A Change Vector Analysis Technique for Monitoring Land Cover Changes in Copsa Mica, Romania, in the Period 1985–2011

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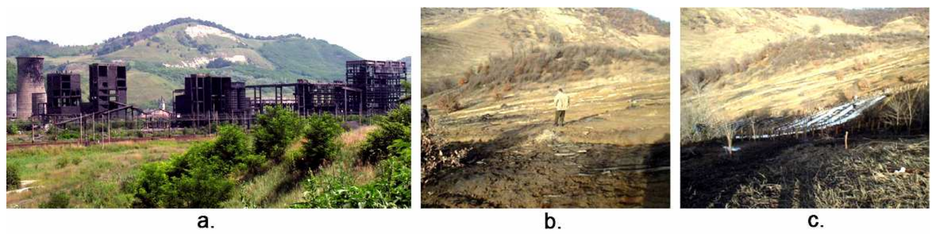
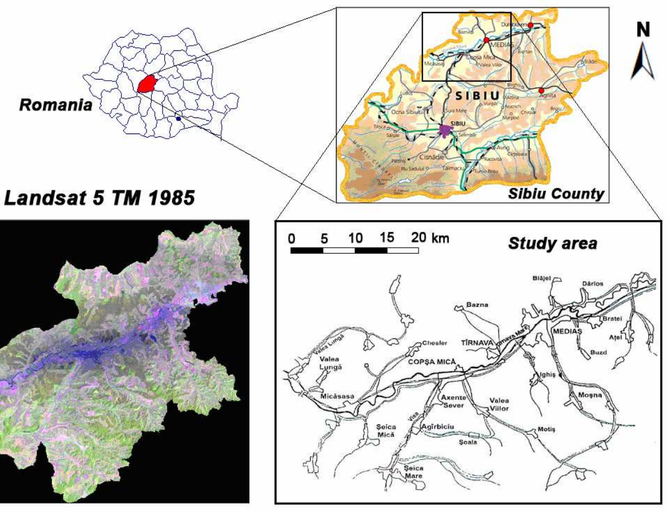
OBJECTIVES: monitoring the land cover changes occurred in the polluted area with carbon black and heavy metals from Copsa Mica, Romania, by means of satellite images. The overall objective is to assess the CVA technique applied to the Tasseled Cap Greenness (TCG) and Tasseled Cap Brightness (TCB) indices resulting from the TC transformation, as well as to the NDVI and BI indices, in order to monitor the land cover changes in the area of Copsa Mica in the period 1985–2011.

Study area

Contour of the Medias Forest Division from Sibiu County
Total surface 64,242 ha
Located: 45º57'08'' and 46º15'44' North latitude,
24º00'33' and 24º29'19'' East longitude



Images from Copsa Mica:
a). factory at Copsa Mica and degraded land behind it. The abandoned factory is on the right side of the picture; b). and c). land damaged by pollution. In the foreground, the land is covered with carbon black and in the background we can see the seriously damaged pastures and forests



Materials

Satellite images: Landsat 5 TM
29 July 1985,
07 August 1994
29 June 2003
22 August 2011
Path 184, row 28
Spatial resolution: 30 m

Other data:
Tree stands from the Medias Forest Division
Ortophotoplans - 1 : 5000 scale
Cadastral maps

Methods

Preprocessing

Image georeferencing
Universal Transverse Mercator
zone 35 N, datum WGS 84 (Level 1T)
18 ground control points
RMSE 0.25 pixels (7.5 m)

Relative radiometric normalization
Automatic Scattergram-Controlled Regression
Image 2011 - reference image
Images 1985, 1994, 2003 - subject images

NDVI calculation

$$NDVI = \frac{NIR - R}{NIR + R}$$

Bare Soil Index calculation

$$BI = \frac{(MIR + R) - (NIR + B)}{(MIR + R) + (NIR + B)}$$

Tasseled Cap calculation
TCG and TCB

Change Vector Analysis
Magnitude of changes

$$\Delta M_{TCG-TCB} = \sqrt{\left(date2_{TCG} - date1_{TCG}\right)^2 + \left(date2_{TCB} - date1_{TCB}\right)^2}$$

$$\Delta M_{NDVI-BI} = \sqrt{\left(date2_{NDVI} - date1_{NDVI}\right)^2 + \left(date2_{BI} - date1_{BI}\right)^2}$$

Direction of changes

$$tg\alpha_{TCG-TCB} = \frac{date2_{TCB} - date1_{TCB}}{date2_{TCG} - date1_{TCG}}$$

$$tg\alpha_{NDVI-BI} = \frac{date2_{BI} - date1_{BI}}{date2_{NDVI} - date1_{NDVI}}$$

Results

Definition of the change classes

Classes of change	1985–1994		1994–2003		2003–2011		1985–2011	
	TCG–TCB	NDVI–BI	TCG–TCB	NDVI–BI	TCG–TCB	NDVI–BI	TCG–TCB	NDVI–BI
Low	8.29–15.35	0.01–0.11	0.73–4.91	0.00–0.10	2.77–7.76	0.02–0.12	1.04–7.66	0.03–0.15
Medium	15.35–18.42	0.11–0.20	4.91–9.09	0.10–0.20	7.76–12.75	0.12–0.22	7.66–14.28	0.15–0.26
High	18.42–23.48	0.20–0.30	9.09–13.28	0.20–0.30	12.75–17.76	0.22–0.32	14.28–20.91	0.26–0.38
Threshold	8.29/23.48 (±2s)	0.01/0.30 (±1.5s)	0.73/13.28 (±1.5s)	0.00/0.30 (±1.5s)	2.77/17.76 (±2s)	0.02/0.32 (±2s)	1.04/20.91 (±2s)	0.03/0.38 (±2s)

Possible change direction classes based on the TCB and TCG components, as well as on the BI and NDVI indices, and related types of change

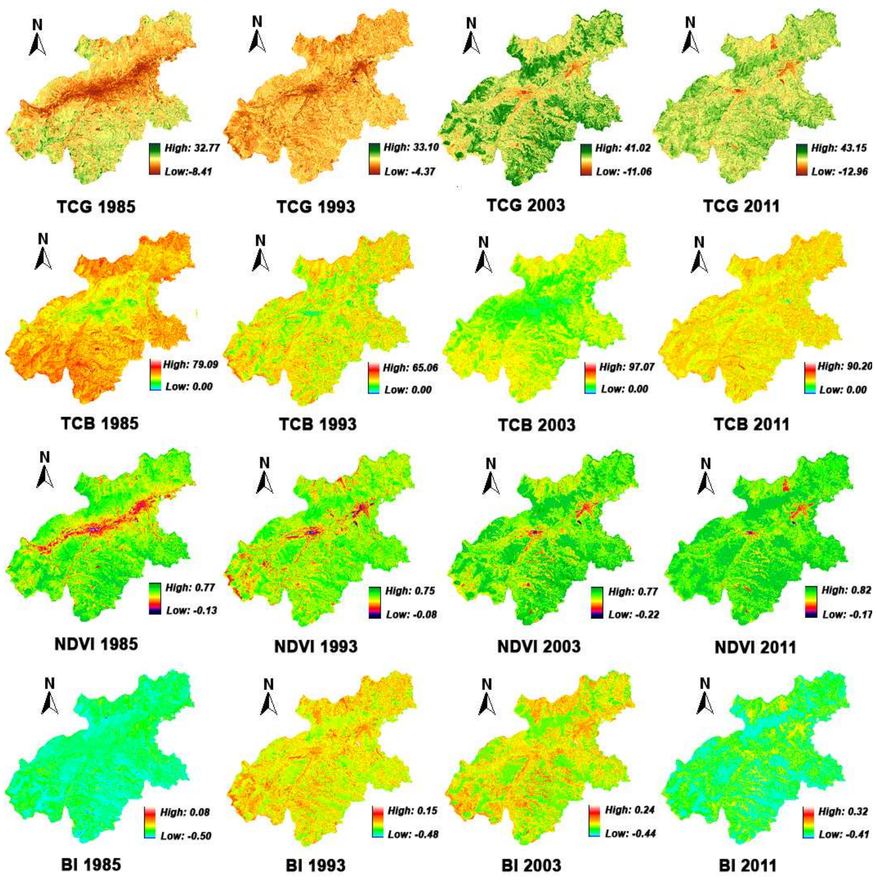
Classes	TCG and TCB			NDVI and BI		
	TCB	TCG	Description	BI	NDVI	Description
Class 1	+	+	Decrease of vegetation	+	+	Decrease of wetness
Class 2	+	–	Bare soil expansion	+	–	Bare soil expansion
Class 3	–	–	Increase of vegetation	–	–	Increase of wetness
Class 4	–	+	Chlorophyll increase	–	+	Chlorophyll increase

Change/no-change error matrix for 1985–2011 (TCG–TCB)

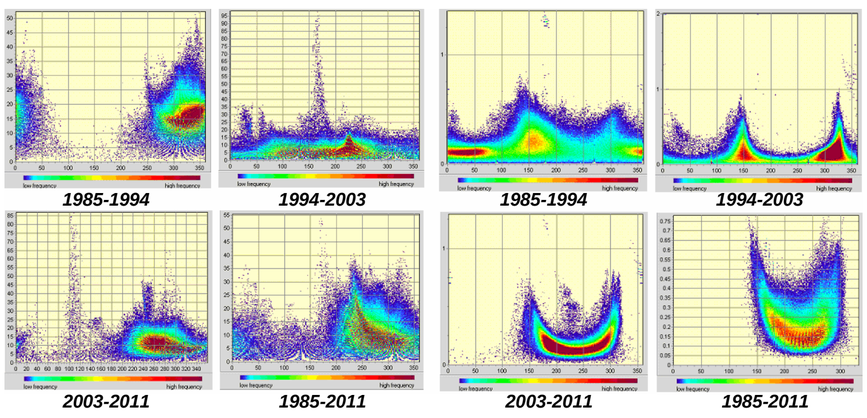
Reference class	Classification		User's accuracy (%)
	Change	No-change	
Change	91	17	84.00
No-change	30	42	58.33
Producer's accuracy (%)	72.20	71.18	
Overall accuracy: 73.88 % Kappa coefficient: 67.87 %			

Change/no-change error matrix for 1985–2011 (NDVI–BI)

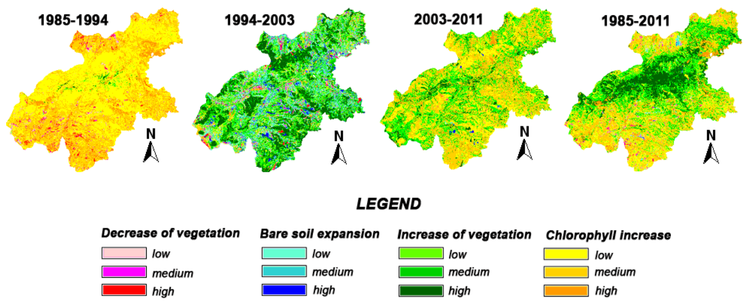
Reference class	Classification		User's accuracy (%)
	Change	No-change	
Change	81	27	75.00
No-change	26	46	63.88
Producer's accuracy (%)	75.70	63.01	
Overall accuracy: 70.55 % Kappa coefficient: 57.96 %			



Images of the indices used in CVA:
a). The TCG index shows that in the period 1985–2011 important land cover changes occurred. In 1985, strong areas affected by pollution were concentrated on the Tarnava corridor, from East to West; b). The TCB index shows that bare soil areas are spread on the slopes of the Tarnava Valley; c) The NDVI index shows that between 1985 and 2011 chlorophyll and vegetation vigor increased (green color). In 2011, only few locations affected by pollution are highlighted (red color); d) The BI index points to areas with bare soil affected by pollution with heavy metals. In 2011, the most affected location lies in the Northern part (red color), while the moderately affected locations are spread across the study area (yellow color)



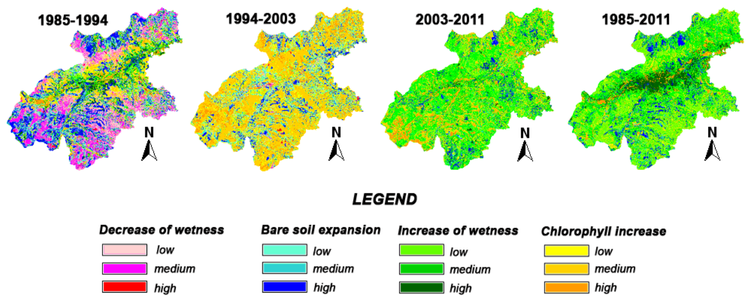
The bidimensional histograms comparing direction and magnitude (the direction is represented on the abscissa, and the magnitude on the ordinate line):
a). TCG–TCB shows that for 1985–2011 most changes occurred in sectors 3 and 4;
b). NDVI–BI shows that for 1985–2011 most changes occurred in sectors 2, 3 and, 4



Cross-tabulation of TCG–TCB images.
During the study period, the landscape gradually recovered its normal appearance through forest and grass regrowth, chlorophyll increase and vegetation vigor (green and yellow colors)

Change vector resultants using TCG and TCB between 1985, 1994, 2003, and 2011

Classes of changes	1985–1994			1994–2003			2003–2011			1985–2011		
	Area (ha)	Percent of landscape	Percent of category	Area (ha)	Percent of landscape	Percent of category	Area (ha)	Percent of landscape	Percent of category	Area (ha)	Percent of landscape	Percent of category
Sector 1 (0º–90º)												
Low	1,109	1.72	41.29	2,256	3.50	51.90	62	0.10	33.16	906	1.41	57.71
Medium	654	1.02	24.35	1,271	1.98	29.24	100	0.15	53.47	534	0.83	34.01
High	923	1.44	34.36	820	1.28	18.86	25	0.04	13.37	130	0.20	8.28
Total	2,686	4.18	100.00	4,347	6.76	100.00	187	0.29	100.00	1,570	2.44	100.00
Sector 2 (90º–180º)												
Low	17	0.03	100.00	7,211	11.23	49.70	90	0.14	34.62	460	0.72	70.23
Medium	0	0.00	0.00	5,478	8.53	37.75	58	0.09	22.31	154	0.24	23.51
High	0	0.00	0.00	1,821	2.83	12.55	112	0.17	43.07	41	0.06	6.26
Total	17	0.03	100.00	14,510	22.59	100.00	260	0.40	100.00	655	1.02	100.00
Sector 3 (180º–270º)												
Low	507	0.79	57.16	10,377	16.15	25.02	2,892	4.50	12.36	4,079	6.35	13.40
Medium	175	0.27	19.73	15,923	24.78	38.40	16,366	25.47	69.97	15,716	24.46	51.63
High	205	0.32	23.11	15,170	23.61	36.58	4,131	6.43	17.67	10,644	16.56	34.97
Total	887	1.38	100.00	41,470	64.54	100.00	23,389	36.40	100.00	30,438	47.37	100.00
Sector 4 (270º–360º)												
Low	28,977	45.10	47.77	2,188	3.41	55.75	11,672	18.18	28.88	10,662	16.59	33.75
Medium	21,289	33.13	35.09	1,178	1.83	30.01	26,055	40.55	64.47	17,849	27.78	56.51
High	10,396	16.18	17.14	559	0.87	14.24	2,689	4.18	6.65	3,077	4.78	9.74
Total	60,662	94.41	100.00	3,925	6.11	100.00	40,416	62.91	100.00	31,588	49.17	100.00
Total general	64,252	100.00		64,252	100.00		64,252	100.00		64,252	100.00	



Cross-tabulation of NDVI–BI images.
The bare soil areas (blue color) significantly decreased in the period 1985–2011. In 2011, isolated locations with bare soil could still be identified, some large ones in the Northern area, due to soil pollution with heavy metals

Change vector resultants using NDVI and BI between 1985, 1994, 2003, and 2011

Classes of changes	1985–1994			1994–2003			2003–2011			1985–2011		
	Area (ha)	Percent of landscape	Percent of category	Area (ha)	Percent of landscape	Percent of category	Area (ha)	Percent of landscape	Percent of category	Area (ha)	Percent of landscape	Percent of category
Sector 1 (0º–90º)												
Low	11,149	17.35	57.51	1,654	2.57	83.54	5	0.01	41.67	–	–	–
Medium	7,797	12.14	40.22	188	0.29	9.49	1	0.00	8.33	–	–	–
High	440	0.68	2.27	138	0.22	6.97	6	0.01	50.00	–	–	–
Total	19,386	30.17	100.00	1,980	3.08	100.00	12	0.02	100.00	–	–	–
Sector 2 (90º–180º)												
Low	5,084	7.91	22.05	6,302	9.80	39.71	160	0.25	2.95	103	0.16	1.49
Medium	7,826	12.18	33.95	5,349	8.33	33.71	2,029	3.16	37.44	2,398	3.73	34.62
High	10,144	15.79	44.00	4,219	6.57	26.58	3,230	5.03	59.61	4,425	6.89	63.89
Total	23,054	35.88	100.00	15,870	24.70	100.00	5,419	8.44	100.00	6,926	10.78	100.00
Sector 3 (180º–270º)												
Low	3,218	5.00	30.97	3,812	5.94	93.59	13,497	21.00	30.61	17,870	27.81	35.89
Medium	3,978	6.19	38.29	254	0.39	6.24	29,055	45.22	65.88	25,902	40.31	52.02
High	3,194	4.98	30.74	7	0.01	0.17	1,546	2.41	3.51	6,019	9.37	12.09
Total	10,390	16.17	100.00	4,073	6.34	100.00	44,098	68.63	100.00	49,791	77.49	100.00
Sector 4 (270º–360º)												
Low	4,279	6.66	37.46	10,260	15.97	24.24	902	1.40	6.13	794	1.24	10.54
Medium	4,737	7.37	41.48	21,867	34.03	51.66	8,007	12.46	54.38	3,528	5.49	46.82
High	2,406	3.75	21.06	10,202	15.88	24.10	5,814	9.05	39.49	3,213	5.00	42.64
Total	11,422	17.78	100.00	42,329	65.88	100.00	14,723	22.91	100.00	7,535	11.73	100.00
Total general	64,252	100.00		64,252	100.00		64,252	100.00		64,252	100.00	

Conclusions

Considering that the area with positive land cover changes is the one from sectors 3 and 4, in the case of CVA applied to TCG–TCB, it can be concluded based on this study that 96.54 % of the study area presented in the period 1985–2011 land cover changes which indirectly point to the reduction of carbon black pollution. The remaining area (3.46 %) is affected by a decrease in vegetation (2.44 %) and an increase in bare soil expansion (1.02 %).

In the case of CVA applied to NDVI–BI, the area with land cover changes which indirectly point to the reduction of carbon black is of 89.22 %, while 10.78 % of the study area is affected by bare soil expansion because of the persistent heavy metal pollution.

Ecological reconstruction at Copsa Mica:
a). slope with returning vegetation behind SC Sometra SA; b). fully forested slope on the Tarnava Mare corridor