NDVI Topographic Shadow Effect Correction

Implementation & Validation Across Five Mountainous Regions
Project Repo : https://github.com/svnsaisathvik/NDVI-Correction

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1 Paper Objective

The paper by Yang et al. (2022) aims to develop a correction method for NDVI topographic shadow effects in rugged terrain that can:

- Eliminate shadow-induced NDVI distortion in mountainous areas
- Avoid overcorrection problems common in traditional topographic correction methods
- Correct both self shadows (back-facing slopes) and cast shadows (terrain occlusion)
- Produce no outliers or null values in corrected NDVI

2 Problem Statement

In mountainous regions, topographic shadows cause severe NDVI distortion:

- Shadow areas show 20-50% lower NDVI than actual vegetation conditions
- Traditional topographic correction (C-correction, Minnaert, VECA) methods fail:

2.1 Problem Impact

Problem	**Impact**	**Details**
Self shadows	Overcorrected	5-20% outliers, unrealistic high NDVI
Cast shadows	Undercorrected	Shadows remain, NDVI still low
Null values	Generated	5% of pixels lost (especially Minnaert)

Table 1: Traditional topographic correction method failures

Traditional methods rely on $\cos(i)$ (solar incidence angle) which is **NEGATIVE** for self shadows $\rightarrow$ division problems $\rightarrow$ overcorrection. Cast shadows have same $\cos(i)$ as sunlit areas $\rightarrow$ not detected $\rightarrow$ no correction.

3 Solution: NTSEC Algorithm

The NDVI Topographic Shadow Effect Correction (NTSEC) method uses a physics-based approach:

3.1 Step 1: Shadow Detection

Shadow Index (SI): Detects BOTH self and cast shadows using spectral properties

$$SI = \frac{\rho_{Coastal} - \rho_{Green}}{(\rho_{Coastal} + \rho_{NIR}) + (\rho_{Green} + \rho_{NIR})} \tag{1}$$

Threshold calculated automatically using Otsu's method.

3.2 Step 2: Shadow Intensity Quantification

Variable coefficient α (0 to 1): Represents shadow strength

- $\alpha = 0$: Sunlit areas (no correction needed)
- $\alpha \to 1$: Stronger shadows (more compensation needed)

3.3 Step 3: Reflectance Compensation

Simulate missing direct solar radiation in shadow areas:

$$\rho_{compensated} = \alpha \times \rho_{original} \times \frac{E_{direct\_top}}{E_{shadow}} \tag{2}$$

Applied separately to Red and NIR bands.

3.4 Step 4: Corrected NDVI

$$NDVI_{corrected} = \frac{NIR_{compensated} - Red_{compensated}}{NIR_{compensated} + Red_{compensated}} \tag{3}$$

3.5 Key Advantage

Unlike traditional methods: NTSEC uses shadow intensity (α) instead of $\cos(i)$, so it treats self and cast shadows equally. No overcorrection, no null values.

4 Our Results: Five Mountainous Regions

4.1 Summary: All Five Locations

Location	Sun Zenith	RMSE Reduction	Bias Reduction	Shadow Coverage	F
Inland Mountains	58.44°	0.088	0.121	High	
Helan (Paper)	57.27°	0.014	0.098	31.35%	
Meghalaya	36.69°	0.020	0.036	Moderate	
Arunachal-Tawang	53.88°	0.011	0.038	High	
Gaoligong (Paper)	32.28°	0.004	0.018	Moderate	

Table 2: Summary of results across all five locations

Key Finding: All 5 locations showed positive RMSE and Bias reductions. Zero outliers. Best performance at lowest sun angles (highest zenith).

4.2 Location 1: Gaoligong Mountains (Original Paper Location)

Location Details: Yunnan Province, China — 25°N, 98°E — Elevation: 588-3578m — Slope: up to 70°

4.2.1 Image Acquisition

- Base (low sun): 2018-03-19 — Sun Zenith: 32.28° — Sun Azimuth: 138.90°
- Verification (high sun): 2019-05-28 — Sun Zenith: 16.75° — Sun Elevation: 73.25°

4.2.2 Shadow Detection

Threshold c: -0.054 — Shadow coverage: ∼25% — Detection accuracy: 94% precision

4.2.3 NDVI Statistics

Condition	Original NDVI (Mean ± Std)	Corrected NDVI (Mean ± Std)
Sunny Slopes	0.541 ± 0.296	0.542 ± 0.296 (unchanged)
Self Shadows	0.826 ± 0.121	0.863 ± 0.109 (+4.5%)
Cast Shadows	0.758 ± 0.146	0.777 ± 0.142 (+2.5%)

Table 3: NDVI statistics for Gaoligong Mountains

4.2.4 Validation Metrics

- Original: RMSE = 0.137, Bias = -0.023
- Corrected: RMSE = 0.133, Bias = -0.005
- RMSE Reduction: 0.004 — Bias Reduction: 0.018

4.3 Location 2: Helan Mountains (Original Paper Location)

Location Details: Ningxia, China — 38°N, 105°E — Elevation: ¿2000m — Sparse vegetation, extensive bare ground

4.3.1 Image Acquisition

- Base (low sun): 2017-11-08 — Sun Zenith: 57.27° — Sun Elevation: 32.73° — Sun Azimuth: 164.56°
- Verification (high sun): 2020-06-18 — Sun Zenith: 19.82° — Sun Elevation: 70.18°
- Paper reference: Nov 21, 2013 (Zenith 60.79°, Azimuth 162.39°)

4.3.2 Shadow Detection

Threshold c: -0.041 — Shadow coverage: 31.35% (extensive!) — Most challenging test case

4.3.3 NDVI Statistics

Condition	Original NDVI (Mean ± Std)	Corrected NDVI (Mean ± Std)
Sunny Slopes	0.157 ± 0.061	0.158 ± 0.061 (unchanged)
Self Shadows	0.307 ± 0.184	0.651 ± 0.136 (+112%!)
Cast Shadows	0.304 ± 0.198	0.422 ± 0.228 (+39%)

Table 4: NDVI statistics for Helan Mountains

4.3.4 Validation Metrics

- Original: RMSE = 0.170, Bias = -0.107
- Corrected: RMSE = 0.156, Bias = -0.009
- RMSE Reduction: 0.014 — Bias Reduction: 0.098

Significance: Most challenging conditions in paper - very low sun (32.73°), extensive shadows (31%), sparse vegetation. NTSEC performed robustly with ZERO outliers.

4.4 Location 3: Arunachal Pradesh - Tawang (India)

Location Details: Eastern Himalayas — 27.5°N, 92°E — Elevation: 2000-4500m — Slope: 20-35° (STEEPEST)

4.4.1 Image Acquisition

- Base (low sun): 2017-12-28 — Sun Zenith: 53.88° — Sun Azimuth: 158.69°
- Verification (high sun): 2020-06-10 — Sun Zenith: 16.95° — Sun Elevation: 73.05°
- Zenith difference: 36.93° (positive, as required)

4.4.2 Shadow Detection

Threshold c: -0.051 — Shadow coverage: High (steep terrain) — Base images found: 2

4.4.3 NDVI Statistics

Condition	Original NDVI (Mean ± Std)	Corrected NDVI (Mean ± Std)
Sunny Slopes	0.539 ± 0.204	0.539 ± 0.204 (unchanged)
Self Shadows	0.805 ± 0.218	0.893 ± 0.124 (+11%)
Cast Shadows	0.638 ± 0.211	0.682 ± 0.197 (+7%)

Table 5: NDVI statistics for Arunachal Pradesh - Tawang

4.4.4 Validation Metrics

- Original: RMSE = 0.173, Bias = -0.068

- Corrected: RMSE = 0.161, Bias = -0.030
- RMSE Reduction: 0.011 — Bias Reduction: 0.038
- Verification scatter samples: 1972

Key Finding: Despite steepest terrain (20-35° slopes), NTSEC handled extreme slopes well. Dramatic Std reduction in self shadows (0.218 → 0.124) indicates uniform, stable correction.

4.5 Location 4: Meghalaya - Shillong Plateau (India)

Location Details: Northeast India — 25.5°N, 91.5°E — Elevation: 800-1800m — Slope: 5-15° (moderate terrain)

4.5.1 Image Acquisition

- Base (low sun): 2018-03-08 — Sun Zenith: 36.69° — Sun Azimuth: 143.67°
- Verification (high sun): 2019-07-01 — Sun Zenith: 17.49° — Sun Elevation: 72.51°
- Zenith difference: 19.20° (positive)

4.5.2 Shadow Detection

Threshold c: -0.058 — Shadow coverage: Moderate — Base images found: 1

4.5.3 NDVI Statistics

Condition	Original NDVI (Mean ± Std)	Corrected NDVI (Mean ± Std)
Sunny Slopes	0.330 ± 0.172	0.330 ± 0.172 (unchanged)
Self Shadows	0.454 ± 0.143	0.581 ± 0.133 (+28%)
Cast Shadows	0.497 ± 0.184	0.539 ± 0.183 (+8%)

Table 6: NDVI statistics for Meghalaya - Shillong Plateau

4.5.4 Validation Metrics

- Original: RMSE = 0.269, Bias = -0.172
- Corrected: RMSE = 0.250, Bias = -0.136
- RMSE Reduction: 0.020 — Bias Reduction: 0.036
- Verification scatter samples: 1943

Key Finding: Dense tropical evergreen forest (70-90% coverage) successfully handled. Moderate terrain shows good correction. Wettest place on Earth - image availability challenging but algorithm worked well.

4.6 Location 5: Inland Mountains - BEST PERFORMER

Location Details: Working Location — Elevation: 1000-3000m — Slope: 15-30° — Mixed land cover

4.6.1 Image Acquisition

- Base (low sun): 2017-11-28 — Sun Zenith: 58.44° — Sun Azimuth: 164.89° (LOWEST SUN ANGLE)
- Verification (high sun): 2019-06-11 — Sun Zenith: 18.62° — Sun Elevation: 71.38°
- Zenith difference: 39.81° (LARGEST - best for validation)

4.6.2 Shadow Detection

Threshold c: -0.040 — Shadow coverage: High (58° zenith creates extensive shadows) — Base images found: 2

4.6.3 NDVI Statistics

Condition	Original NDVI (Mean ± Std)	Corrected NDVI (Mean ± Std)
Sunny Slopes	0.133 ± 0.090	0.133 ± 0.090 (unchanged)
Self Shadows	0.135 ± 0.056	0.288 ± 0.098 (+113%!!)
Cast Shadows	0.202 ± 0.100	0.316 ± 0.103 (+56%)

Table 7: NDVI statistics for Inland Mountains

4.6.4 Validation Metrics - BEST RESULTS

- Original: RMSE = 0.250, Bias = -0.200
- Corrected: RMSE = 0.162, Bias = -0.079
- RMSE Reduction: 0.088 (HIGHEST!) — Bias Reduction: 0.121 (HIGHEST!)
- Verification scatter samples: 606

4.6.5 Why Best Performance

1. Lowest solar elevation (31.56°) = most severe shadows = maximum correction potential
2. Largest zenith difference (39.81°) = strongest validation signal
3. Optimal terrain (15-30° slopes) = significant shadows without being too extreme
4. Mixed land cover = diverse test cases

Lesson: NTSEC provides greatest value when shadows are most severe. Algorithm most beneficial under challenging conditions.

5 Conclusion

5.1 Summary of Achievements

- We successfully validated NTSEC across 5 diverse mountainous regions
- ALL locations showed positive RMSE and Bias reductions
- ZERO outliers across all 5 locations (vs 0.1-5% for traditional methods)
- We successfully replicated original paper results (Gaoligong & Helan)
- We extended validation to 3 new India locations

5.2 Key Findings

1. Performance increases with shadow severity (lower sun angles → better correction)
2. Both self and cast shadows effectively corrected (self: +4.5% to +113%, cast: +2.5% to +56%)
3. Sunlit areas unchanged (preserves classification stability)
4. Best performance: Inland Mountains (0.088 RMSE reduction at 58° zenith)

5.3 Comparison with Traditional Methods

Feature	**Traditional TC**	**NTSEC**
Self shadow overcorrection	Common (5-20% outliers)	Eliminated (0 outliers)
Cast shadow correction	Undercorrected	Properly corrected
Null values	Yes (5% for Minnaert)	None (0%)
Physical basis	Empirical ($\cos i$)	Radiative transfer (α)

Table 8: Comparison between traditional topographic correction and NTSEC

5.4 Recommendation

NTSEC should be standard pre-processing for NDVI applications in:

- Mountain forest monitoring and alpine vegetation studies
- High-latitude winter imagery (sun elevation ¡40°)
- Very steep terrain (slopes ¿20°)
- Time-series vegetation monitoring in mountains

6 Reference

Yang, X., Zuo, X., Xie, W., Li, Y., Guo, S., & Zhang, H. (2022). A Correction Method of NDVI Topographic Shadow Effect for Rugged Terrain. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 15, 8456-8472. doi:10.1109/JSTARS.2022.3193419