SATELLITE MONITORING OF FOREST OF THE CHERNOBYL DISASTER INFLUENCE AREA FOR ECOLOGICAL AND FIRE RISK ASSESSMENT

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ABSTRACT

The vegetation had a great role for localization of toxicants within the Chernobyl disaster area, and also it is influenced by impact of pollution. Therefore, the control of vegetation state is necessary for ecological investigations.The methodology is based on the vegetation spectral characteristic research in different spectral bands. Control of ecological state has been carried out using multitemporal multiband high resolution space images acquired from different satellites in 1980 - 1998 years. It had been solved two main tasks: - the evaluation of radionuclides pollution on vegetation state, - classification of forests composition and sanitary state. The vast ground truth data have been used for analysis of correlation dependencies. As a result of first task solution it was find that all species of vegetation are influenced by radionuclides. The most changes have been registered for pine-tree forests. The classification allows to indicate 21 classes of vegetation. The schemes of ecological state and fire risk of the region have been constructed. The results are verified by ground truth investigations.

1 INTRODUCTION

The use of space images is especially effective in areas of act of nature, ecological accidents, which cover significant territory, where the presence of the people should be limited. It completely concerns to the Chernobyl Exclusion Zone, where in the greatest measure influence of Chernobyl disaster was displayed.

The Exclusion Zone represents hilly, swamping plain, with net of river valleys, beams, closed hollows. It is covered with pine and deciduous forests, which occupy about 50 % of its area. The main forests in the Zone territory were and remain a pine, birch, alder, oak and aspen. The land use structure of the Zone has strongly changed after disaster. The forestation of former farmland occurs. The woods of the Zone have undergone to radiating defeat, are weakened by the centers of wreckers and illnesses. Last 3-4 years the bursts of development of wreckers of a pine are marked that conducts to accumulation of significant volumes dry trees and increasing of probability of occurrence of fires. For prevention of damage of woods by wreckers the air treatment will be carried out but the opportunity of occurrence again of bursts of the centers of wreckers remains enough high during 3-5 years after their first occurrence.The termination of cleaning of the forests considerably have increased risk of occurrence of fires. As a consequence especially significant areas of forests were damaged by fires in 1992.

On the basis of above-stated, main tasks, which cost with study of vegetation of the Exclusion Zone will be:
* Specification of borders of vegetative communities,
* Definition of sanitary conditions of forests,
* Definition of a degree of fire danger of territories.

2 METHODS AND RESULTS

2.1. Radioecological investigations

For study of radioecological conditions in the Exclusion Zone we used a method of fitoindication using remote sensing materials. It is based on the analysis of spectral brightnesses of vegetation composing basic plant of the Zone. As is known, between spectral properties of foliage and needles in narrow zones of a spectrum and conditions of vegetation growth there is a functional dependence (Cronberg, 1988, Lyalko etc., 1992).

The method of fitoindication of ecological conditions is operative and is economic. The presence of space images of the last years allows almost for 20 years to carry out comparative study of an ecological situation within the limits of the Exclusion Zone, that it is impossible to make by other methods. Initial materials for researches were multiband space images from satellites: " Kosmos", made 10.06.1980 by camera KATE-200; Landsat TM (16.04.1984); SPOT (6.05.1986); Landsat TM (29.05.1988); Resource, (27.07.1989), camera MK-4; SPOT (23.08.1995).

The analysis, executed in a mode of monitoring, using multitemporal space images, has shown, that for all kinds of vegetation dependence between spectral brightness in red and near infra-red zones of a spectrum and contents of ^{137}Cs in ground (are taken off from the map of V.A.Nagorsky,1992) has precise one dome character. Most precisely this dependence was displayed for a pine tree. Probably radionuclides have influenced the pigments of leaves, and a structure of crates. It is proved to be true by displacement in area of the increased meanings of spectral brightness of vegetation in all zones of a spectrum with increase of the contents of radionuclides in ground.

The maximal distinctions between abnormal and background meanings of a radio-activity soils, by the constructed diagrams, were observed in 1986, minimal - in 1995. The reduction of distinctions has taken place first of all at the expense of increase of background meanings, that is connected with horizontal migration of radionuclides.
For 10 years there was easing influence on vegetation, however to speak about complete its restoration there are no bases.

The dependences between spectral brightness of various kinds of vegetation and contents of ^{137}Cs in soils were used for an estimation of a radioecological condition of vegetation of the Exclusion Zone per different years and analysis of dynamics of changes of the environmental conditions. So, measurements of optical properties of vegetation on a multiband space images from "Resource" (27.07.1989 have allowed to construct the scheme of a radioecological condition of the Exclusion Zone. On the scheme the integrated influence of toxicants on vegetation for a period since 26.04.1986 to 27.07.1989 is reflected.

The largest area of intensive radionuclides influence on vegetation and of an adverse ecological condition is located in area of the Chernobyl NPP. Three zones are stretched from it , where the ecological conditions are little bit better. Within the limits of each of zones the sites with more and less favorable ecological conditions are allocated, which arrangement in many respects is supervised by the relief structure. Just a relief defined an arrangement of maxima and minima of the contents of the radionuclides and others toxicants in soils.

The zone in unfavourable ecological conditions, located to the south from Chernobyl NPP, spatially coincides with a known southern trace of disaster. The more adverse conditions, as well as increased contents of toxicants in soils are noted for valleys of the largest rivers, for northern edges of forests and for local raising in the relief.

The more favourable ecological conditions answer sites with the lowered contents of radionuclides and are characteristic of southern slopes of watersheds, southern edges of forests and large downturn in a relief. The ecological conditions of vegetation in a valley of the river Pripyat is weak distinguished. In general the advanced here vegetation has undergone by insignificant change as is submitted by grass, bushes and by deciduous trees, which are steadier against influence of radionuclides than pine.

The laws, noticed on the scheme, in distribution of radioecological conditions are well correlated with the contents of radionuclides and others toxicants in soils, that is established on the data of ground researches. However, constructed scheme is not simply copy of the map of soil pollution of the Exclusion Zone.

2.2. Classification of vegetation cover of the Chernobyl Exclusion Zone

For classification of territory we applied a program ERDAS IMAGINE (v. 8.2). For the forests control in the Exclusion Zone was used a multiband space image from the satellite SPOT-4 (France), in four channels: green in a range 500-590 nm, red (610-680 nm), near infra-red NIR (790-890 nm), and average infra-red (1600-1750 nm) acquired from 14.07.1998. It spatial resolution is 20 m. The size of view is 60x60 km, it covers a large part of the Exclusion Zone.

Initial signatures of separate classes of objects were created on the basis of ground study of forests of the Zone. The 65 test sites have been used which characterize the basic types of vegetation communities. The signatures of 21 classes of forests

vegetation and natural objects were generated, the estimation of signatures of these classes is carried out with the purpose of forecasting of reliability of results of different methods of the classification.

It had been established, that the most suitable method of classification of the given data is the method of the maximum likelihood. It is confirmed by the data of field observation. On the data of other researchers the method of the maximum likelihood also is one of the most productive for the classification of forest vegetation. The generalized results of classification of vegetation are given on figure 1.

The carried out researches allow to make the following conclusions.

A) The most successfully by all methods are defined: Pine ordinary, more old than 30 years; Pine ordinary, age is 15-30 years old; Pine ordinary, damaged by pine moth; the deciduous forests of different structure are enough reliably separated from pine.

B) There is the method of maximum likelihood more accurate for classification of deciduous forests with prevalence of separate kinds. With its help the forests with prevalence of an alder and planting of an acacia white, planting of a birch more young then 15 years, deciduous forests with prevalence of a birch are enough successfully allocated.

C) The following classes less reliably are allocated: the deciduous forests with prevalence of an oak and aspen, which can be sometimes referred to forest with prevalence of a birch; burned sites are badly separated from long- fallow lands;vegetation of flooded lands of the rivers by places does not differ from vegetation of long- fallow lands; garden vegetation poorly differs from plantings of an acacia white and consequently they were united in one class.

Thus it is possible to consider that the received results of classification are rather positive.

Taking into account, that a space image from the SPOT-4, which we used, was made in four spectral channels, it is logical to use similar NDVI normalized index, which will take into account spectral brightness in average infra-red (IR) and green (GR) bands. This index is : $I = (IR - GR)/(IR + GR)$.

For an estimation of indexes information capacity, the diagram (figure 2) was constructed, on which 16 classes of vegetation and their associations are submitted. The data of field observations were a basis for reference of vegetation to separate class. The modal meanings of spectral brightness in each band were used for indexes calculation.

The analysis of the diagram has shown, that from 16 classes, used for training, is enough confidently defined 8. It is the following classes: pine forests; pine forests damaged with pine moth; the mixed forests, which consist of pine and deciduous trees; the mixed deciduous forests, with prevalence of an oak, birch, alder; natural and artificial plantings of a birch and acacia; burned sites; vegetation of long-fallow lands and in flooded lands of the rivers.

The artificial and natural planting by a pine by age till 15 years considerably differ from pine forests. The increase of indexes in a chain oak - birch - acacia - alder is marked. The sites of pine forests damaged by pine moth differ from all classes of pine forest. The burned sites are defined better on the indexes then on spectral brightness.

Thus, the carried out researches have shown, that vegetation indexes give the useful information, which is expedient to use for classification of vegetation together with meanings of spectral brightnesses. The above mentioned methods were used for definition of sanitary condition of pine forests and natural fire danger of the territory of the Exclusion Zone. The ecological state of pine forests of Chernobyl Zone is determined , besides of radionuclides pollution, also by wreckers, first of all by pine moth, pine fungus and by hydrological regime changes. This factors reflected in spectral characteristics of the vegetation have been fixed on the image.

To assesses natural fire danger of vegetation cover within of Chernobyl zone it has been used the classification of combine image, constructed using index NDVI, which reflect vegetation state and biomass and pixel values of image from SPOT-4 in infrared chanel, that indicate amount of water in plants. The classification of this new combined image allows to construct the scheme of fire risk of central part of Chernobyl Zone, where the landscapes are divided on three classes according to degree of natural danger of fire. The forest damaged by pine moth are the most dry and dangerous. The squires covered by leaves forest first of all by alder forests are the least dangerous. Others territories occupied intermediate position (figure 3).

0   2   4   6   8   км

■ water		forestation of long –fallow lands and bottom lands
■ pine forests		meadows
■ deciduous forests		sand, bare soil, industrial plots
■ pine firests, damaged by pine moth		test site, see figures 4 and 5

Figure 1. The scheme of classification of vegetation of the Exclusion Zone

To improve thematic interpretation of space images, it was developed new approach of determination of analog of red edge position (REP) of spectrometric curve using data of multiband image from SPOT-4 in Green, Red and NIR bands. It was determined analog of REP for 8 test sites of different forests with healthy and damaged vegetation within the Chernobyl Exclusion Zone. The average values of pixel values in every band and for every site have been identified for REP evaluation. The results are presented in the table 1.

NDVI x 10³
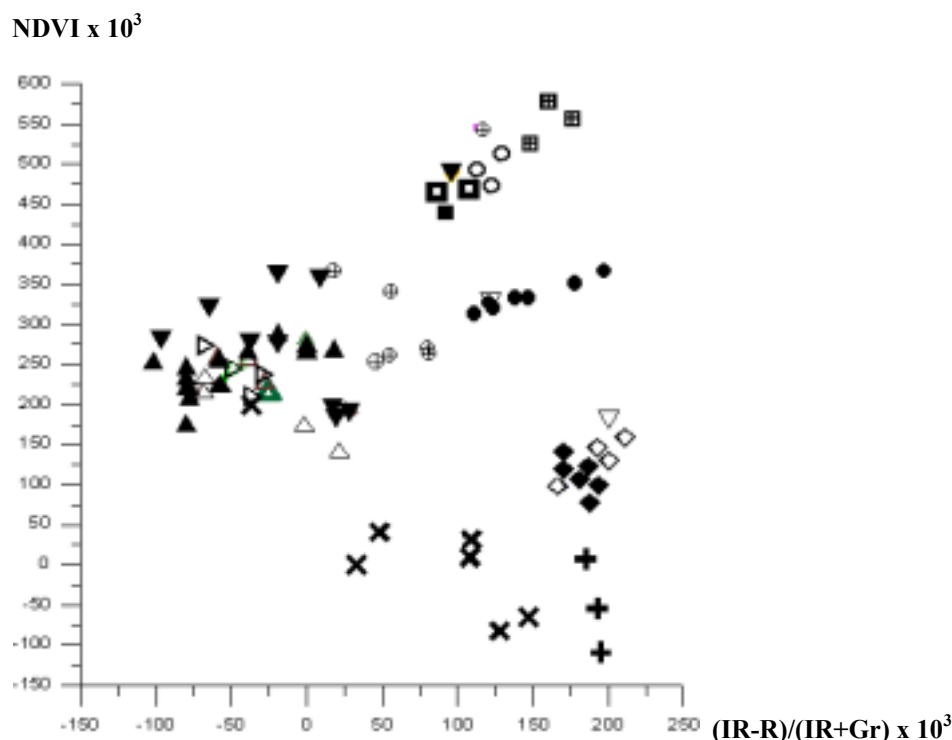
△ - The pine forests are more old than 60 years; ▲ - The pine forests are 30-60 years old;

▷ - The pine forests are 15-30 years old; ▽ - The pine forests are more young then 15 years;

▼ - The forests, in which pine occupies 70-90 %; ✖ - The pine forests, damaged by pine moth.;

⊞ - The forests with prevalence of alder , ■ - The forests with prevalence of oak;

○ - The forests with prevalence of birch which is more old then 15 years;

■ - The sites of long-fallow lands with planting of a birch more young then 15 years;

⊕ - The mixed pine and deciduous forests, ● - The mixed deciduous forests; ✚ - The burned sites;

◇ - The vegetation of long-fallow lands; ◆ - The vegetation of flooded lands.

Figure 2. The diagram of distribution of vegetation indexes of different vegetative communities

According to presented data, the values of REP for healthy sites change from 722 to 725 nm, about 716 nm for forests damaged by root wreckers, and about 707 for forests damaged by pine moth. The fixed "blue shift" confirm the potential possibility of REP to be indicator of fitosanitary state of pine forests. New method of REP identification, used for image (from SPOT-4) processing, allow to produce REP-images of vegetation cover of the Earth. One of the example of REP image is shown on figure 5.

Thus, it was found the new method of identification of vegetation stress and monitoring of fitosanitary state of pine forests within the Chernobyl Exclusion Zone using Images from SPOT-4.

CONCLUSIONS

As a result of the carried out researches the various questions of methods of an estimation of radioecological conditions and classification of vegetation of the Exclusion Zone were decided.
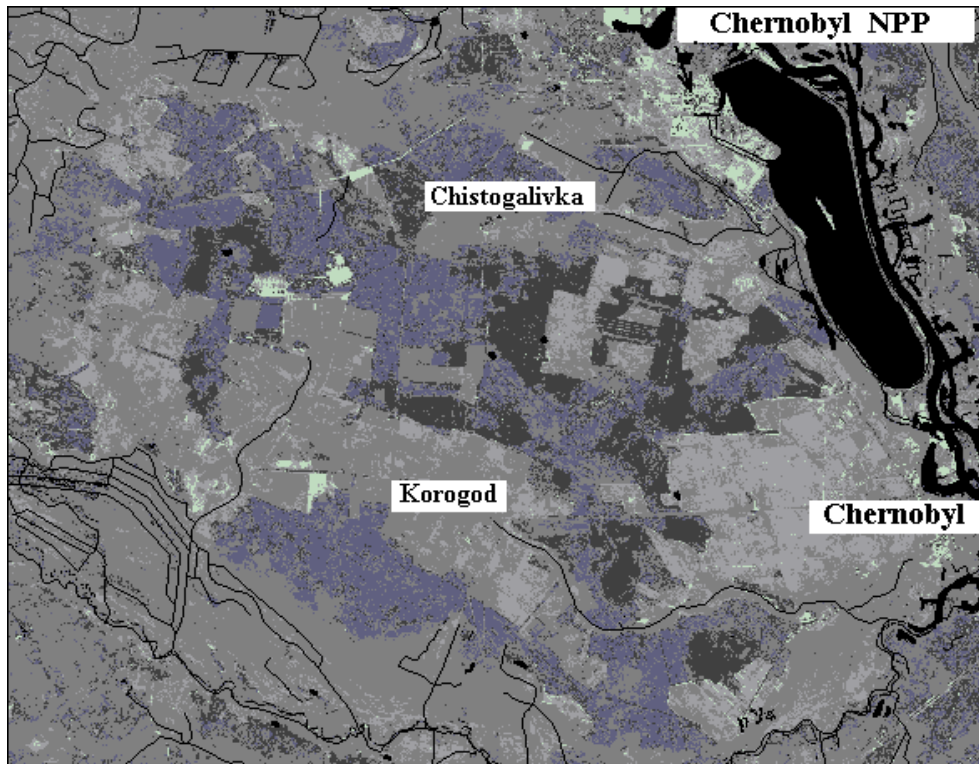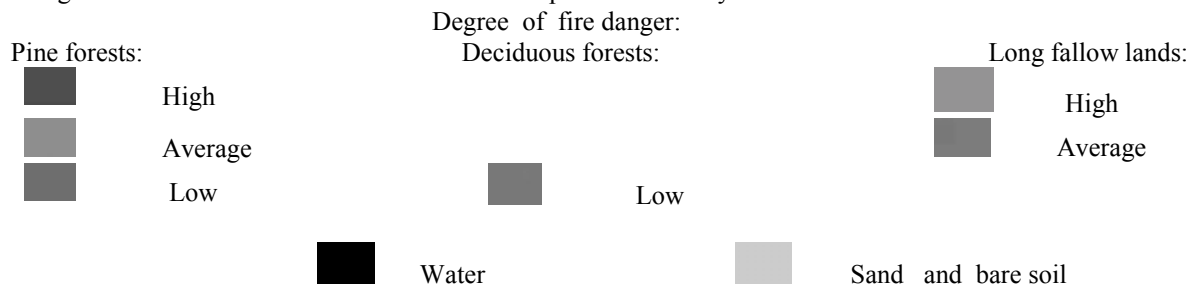
Figure 3. Scheme of natural fire risk of central part of Chernobyl Zone

Degree of fire danger:

Pine forests: Deciduous forests: Long fallow lands:

High   High

Average   Average

Low   Low

Water   Sand   and bare soil

The comparative analysis of changes of radioecological conditions in Chernobyl NPP area for the period 1984 - 1995 has shown:

- the station rendered appreciable influence on ecology of area and before disaster;
- the radionuclides have rendered the greatest influence on pine forests, smaller - on deciduous and still smaller - on grassy vegetation;
- the influence of consequences of disaster on pine forests is displayed till now;
- for 10 years from the moment of disaster, the gradual cleaning of an environment from radionuclides pollution has taken place, but thus a level of a radiating background appreciably has increased;
- even low, less than 10 Ci/km^2, the contents of ^{137}Cs in soil render appreciable influence on spectral brightness of vegetation and are fixed on multiband space images;
- in view of terms of vegetation, it is necessary to consider the end of May - June as optimum terms of realization of multiband space survey of the Exclusion Zone, with clouds no more than 5 %, at midday o'clock;
- the proposed methods allow to receive comparable results on space images from different satellites   with the specific equipment, acquired in different time and under various weather conditions;
- the use of remote sensing materials allows in tens time to reduce expenses for realization of radioecological researches due to reduction of volumes of ground works, which would be done more teleologically and operatively within the significant areas;

- the developed methods of processing of multiband space images are applicable for an objective estimation of influence of Chernobyl accident at any moment of time on ecological conditions, both within Ukraine, and in the countries of Europe and for the control of influence of NPP , buried radioactive wastes, influence of thermal power stations and others industrial objects on an environment.
- for classification of vegetation, using program ERDAS IMAGINE, most suitable is the classification with training, which is carried out using the method of the maximum likelihood. It best answers the data of control points of supervision.
- it is offered new normalized vegetation index and the graphic dependence is constructed which evidently demonstrates distinctions between separate classes of vegetation on a basis of vegetation indexes, that can be used for improvement of results of classification.
- the new approach were used for construction of the scheme of the sanitary conditions of forests of the Exclusion Zone and estimation of natural fire danger of vegetation.
- it was developed new approach of determination of analog of red edge position (REP) of spectrometric curve using the data of multiband image from SPOT-4 in Green, Red and NIR bands. Thus, it was found the new method of identification of vegetation stress and monitoring of fitosanitary state of pine forests within the Chernobyl Exclusion Zone using images from SPOT 3/4.

N	Vegetation Type	Pixel values (satelitte data)						Number of Measurements	Analog of REP (nm)
		Gr (500-590)		Red (610-680)		NIR (790-890)			
		Aver.	Stand.Dev.	Aver.	Stand. Dev.	Aver.	Stand. Dev.		
1	Pine forest More then 25 years old	54.33	1.48	38.86	2.02	68.10	8.10	6930	719
2	Pine forest 15 – 25 years old	57.33	2.16	43.22	3.10	69.37	6.30	693	719
3	Planting of A pine	64.16	1.46	49.60	1.87	97.29	3.24	129	725
4	Pine-trees on unfavourable places	55.38	3.27	41.63	4.56	59.84	8.41	667	716
5	Pine-tree damaged by pine fungus Root wreckers	56.36	2.01	42.75	3.58	59.98	8.05	1492	716
6	Pine-tree damaged by pine moth	58.62	1.78	48.49	2.65	49.93	5.06	1103	707
7	Regeneration of pine tree	66.57	2.99	56.81	4.21	81.17	9.58	3466	722
8	Mixed pine and leaves forests	52.53	1.36	35.33	1.42	101.83	13.45	1028	728

Table 1. - The statistic characteristics of pixel values of forests and values of analog of REP for test sites within the Chernobyl Exclusion Zone (image from SPOT-4 , 14.07.1998)
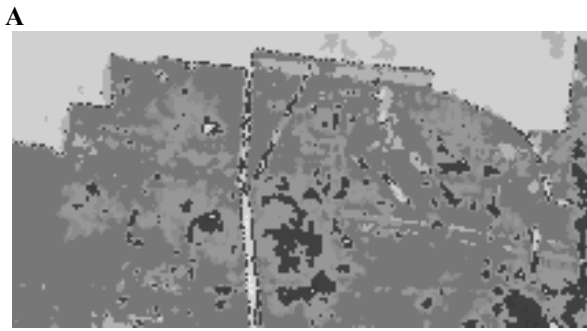
A

B

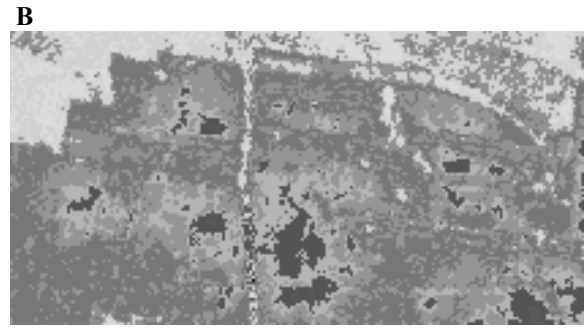Figure 4 – Fragment of classification image of fitosanitary state for test site   (A)

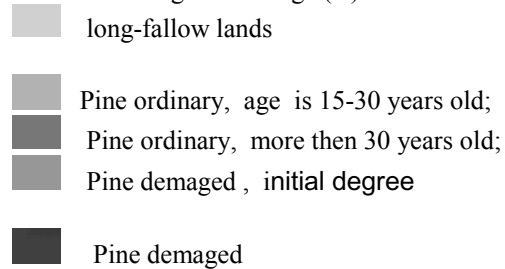Figure 5 - REP-image of test-site   (B)

Conventional signs for image (A)

long-fallow lands

Pine ordinary, age is 15-30 years old;

Pine ordinary, more then 30 years old;

Pine demaged , initial degree

Pine demaged

Conventional signs for image (B)

value of REP analog   more then 728 нм

REP analog from 725 to 728 нм

722   -   725 nm

719   -   722 nm

716   -   719 nm

713   -   715 nm

less then 713 nm
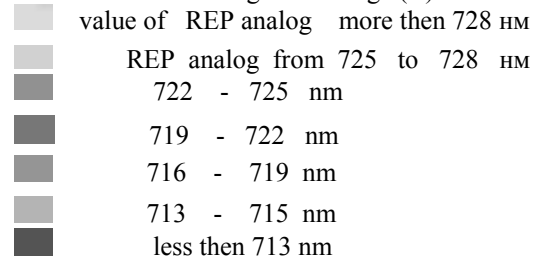
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