

**Sentinel-2 derived Phenometrics of three tree species growing in Protected Area
(Shoolpaneshwar Wildlife Sanctuary, Gujarat, India)**



Dissertation Thesis Submitted to
The Maharaja Sayajirao University of Baroda
In a partial fulfillment for the award of degree of
Masters of Science in Botany
Year of Submission: 2024

BY
DHRUVISHA DESAI

ECOLOGY LABORATORY
DEPARTMENT OF BOTANY, FACULTY OF SCIENCE
THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA
VADODARA – 390002

Author's Note

This MSc Botany dissertation was conducted under the supervision of
Dr. N.S.R. KRISHNAYYA,
Department of Botany,
The Maharaja Sayajirao University of Baroda.

This uploaded version has been prepared and shared solely by the author,
Dhruvisha Desai,
for academic visibility.

INDEX

Content	Page No.
Abstract	4
Introduction	4-5
Objectives	5
Methodology	5-10
Result and Discussion	11-16
Conclusion	16-17
References	17-18

Abstract

This study investigates the phenometrics of three tree species two deciduous and one evergreen growing in the Shoolpabeshwar Wildlife Sanctuary, Gujarat, India using Sentinel-2 satellite imagery. The study aims to extract key phenometrics for each species and analyze variability between deciduous and evergreen trees. High-resolution remote sensing data were processed using QGIS, Google Earth Engine (GEE), and R Studio to derive phenological metrics such as seasonal greenness dynamics. Comparative analysis revealed significant differences in the phenometrics of deciduous versus evergreen species, reflecting their distinct physiological and ecological traits. Results showed that deciduous and evergreen species exhibited strong seasonal dynamics with sharp increase in greenness during monsoon with high VI values. *Tectona grandis* L.f shows clear SOS with development of new leaves during growing season while EOS will be reduced due to shedding of vegetation. As per the results NDVI is more sensitive to vegetation change compare to EVI2. But prior study determines that by minimizing the atmospheric condition and background noise extracted value of EVI2 will be relatively high compare to NDVI. The length of growing season of *Madhuca longifolia* J.F.Macbr is relatively higher compare to evergreen species, variation in this is due to the climate condition prevailing in that year and also it depends on species composition, its relative abundance. Evergreen species i.e *Mangifera indica* L. shows high seasonal VI value than both deciduous species due to their consistent greenness by maintaining their foliage throughout year. The findings highlight ecological knowledge for better decision making in environmental conservation.

Keywords - Sentinel-2, Phenometrics, Beckfit Phenoextracts, Google Earth Engine.

Introduction

Phenology is the climate dependent periodical phenomena (Misra et al., 2020). Remote sensing based phenology assessment provide valuable information on ecosystem health, productivity and functioning with spatial and temporal scale. Remotely sensed data can help to identify variation in phenological patterns like early or delaying of growing season shows distinct foliage activity which is monitor by vegetation indices and helps in understanding vegetation dynamics with respect to climate change impacts, carbon sequestration (Agrawal, 2003). Changes in vegetation phenology, distribution and growth status serve as crucial indicators of climate change as well as having significant influence on the carbon cycle and energy budgets (Ranjan & Gorai, 2022).

Climatic parameters play central role in regulating phenology. Biological timing in plants are depend on temperature, precipitation and day length. Spectral vegetation indices (i.e. Normalized difference vegetation index NDVI, Enhanced vegetation index EVI2) derive from satellite imagery have been identified as indicator of vegetation health, density, vigor and growth (Karkauskaite et al., 2017).

Traditional phenology was depending on field study; this allows observation on species phenological event (Cabacinha & Castro, 2009). And this depends on their climate conditions with their geography. So this study was in limited scope. Due to advancements in technology in remote sensing phenological research becomes easy to study, with the help of multispectral and hyperspectral imagery the identification can be done at species level. This allows for large scale with higher resolution monitoring of phenological events. Satellite data capture changes in vegetation green up which help in understanding seasonal patterns. Due to this study it helps in policy making like

biodiversity conservation and climate change impacts. Species like deciduous and evergreen influence species composition of forest. Both species with respect to their leaf shedding periods affect the nutrient cycling in forest community(Cabacinha & Castro, 2009).Forest integrity is measured by vegetation indices and is aim to characterized the structural, functional and diversity of species(Cabacinha & Castro, 2009).

Time-series graph of NDVI, EVI2 derived from remotely sensed images was applied in various applications for the vegetation change monitoring, its phenology extraction and land cover-land use classification. NDVI determines consistent relation with vegetation dynamic and vegetation biomass(Liao et al., 2015). This index offers measurement of land degradation process that can be impact on productivity.

The study implies that SOS occurred during late March to early April, the EOS has observed during early March to end of March(Ranjan & Gorai, 2022).Changes in SOS & EOS in vegetation types is due to climate change activity.

Land surface phenology metrics are associated with yearly vegetation changes interpreted from spectral remote sensing imagery such as Start of season (SOS), Peak of season position (POP), End of season (EOS) and Length of season (LOS). Due to the temporal and spatial variability of vegetation phenology helps in distinguished between different vegetation types for the plants which are in stress conditions and those which shows delay in growing season in response to climatic conditions(Ranjan & Gorai, 2022).The interpretation of two species, deciduous and evergreen is aided by using image collections from Sentinel-2, Level-2A MSI: Multispectral instrument processed data provided by Copernicus(Roy et al., 2017).

The study has been conducted in a protected area in Shoolpaneshwar Wildlife Sanctuary.

Objectives:

1. Extraction of phenometrics for three tree species (two deciduous *Tectona grandis* L.f, and one evergreen).
2. To find out variability in the phenometrics of deciduous and evergreen species.

Methodology:

Study Area: Shoolpaneshwar wildlife Sanctuary (SWS): Shoolpaneshwar wildlife sanctuary is a protected area located in Navsari district of Gujarat, India. It is 607.7km² and is in western satpura range south of the Narmada river. Latitude and longitude of a study area is 21°29'N - 21°52'N and 73°29'E - 73°54'E respectively. Forest cover is of dry deciduous typesand few are evergreen species. Major deciduous species includes *Tectona grandis* L., *Dendrocalamus strictus* Nees. The sanctuary has a vast undulating terrain, deep valleys and tall canopy. The area is important for its support to wildlife, tribal population and a catchment are for local water bodies (Sabnis & Amin,

1992). There are vast groves of bamboo and the sanctuary has 575 species of flowering plants (Nirmal Kumar et al., 2005). The forest is mainly dry deciduous and tropical evergreen forest consists flora such as *Madhuca longifolia*, *Haldina cordifolia*, *Terminalia crenulata*, *Bambusa vulgaris* L., *Zanthoxylum armatum* DC, *Sapindus mukorossi* Gaertn, *Pongamia pinnata* (L.) Pierre, *Mangifera indica* L.

Sentinel-2 is a wide-swath, high-resolution, multi-spectral imaging mission supporting Copernicus Land Monitoring studies, including the monitoring of vegetation, soil and water cover, as well as observation of inland waterways and coastal areas. Three spectral bands are used to process cloud mask i.e. B1-443nm, Blue band B2-490nm and SWIR (Short wave infrared Band B10, B11, B12 at 1375nm, 1610nm, 2190nm respectively (R). L2A product provides Bottom of atmosphere reflectance (European Union/ESA/Copernicus) <https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/processing-levels/level-2>.

Hence, Sentinel satellite offers atmospheric correction and cloud masking (Jiang et al., 2008). NDVI and EVI2 is widely used for applications such as land cover classification, assessing changes in vegetation over time. EVI2 provides improvement in atmospheric correction and sensitivity to canopy structure by using Sentinel-2 data in Google Earth Engine (GEE). The earth engine data catalog is commonly used for geospatial datasets, consists of remote sensing images of earth which involve the store data capture by Sentinel-2 (Xing et al., 2021). Time-series graph of NDVI, EVI2 derived from remotely sensed images was applied in various applications for the vegetation change monitoring, its phenology extraction and land cover-land use classification.

Google Earth Engine is a cloud computing planetary scale geospatial analysis platform which was launched by Google, in 2010. GEE uses Google's computational infrastructure and available open access Remote sensing datasets (Kennedy et al., 2018). GEE is the most popular large geo-data processing platform, facilitating the scientific discovery process by providing users with free access to numerous remotely sensed datasets. Users can access GEE via an internet-based Application Programming Interface (API) and a web-based Interactive Development Environment (Khamdamov et al., 2021).

RStudio is the user-friendly interface for writing and editing R code. R is a programming language and free integrated development environment software (CRAN) for statistical computing, plotting and graphics, data analysis. R packages contain code, data and documentation. The methodology of phenology metrics extraction is based on model fitting (Brunsdon & Comber, 2018).

This study involves the use of Phenopix an RStudio package which enables data processing such as curve fitting to seasonal trajectories, extract relevant phenological thresholds (phenophases) (Filippa et al., 2016). Beckfit function in phenopix package fits the phenological model proposed by Beck et al. Thereby this model is used to estimate period of phenophase, phenological changes (Filippa et al., 2016).

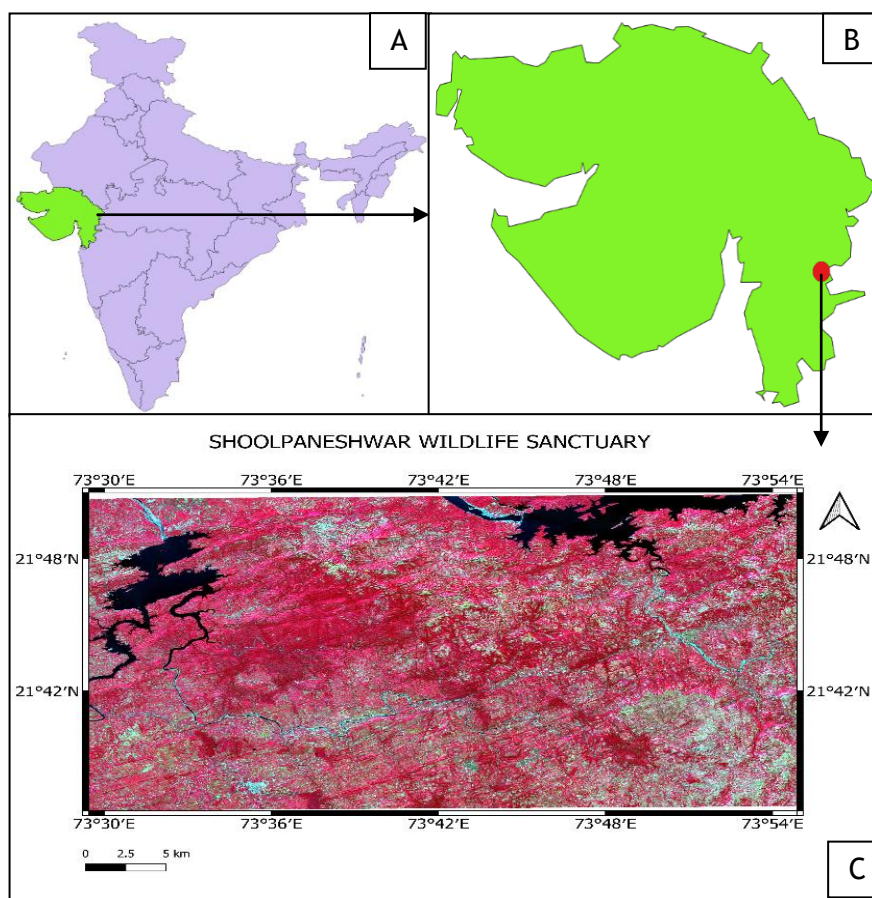


Fig.1: (A) Study area showing the location of protected area Shoolpaneshwar wildlife Sanctuary within India, (B) Gujarat & (C) SWS-false coloration image (Red: 665 nm Green: 560 nm Blue: 490 nm).

1. Earth Engine (EE) explorer- Consists datasets available in the EE data catalog.
2. EE Code Editor- Designed for the processing of large data using JavaScript programming language. It comprises of Map, Code editor, Layer manager, geometry tools and tabs which includes Doc, Assets, Inspector, Console, Script and tasks. Central panel is for users to write their JavaScript code. GEE run this written codes and shows the results as images in the map panel and in console tab. Geometry tools allows to draw geometric features such as polygons, points etc in (Fig:2)
Script tab facilitate the developing applications. Doc tab provide API reference documentation. (Amani et al., 2020)
3. EE Timelapse- It is the computing platform. Provides detail picture of earth with respect to changes over time.

Google Earth Engine (GEE)

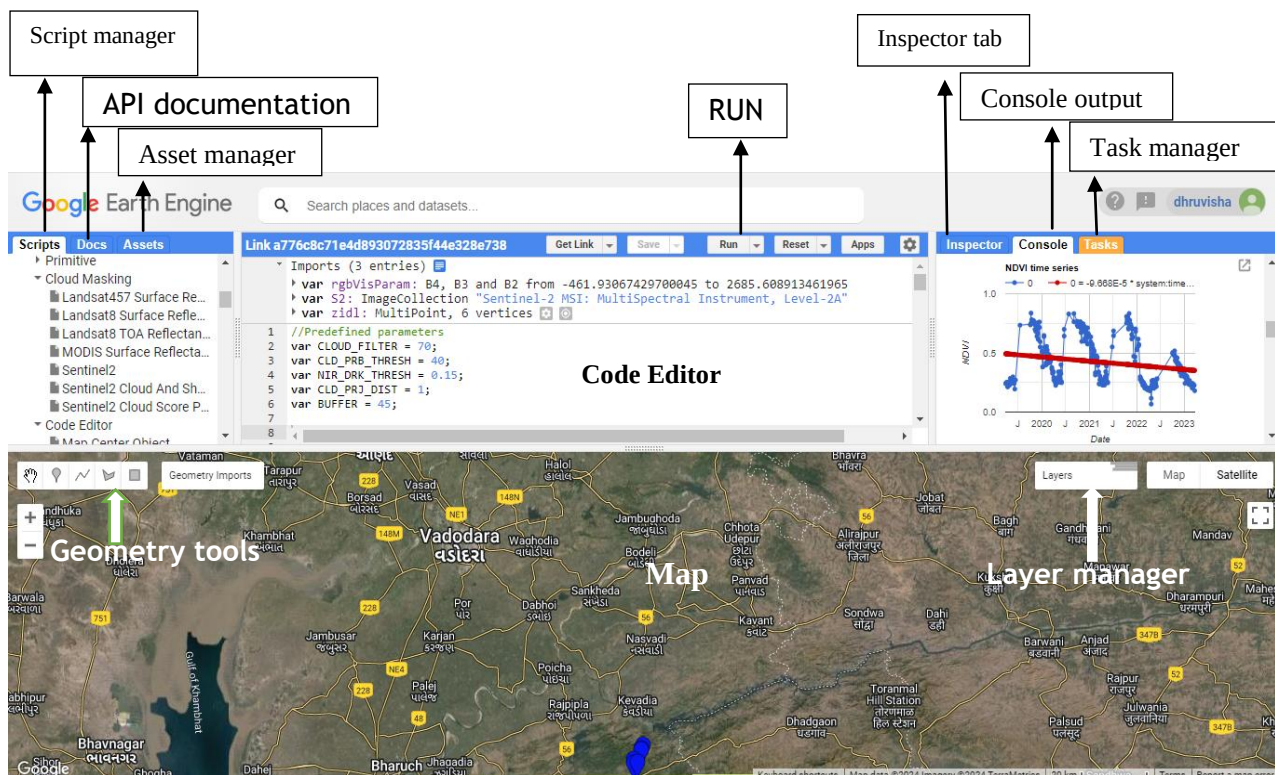


Fig2:Overview of Google Earth Code Editor.

Sentinel-2 MSI, Level-2A imagery and processing

Sentinel-2 is a satellite imagery mission operated by European Space Agency in Copernicus program consists two satellites Sentinel-2A, Sentinel-2B(Pahlevan et al., 2017). Phenological year (March 2021 to 2022) data of study area is acquired from Sentinel-2A & S2B MSI, Level-2A, Copernicus program.

Phenological year is the cycle of seasonal events, it is used for understanding the timing of life cycle of species and to detect the change in its greenness with respect to its life cycle events.

MSI captures imagery every 5 days in 13 bands (table-1) at spatial resolution from 10 to 60 meters which is utilized for the phenology studies. Level-2A product provides atmospherically corrected surface reflectance images.

Atmospheric correction includes correction scattering of air molecules, gases and water vapor present in atmosphere(Roy et al., 2017). It has wide swath width of 290 km which provides wide coverage.

The correction process of sentinel-2B, L-2A enhance the quality of image.

Table 1: Spectral and spatial resolution of the Sentinel-2 MSI band

Sentinel-2 MSI Band	Spatial Resolution (m)	Central Wavelength (nm)	Band Width (nm)
Band 1: Coastal Aerosol	60	443	20
Band 2: Blue	10	490	65
Band 3: Green	10	560	35
Band 4: Red	10	665	30
Band 5: Red-edge 1	20	705	15
Band 6: Red-edge2	20	740	15
Band 7: Red edge 3	20	783	20
Band 8: NIR	10	842	115
Band 8A: NIR narrow	20	865	20
Band 9: Water Vapor	60	945	20
Band 11: SWIR	20	1610	90
Band 12: SWIR	20	2190	180

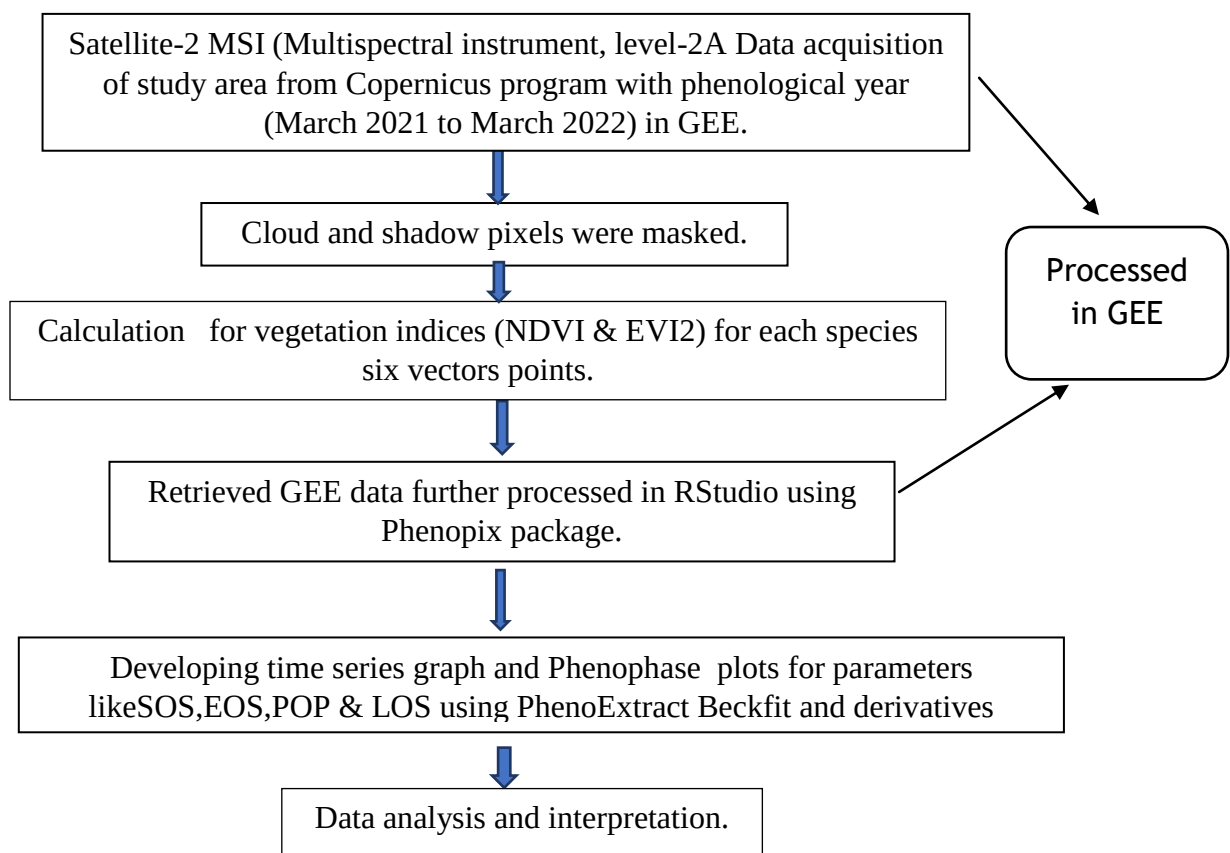


Fig 3: Schematic view of work flow of data processing.

Table2: Number of Sentinel-2 images of three species obtained for Phenological year 2021-22.

Indices	Number of Images		
	<i>Tectona grandis</i> L	<i>Madhuca longifolia</i> L	<i>Mangifera indica</i> L
NDVI	39	62	50
EVI2	39	62	50

Image collection is acquire from GEE is extracted as CSV file by using specific tile T43QCE for SWS. This provides different image collection for each species. Retrived data can be further processed in RStudio to get time series graph of VI and Phenophase extracts.

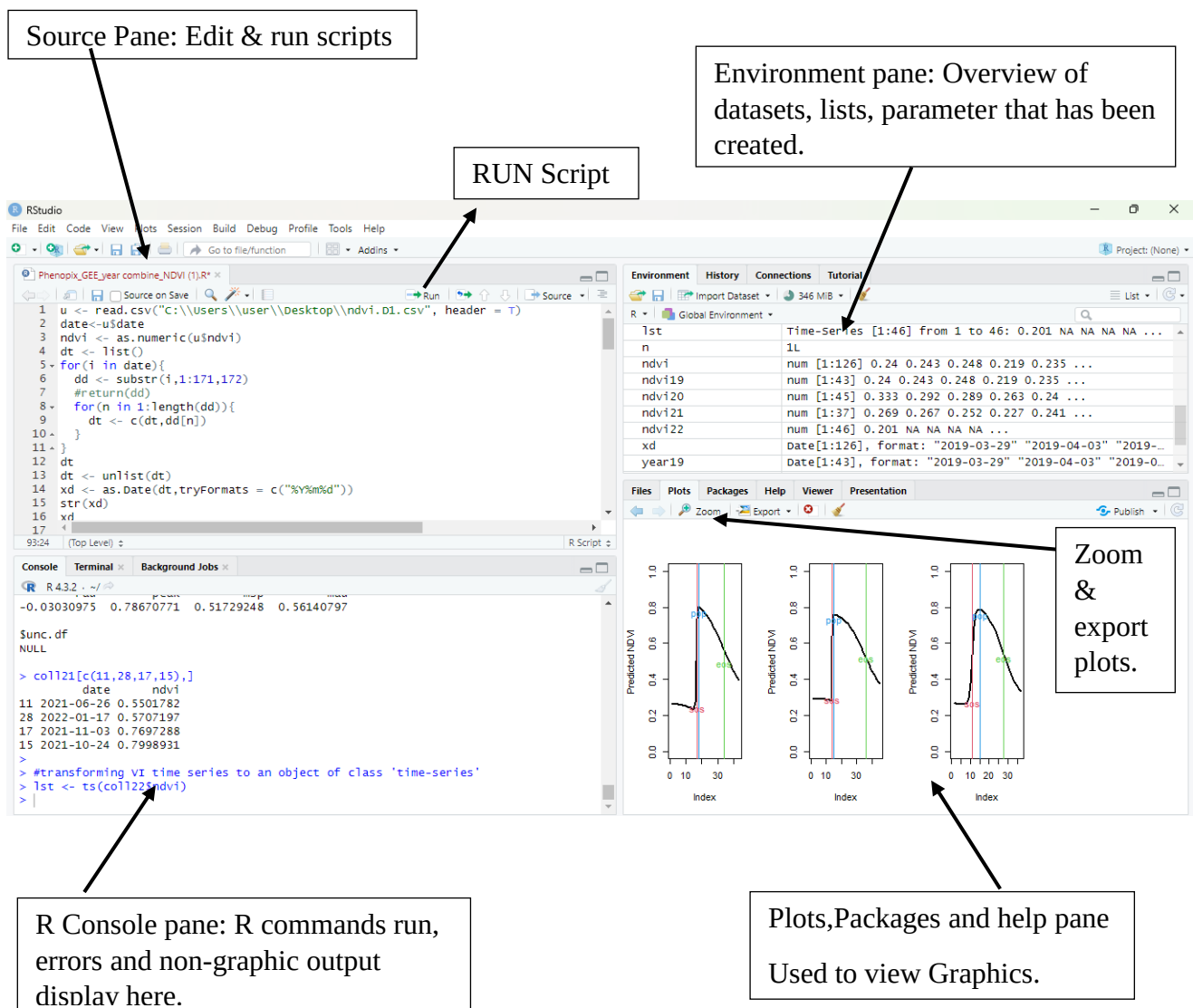


Fig3-Overview of RStudio.

Result and discussion:

NDVI

It is the vegetation index used for the calculation of satellite imagery. This helps to assess vegetation health, density and vigor, thereby its mainly used for detecting land use land cover classification for monitoring changes and patterns.

Chlorophyll present in vegetation absorbs mostly in visible light (red region) for photosynthesis while the cell structure of leaves reflects large proportion of near-infrared light and small portion of visible light. It measures the amount of visible and near-infrared light by comparing this two, which is reflected by vegetation.

NDVI is the ratio of the NIR and red bands.

$$NDVI = \frac{NIR - RED}{NIR + RED} \text{ (Rouse, 1974)}$$

Sentinel-2 satellite uses Band-8 in NIR and Band-4 in Red with 10m resolution.

It is used to monitor seasonal variation. Generally, NDVI value ranges from -1 to 1, for vegetation ranges from 0.2 to 0.6 (Ranjan & Gorai, 2022).

EVI2

EVI2 is the creative version of NDVI. EVI2 reduces the influence of atmospheric conditions and soil background on vegetation measurements (Liao et al., 2015). EVI2 can be used as substitute of EVI for good observations. Its functions is to maintain improved sensitivity, it can be analyzed at global scales, it can be also used for sensor without blue band (Jiang et al., 2008). Its prediction is similar to NDVI, higher value indicates healthy and dense vegetation. Thereby, it shows accurate representation (Huete et al., 2002).

$$\text{EVI2 is calculated as } EVI2 = 2.5 \frac{NIR - RED}{NIR + 2.4 * RED + 1} \text{ (Jiang et al., 2008)}$$

where NIR and RED are surface reflectance values for near-infrared and red. It is also a unitless continuous variable like NDVI. Ranges from -1 to 1 (Jiang et al., 2008). It improves the sensitivity with high biomass.

Below given fig. 4 for two species (Deciduous species-*Tectona grandis* L.f, *Madhuca longifolia* J.F. Macbr and Evergreen species *Mangifera indica* L with phenological year (2021-2022) starting from end of march (growing season) to beginning of march (end of the growing season). The time series graph is extracted for NDVI and EVI2 from RStudio.

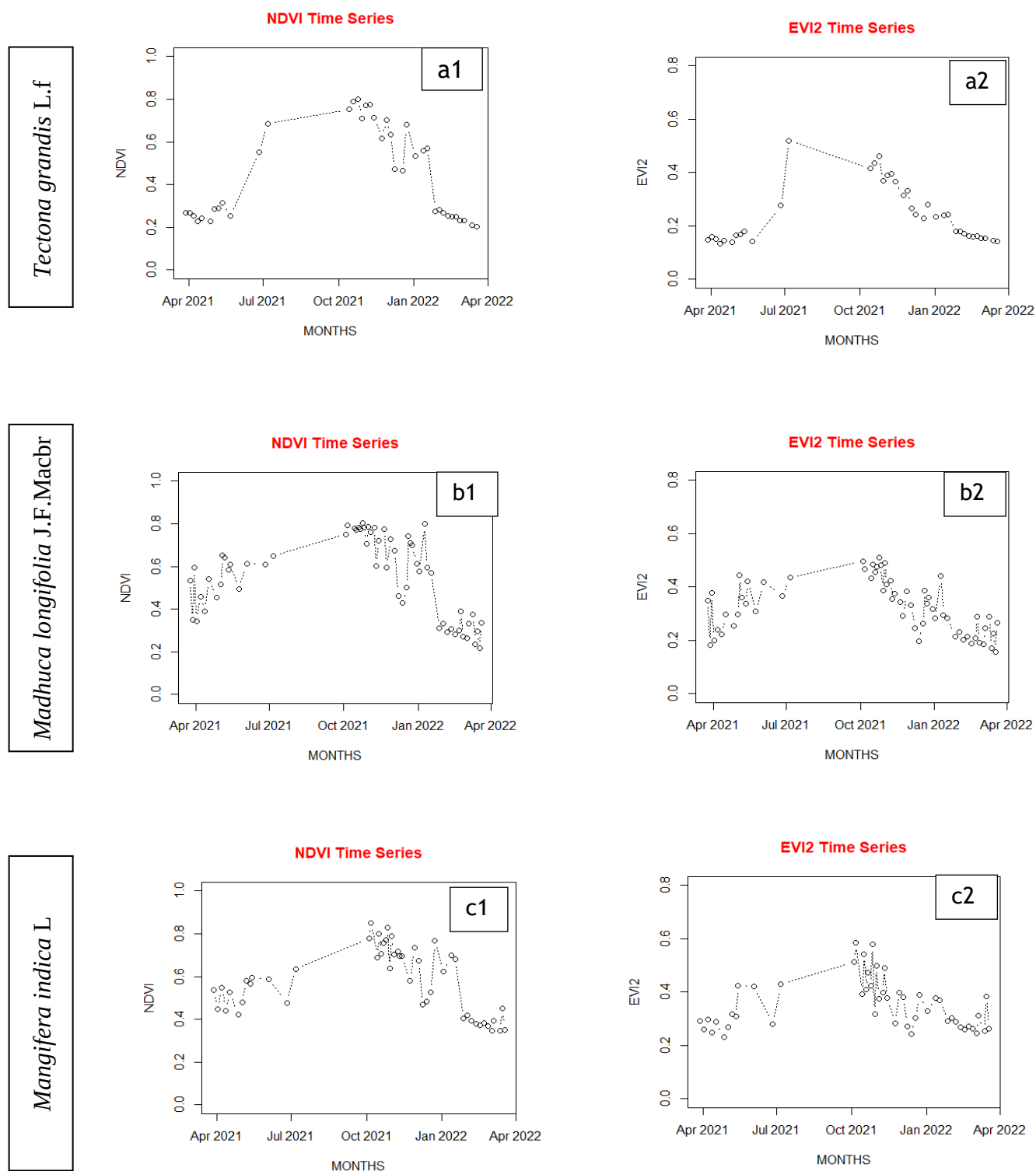


Fig 4: VI- time series graph for NDVI (a1,b1,c1) and EVI2 (a2,b2,c2) and *Tectona grandis*L.f (a1 & a2), *Madhuca longifolia* L.(b1 & b2) & *Mangifera indica* L. (c1,c2).

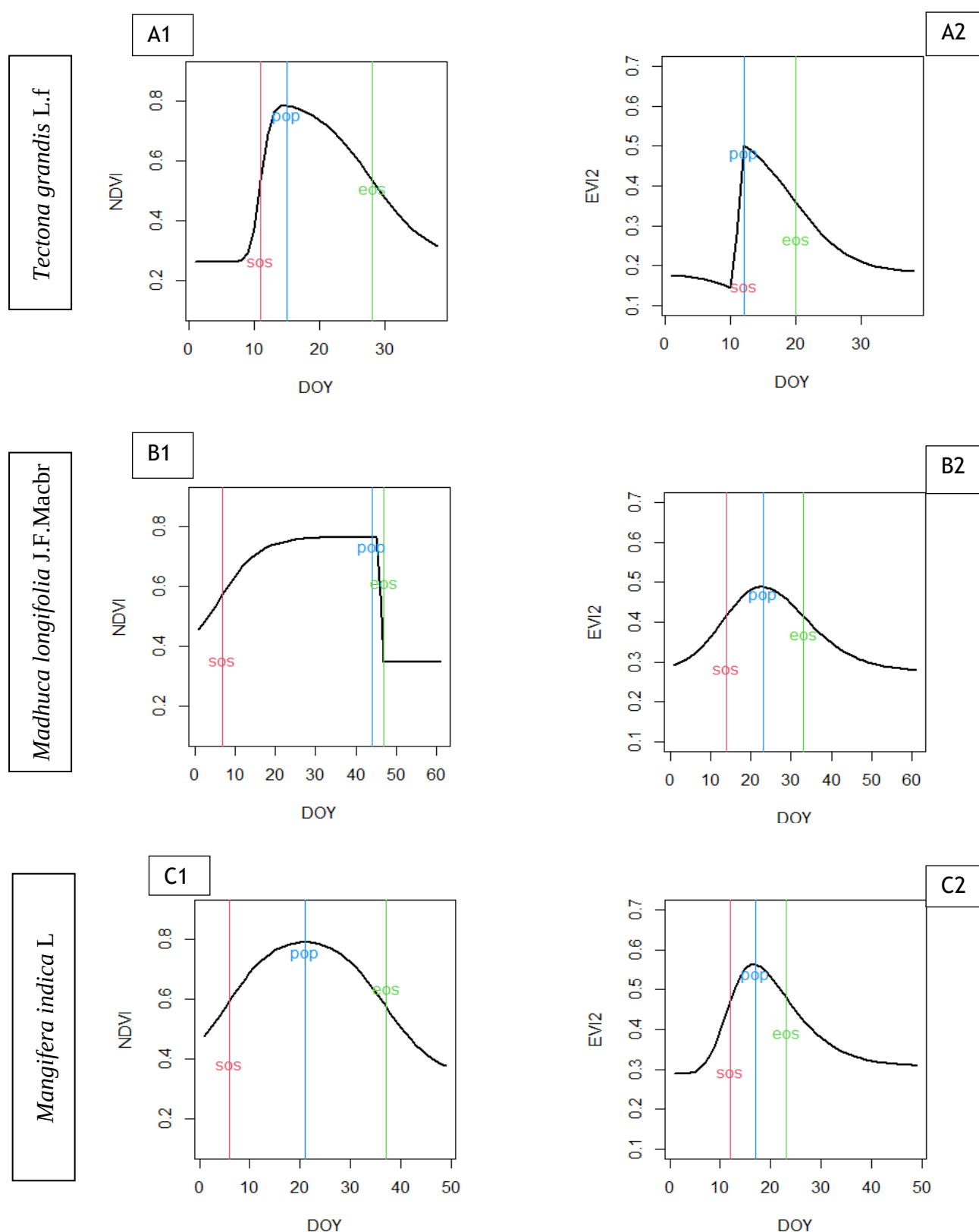


Fig5: Phenology metrics seasonal plots of phenological year 2021-2022 in the phenopix package using Beckfit PhenoExtract method and Derivatives. NDVI-A1,B1,C1 and EVI2-A2,B2,C2 . *Tectona grandis* L.(A1,A2) , *Madhuca longifolia* L.(B1,B2) , *Mangifera indica* L.(C1,C2).

Table 3: Extraction of phenological metrics of three species for phenological year.

Species	VI	SOS	Value	POP	Value	EOS	Value	LOS (in weeks)
<i>Tectona grandis</i> L.f	NDVI	26-6-2021	0.55	24-10-2021	0.799	17-1-2022	0.570	29
	EVI2	6-7-2021	0.518	6-7-2021	0.518	23-11-2021	0.314	20
<i>Madhuca longifolia</i> J.F	NDVI	17-4-2021	0.540	9-1-2022	0.798	27-1-2022	0.312	40
	EVI2	24-5-2021	0.307	21-10-2021	0.477	23-11-2021	0.292	26
<i>Mangifera indica</i> L.	NDVI	27-4-2021	0.420	26-10-2021	0.828	17-1-2022	0.679	37
	EVI2	26-6-2021	0.280	16-10-2021	0.542	31-10-2021	0.500	18

In fig4. VI time series graph shows the consistent greenness during the period of post-monsoon from (Oct'21 to Jan'22) by attaining sharp peak 0.8 in NDVI and 0.6 in EVI2 for all three species.

While there is beginning of greenup due to increasing in activity of photosynthesis result in active grow in vegetation during this NDVI and EVI2 value is low in the initial phase of growing from End of the march to april'21 (Late spring to early summer) and shows gradual increase in value from July to Oct'21 (month of monsoon).

NDVI-time series graph for both evergreen and deciduous species shows relatively higher value because it is more sensitive to change in vegetation, while EVI2 shows lower peak values compared to NDVI (>0.5). This is because EVI2 reduces the influence of atmospheric conditions and soil background on vegetation measurement (Liao et al., 2015). Thereby, it results in minimal vegetation value during growing seasonal peak.

It shows that peak value occurs only in growing season (new leaf flush), but in January end VI value decreases due to shedding of leaves. NDVI shows peak ranges at 0.8 and EVI2 at 0.58. For all the three species.

T. grandis (Fig-4a & b) deciduous species shows the fluctuation in both index related to seasonal change and there is gradual change in seasonal variation.

M. longifolia (Fig-4b & c) deciduous species there is no gradual seasonal variation been observed from time series graph for both index. This might be depending on type of species.

M. indica (Fig-4d & e) Evergreen species shows the consistent high values for both the index throughout the phenological year compare to deciduous species. Because of persistent foliage throughout the year evergreen species don't show the distinct peaks as a result their will be consistent higher value of vegetation index (Gamon et al., 2016). And there is less variation between two vegetation index of these species in response to seasonal change while NDVI consists higher value (~ 0.85) than EVI2 (0.6).

From the time series graph it is clear that within species there is a variation between two indices range. However, there is minimal difference in the range of same index for different species.

Beck fit function in the phenopix package provides data fitting and extracts seasonal trajectories such as Start of season (SOS) represents beginning of growing season when vegetation starts active growth and photosynthesis. Position of peak (POP) means the period where the maximum photosynthesis activity and vegetation biomass occurs.

Start of season (SOS) represents beginning of growing season when vegetation starts active growth and photosynthesize. VI is lower because vegetation present over there may be in the dormant stage. Position of peak (POP) means the period where the maximum photosynthesize activity and vegetation biomass occurs.

NDVI index shows the highest value which determine increase in greenness and vigor compared to EVI2. End of season (EOS) shows the decline in growing season which also senescent phase. Index value decreases due greenness reduction or leaf fall.

Length of season (LOS) refers to period of vegetation activity from SOS to EOS. So, it's a length of time during vegetation growth forms. It is one of the important phenological metrics used to determine the temporal patterns in vegetation. And is also used to assess changes in growing seasonal length.

SOS mainly start from end of march (growing season) and ends during early march (EOS). The duration between these two is the length of season where the vegetation achieves its maximum growth (peak of season) in the month from September to November.

Fig5-A1,A2,B1 and B2 shows the phenophase plots for both the deciduous species& their VI which indicates that the plots determine the high peak in both index only during growing season when the vegetation will be in active growth. Deciduous species-1 shows POP curve at 0.8 in NDVI and 0.5 in EVI2. Species *Madhuca longifolia* L, POP curve will be somewhere around 0.78 in NDVI and 0.5 in EVI2.

Fig5-C1,C2 represents evergreen species for both NDVI and EVI2 determines gradual seasonal variation due to consistent green up of vegetation. It shows the peak(POP) curve at 0.8 in NDVI and ~0.58 in EVI2.

The seasonal variation for both index value is due to EVI2 which reduces the influence of atmospheric conditions and soil background on vegetation measurements. Thereby, it results in minimal vegetation value during growing seasonal peak., which was result in time series graph

In Table-3 start of season prevailing during the month from April to June, POP from July to November, EOS from late November to January in both the deciduous species. Evergreen species shows SOS from late April to June, EOS in month of Januaray'22 (NDVI) and in October'21(EVI2) results into 3 month gapbecause evergreen species maintain their foliage throughout the year(Gamon et al., 2016),POP in the month of October .

The length of season in these two types of species from 2021 to 2022 phenological years was in the range of 20 to 40 weeks. The maximum LOS was observed in deciduous species-II (NDVI) about 40 weeks and lowest LOS is in evergreen species around 18 weeks (EVI2).

NDVI represents high LOS(in weeks) compare to EVI2 in species. EVI2 results in shorter LOS as it provides accurate results by reducing the influence of atmospheric effects.LOS of NDVI is higher due to its high sensitivity to vegetation change.

Prior field studies in SWS reveals that dry season length comprises 38 weeks (Chaurasia et al., 2021). Hence, in table-3 LOS ranges near to 38 weeks for NDVI, whereas EVI2 comprises low value of LOS which is not up to the range which was studied earlier. Thereby, NDVI is the precise VI than EVI2 because it relates to the prior field based study which provides authentic result of seasonal length.

Table 4: Seasonal Mean of deciduous and evergreen species for phenology year 2021-2022.

Seasons	<i>Tectona grandis</i> L.		<i>Madhuca longifolia</i> L.		<i>Mangifera indica</i> L.	
	NDVI	EVI2	NDVI	EVI2	NDVI	EVI2
Summer	0.305	0.168	0.488	0.288	0.52	0.292
Monsoon	0.748	0.44	0.761	0.466	0.749	0.469
Winter	0.489	0.248	0.549	0.299	0.561	0.33

Table 4. Determine high value for both index prevailing during monsoon season. Due to the atmospheric correction EVI2 shows lesser seasonal mean compare to NDVI. Hence NDVI is more sensitivity to vegetation change according to this analysis. Monsoon season determines high VI value due to increase in green up. Evergreen species i.e *Mangifera indica* L. shows high seasonal VI value than both deciduous species due to their consistent greenness by maintaining their foliage throughout year (Gamon et al., 2016).

Conclusion

The study concludes *Manifera indica* and *Tectona grandis* both shows the distinguishable phenological pattern. High seasonal mean value for both index for both the species prevailing during monsoon season, high VI value is due to increase in green up. Evergreen species i.e *Mangifera indica* L. shows high seasonal VI value than both deciduous species due to their consistent greenness by maintaining their foliage throughout year. Thereby, vegetation shows maximum VI range (i.e 0.8 in NDVI & 0.6 in EVI2), shows high peak at this value, which determines healthy, dense vegetation and vigor during post- monsoonal period. *Tectona grandis* shows clear SOS with development of new leaves during growing season while EOS will be reduced due to shedding of vegetation. Hence, this species determines distinct peaks. *Mangifera indica* time series graph determine less variation due to the high proportion and persistent foliage.

The length of growing season of *Madhuca longifolia* is relatively higher compare to evergreen species, variation in this is due to the climate condition prevailing in that year and also it depends on species composition, its relative abundance.

Thus there is large variation in phenological events in deciduous species consists lower VI values due to reduced chlorophyll content by growing seasonal changes in leaf color and canopy structure. While evergreen species continue their photosynthetic activity and hold their leaves throughout year with consistent greenness, showing higher value of VI.

EVI2 results in shorter LOS as it provides accurate results by reducing the influence of atmospheric effects. NDVI show longer LOS in weeks due to its high sensitivity to vegetation change.

The study concludes that though EVI2 is creative version of NDVI being ideal in vegetation studies, but still NDVI perform better in extracting phenometrics of the study area species. It provides accurate phenological extraction of VI. As per the results NDVI is more sensitive to vegetation change compare to EVI2. But prior study determines that by minimizing the atmospheric condition and background noise extracted value of EVI2 will be relatively high compare to NDVI. Thus, previous studies reveals EVI2 as better VI with changing in seasonal pattern. Which is not the case for SWS as here NDVI seems to be more reliable in addressing phenology.

NDVI provides accurate phenological extraction of all the three species. NDVI is widely used index for vegetation studies. Owing to the ability of two spectral indices namely NDVI & EVI2 to monitor phenology, the study gives the insights of the phenophases extraction for both the indices for two deciduous and one evergreen species over a period of one year. The study shows that NDVI is more sensitive to the changes in vegetation due to climatic parameters.

As per as prior studies in this site revealed that dry seasonal length determines the range of LOS (i.e 38 weeks). NDVI is confer to accurate VI compare to EVI2 due to its similar alignment of LOS to the prior seasonal length. Thus NDVI showing LOS between 30 to 40 weeks provides precise results of seasonal length.

References

- Agrawal, S. (2003). Spot-Vegetation multi temporal data for classifying vegetation in South Central Asia. *Current Science*, 84(11), 1440–1448.
- Amani, M., Ghorbanian, A., Ahmadi, S. A., Kakooei, M., Moghimi, A., Mirmazloumi, S. M., Moghaddam, S. H. A., Mahdavi, S., Ghahremanloo, M., & Parsian, S. (2020). Google earth engine cloud computing platform for remote sensing big data applications: A comprehensive review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 13, 5326–5350.
- Brunsdon, C., & Comber, L. (2018). *An introduction to R for spatial analysis and mapping*.
- Cabacinha, C. D., & Castro, S. S. de. (2009). Relationships between floristic diversity and vegetation indices, forest structure and landscape metrics of fragments in Brazilian Cerrado. *Forest Ecology and Management*, 257(10), 2157–2165. <https://doi.org/10.1016/j.foreco.2009.02.030>
- Chaurasia, A. N., Parmar, R. M., Dave, M. G., Mehta, N., Kallaje, R., Sahu, A., Murthy, I. K., Singh, C., & Krishnayya, N. (2021). Syncing phenology phase and canopy spectral reflectance of common tree species of four forest covers in India. *Current Science*, 567–570.
- Filippa, G., Cremonese, E., Migliavacca, M., Galvagno, M., Forkel, M., Wingate, L., Tomelleri, E., Cella, U. M. di, & Richardson, A. D. (2016). Phenopix: A R package for image-based vegetation phenology. *Agricultural and Forest Meteorology*, 220, 141–150. <https://doi.org/10.1016/j.agrformet.2016.01.006>
- Gamon, J. A., Huemmrich, K. F., Wong, C. Y., Ensminger, I., Garrity, S., Hollinger, D. Y., Noormets, A., & Peñuelas, J. (2016). A remotely sensed pigment index reveals photosynthetic phenology in evergreen conifers. *Proceedings of the National Academy of Sciences*, 113(46), 13087–13092.

- Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., & Ferreira, L. G. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment*, 83(1–2), 195–213.
- Jiang, Z., Huete, A. R., Didan, K., & Miura, T. (2008). Development of a two-band enhanced vegetation index without a blue band. *Remote Sensing of Environment*, 112(10), 3833–3845. <https://doi.org/10.1016/j.rse.2008.06.006>
- Karkauskaite, P., Tagesson, T., & Fensholt, R. (2017). Evaluation of the Plant Phenology Index (PPI), NDVI and EVI for Start-of-Season Trend Analysis of the Northern Hemisphere Boreal Zone. *Remote Sensing*, 9(5). <https://doi.org/10.3390/rs9050485>
- Kennedy, R., Yang, Z., Gorelick, N., Braaten, J., Cavalcante, L., Cohen, W., & Healey, S. (2018). Implementation of the LandTrendr algorithm on google earth engine, *Remote Sens.*, 10, 691.
- Khamdamov, R., Rakhmanov, K., & Fattaeva, D. (2021). Algorithm for Calculating Vegetation Indices NDVI for Time Series of Landsat 8 Multispectral Satellite Images on Google Earth Engine Platform. 01–03.
- Liao, Z., He, B., & Quan, X. (2015). Modified enhanced vegetation index for reducing topographic effects. *Journal of Applied Remote Sensing*, 9(1), 096068–096068.
- Misra, G., Cawkwell, F., & Wingler, A. (2020). Status of phenological research using Sentinel-2 data: A review. *Remote Sensing*, 12(17), 2760.
- Nirmal Kumar, J., Soni, H., & Kumar, R. (2005). Assessment of anthropogenic interventions in? Shoolpaneshwar Wildlife Sanctuary, Gujarat, India. *International Journal of Nature And*, 1–25.
- Pahlevan, N., Sarkar, S., Franz, B., Balasubramanian, S. V., & He, J. (2017). Sentinel-2 MultiSpectral Instrument (MSI) data processing for aquatic science applications: Demonstrations and validations. *Remote Sensing of Environment*, 201, 47–56.
- Ranjan, A. K., & Gorai, A. K. (2022). Evaluating phenological trends of different vegetation types in response to climate change over the Rajmahal Hills in India during 2001-2019. *Remote Sensing Letters*, 13(9), 898–911.
- Rouse, 1974. (n.d.). Rouse Jr, J. W., Haas, R. H., Deering, D. W., Schell, J. A., & Harlan, J. C. (1974). Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation (No. E75-10354).
- Roy, D. P., Li, J., Zhang, H. K., Yan, L., Huang, H., & Li, Z. (2017). Examination of Sentinel-2A multi-spectral instrument (MSI) reflectance anisotropy and the suitability of a general method to normalize MSI reflectance to nadir BRDF adjusted reflectance. *Remote Sensing of Environment*, 199, 25–38.
- Sabnis, S. D., & Amin, J. C. (1992). Eco-environmental studies of Sardar Sarovar environs. *MS University, Baroda*, 388.
- Xing, H., Hou, D., Wang, S., Yu, M., & Meng, F. (2021). O-LCMapping: A Google Earth Engine-based web toolkit for supporting online land cover classification. *Earth Science Informatics*, 14, 529–541.