WARFARE-INDUCED VEGETATION COVER CHANGE MAPPING IN EAST UKRAINE USING MULTITEMPORAL SATELLITE IMAGERY

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ABSTRACT

Analysis of vegetation cover changes using multispectral satellite imagery is performed along the delimitative line, so called "grey zone", which conditionally divides the Ukrainian territory from the area under anti-terrorist operation in the eastern part of Ukraine. The primary tool for landscape changes detection is the remote mapping of vegetation cover change over the study area. Deforestation is detected within zones of warfare operations and characterized by spotted distribution through all over the "grey zone". It is correlated with anthropogenic activities led to vegetation clearance along the highways and railways, along the artificial forest plantations, infrastructure destructions within urban areas because of fire spread, direct military operations followed by fire explosions and landscape degradation.

1 INTRODUCTION

The warfare operations on the east of Ukraine lead to unprecedented environmental impact. Lack of controllability and observability over the study area and periodic shelling do not allow assessing damage to the environment without bias.

As it is known, the steppe Donbass landscapes were severely transformed and vegetation cover degraded before the armed conflict because of intensive industrial stress. This makes the warfare load even more stressful. The environmentalists already ring the alarm and emphasize on international legislation in protecting the environment during armed conflicts [1]. Recent publications on effects of the warfare impact on the processes in ecosystems have demonstrated benefits from remote methods application and necessity of their further development [2, 3].

It has also to be considered their application for the environment risk assessment and ecosystem vulnerability during war disasters and in the context of climate change.

2 STUDY AREA

All the Donbass landscapes components from parent material, underground and surface water bodies, to soil-vegetation cover, have been severely suffered for the period from May, 2014 till present. The natural vegetation cover of the study area is presented mainly with motley grass and remains of ravine forests. The last ones are left along the small river valleys, on the slopes of gullies and ravines. But they are still there and it is a high threat to the environment when those rare remnants fall under fire destruction. Since vegetation is a key component of an ecosystem and involved in the regulation of various natural cycles, in this publication the authors concentrate their attention on vegetation cover change detection through comparison of satellite images taken before and after the warfare activities started. Analysis of vegetation cover was performed along the delimitative line, so called “grey zone”, which conditionally divides the Ukrainian territory from the area under anti-terrorist operation in the eastern part of Ukraine.

3 DATA AND METHODS

Leaf area index (LAI) was assigned as the main indicator of vegetation state. LAI can be determined by special processing of multispectral satellite imagery [4]. Processing dataflow is presented in the Figure 2 diagram with unified modeling language (UML) standard.

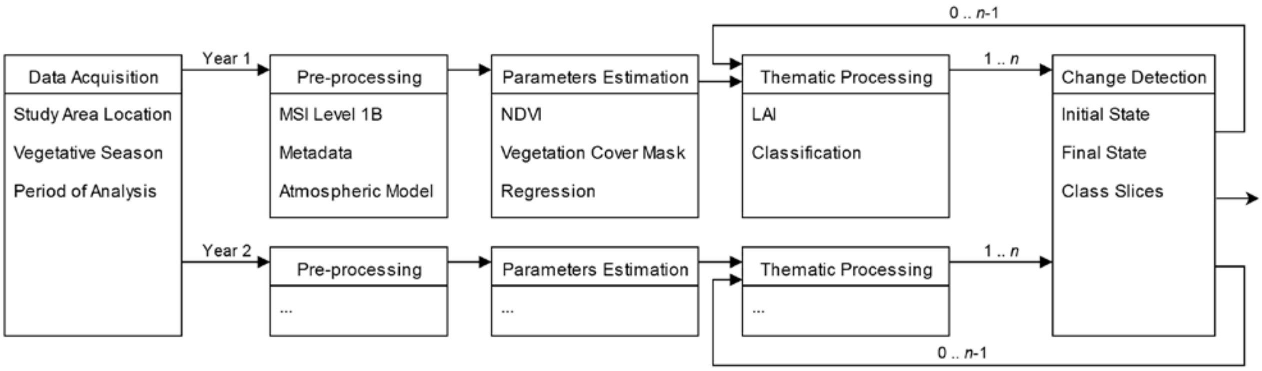


Figure 1: Satellite data processing flowchart

After the data acquisition the vegetation analysis process is subdivided into 3 main components. The first component is pre-processing, which consists of radiometric and atmospheric correction.

Vegetation parameters estimation is the second component. The woodland vegetation analysis was performed on this stage. Normalized difference vegetation index (NDVI) was calculated. The farmlands area was suppressed using vegetation cover mask. The resulting NDVI map for woodland vegetation has been obtained.

Thematic processing is the third component. NDVI map was transformed into LAI using a known regression relationship [5].

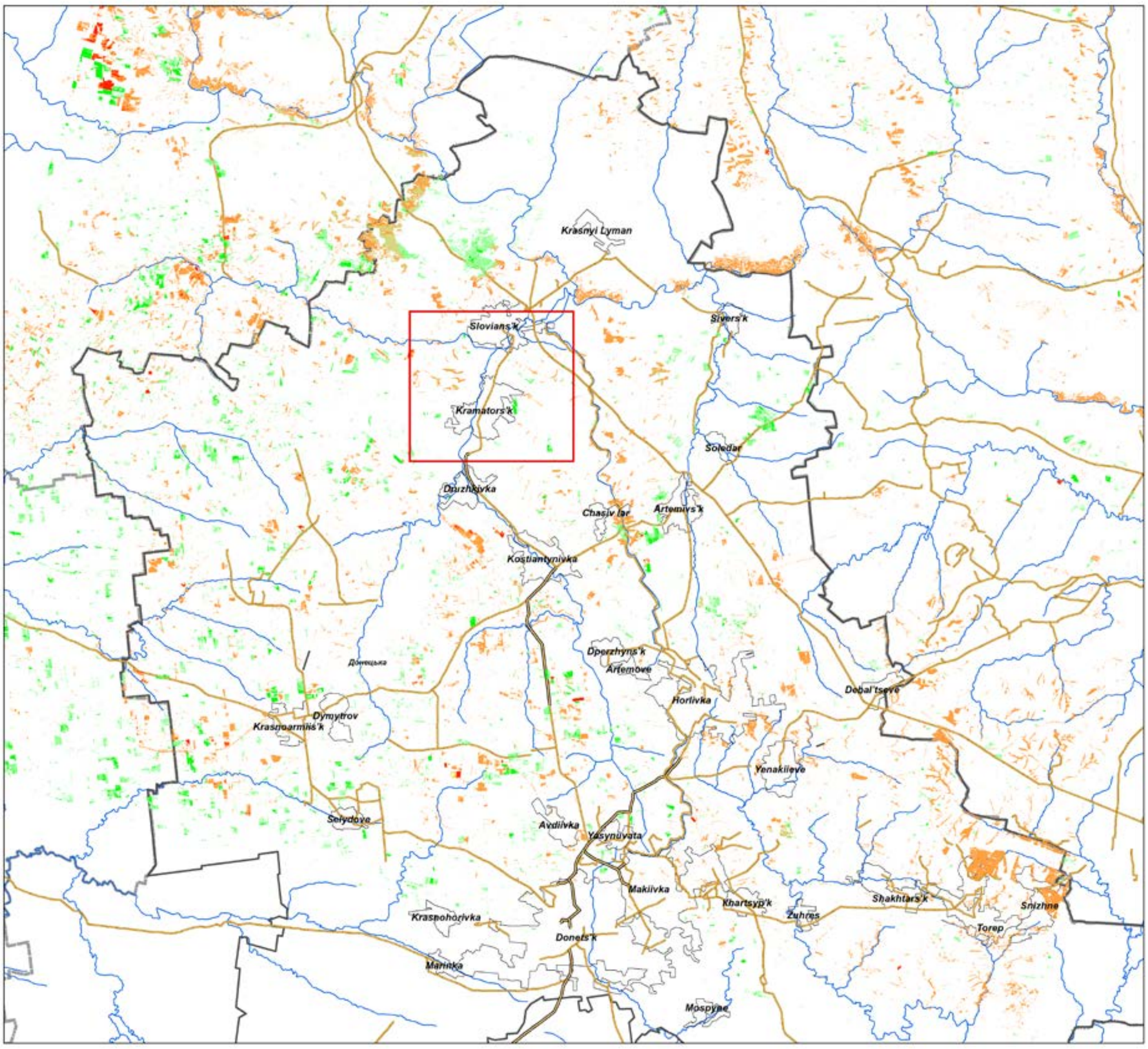
Finally, the change detection procedure is performed [6], which one repeated iteratively with thematic processing and classification component. In the Figure 1 the *n* is an iterations number.

Upon change detection completing the vegetation state final map was produced. The map provides information on seven classes of vegetation state, between strong growth and high degradation [7], as shown in the Table below.

Table: Vegetation cover change classes legend

Code	Class [Color]
	Strong growth [Bright Green]
	Moderate growth [Pastel Green]
	Weak growth [Pastel Grey]
	No change [Sea Shell]
	Low degradation [Yellow]
	Medium degradation [Pastel Orange]
	High degradation [Alarm Orange]
	Water surface [Blue]

Changes in vegetation patterns were detected using the images of Landsat/OLI Level 1B for the period from May 2013 to May 2014 (Figure 2) and from May 2014 to May 2015 (Figure 3) for the northern part of the Donetsk region and the western part of the Lugansk region.



a

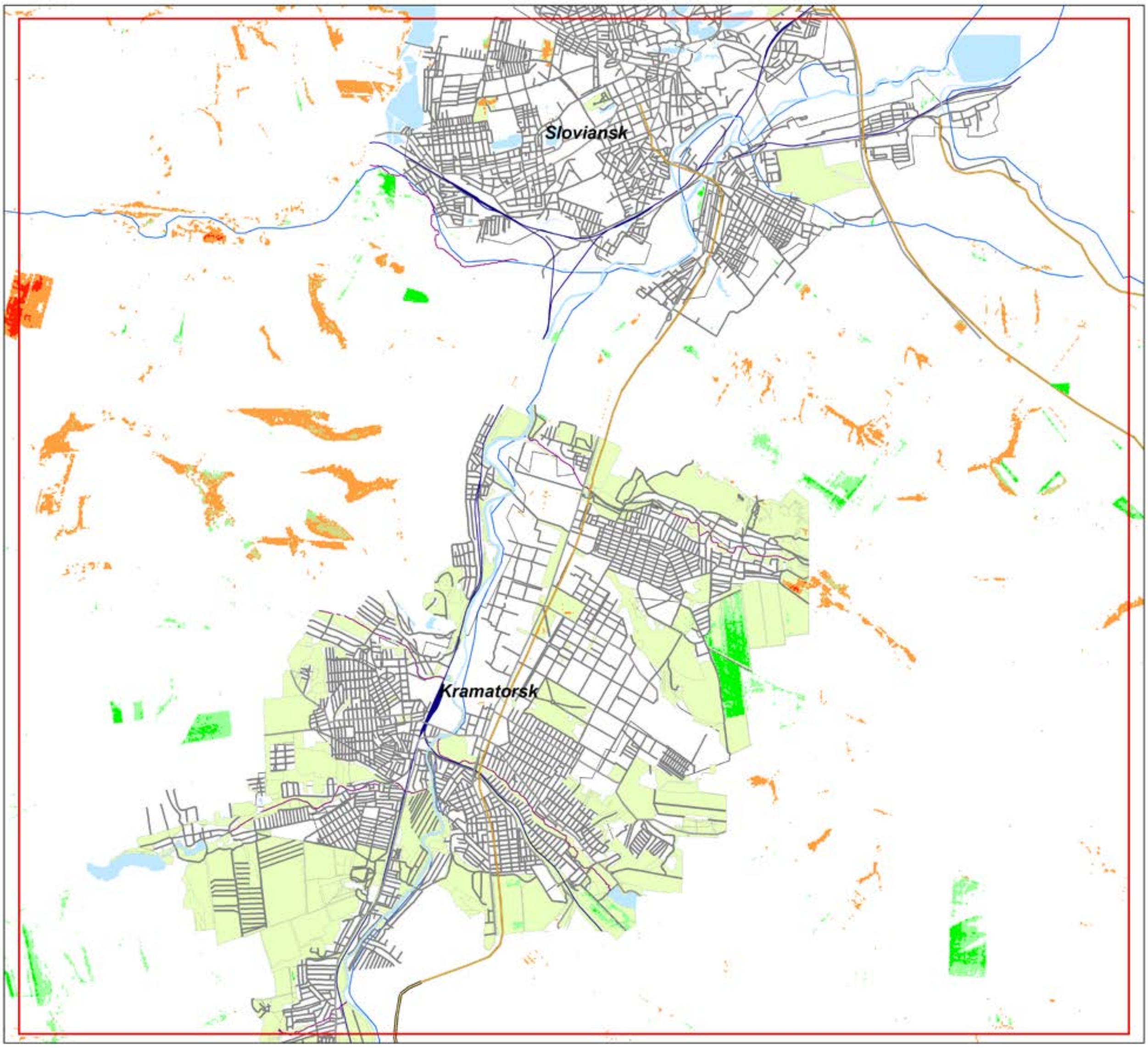


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Figure 2: Vegetation change map for the period from May 2013 to May 2014:
a – overview map, *b* – Sloviansk-Kramatorsk area enlarged

When it comes to warfare consequences, vegetation is the first to be influenced as it is very sensitive towards abrupt change of environmental conditions. Unfortunately, the nature reserve fund of the study area has been significantly decreased partially because of fortifications on their territories and development of severe fires through all over the study area. The images of 15 May 2013 and 18 May 2014 were used (Figure 2*a*) and high level of vegetation degradation is obvious.

Upon a closer view, deforestation is detected within zones of warfare operations and characterized by spotted distribution through all over the "grey zone". It is correlated with anthropogenic activities led to vegetation clearance along the highways and railways, along the artificial forest plantations, infrastructure destructions within urban areas because of fire spread, direct military operations followed by fire explosions and landscape degradation.

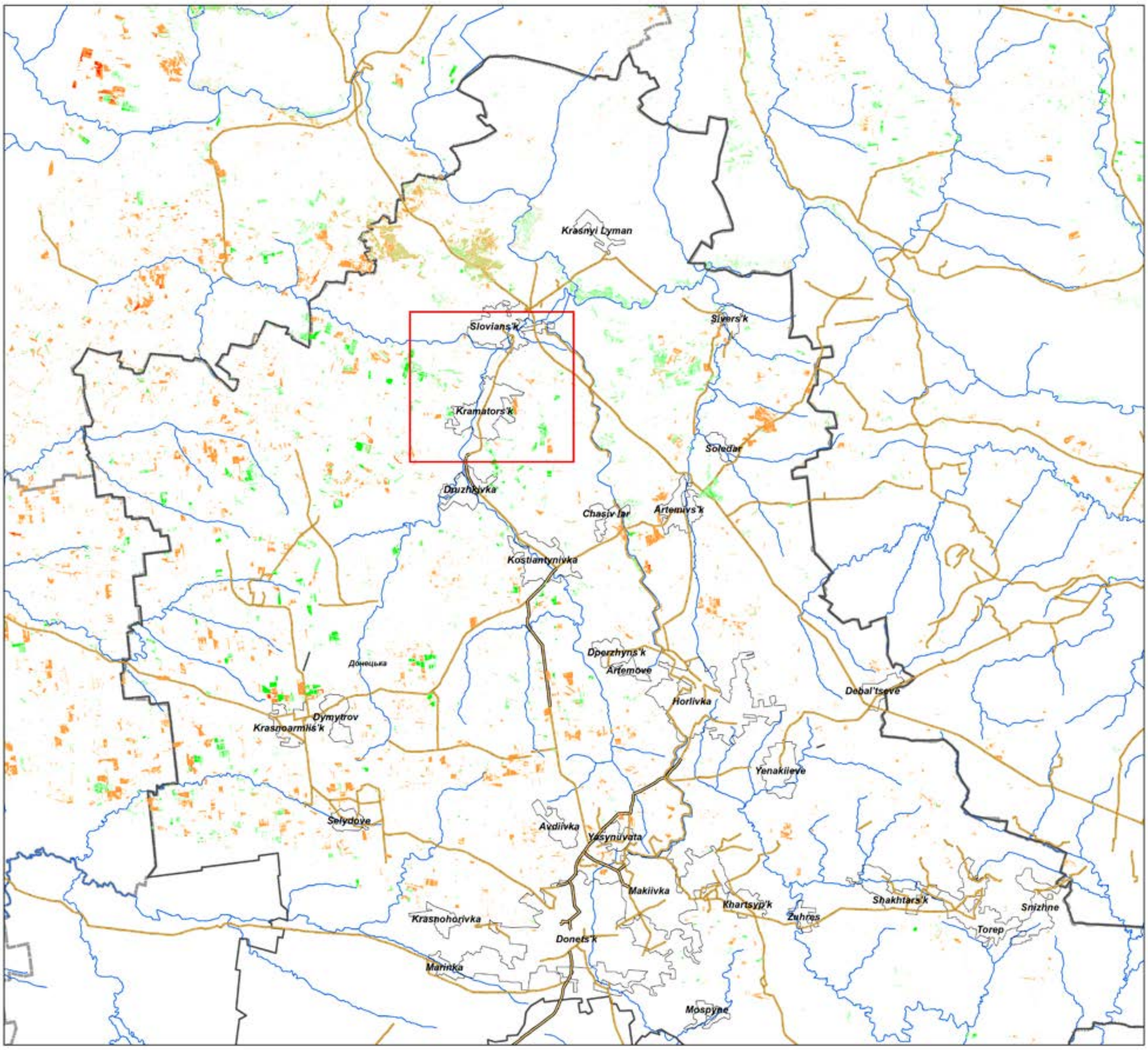
Let us consider the northern suburbs of the Sloviansk city (Figure 2*b*). It was one of the focal points in the early stages of the 2014 conflict in Ukraine. The territory is covered with dense vegetation that was recently planted and known as one the youngest among the regional landscape parks called "Sloviansk resort".

Different levels of vegetation degradation (mostly medium and high) are fixed along the green massif in the north-western part of the Svyatogorsk resort area, sparsely spotted around the Slaviansk radon resort area, and the area around the city itself. At the same time a green forested massif is observed between two cities – Krasnyi Luch and Svyatogorsk. It was not disturbed and bright and pastel green colors prove the environmental enhancement.

The territory south of the Sloviansk city is less covered with vegetation (Figure 2*b*) and thus any apparent change is observed. Nevertheless the Kramatorsk Park located within the city area and its vegetation has not been degraded. Significant vegetation growth is observed on the eastern part of the city suburbs.

Another example is the city of Gorlivka and its suburbs. It is located on the up hills of the former upland ridge with gentle slopes. This mining area is very rich of coal and other metal deposits and so was highly transformed before the warfare activities started. Vegetation cover in the eastern and south-eastern suburbs of the city is highly degraded as well as within the eastern area of the town of Chasov Yar where famous clay deposits were operated through development of open pits. The mystery of nature is how vegetation remains life-asserting and manages to improve life conditions wherever human beings do not interfere.

The same research was made for the period from May 2014 to May 2015. Different levels of vegetation cover degradation (mostly low and medium) are fixed along the woods areas, sparsely spotted through all over the study are but obviously less than a year before (Figure 2a and 3a). Especially it is evident when a closer look at the enlarged territory between the same cities (Sloviansk-Kramators). Moderate and even strong vegetation growth is fixed to the south-east and north-west of the city of Kramatorsk (Figure 3b). On the one hand, it may be forced because of climate conditions change during the study period. On the other hand, private farming acreages were not properly cultivated and nature invasion took place.


Krasnyi Lyman
Slovians'k
Sivers'k
Kramators'k
Soledar
Druzhkivka
Chasiv Iar
Artemivs'k
Kostiantynivka
Донецька
Dzerzhyns'k
Artemove
Horlivka
Debal'tseve
Dymytrov
Krasnoarmiis'k
Yenakiieve
Selydove
Avdiivka
Yasynuvata
Makiivka
Khartsyz'k
Shakhtars'k
Snizhne
Krasnohorivka
Zuhres
Torez
Donets'k
Marinka
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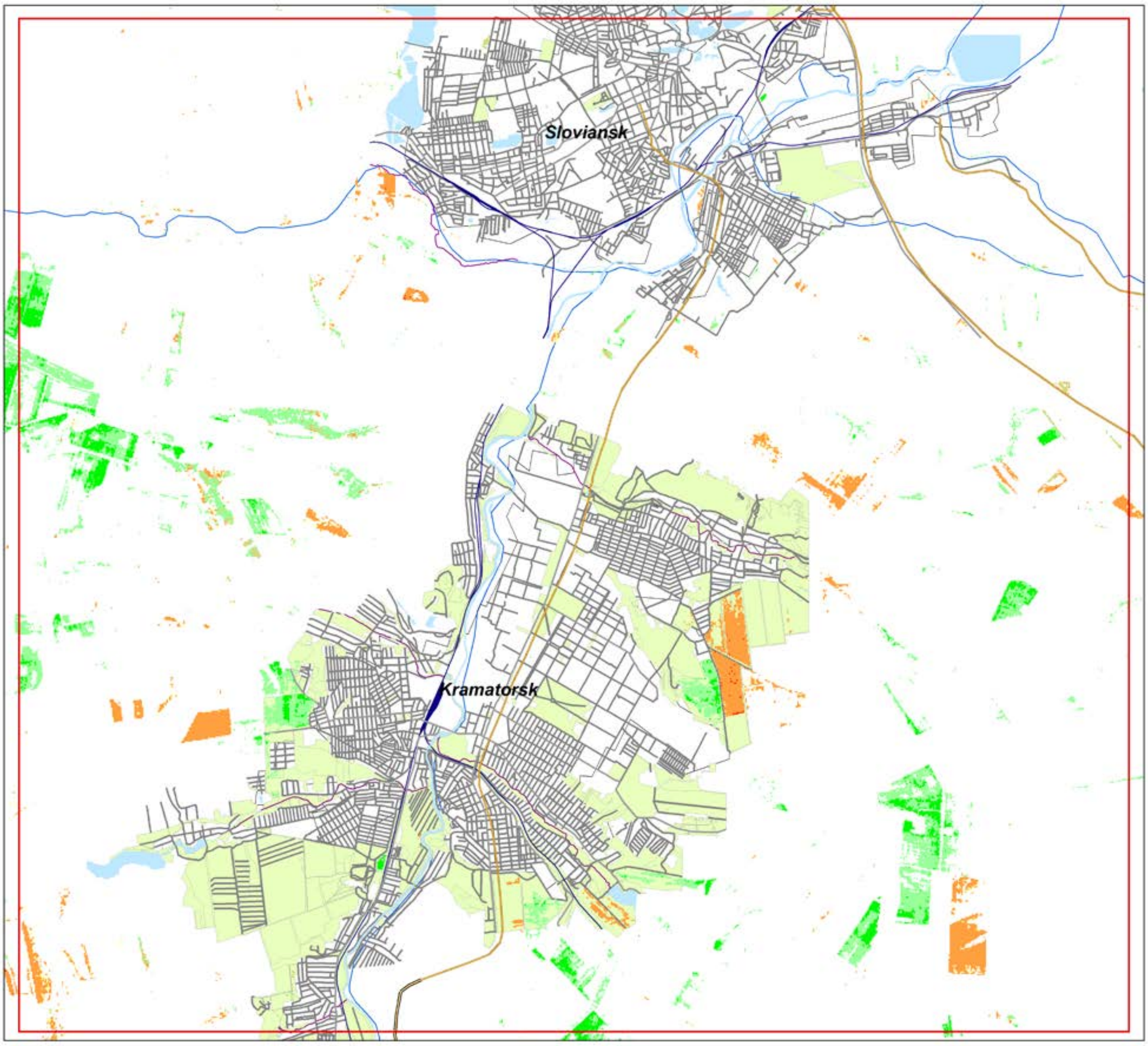

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Figure 3: Vegetation change map for the period from May 2014 to May 2015:
a – overview map, *b* – Sloviansk-Kramatorsk area enlarged

CONCLUSIONS

Since vegetation cover is very vulnerable towards environmental conditions abrupt change, the sites of high level vegetation degradation might serve as "hot spots" to be taken attention to in terms of their rehabilitation. Vegetation cover degradation is detected within zones of warfare operations and characterized by spotted distribution through all over the "grey zone". It is correlated with anthropogenic activities led to vegetation clearance along the highways and railways, along the artificial forest plantations, infrastructure destructions within urban areas.

Remote detecting of vegetation cover change is of high importance when direct measurements are not possible. Early detection of "hot spots" can help for further improvement of environmental condition.

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