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# Forest Resilience, Precipitation, and Ecosystem Service Value: A Correlation and Trend Analysis

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Ecosystem service value (ESV) is critical for understanding ecosystems' economic benefits and their responses to environmental change. This study uses Earth Observation (EO) data, statistics, and machine learning methods to evaluate ESV trends across multiple continents from 2000 to 2024. Three key datasets were used: MODIS NDVI for vegetation monitoring, CHIRPS precipitation data, and the ESVD database. Data preprocessing includes data cleaning, feature engineering, and outlier detection. We compared Random Forest, XGBoost, and ensemble stacking models to predict key variables and their relationships, such as kNDVI, as a proxy of forest resilience and ESV trends, precipitation patterns, and biome-specific variables. Our results show that kNDVI changes across continents reveal various patterns in vegetation dynamics that are in-line with precipitation patterns and are weakly correlated with ESV changes for forest biomes. Our study emphasizes the significance of time interdependence and climate variability in ESV predictive modelling. Future efforts focus on refining the time/space granularity of data collection and aggregation techniques and incorporating more environmental indicators to improve model robustness and application in policy-making.

**Keywords: Forest, Landscape, Ecosystem, Service, Valuation.**

## 1. Introduction

Ecosystem services valuation (ESV) is the monetary advantage that humans derive from ecosystems. The forest ecosystem covers approximately 30% of the land surface [1]. Forest ecosystems are essential in offering a wide range of benefits [2], such as soil preservation, carbon sequestration, habitat for biodiversity, flood control, etc. It absorbs over 33% of anthropogenic carbon emissions, playing a crucial part in the global carbon cycle and preventing further climate change. However, the forest ecosystem faces tremendous human and natural depletion, hampering its resilience. Regrettably, disruptions like wildfires, insect outbreaks, and extreme weather occurrences are becoming more frequent threats to forest ecosystem resilience across the globe. Additionally, the frequency and severity of disturbances are increasing due to climate change, placing tremendous strain on the forest ecosystem across the globe. Forest resilience refers to its ability to endure, adjust, and recover from natural disasters like wildfires, insect outbreaks, and severe climate change-induced catastrophes. Remote sensing technology has emerged as an indispensable tool for assessing forest resilience. Furthermore, vegetation indicators such as the NDVI and Kernel NDVI (kNDVI) can determine forest health and dynamism [1]. In this study, we aim is to better understand the connection between kNDVI as a proxy of resilience of global forests (vegetated areas with a canopy ≥5 meters [3]), precipitation, and global ESV.

## 2. Materials and Methods

We used three datasets: 1) MOD13A3 V6.1 data product provided monthly at 1 km spatial resolution and processed the Summary Quality Assurance (*SummaryQA*) band of MODIS; 2) the CHIRPS dataset (*Climate Hazards Group InfraRed Precipitation with Station data*) with global monthly precipitation means from 2000-02-01 to 2024-04-30 at a 0.05° x 0.05° resolution. CHIRPS dataset combines satellite infrared and ground station data; 3) Ecosystem Services Valuation data (ESVD). We computed kNDVI from high-quality-filtered MODIS pixel data and analyzed the correlation between ESV and precipitation and resilience variables. Gradient Boosting, XGBoost, Stacking Ensemble and Random Forest were used to predict dynamic ecosystem service. Source code and data are available at: https://github.com/LaureBerti/CEST_2025

## 3. 3. Results and Discussion

4. We consider 2,801 ESV sites only in forest areas, as illustrated in Fig. 1 and observed that ESV in Europe increased significantly between 2014 and 2018, potentially due to policy changes (**Fig. 2**).

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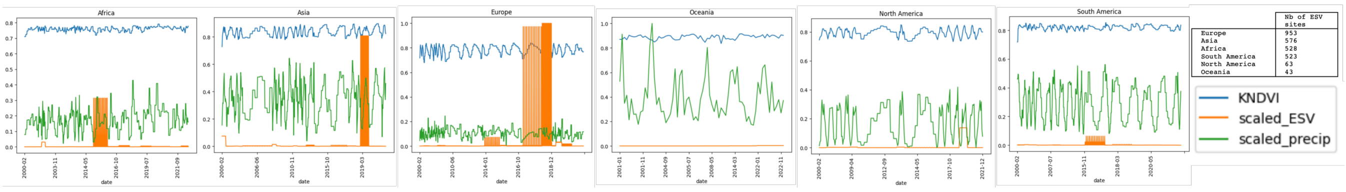


**Figure 2.** Precipitation, ESV and kNDVI Changes for ESV sites

Asia saw high peak in 2019, whilst Africa has smaller peaks in 2002 and 2015 and South America in 2016.

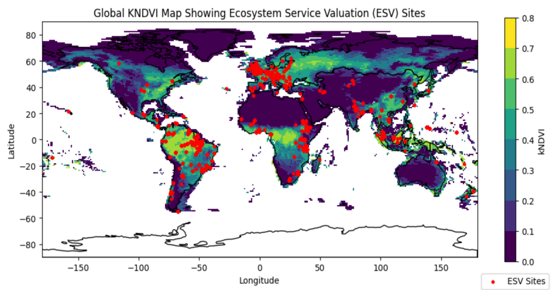


**Figure 1.** Map of kNDVI and ESV forest sites

In **Fig. 3**, kNDVI and precipitation show a positive correlation in Asia (+0.76) and North America (+0.70), indicating vegetation cover significalty increased with rainfall. ESV has weak correlations with both kNDVI and precipitation across continents suggesting other factors drive ecosystem service valuation of forests. Precipitation significantly impacts vegetation but minimally influences ESV trends. Other variables likely affect ESV dynamics.

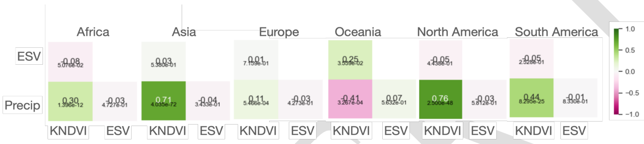


**Figure 2.** Pearson correlation and p-values between scaled ESV, precipitation, and kNDVI per continent.

Across the continents, ESV correlation with kNDVI is very weak, with negative relationships in Americas and Africa, indicating minimal impact. Precipitation-ESV shows mixed effects: weakly negative in all continents except Oceania. Correlations between kNDVI and precipitation are strong in Asia and North America (.71 and .76) and negative in Oceania (-.41). Surprisingly, precipitation and kNDVI do not significantly increase overall ESV, indicating that other factors affect the valuation of forest ecosystem services. When comparing the correlations between KNDVI, precipitation and ESV for forest biomes in **Fig. 3**, we observe strong correlations between precipitation and KNDVI in Asia, North and South America but other values remain weak, indicating ESV is again influenced by additional factors beyond kNDVI and precipitation. Overall, no strong direct and linear relationship of ESV is observed, highlighting the complexity of ecosystem valuation.

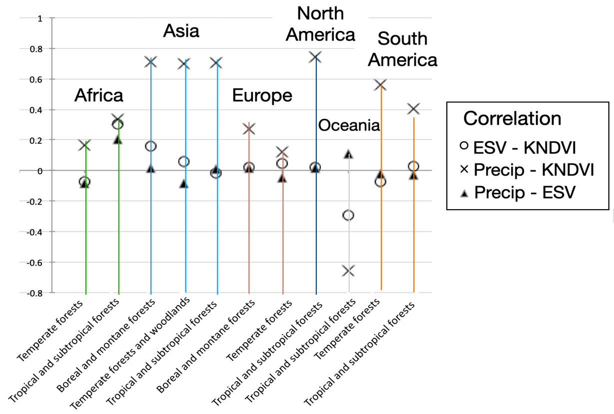


**Figure 3.** Pearson correlation of between different ESV forest biomes, precipitation and kNDVI.

For ESV trend prediction, we compared Random Forest (RF), XGBoost, gradient boosting, and ensembling models and we observed that stacking RF and XGBoost outperforms single models with the lowest MAE (.0047), RMSE (.0245), and $R^2$ score (.2082), making it the best model for ESV prediction over time as illustrated in **Fig 4**.

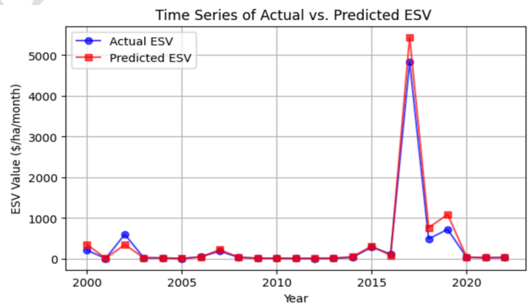


**Figure 4.** Performance for ESV prediction.

## 5. Acknowledgement

6. This work is supported by the European Horizon Project eco2adapt [grant agreement ID 101059498].

## 7. References

[1] G. Forzieri *et al.*, 'Emerging signals of declining forest resilience under climate change', *Nature*, vol. 608(7923), pp. 534–539, 2022, doi: 10.1038/s41586-022-04959-9.

[2] E. G. Brockerhoff *et al.*, 'Forest biodiversity, ecosystem functioning and the provision of ecosystem services', *Biodivers. Conserv.*, vol. 26, no. 13, pp. 3005–3035, Dec. 2017, doi: 10.1007/s10531-017-1453-2.

[3] P. Potapov *et al.*, 'The Global 2000-2020 Land Cover and Land Use Change Dataset Derived From the Landsat Archive: First Results', *Front. Remote Sens.*, vol. 3, p. 856903, Apr. 2022, doi: 10.3389/frsen.2022.856903.