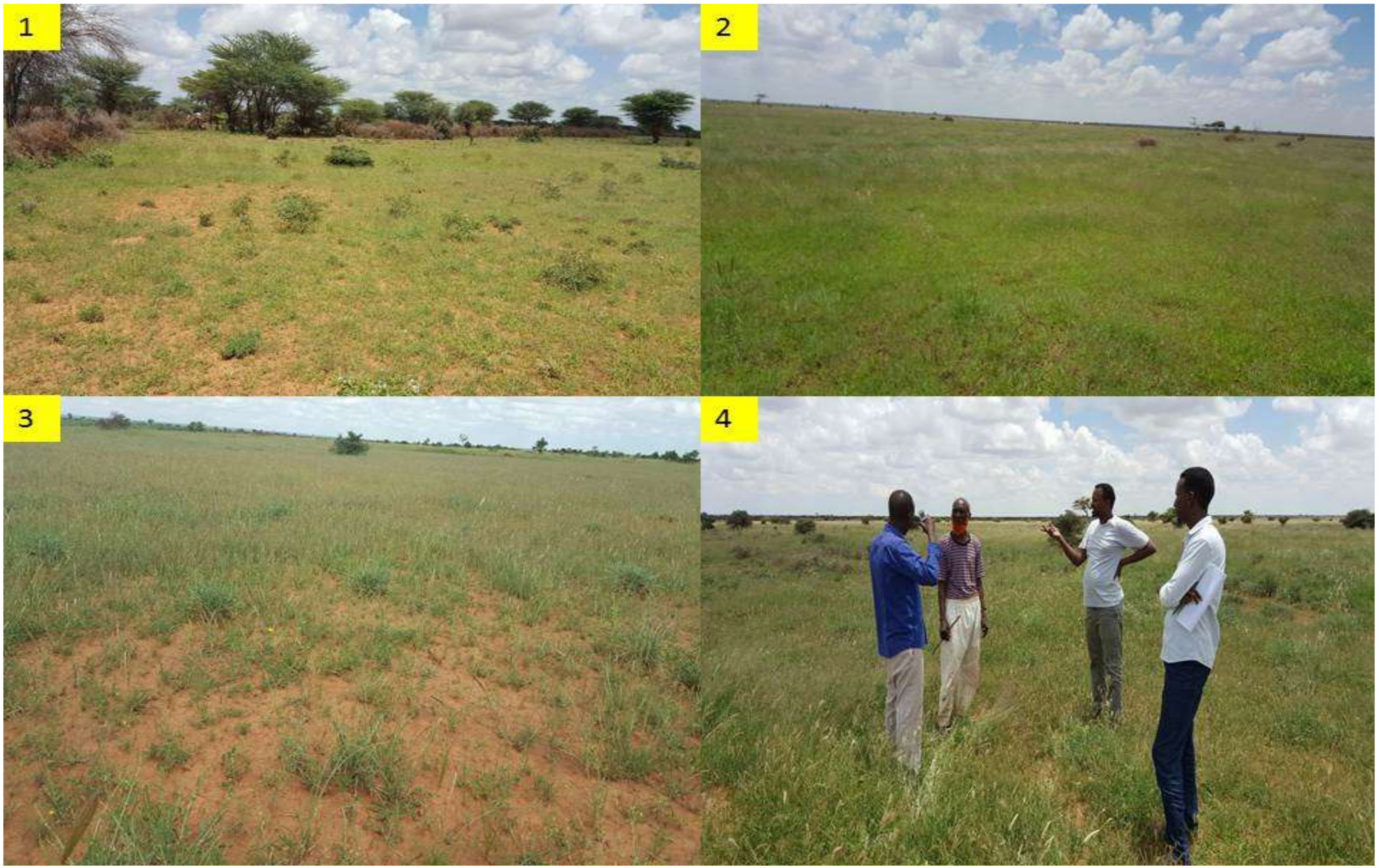


Figure 8. Area closed grazing lands: low (1 and 3) to medium (2 and 4) forage productive areas

Productivity of rangelands cont'd

Ground truthing : measure forage biomass

Productivity of rangelands cont'd

Species diversity, productivity and carrying capacity of rangelands in Harshin district, Somali region, Ethiopia (July 10 to 20, 2018).

Plot No.	Level of productivity	GPS coordinates		Height and weight of dry matter			Carrying Capacity (CC)		Dominant grass species	
		X-reading	Y-reading	Grass height (meter)	Mean DM (gm/m^2)	DM (ton/ha/yr)	TLU/ha /yr	ha/TLU /yr	Local name	Scientific name
1	High	378660	981063	0.6	126	1.26	0.6	1.8	Baldhoole	P.maximu
2	High	378741	981111	1.0	168	1.68	0.7	1.4	Baldhoole	P.maximu
3	High	378878	981127	1.0	231	2.31	1.0	1.0	Baldhoole	P.maximu
4	High	378924	981132	0.9	231	2.31	1.0	1.0	Dhikil	H.u conto
5	Medium	378983	981164	0.5	84	0.84	0.4	2.7	Xarfo	C.virgata
6	High	379025	981167	1.0	126	1.26	0.6	1.8	Baldhoole	P.maximu
55	Cont'd	Cont'd	Cont'd	Cont'd	Cont'd					

4.5 Species diversity in the range lands

- The dominant grass species in order of their qualities to increase animal weight (meat) includes Dareemo, Baldhoole, Rist, Xarfo and Nafier respectively

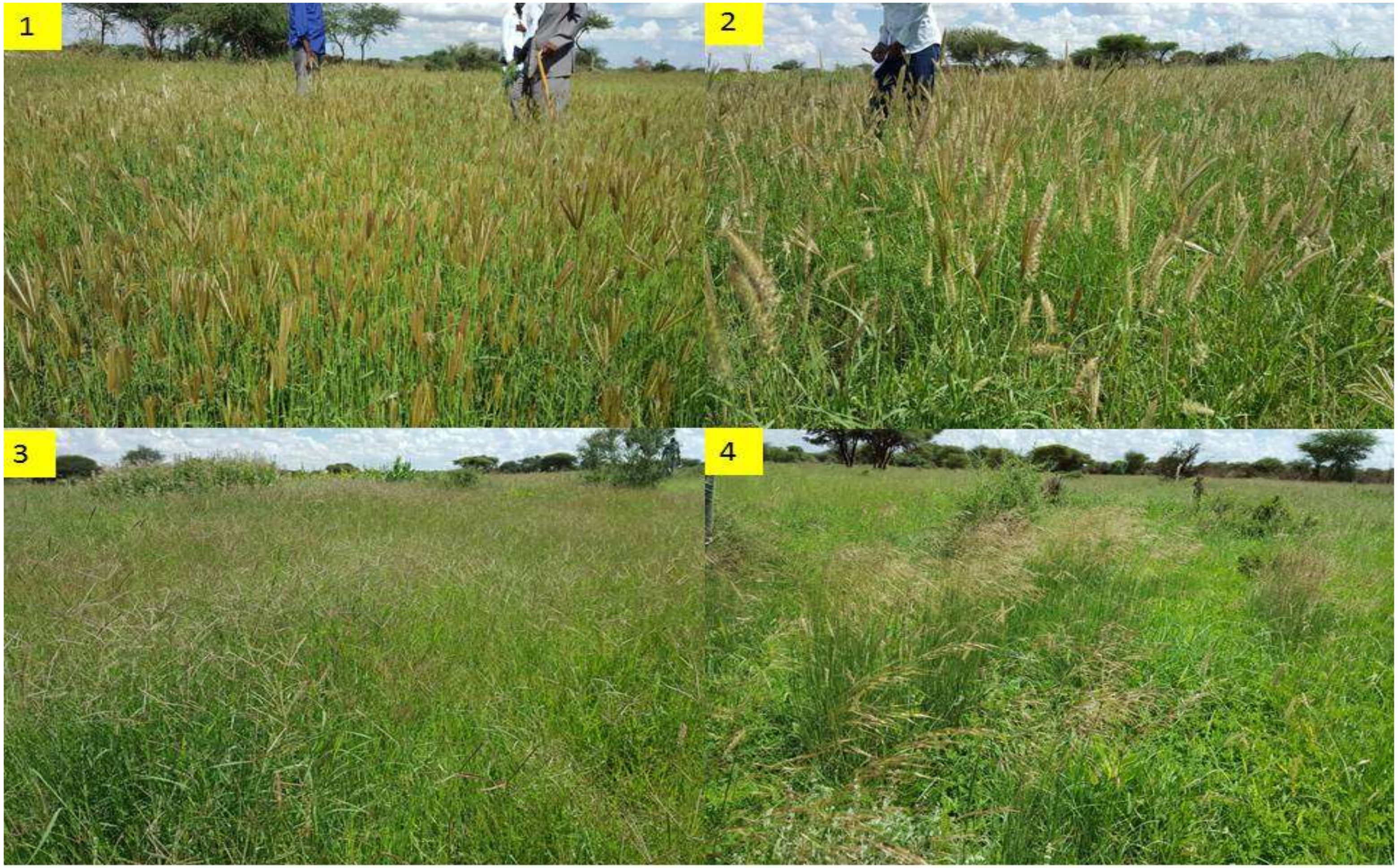


Figure 7. High biomass productive area with dominant grass species: 1(Baldhoole); 2(Ciirdhuuq); 3(Xarfo); 4(Dareemo).

4.6 Carrying capacity vs. stocking rates

- The calculated average carrying capacity (CC) of the district is 0.3 TLU/ha/yr (4.9 ha/TLU/yr);
- The existing stocking rate (grazing pressure) has become 5.4 TLU/ha/yr (0.18 ha/TLU/yr).
- Thus, it becomes apparent that there is a great disparity between the observed stocking rate and the carrying capacity of the production system.
- Because, the existing stocking rate has grazing pressure excess of 5.1 TLU/ha.
- If this trend continues, there will be overgrazing pressure and expansion of land degradation, which will have immense consequence on the sustainable use of grazing lands in the future.

5. Result2: Developing forage biomass estimation system using satellite image

5.1 Remote sensing and biomass estimation (AGB)

- The theory: the spectral reflectance value of plants is dependent on canopy parameters: leaf area index, chlorophyll content, maturity level, and plant density (1).
- A given plant with better health, leaf area index, and density (canopy cover) will have higher reflectance in some bands (e.g., NIR and SWIR) of the electromagnetic spectrum than the same plant with some kind of stress (disease, low soil moisture, poor land fertility) (2).
- Thus, animal forage which has better health and higher density (biomass) will have higher reflectance values in NIR and related indexes (3).
- Therefore, this theory (hypothesis) of remote sensing (Satellite image) was applied and tested in in our study to: identify the spatial variation of forage productivity and to estimate the available forage of the district (2 month ahead of harvest time).

5.2 Vegetation index & biomass model development

What are vegetation indexes?

- A vegetation index is an indicator that describes the greenness (the relative biomass) in a satellite image.
- One of the most widely used indexes is Normalized Difference Vegetation Index (NDVI). NDVI values (1.0 to -1.0).
- Areas of barren rock/sand have low NDVI values (0.1 or less); Sparse vegetation (shrubs and grasslands) have moderate values (0.2 to 0.5); dense vegetation has High NDVI values (0.6 to 0.9).
- NDVI is not the only index to identify vegetation cover; rather there are indexes such as Enhanced Vegetation Index (EVI) can be good alternatives tools. GCVI (green chlorophyll vegetation index)

Index and biomass model development

- The indexes for each pixel were calculated as follows:

$$NDVI = (NIR - Red)/(NIR + Red) \quad \text{(Eq. 1)}$$

$$EVI = 2.5 \times (NIR - red)/(NIR + [6 \times red] + [7 \times blue] + 1) \quad \text{(Eq. 2)}$$

Finally: we developed polynomial regression models that relate the spectral values (NDVI and EVI) to field-measured biomass.

5.3 Forage biomass prediction model development

First, the necessary bands (Band 2, 3, 4 and 8) for the index development were selected among the multispectral images of Sentinel -2 and processed.

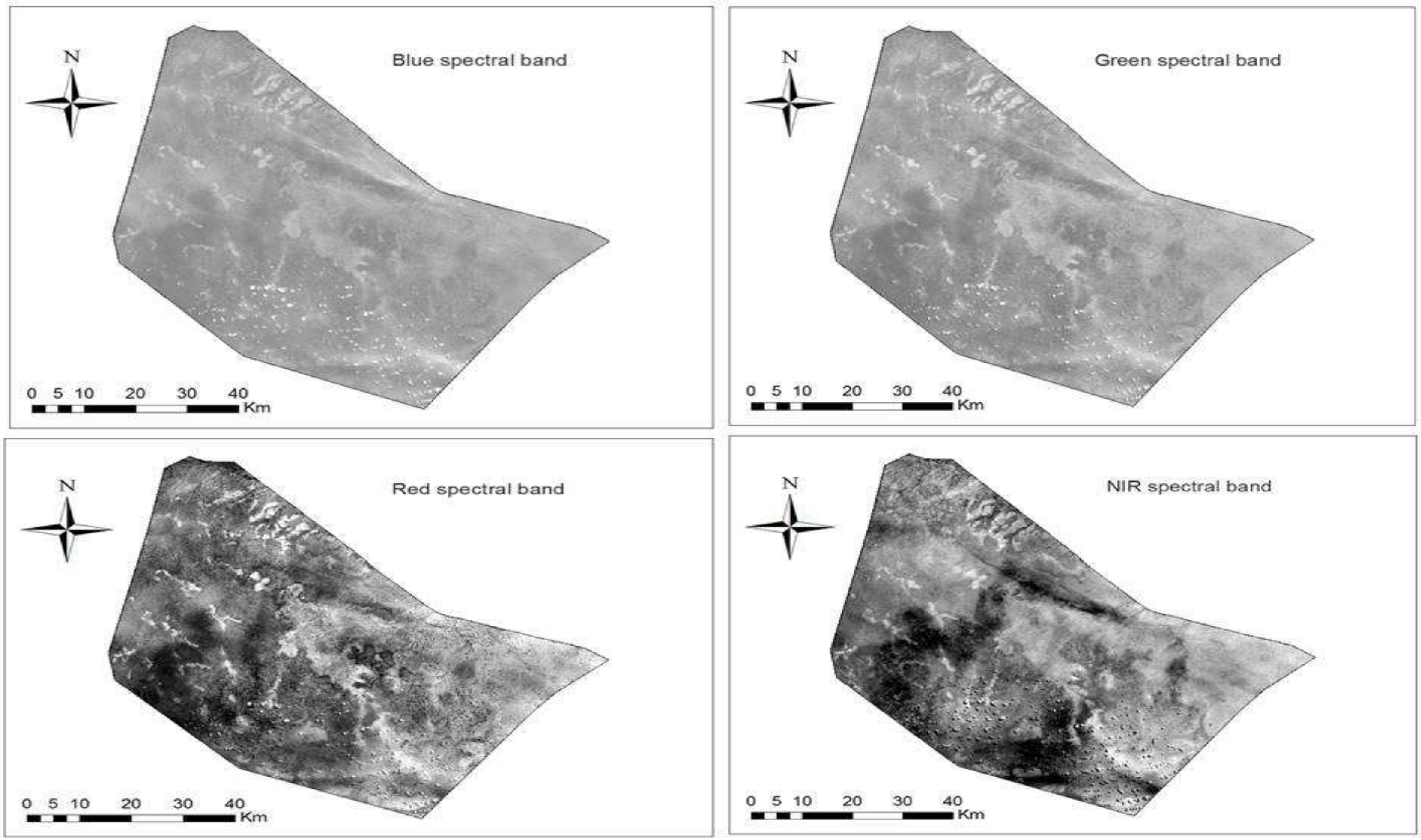


Figure 1. Raw satellite data: four-spectral bands of sentinel image used for EVI and NDVI index development

Forage biomass prediction cont'd

Vegetation index maps developed from selected bands

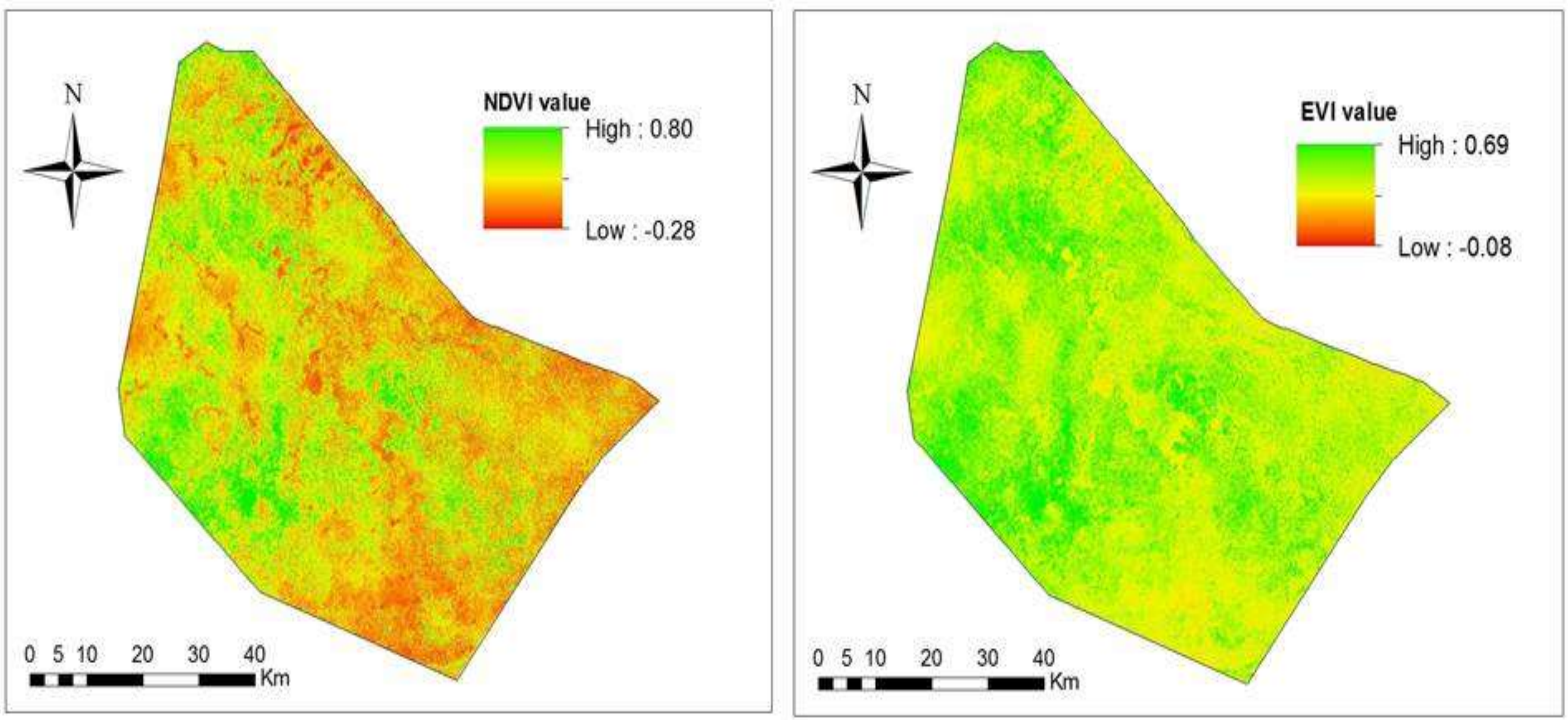


Figure 2. Transformed satellite data (images): EVI and NDVI maps of Harshin district

The higher the value the higher the biomass and health of vegetation

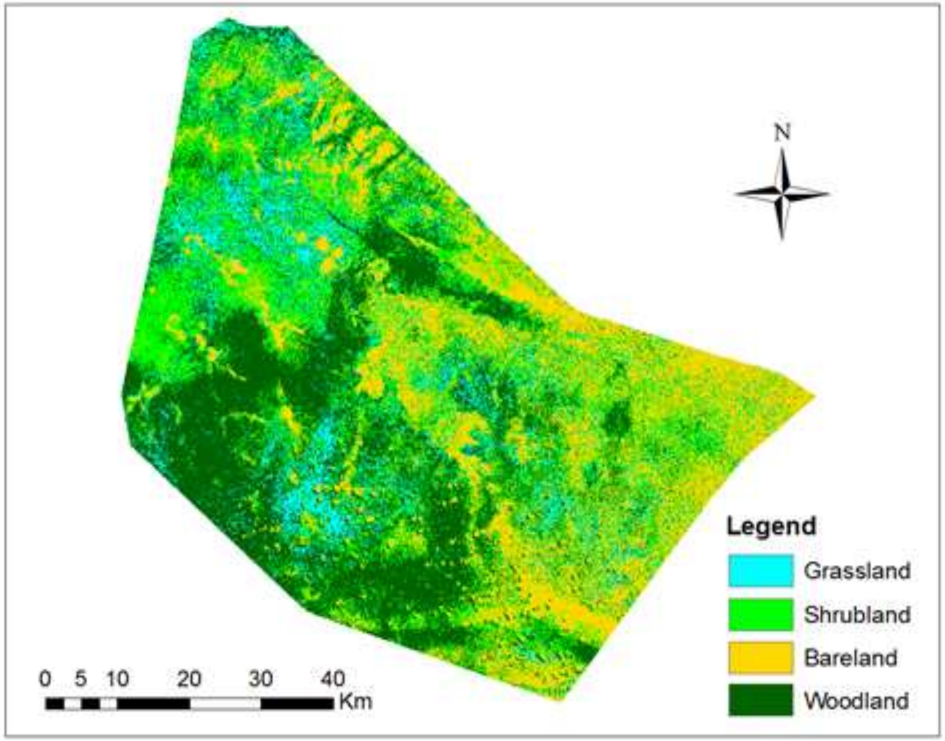
Forage biomass prediction cont'd

- From the index maps point values were extracted and fitted against the ground measured forage biomass data
- Accordingly, the best-fitting curve was obtained between forage biomass ; EVI (R^2=0.87; P<0.001), followed by NDVI (R^2=0.81; P<0.001)
- Even though EVI is better, both index have good and reasonable prediction efficiencies in polynomial function and hence can be alternatively used.
- However, using NDVI has advantage of downloading directly from land sat and other data sets and can be easily transformed to predict the target outcome; while, EVI should be developed every time using the 3 different bands.
- **Forge biomass (ton/ha/yr)** = 11.59 $(NDVI)^2$ – 4.96 (NDVI) + 0.76 (R^2=0.81)
- **Forage biomass (ton/ha/yr)** = 11.21$(EVI)^2$ + 0.27(EVI) + 0.038 (R^2=0.87)

5.4 Upscale the models to predict forage biomass in Harshin

Quantifying and mapping the spatial distribution of forage biomass

In order to do this, firstly, land use and cover map of the district was taken and then pixels of grassland were selected and screened out.



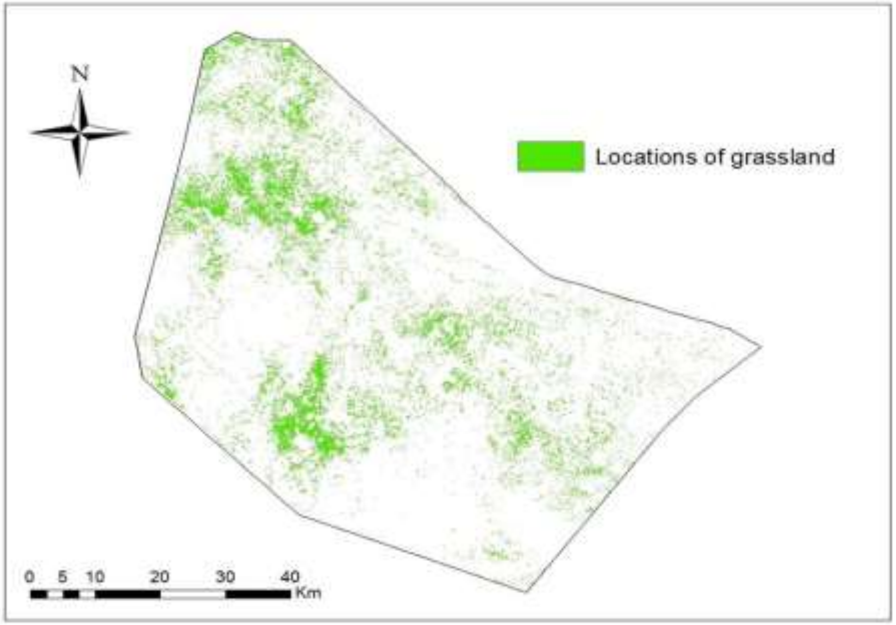


Figure 3. Spatial distribution of grassland pixel in the district

Quantifying and mapping cont'd

- Then, those grassland pixel locations was used to mask and extract NDVI and EVI index values of the grasslands, from the LULC map

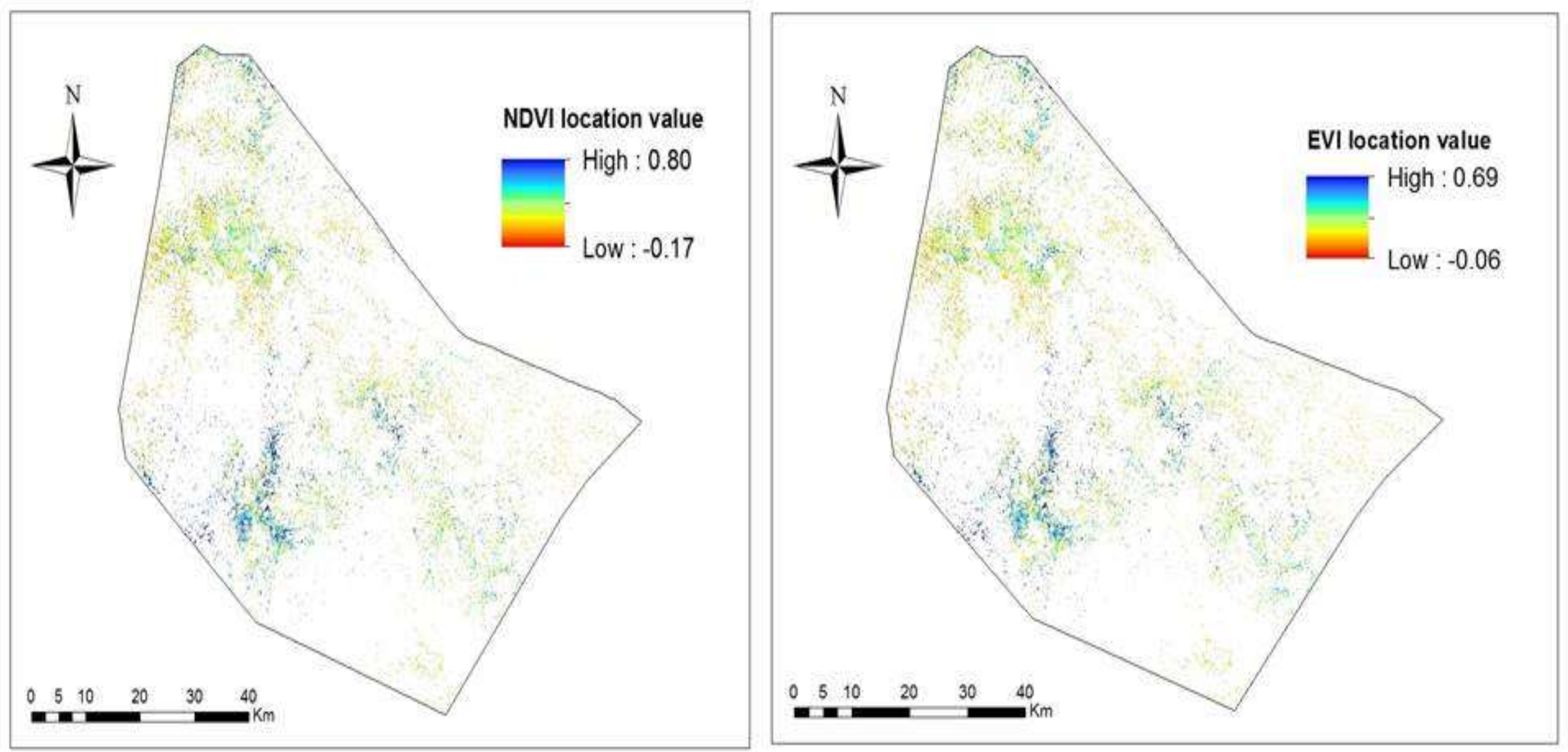


Figure 4. NDVI and EVI values of the specific grassland locations

Quantifying and mapping cont'd

- Thereby, the spatial index maps of the grasslands were transformed to forage biomass maps using developed polynomial regression models.

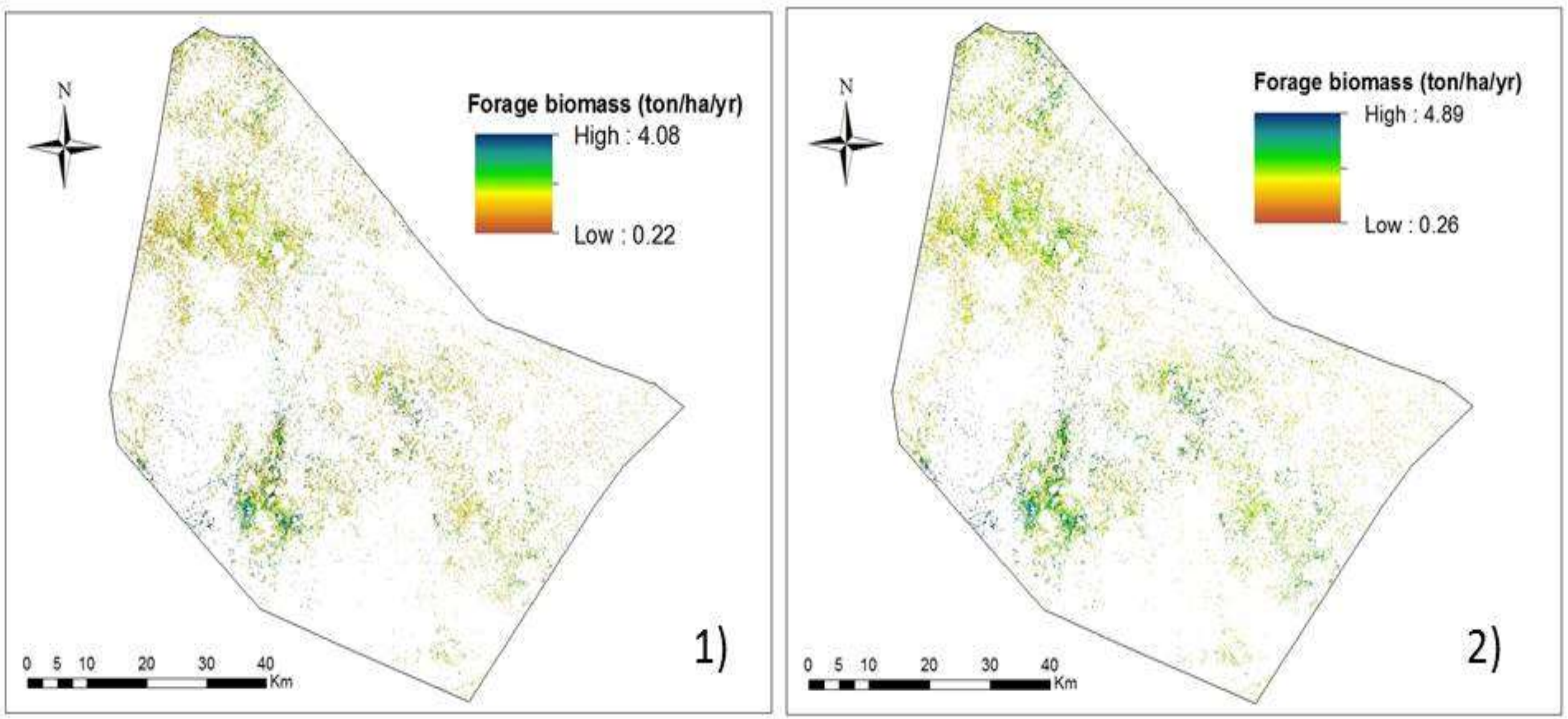
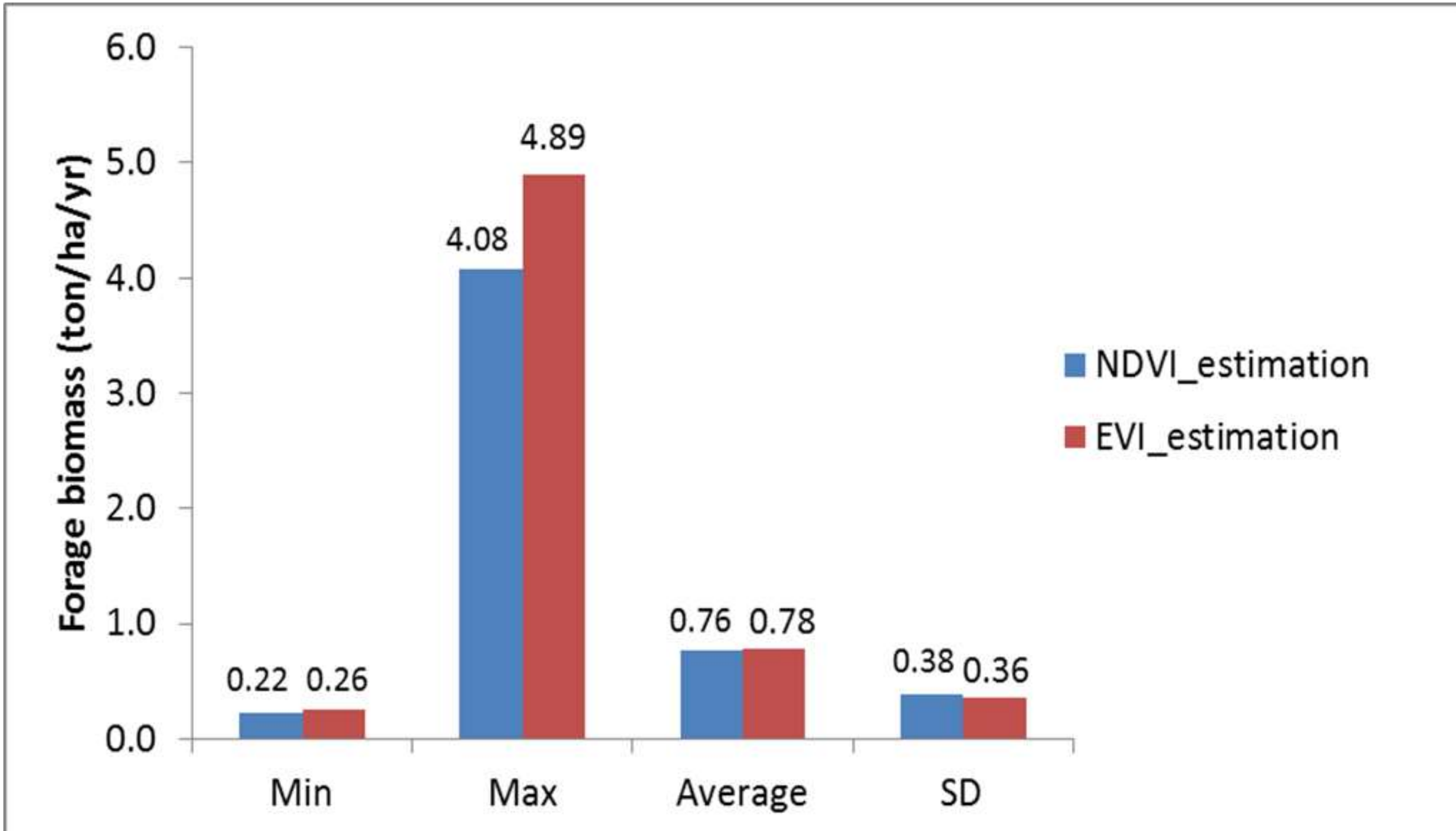


Figure 5: Estimation of forage biomass using transformed NDVI (1) and EVI (2) indexes

Quantifying and mapping cont'd

- Summery of forage biomass estimation values for Harshin



NDVI estimation (average 0.76 ton/ha and the total 38, 772.2 ton); EVI estimation (average 0.78ton/ha and the total 39,792.3 ton) for the district

5.5 Model calibration and validation

- We divided the observed data (55 plots) into two categories: 28 of them for model calibration and 27 plots for validation.
- Calibration: The degree of correlation between the indexes and forage biomass was evaluated using Pearson's correlation coefficient (*r*); a regression test was conducted to examine the statistical significance of the relationship between the different indexes and the biomass.
- Validation: To evaluate performance of the model, predicted and measured biomass values were compared using R^2 ; the *ME* (Nash and Sutcliffe, 1970) and *RRMSE* to measure efficiency and accuracy.
-

$$ME = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_{mean})^2}$$

$$RRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}}{\frac{1}{n}\sum_{i=1}^{n}O_i}$$

Model calibration and validation cont'd

- The validation results revealed that the EVI index model explained about 92 % of the forage biomass variability in the district, while the NDVI based model explained about 87%.

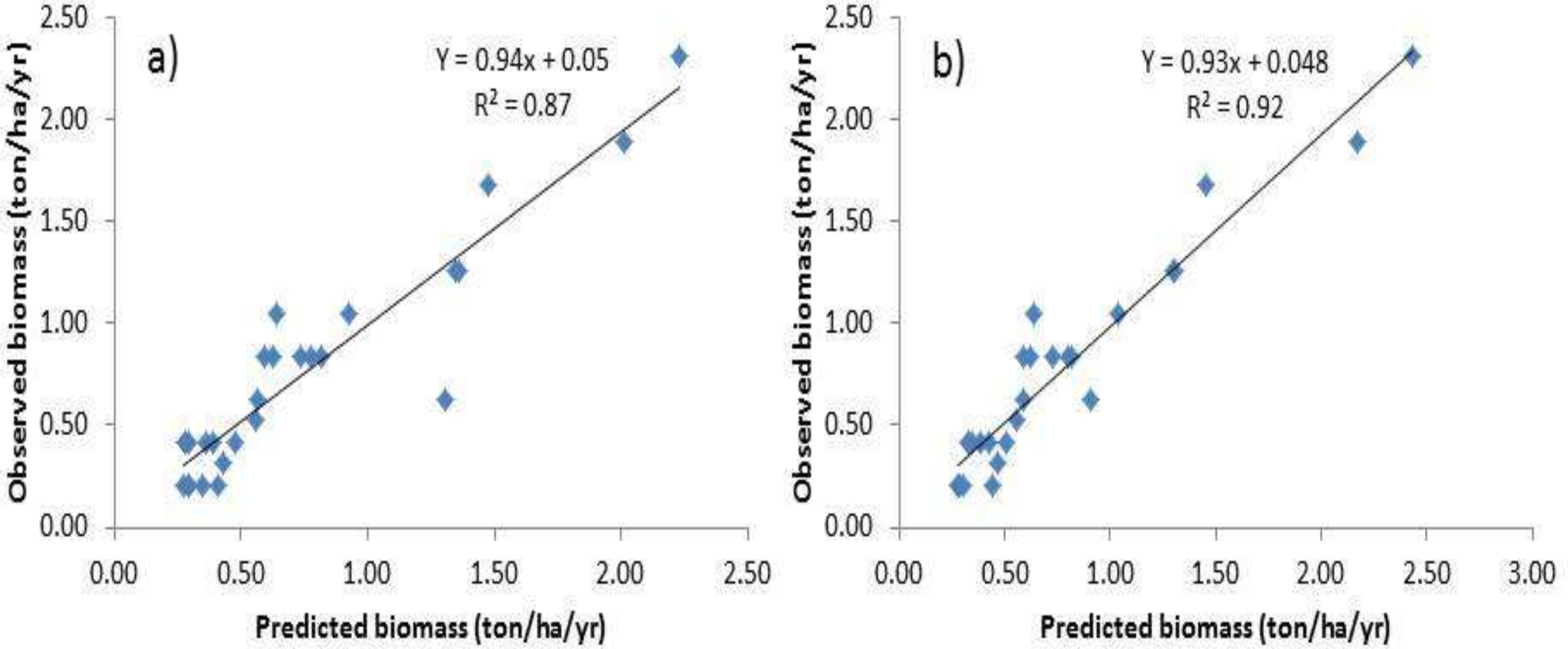


Figure 8. Results of model validation for NDVI (a) and EVI (b) indexes.

Model calibration and validation cont'd

Summary of performance evaluation of the calibrated models

Model statistics	Spectral Index		Remarks
	NDVI	EVI	
Calibration (R^2)	0.81	0.87	Indexes Vs. Observed
Validation			Predicted Vs. Observed
R^2	0.87	0.92	
ME	0.87	0.92	
RRMSE	0.26	0.21	

EVI performed better than NDVI during calibration and validation

5.6 Caution when applying the models

- The models were developed on the basis of spectral data (satellite image) taken at a specific time of **grass phenology**.
- There are important references time: **March 20th, May 20th and July 20th, 2018**. Rain started on March 20th, satellite images (spectral data) acquired on May 20th (2 month later) was downloaded and processed, and forage harvest (ground truth measurement) was carried out on July 20th, 2018.
- Thus, the models we developed are expected to estimate forage biomass on the specified time frame: 2 month after rain starts (grass start growing) and 2 month before forage maturity (harvest as hay).
- The rain may start earlier or later than our time (March 20th) but images which will be used for prediction should be acquired (taken by the satellite) about 2 month (with some plus or minus days) after the rain starts.
- The reflectance and index value might be higher or lower if images are downloaded for the period too much earlier or later than 2 month after rainfall starts.
- However, since we cannot obtain images which are acquired exactly 2 months, we can use images with a maximum of 2 weeks ahead or later.

Major steps to be taken when applying the model

- First, sentinel images that are taken (acquired) about 2 months after the rain start will be downloaded.
- Specific bands (B2, B3, B4, and B8) that are needed to establish NDVI and EVI indexes will be selected among the 13 spectral bands and processed.
- Second, geometric and radiometric correction will be carried out on these bands.
- Third, mosaicking and sub-setting of each bands.
- Fourth, transform the bands to index maps (NDVI and EVI) using the equations (1 and 2 above).
- Fifth, select and screen out grass pixels from the land use map.
- Six, use those pixels (grass land) to mask and extract NDVI and EVI index maps (values) of the grasslands.
- Seventh, apply the developed polynomial function and transform the grass land index maps to forage biomass distribution maps. Thereby, the expected total forage biomass of a given area will be known, 2 month ahead of maturity.

6. Conclusion and recommendations

- The aim of this research was to develop forage biomass estimation models using remote sensing techniques, and to assess the current production (biomass) of Harshin district.
- EVI has better fitness and correlation with forage biomass compared to NDVI. Polynomial function provides better results in both indexes than any other functions.
- The validation indicated that the EVI index model explained about 92 % of the forage biomass variability in the district, while the NDVI based model explained about 87%.
- Thus, the results from both models are acceptable to be widely implemented for biomass prediction in the district.
- After calibration and validation, both models were applied to predict forage biomass of Harshin district. Thus, the NDVI based model estimated the average biomass value of the area to be 0.76 ton/ha and the total 38, 772.2 ton, while EVI based model estimated the average forage biomass 0.78ton/ha and the total 39,792.3 ton.
- Cautious: the models are expected to estimate forage biomass on the specified time frame: 2 month after rain starts (with some plus or minus) and 2 month before forage maturity (harvest as hay).

Conclusion and recommendations cont'd

- The developed models are validated and proved to work properly in Harshin district.
- However, before up-scaling to other woredas and zones of the region, their validity should be checked through massive ground survey and assessment using GPS in the intended woreda and zone.
- Therefore, the remaining work is to validate and calibrate (where necessary) the models in other locations of the regions where they are not developed. The appropriate time of validation is during grass maturity season (about July).
- Some variation on grass species, density, soil type and other biophysical factor is expected among range lands of the region, and this leads to variation on spectral responses and index values of available forages.
- If the variation on these entities is high and significant compared to Harshin (where the model is developed), the model may not work properly unlike Harshin;
- In this case, we may need further calibration taking into account the local environmental conditions.

Thank you!!!
Mahadsanidiin