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Risk Assessment of Land Degradation Using Satellite Imagery and Geospatial Modelling in Ukraine

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Additional information is available at the end of the chapter

Abstract

In this publication, the authors considered the effect of unprecedented human activity into land degradation and desertification processes in Ukraine. The land degradation mapping technique based on processing of a two-level model for multispectral satellite imagery of low and medium spatial resolution was described. This technique was used to investigate land degradation and desertification within relatively pristine and human-inspired mining and industrial landscapes located in the central, southern, and eastern parts of Ukraine. In each particular case, the authors offered thematic land degradation maps obtained as a result of multispectral images processing, allowed assessing the state and tendencies in land degradation processes within the study areas. Data obtained visually emphasize the level of anthropogenic stress, impact of long-term change of vegetation cover, and correlation of intensive development of mining, construction, agricultural and other human activities with high level of land degradation within investigated areas. The transition to adaptive farming systems implies the achievement of maximum compatibility between soil and plant, development of crop rotation, soil conservation tillage system. Conducted research on the creation of adaptive systems of crop production takes into account the environmental, landscape and geochemical peculiarities of the steppe zone of Ukraine, to get the production of environmentally safe agricultural products. They can be used in further studies of a differentiated approach to achieving a balanced potential of agricultural landscapes. Remote detecting of degradation and desertification processes intensification at early stages will be able to promote further measures for improving the territories conditions. The further research has to be directed on development of geoinformation technologies for landscape changes remote mapping.

Keywords: Anthropogenic landscape, Land degradation, Soil erosion, Satellite imagery, Geospatial modelling

1. Introduction

Land degradation is a relevant and important problem for Ukraine. The solution to this problem requires not only a detailed study of land degradation causes, but also involves identifying a risk of land degradation [1]. Unprecedented human activity destroys the landscape complexes globally. In this publication, the authors consider in brief the effect of such unpractical land use into land degradation and desertification processes in Ukraine on the examples of natural and human-inspired landscapes [2].

Ukraine is known for its fertile arable lands as a key natural resource. But throughout the twentieth century, Ukraine's lands were dramatically changed by anthropogenic stress. Virgin lands were ploughed and mires, swamps and wetlands drained, forests shrunk and steppe lands were severely mined. According to the UN Food and Agriculture Organization (FAO), data as much as 76% of the total land are severely degraded due to human activities [3]. This high figure results largely from a history of intensive agriculture and mining development. As land degradation is considered one of the major environmental problems, Ukraine joined the UN Convention to Combat Desertification (UNCCD) [4] in 2002. The Convention's annex on Regional Implementation for Central and Eastern Europe cites Ukraine as an example of serious land degradation [5].

The Law on land protection (2003, No. 962-IV) and the Law on state control of use and protection of land (2003, No. 963-IV) approved after joining UNCCD, include provisions to restrict improper use of land, but resources for ensuring their application are strictly limited.

From year to year, we observed the great growth of lands under mines, open pits and other industrial facilities that led to numerous lands subsidence, rocks slide, decrease areas of arable lands, etc. The arable areas had also greatly suffered from development of terricones, waste banks, pit refuse heaps as well as from building of an earth dams, bridges, roads, water reservoirs, etc. The enormous contaminants emitted into the environment from different industries have tangible effect on almost all the landscapes in the country.

Soil dehumification and consequently increased emissions of carbon dioxide (agent of the greenhouse effect) are significant causes of change in meteorological conditions. This enables another destructive mechanism of land degradation—desertification. In the spatial context, desertification can be considered as the phenomenon, which is to increase the area of depleted ecosystems. Desertification is a manifestation of the effects of biodiversity and biomass loss, and evaluation of the soil fertility impacts on primary productivity of ecosystems formed in the agrarian landscapes.

Large extent or inaccessibility of degraded areas, insufficient funding for soil and vegetation cover research, as well as unsatisfactory quality of relevant archival materials, makes multi-spectral satellite imagery a reliable information source for the assessment of potential land deterioration.

2. Natural and anthropogenic landscapes of Ukraine

As a result of long-term landscape changes, the level of territory transformation has deviated significantly in different parts of the country, the highest percentage of natural landscapes being observed in mountainous areas (**Figure 1**). However, mountainous landscapes occupy relatively insignificant parts of the territory (around 6%). According to **Figure 1**—the northern, northern-western, the mid reaches of the Dnieper River and the part of the territory under natural components makeup to 50%, and the forest–steppe and steppe geographical zones transformation exceed 90% of the total area. Natural components here are located on the restricted areas adjacent to rivers and to the Black sea coastal area.

Figure 1. Anthropogenic landscapes of Ukraine.

Out-of-balance and unpractical natural resource management from the previous century have led to the environmental situation and the landscape architecture we see nowadays. It is too far from optimism. However, what is evident is that the level of land degradation is unequal (**Figure 1**). It is associated with human impacts of different intensities depending on territorial differentiation of natural conditions and resources, level of social and economic development and other factors peculiar to different areas of Ukraine.

In general, the percentage of tilled lands at the level of 60–80% (from the total area) is considered as unfavourable; 25–60%—conditionally favourable; and <25%—favourable. Optimal assessment of tillage is still met in the Ukrainian Polissya, mountainous areas of Carpathians and Crimea. Ukraine is characterized by highest percentage of tilled lands: As it mentioned above, just around 8% (5 million ha) of lands are in natural conditions. Agricultural develop-

ment of the land resources is 72.2%. And the steppe oblasts are characterized by the highest value of cultivated lands: Zaporizhia (88%), Kirovograd (86%), Dnepropetrovsk and Odessa oblasts (83% each), and Kherson (82%). A bit lower level is observed in the forest–steppe oblasts, and significantly lower level of cultivation (by 1.5–2 times) is within the Polissya territory. The percentage of cultivated lands in Ukraine is the highest in the world and the main contributors to that are the territories of forest–steppe and steppe zones [6]. For comparison: the percentage of tilled lands in the USA is 19%, France and Germany—33%, Italy—31% [7], that is these factors correspond to favourable and conditionally favourable characteristics. Such a high level of cultivated lands is unfavourable as from economic as well as from environmental points of view. It abruptly decreases a natural potential of the territory and makes it monotonous, and economy activity—highly specialized [8].

3. Soil erosion and other exogenous processes

As it was highlighted in the Land Code of Ukraine (art. 171), degraded lands are specifically those where erosion, landslides, karsts, floods, etc., are developed [9]. Ukraine's soil is prone to erosion, and over 30 million hectares (i.e. about half Ukraine's total territory) of land is strongly affected by erosion. Some agricultural practices, like planting of row crops (sugar beet, sunflower, etc.) in plantations, exacerbate the problem. Soil erosion is a significant problem which also decreases humus levels in soil.

Ukraine's relief and climate and its very high proportion of arable lands make erosion a widespread natural phenomenon. About a third of the arable lands are threatened by water and wind erosion. Poor land management practices, such as crop cultivation on steep slopes, excessive cutting of forests, shrubs and bushes, and overgrazing accelerate erosion. As a side effect, erosion is causing sedimentation in rivers, lakes and water reservoirs. As a result of erosion fertile soil is lost, plant nutrients are removed and there has been soil textural changes, deterioration of soil structure, declining land productive capacity, increased dissected fields, and increased streams and lakes pollution and pile ups on bottomlands, in stream channels, and in lakes and reservoirs. Over 500 million tons of soil is subjected to erosion processes annually leading to decrease of soil fertility. It is argued that with each dollar of added cost created by agricultural producers, one third is lost due to erosion [10]. The soil fertility decrease inevitably leads to increase in production cost. For the last 15 years, the intensity and frequency of droughts has significantly grown in the steppe zones of Ukraine. Droughts are observed to happen once in 3 years causing decrease of arable lands productivity. The climate change and expected extreme phenomena growth are supposed to exacerbate this tendency in the nearest future. Right in the steppe zone, the soil degradation processes are developed much harder than in the other parts of Ukraine. It is important to remember that a half of grain crops in the country are grown on the fertile chernozems in the steppe climate zone. In some south-east areas, the soils are degraded so heavily that additional donations are needed to restore their fertility.

The steppe zone occupies the southern part of Ukraine. It is spread from south-west to north-east up to 1100 km, and from north to south up to 500 km (**Figure 1**). Its total area is about 25

million hectares that makes up 40% of the whole territory of the country. The biggest steppe area is occupied under typical chernozems—10.4 million hectares. They are formed under grassland-fescue-feather vegetation in the northern part of the steppe zone. Because of the climate change, the humus layer thickness is gradually decreasing, and the typical chernozems are subdivided into medium-humic and low-humic chernozems of high (85–100 cm), medium (65–85 cm), and low (45–65 cm) thickness [11]. Agricultural activity promoted water and wind erosion spread. The wind erosion has covered more than 220,000 km^2 so far and spread even in those areas where it has never been noticed before. For some time past, the dust storms of 8–17 h duration happened three to five times per year [12, 13]. The wind speed reached up to 20 m/s. It is known that the southern chernozems structure damage can occur when the wind speed is of 5–6 m/s [14]. With an exception of soil erosion phenomena, the UNCCD Country Profile of 2006 consider other exogenous geological processes caused land degradation in Ukraine (**Table 1**, UNCCD Country Profile, 2006) [3].

Land degradation	Land area	
	Million ha	**Percent of total area**
Wind erosion	13.3	22.0
Water erosion	19.4	32.1
Combined erosion	2.1	3.4
Soil acidification	10.7	17.7
Soil salinization	1.7	2.8
Soil alkalization	2.2	3.7
Land slides	0. 2	0.3

Table 1. Land degradation drivers in Ukraine.

4. Dust storms in the southern part of Ukraine

The dust storm plume fixed in the central regions of the European part of the troposphere was observed on the space images dated 24 March, 2007 (**Figure 2**).

It turned out that that headwaters of this dust storm point out to the south of Ukraine. The wind currents of 30 m/s speed lifted up huge masses of the surface soils. The dust plume trajectory went through the territories of the Slovak Republic, the Czech Republic, and Germany. The solid particles concentration in that plume was between 200 and 1400 μg/m^3. The MODIS image analysis proved that the origin of dust plume was in the Kherson oblast, close to the Kakhovsky water reservoir. Huge masses of dust were lifted up in the air from the territory of 20,000 km^2 area under arable lands. The wind speed reached up to 25 m/s [15]. This unusually high wind speed together with the preceding of a 2-week drought and lack of vegetation caused that dust storm in March 2007. It has to be noticed that until quite recently, the Sahara desert was considered to be the main source of transboundary transfer of mineral
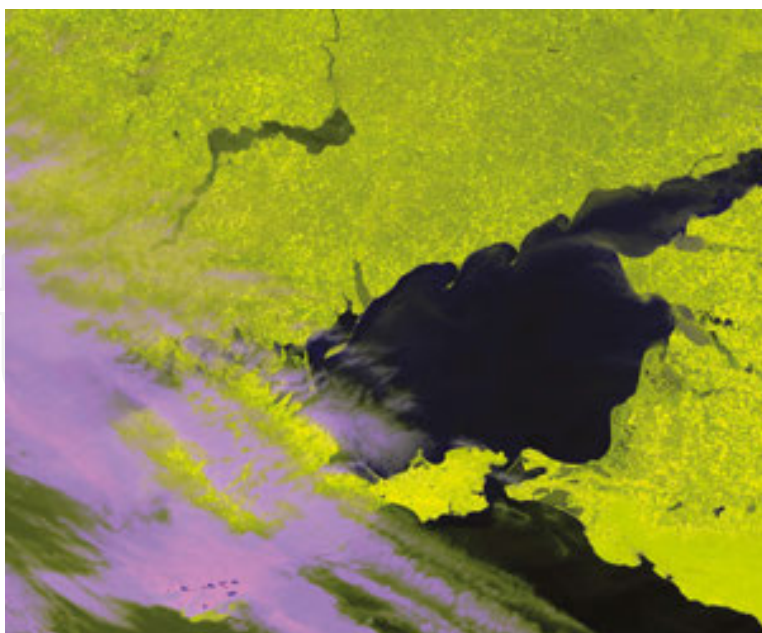
Figure 2. Dust storm in the region of the Kakhovske water reservoir, EOS/MODIS, 23.03.2007.

dust to Central Europe. Dust from the Sahara desert is transferred with windblast into the Central Europe several times per year. The solid particles concentration in the dust plume in the south of Germany is made up on the average 280 µg/m^3. According to the monitoring data from the "Borna" station in Germany, the concentration of solid particles from the Ukrainian dust reached 640 µg/m^3. As it is obvious, this value exceeded the African plume parameters by two times.

Up to 70 tons of soils per hectare and per hour is blown away during the dust storms. The storm of March, 2007 was not an extraordinary phenomenon for the south of Ukraine. It is known that in the early 1950s, the countermeasures were taken to prevent the wind erosion spread. The wind protective forest strips were planted on more than 440,000 hectares in all the natural zones of Ukraine [16].

Until recently, the soil dust natural particles were traditionally considered as harmless for the human health. But new research proved chronic bronchitis happened quite frequently in farmers [17] or increase of respiratory diseases in population residing in the territories of Karakalpak (Uzbekistan) [18], that is. in regions with the similar conditions described for the south of Ukraine.

5. Satellite imagery for the purpose of land degradation mapping

As it is obvious, land degradation phenomena is of high priority to be researched and different techniques are to be considered for that. The solution to this problem requires not only a detailed study of the land degradation causes, but also involves identifying the risk of degradation. Satellite imagery has its advantages and widely used for investigation of

landscape changes dynamics as a result of anthropogenic impact since it is able to cover areas at different scales. Processing of time series of geoinformation products allows reliable detecting and mapping of landscape changes at local, regional and even global level.

As it was mentioned above, large scale or inaccessibility of degraded areas, insufficient funding for research on soil and vegetation cover condition, as well as unsatisfactory quality of the relevant archival materials, make multispectral satellite imagery a reliable information basis for the assessment of potential land deterioration. At the same time, the main task of multispectral satellite imagery processing is the selection of land degradation indicators. In this study, vegetation change and soil erosion dynamics are defined as such indicators. To map them, besides medium spatial resolution multispectral satellite images, auxiliary geospatial data—digital terrain, soil maps and climatic parameters of the study area—are required.

The authors used the land degradation mapping technique to investigate land degradation within relatively pristine (Oleshki sands) and human-inspired mining and industrial areas (central part of Ukraine) [19]. In each particular case, the authors offered thematic land degradation maps obtained as a result of multispectral images processing, allowed assessing the state and tendencies in land degradation processes within the study areas. The research visually emphasizes the level of anthropogenic stress within investigated territories.

6. Land degradation geospatial model

The land degradation mapping technique was used on the basis of processing of a two-level model for multispectral satellite imagery of low and medium spatial resolution. First-level model applies several different thematic classifications of source multispectral images, for example vegetation change, soil erosion, etc. Second level gives data fusion of specific thematic classifications of the first level into final thematic map to improve accuracy and reliability owing for information support systems to provide land management.

Vegetation changes are usually detected on the multispectral satellite images by unified well-known methods [20]. It should be noted that a modified soil-adjusted vegetation index MSAVI F_v is more preferable over generic normalized vegetation index NDVI for vegetation mapping in terms of steppe soil erosion in the southern Ukraine. The MSAVI index can be calculated by special equation:

$$F_v = \rho_{inr} + \frac{1 - \sqrt{(2\rho_{nir} + 1)^2 - 8(\rho_{nir} - \rho_{red})}}{2} \tag{1}$$

where ρ_{nir} and ρ_{red} are land surface spectral reflectances in the near infrared and red spectral bands, respectively [21].

Water erosion depends on soil type and mineral composition, rainfall, slope steepness and vegetation density. The value of water erosion z_s (mm/month) can be calculated from the regression relationship of the form [22]

$$z_S = k_S Q^2 (\mathrm{tg}\,\alpha)^{1.67} \exp(-0.07V) \tag{2}$$

where k_s is a soil erosion factor, $k_s \cong 0.13$ (mm/month)$^{-1}$ for clay and sandy soils of the study area [23], Q is runoff (mm/month), α is a slope angle of the terrain, V is the vegetation cover fraction. Runoff is determined by the ratio of precipitation P (mm/month) and water retention in soil R (mm/month):

$$Q = \frac{(P - 0.2R)^2}{P + 0.8R} \tag{3}$$

where R depends on the table hydrological soil index C_s as [24]

$$R = 25.4 \left(\frac{1000}{C_S} - 10 \right) \tag{4}$$

The percentage of vegetation coverage V is generally considered to be proportional to scaled NDVI value square within the study area [25] and is easily calculated by multispectral imagery [26]:

$$V = \left(\frac{N_v - N_{v0}}{N_{v1} - N_{v0}} \right)^2 \tag{5}$$

where N_{v0} is NDVI threshold for open soil, N_{v1} is NDVI threshold for full coverage of vegetation,

$$N_v = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} - \rho_{red}} \tag{6}$$

Wind erosion is caused by the interaction of the structural soil particles from the ground-level air flow. A simplified model of wind erosion is given by [27]:

$$z_w \approx 0.059 (w - u) d_S^{-3.67} \tag{7}$$

where z_w is the quantity of wind erosion (mm/month), w is the near-surface airflow velocity (m/s), u is critical air flow velocity (m/s),

$$u = 3.202 + 0.025 d_S \tag{8}$$

and d_s is soil structural particles equivalent size (mm). The near-surface airflow velocity at a steady dynamic wind velocity w_0 is determined mainly by vegetation resistance [28]:

$$w = w_0 \exp\left(-0.0139V\right) \qquad (9)$$

The total soil erosion is a summation of (2) and (7) values.

To map land degradation of the study area calibrated multispectral images from medium resolution, Earth observation satellite systems can be used for the period of analysis. All multispectral satellite images must be undertaken with atmospheric correction and then converted to surface reflectance for each spectral band. The MSAVI F_v (1) index must be calculated, and its changes must be mapped. At the same time, the total erosion $z = z_s + z_w$ must be estimated and its changes must be mapped too. Required auxiliary parameters can be extracted directly from the input multispectral satellite imagery (fraction of vegetation cover), digital terrain elevations data (DTED—slopes), soil and climatic data [29, 30] (particle size distribution and hydrological parameters of soil, the average monthly rainfall, wind velocity profiles).

At the first stage of processing, time-series of satellite imagery-based classifications should be built. These classifications represent principally different land degradation indicators that are appeared in vegetation and soil erosion changes. At the second stage, the previously obtained partial first-level classifications should be fused into the resulting classification by data fusion methods [31]. In this study, Bayesian statistical inference can be applied as data fusion model [32]. Values obtained by fusing the partial classifications are subdivided conveniently into few classes. The first half of classes with negative values describes the negative changes of indicators which provide increasing land degradation risk.

The second half reflects the positive trends in land degradation indicators and shows a decrease in the risk of land quality deterioration. The special class must be reserved to map the territory where the evident changes did not occur during the period of analysis.

Thus, a hybrid two-level model for data fusion appears in land degradation risk mapping using remote sensing data and geospatial modelling: A few partial raster classifications are performed at the first level, and then, these classifications are fused into final map [33].

As relating to land degradation mapping, the geospatial model also has two levels. The model's first layer includes the spatial distribution of two main indicators of land degradation, namely trends in vegetation change and soil erosion. The model second layer provides the Bayesian fusion of the first-level data into the final map of land degradation. In detail, the geospatial model data flowchart is described in **Figure 3**.

At the model's first level, the data processing is performed in multiple concurrent threads to extract a temporal trends of land degradation indicators. For simplicity, **Figure 3** shows the multispectral imagery (*a, c*) and DTED (*b, d*) for the initial and final stages only. By the MSAVI (*e, g*), vegetation index maps the vegetation cover fractions (*h, j*) are estimated, and using additionally, the DTED and soil map (*f*) of territory the levels of soil erosion (*i, k*) are deter-

mined. At the model's second level, the partial classifications of trends in vegetation cover change (*l*) and soil erosion change (*m*) are fused into the land degradation final map (*n*) of study area.
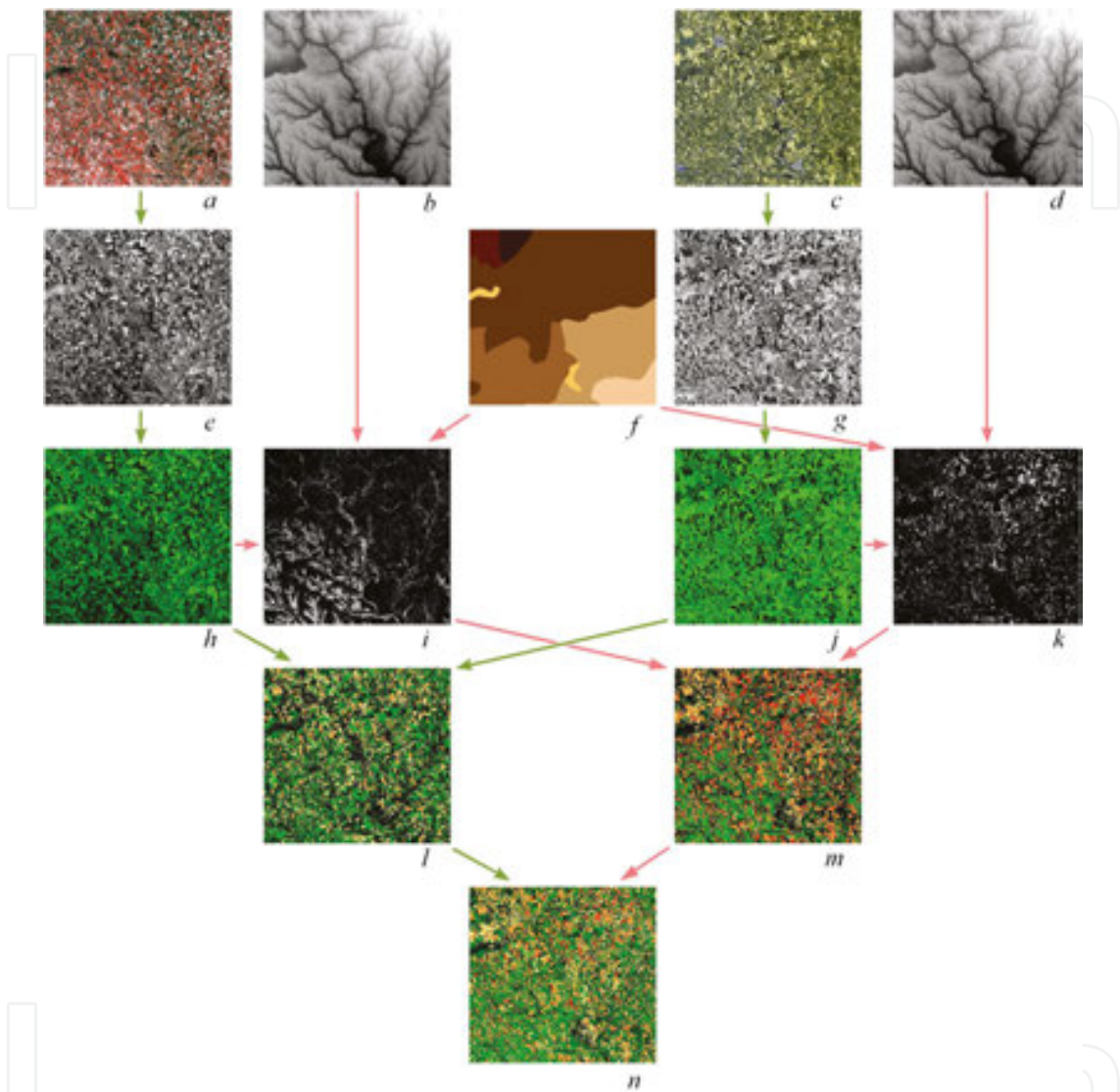

Figure 3. The land degradation mapping dataflow diagram.

7. Remote assessment of natural landscape degradation in the southern part of Ukraine

The research was carried out for parts of the Lower Dnieper Sands—Kozachelagerska and Oleshkovskaya arenas and Shelemensky sands located on the left bank of the Dnieper River in Tsyurupinsk and Golopristan districts of the Kherson oblast (**Figure 4**).

The Lower Dnieper Sands is a unique natural complex of forest–steppe. It is the greatest sandy area of Europe, restrained all around by largest artificial forest [34]. However, as a result of human activity and fires, changes in vegetation and forest cover and destruction of natural psammophyte communities are observed, which leads to increased erosion processes and may ultimately lead to a complete desertification of the area. The main factors of land degradation within the study area are water (about 78%) and wind (20%), erosions [35].
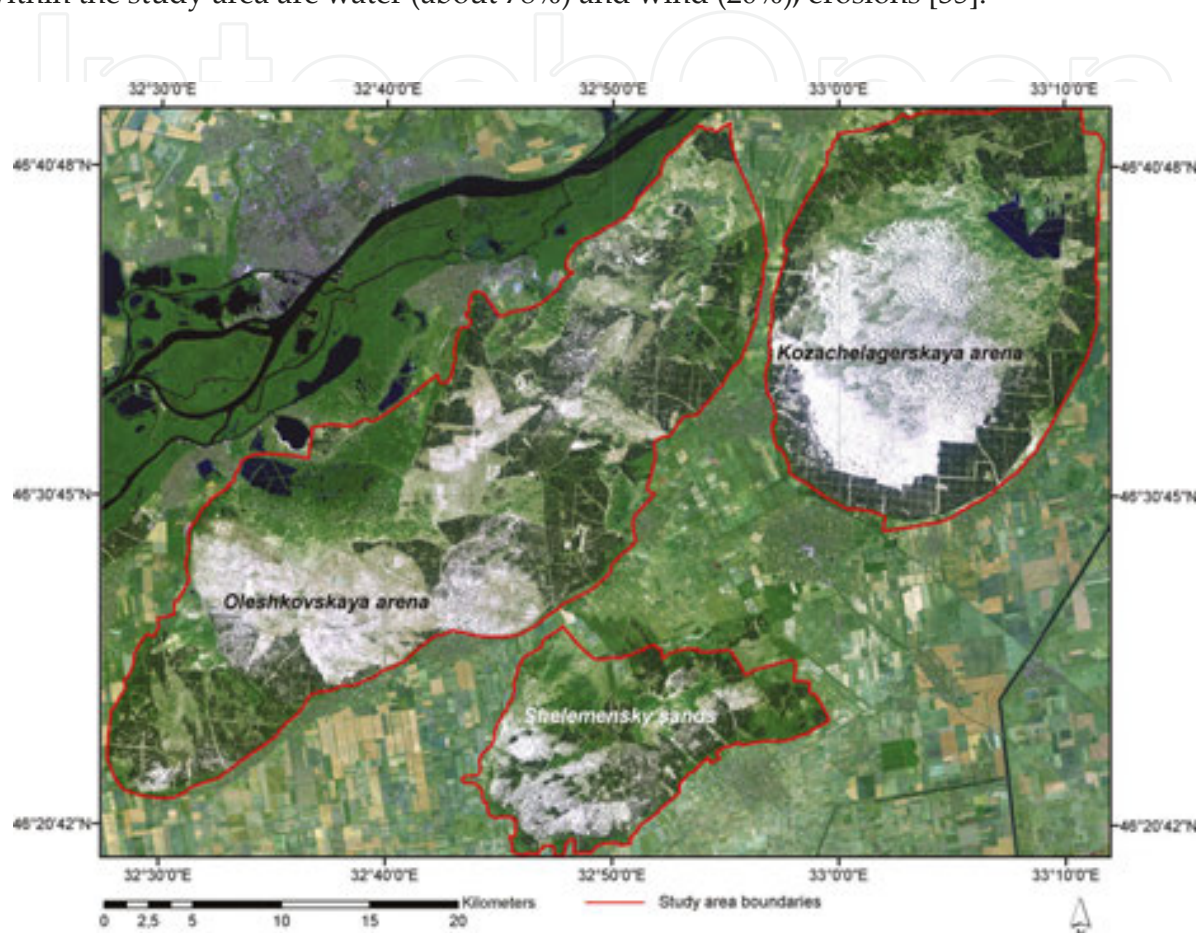
Figure 4. The research area located in Kherson oblast. The Landsat 5/TM scene from August 16, 2010 (RGB—321) shows three arenas of the Lower Dnieper Sands: Kozachelagerskaya, Oleshkovskaya and Shelemensky sands.

The resulting map of land degradation risk changes in the study area is shown in the **Figure 5**. Visual analysis of the map shows that, in general, the risk changes in land degradation are associated with changes in vegetation cover. During both periods under consideration, the degree of risk change was weak. A significant extension of the areas with increased land quality deterioration risk in the period from 1991 to 2010 is caused by the large-scale fires that took place in August 2007.

Thus, multispectral satellite imagery can be effectively used for studying land quality deterioration indicators as well as for change detecting the risk of degradation in vast areas during a certain period of time [36]. Furthermore, the use of satellite images allows not only cover a
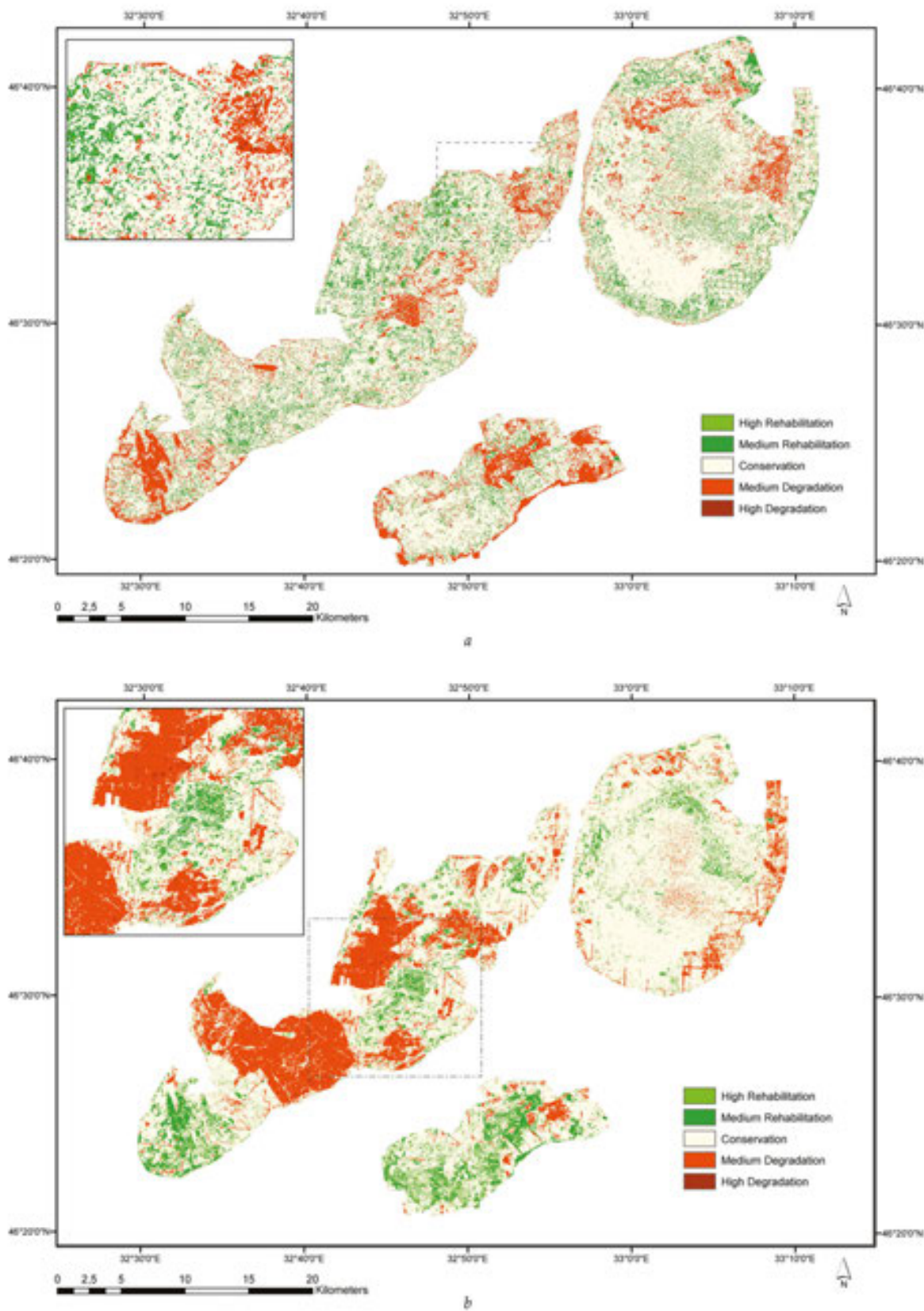
Figure 5. Land degradation risk within the study area for the periods: 1983–1991 (a) and 1991–2010 (b).

huge area of land affected by degradation and to establish reliable information from remote areas, but also significantly reduce the cost of the works on determination the land quality and its deterioration risks. In the future, the model proposed in this paper can be integrated in the geographic information system to support land management at the local and regional levels.

8. Arable land degradation in industrial area of south-eastern part of Ukraine

As it is known, the main sources of anthropogenic contamination are considered metallurgical and chemical enterprises, thermopower plants, and auto-transport. The arable lands within such industrialized areas are heavily degraded. As an example, let us consider the Dnepro-petrovsk oblast located in the south-east of Ukraine, where anthropogenic stress of different origin is apparently available.
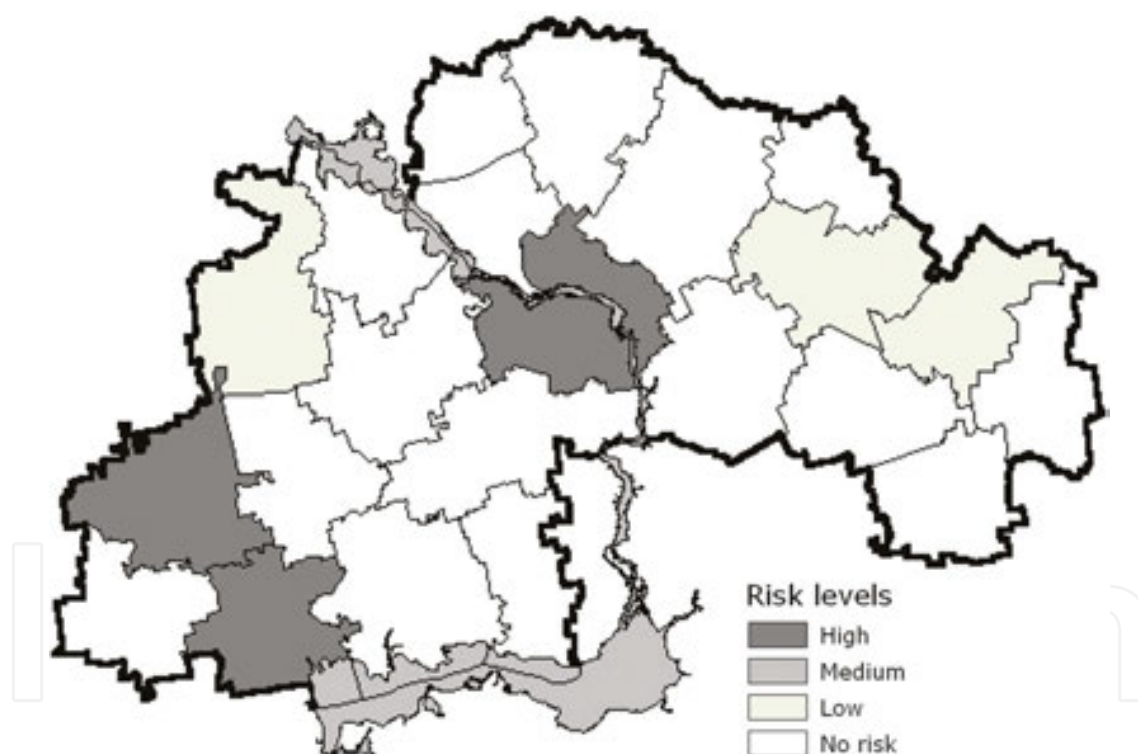

Figure 6. Integrated levels of anthropogenic impact on soil conditions within the Dnepropetrovsk oblast.

Agricultural chernozems here also suffer from erosion processes [37]. The humus accumulation regime is disturbed. As a result of ground ablation even of low level, from 0.5 to 2% of ordinary chernozem, humus content is lost. On the average for the oblast, the humus content used to be 5%, but this number is gradually decreasing to 3.7%. The average humus reserves in arable soil level are made up 120 tons/ha. Because of ablation, these reserves decrease up to 73–100 tons/ha.

Previous research [14, 37, 38] studied spread of water erosion and aerotechnogenic contamination on the territory of the Dnepropetrovsk oblast (**Figure 6**). Threaten condition for the small rivers ecosystems were emphasized. Surface layer washing out from the slopes led to water reservoirs silting-up, eutrophication, etc. [39]. The areas where agricultural works are worth carrying out are shown on the map. The soils here are the least subjected to water erosion and anthropogenic contamination, and so they are eligible for the safe crop growth.
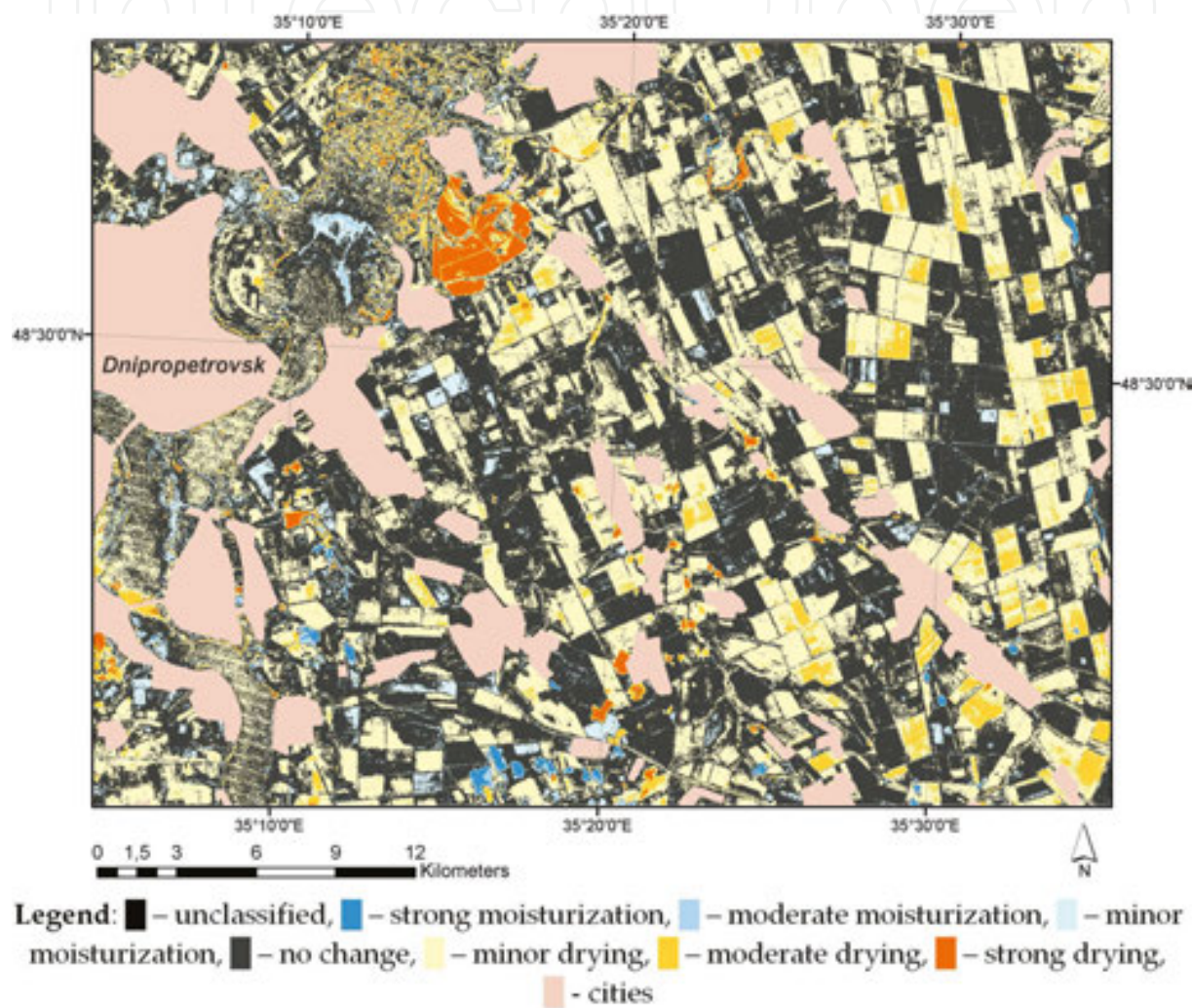

Figure 7. Soils moisture change within the left bank area of the Dnepropetrovsk oblast in 1988–2013.

Previous research [14, 37, 38] studied peculiarities of arable land degradation caused with several factors (arid climate, water and wind erosion, irrigation, salinization, old tillage systems application, acid rains, etc.). Additional environmental risks for the small rivers ecosystems were emphasized. In particular, surface layer washing out from the slopes led to water reservoirs silting-up, eutrophication, etc. [39]. Thus, all environmental risks of land degradation were taken in account to overlay them to select areas with four levels: high, medium, low and no-risk. High and medium levels of land degradation are the reason to

recommend a special phytoremediation and biomelioration measures. Low level of land degradation can be improved with low external input and sustainable agriculture.

Agricultural practices strongly depend on precipitation level. In the southern parts of the country, the amount of moisture in the soils remains one of the most important factors for the safe crop growth. To assess remotely the soil moisture, we used satellite imagery of Landsat-4,5/TM, Landsat-7/ETM+ and Landsat-8/OLI,TIRS with 30 m spatial resolution for the period 1998–2013. Registered at sensor radiance was recalculated into spectral reflectance of land surface taking into account the atmosphere influence—for visible, near, and short-wave infrared bands, and into the land surface temperature—for the thermal infrared bands [40]. Based on the ground measurements of the soil moisture on the test sites, the curvilinear regression relationship with remotely determined value $\ln(I_w/T+1)$ [41] was restored, where I_w = $\rho_{green}/(\rho_{green}+\rho_{swir})$—normalized water index, ρ_{green} and ρ_{swir}—land surface reflectance in green and short-wave infrared spectral bands, respectively, T—the land surface temperature. So, in this way, the soil moisture spatial distribution was mapped. Comparison of the remote sensing data and ground measurement results allowed us to study the soil moisture change within the left bank area of the Dnepropetrovsk oblast for the last 25 years (**Figure 7**).

Analysis of long-term change of soil moisture within the left bank of the Dnepropetrovsk oblast allowed us to elicit trends and to interpolate the results spatially. In particular, it was discovered that more than 50% of studied arable lands were in unfavourable conditions of different level drying.

9. Landscape degradation within mining area of central part of Ukraine

Mining is one of the most anthropogenic threats to the environment. The mineral deposits and operating mines are unevenly spread on the territory of the country. The Donetsk Basin in the south-east has large deposits of coal, while the east central area is rich in iron and uranium ores. Ukraine also has some of the world's largest manganese deposits, located in the southern Ukraine.

Mining industry stress promotes the creation of new elements in the landscape. These are refuse heaps of empty rocks, open pits, technogenic subsidence, disturbances created by technogenic accumulation—terricones, dumps, sludge depositories, etc. They are characterized by emergence of toxic rocks on the surface. Vegetation here is developed very slowly, and biocenosis is unstable. In case of the complete recultivation (deactivation of toxic rocks, formation of soil cover and remediation of phytocenosis), the secondary landscapes are formed.

The researched territory is called the Kirovograd uranium ore region and located in the central part of the Ukrainian Shield. It is subjected to a power pressure on the environment with consequent significant and often critical landscape transformations as a result of imperfect technologies and management. The mining development is accompanied by condemnation of considerable areas of fertile agricultural lands, predominantly chernozem. After temporal use,

the last ones are often transferred to a category of an anthropogenic desert. Next to each dumped fill of empty rocks, a risk zone is allotted (the first one is 200 m, the second one is 500 m) that leads to the significant loss of the land resources. Within such zones, the atmospheric air is polluted and the soils are salinized and waterlogged that makes impossible to use them in agriculture. Considerable areas are occupied with the solid wastes from reclamation industry, namely with ash dumps, storage tales, sludge pits. They have a significant amount of toxic elements that contaminate the atmospheric air, soils, surface and underground waters of neighbouring and remote landscape complexes.
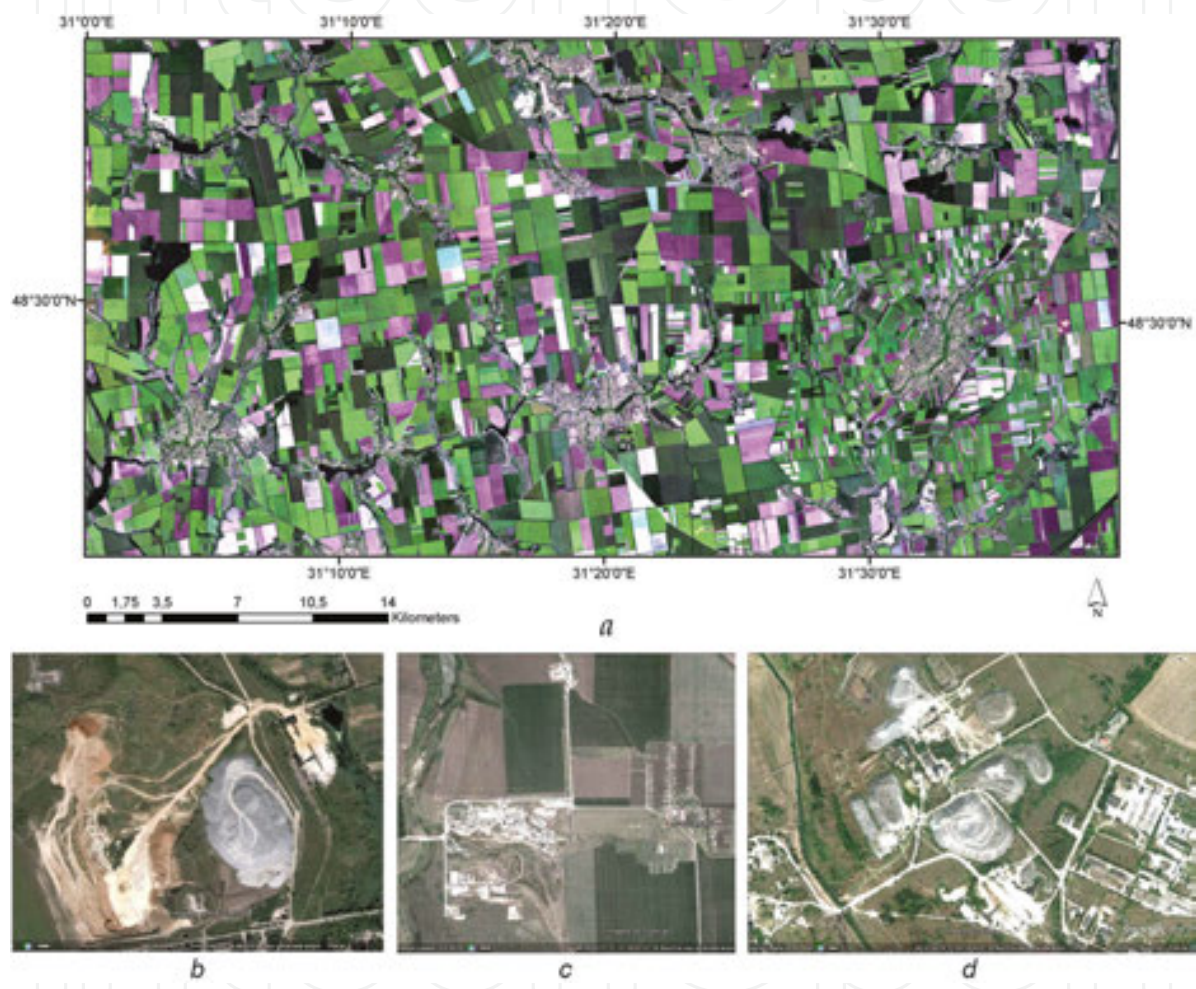

Figure 8. Study area source multispectral satellite image (Landsat-5/TM, 23.08.2010, 30 m resolution pseudo-natural colour composite, Kirovograd oblast, Ukraine) (*a*); high-resolution images of researched mines: Smolinska mine (*b*), Novokostyantynivska mine (*c*) and Ingulska mine (*d*).

The Ukrainian uranium deposits are characterized by a low content of uranium. Nevertheless, developed infrastructure of their mining and uranium concentrate production along with big sizes of uranium deposits, high thickness of uranium-containing rocks, relatively low water content in mining tunnels, relatively simple measure of radiation protection (because of low content of uranium in ores)—all these facts provide competitive capacity for the uranium concentrate on the market and thus stipulates the development of uranium mining [42].

To investigate vegetation cover and soil erosion processes as the most reliable indicators of land degradation, we followed the same technique as it is described above at Section 6. We used Landsat-5/TM multispectral images for the period 1992–2010 from Landsat data store (http://landsatlook.usgs.gov) through the Earth Explorer geoportal. DTED SRTM (http:// srtm.csi.cgiar.org) as of 1991 and ASTER GDEM (http://gdem.ersdac.jspacesystems.or.jp) as of 2010, soil map of the Kirovograd region, and climate characteristics by World Climate portal (http://www.climate-charts.com/Countries/Ukraine.html) were additionally involved into calculations. Source images that were used for further processing are shown in the **Figure 8**.
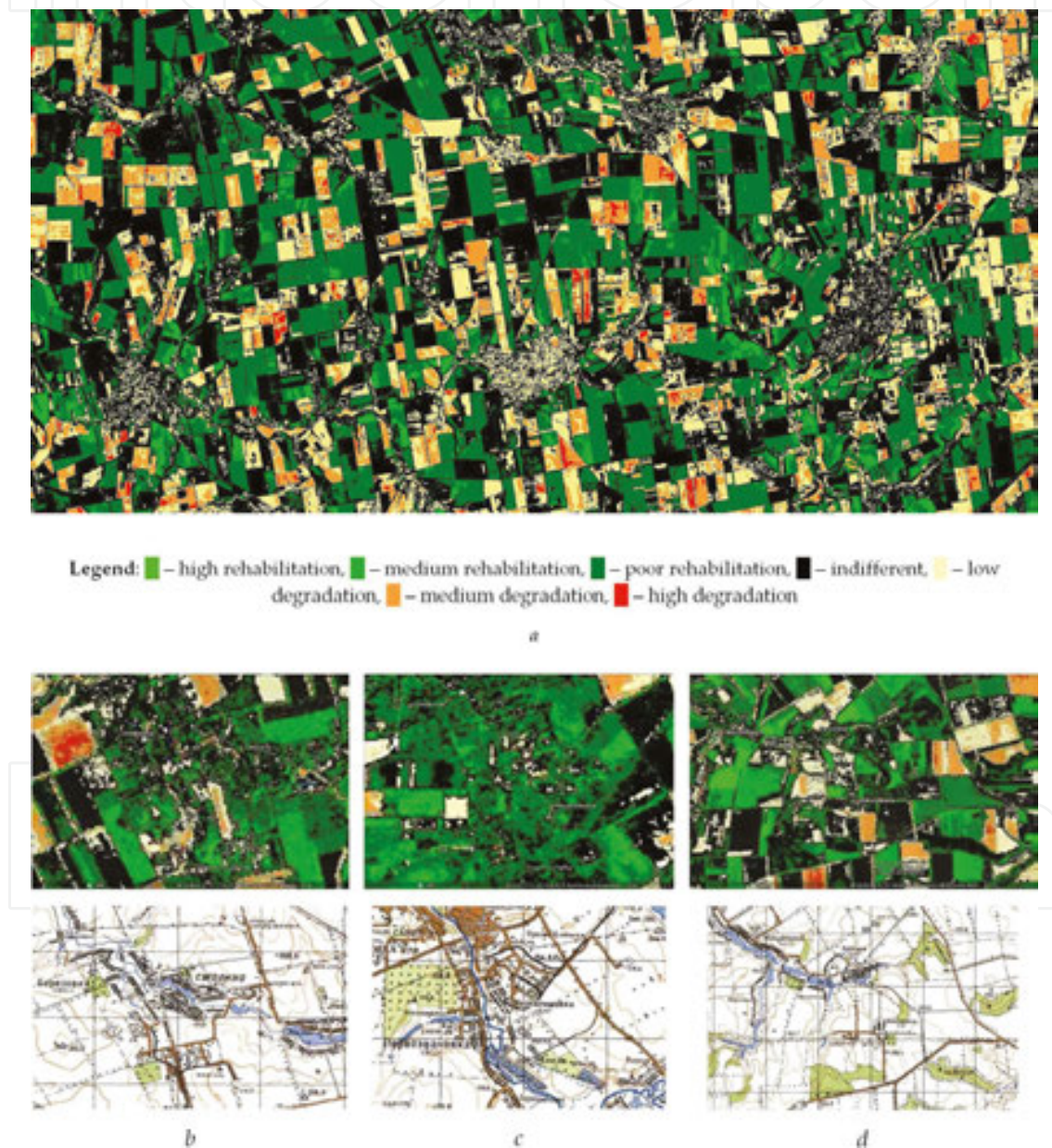

Figure 9. Mining area land degradation for the period from 1992 to 2010 (a); land degradation map within the Smolin-ska mine vicinity and the topographic base (b); c—land degradation map within the Ingulska mine vicinity and the topographic base (c), d—land degradation map within the Novokostyantynivska mine and the topographic base.

As a result of multispectral imagery processing, the land degradation map was obtained where seven classes of land degradation are depicted (**Figure 9a**) [43]. The areas of high degradation can be noticed within the territory of mine's infrastructure. But on the other hand, high level of anthropogenic transformation (the same yellow-orange colour) is also observed along the highway infrastructure and agricultural lands (overburden with unprecedented usage of fertile chernozem).

Negative and positive changes within the study area can be described for the period researched. The main part of the territory (around 35%) remains indifferent. These are urban areas of the Smolino town, woods and meadows around [44]. The same as we mentioned above for the Kirovograd ore region, high-degradation sites are observed in more detail on the arable lands perhaps due to crop rotation and poor management, along the small rivers and irrigated channels perhaps due to water erosion. The area around the mine itself is highly degraded which is understandable especially if to look at huge refuse heaps located nearby (**Figure 10**).

Figure 10. Refuse heaps of the Smolinska mine: directly next to the heap (a) and at a 200 m distance of from the heap (b).

The land degradation mapping technique on the basis of processing of a two-level model for multispectral satellite imagery can be used to investigate land degradation within human-inspired areas elsewhere, for example within energy facilities [45]. Let us consider the last example of the South-Ukrainian power-generation territory. This area where several energy facilities are located is considered as the one of high priority for further development of energy sector in Ukraine. Even though the environmental impact in this respect is expected to grow, the scientific research on impact assessment are being constantly held for the last time, their importance and new techniques development are always being brought to the agenda.

The aim of this study is preliminary assessment of land resource degradation within a radius of approximately 30 km around the South-Ukrainian Nuclear Power Plant (NPP) using multispectral satellite imagery and further development of geoinformation technologies for remote mapping of landscape changes.

In terms of physical and geographical location the researched area belongs to the Novo-Ukrainsk region of the steppe zone. The basic soil-forming rocks here are loess that determines formation of chernozem soils of different level salinity and humus content. Fertile chernozem soils were formed on Quaternary loess and loess-like loams within watershed divides and their slopes. Specific soil type called solonchak was formed within close location of high mineralized underground waters. Altogether around 60 different soil subtypes are found within the researched area. That is why auxiliary geospatial data were needed for remote land degradation research—digital terrain elevations, soil maps, climatic characteristics of study area, etc.
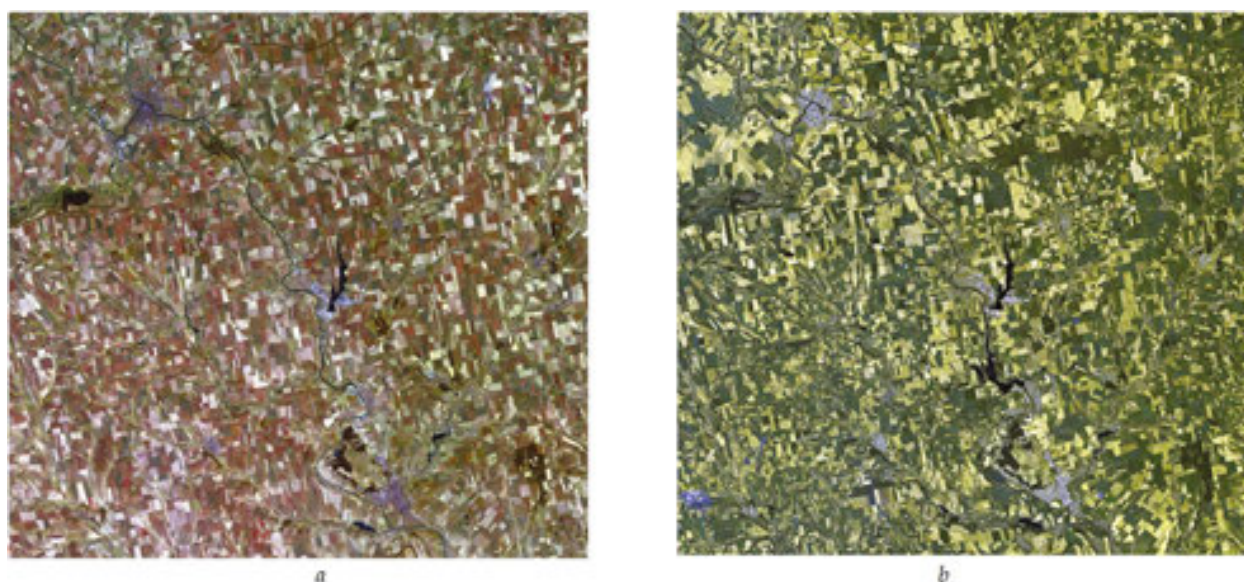

Figure 11. Study area source multispectral satellite images Landsat-5/TM, 24.08.1993 (a) and Landsat-8/OLI, 30.07.2013 (b); both ones are 30 m resolution pseudo-natural colour composite, Yuzhnoukrainsk, Ukraine.

In this case following the same technique, we used Landsat/TM and Landsat/OLI multispectral images of 1993 and 2013 correspondingly, obtained from the USGS Landsat Global Archive.

Thematic landscape changes maps obtained as a result of multispectral images processing (**Figure 11**), allowed assessing the state and trends in land degradation processes within the territory researched (**Figure 12**). The thematic map reflects the areas of low, medium and high degradation level. More than 40% of the territory within a radius of approximately 30 km from the NPP is subjected to anthropogenic impact of medium and high level [46]. These are mainly agricultural lands highly transformed due to crop rotation and poor management technique. The data demonstrate correlation between long-term industrial and agricultural impact and land degradation.

In all cases study, the research visually emphasizes the level of anthropogenic stress within the mining and energy facilities location and within arable lands around those facilities.
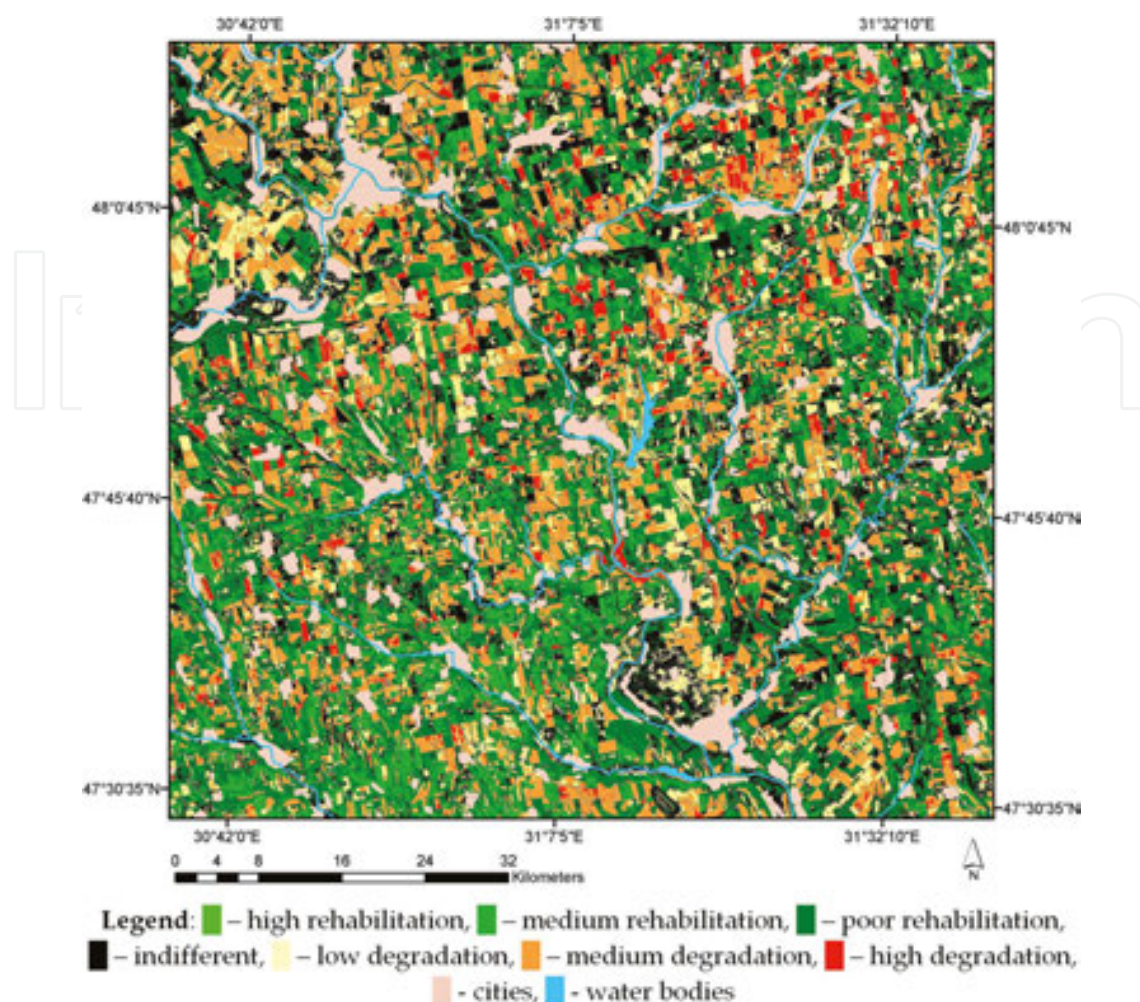
Figure 12. Land degradation map of the South-Ukrainian power-generation territory for the period from 1993 to 2013.

10. Conclusions

Remote methods introducing new dimensions into the study and understanding of long-term land degradation and desertification processes is of high priority for Ukraine because of their low cost, reliability and ability to cover large areas. Thematic landscape changes maps obtained as a result of multispectral images processing, allowed assessing the state and tendencies in land degradation and decertification processes occurred within landscape complexes under-gone different level of anthropogenic stress.

Data obtained visually emphasize the level of anthropogenic stress, impact of long-term change of vegetation cover and correlation of intensive development of mining, construction, agricultural and other human activities with high level of land degradation within investigated areas. Especially, it is obvious within the territories of mining activities of the Kirovograd region.

The transition to adaptive farming systems implies the achievement of maximum compatibility between soil and plant, development of crop rotation, soil conservation tillage system. Conducted research on the creation of adaptive systems of crop production takes into account the environmental, landscape, and geochemical peculiarities of the steppe zone of Ukraine, to get the production of environmentally safe agricultural products. They can be used in further studies of a differentiated approach to achieving a balanced potential of agricultural landscapes.

Remote detecting of degradation and desertification processes intensification at early stages will be able to promote further measures for improving the territories conditions. The further research has to be directed on development of geoinformation technologies for landscape changes remote mapping.

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