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ПРИМЕНЕНИЕ СПУТНИКОВЫХ СНИМКОВ ДЛЯ ОЦЕНКИ УСТОЙЧИВОСТИ ЭКОЛОГИЧЕСКОГО БИОРАЗНООБРАЗИЯ ЗАБОЛОЧЕННЫХ ТЕРРИТОРИЙ АРКТИКИ

П.А. Леменкова

Карлов университет, Институт экологических исследований, Чехия, Прага, pauline.lemenkova@gmail.com

Представленная работа рассматривает экологические проблемы уникальных экосистем п-ова Ямал на севере центральной части России. Физико-географически, территория представлена распространением покрова мохово-лишайниковых тундр в условиях вечной мерзлоты. Глобальные экологические изменения и климатические вариации, способствуют деградации ценных ландшафтов окружающей среды тундры, увеличивает активность криогенных процессов и способствуют деградации биоразнообразия. Статья представляет обзор локальных экологических аспектов, вызванных процессами изменения климата на п-ве Ямал, в т.ч. анализ воздействия склоновых геоморфологических процессов на окружающую среду тундры. В работе подчеркивается необходимость бережного и щадящего внешнего воздействия на окружающую среду в условиях тундры, благодаря крайне специфическим экологическим условиям местной природы, имеющей природоохранную ценность планетарного масштаба.

Ключевые слова: Арктика, заболоченные территории, спутниковые снимки

THE USE OF SATELLITE IMAGES FOR ASSESSMENT OF ENVIRONMENTAL VULNERABILITY AND RESILIENCE OF THE ARCTIC WETLANDS

Lemenkova P.

Univerzita Karlova V Praze, Pшнrodovмdeckб Fakulta, Praha, Иeskб Republika,

pauline.lemenkova@gmail.com

The research paper focuses on the environmental problem of Yamal region, geographically located in the Russian Yamal-Nenets autonomous region, northern-central Russia. This region is characterized by the unique nature and environmental conditions, combining two physical-geographical regions: sub-Arctic and Arctic moss-lichen tundra and permafrost conditions. The recent changes in global climate and overall warming highly contribute to the degradation of the tundra environment and increases cryogenic slope processes. This paper focuses on the investigation of the ecological aspects of the global climate change in Yamal peninsula, and analysis the development of slope processes on the local tundra environment.

Key words: Arctic, wetlands, satellite images

The Russian Arctic tundra is a very specific ecoregion of our planet, highly important for the world environmental heritage. Lots of tundra species have only circumpolar spread. Arctic ecosystems have complex structure with functional linkages between soil and plant communities, highly adapted to the polar climatic and environmental conditions. Thus, the biodiversity in Yamal tundra is in general low, with limited taxonomic diversity of plant communities [17]. There are only 26 mammal species, 32 species of valuable fishes (with up to 70 % of Russian salmon) and 186 species of mostly Arctic spread birds [10]. Major role in the functioning of Yamal ecosystems plays reindeer, lemmings and arctic fox.

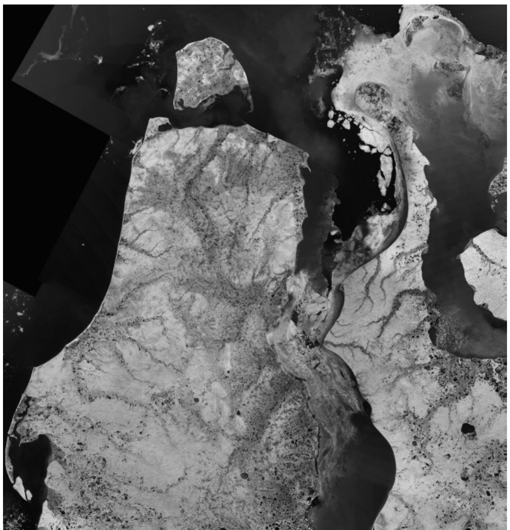

Figure 1 – Yamal Peninsula: a mosaic of color composites of Landsat TM satellite images

The Yamal peninsula occupies low plain, so that the relief of the region is almost completely flat with dense river network, which leads to the seasonal river flooding and active erosion processing that intensify local landslides formation. The adjusting shelf area of Kara Sea is also shallow: almost 40 % of the continental shelf is no deeper than 50 meters, and the sea coasts are mostly flat, flooded during the high tide [12]. Located in the area of permafrost distribution, the soils in the region are frozen for the most of the year, with the depth of the frozen soil reaching up to 0.2 m in the north and 2 m in the south [12]. In such conditions the processes of superficial cryogenic landslides are especially active. The distribution of the permafrost serving as a shear surface for sliding highly contributes to the landslide formation. Therefore, the cryogenic landslides developed on the fine-grained, saline marine sediments, occupy almost 70% of the area [28].

The ecosystems of the region are highly adapted towards specific environment of Arctic. The development of permafrost results in scarce vegetation coverage in general and landslides also change local landscapes and vegetation cover. Thus, several years after the landslide formation the vegetation coverage changes gradually, being dominated by grass, moss, lichen and shrub, then by sedge and finally by willow meadows [29]. As a result, landslide-affected areas of bare slopes are usually occupied by willow shrubs, which can serve as an indirect, yet reliable, indicator for former landslide processes, which happened in this area [25]. Moreover, different stages of the vegetation coverage may provide additional information about the possible age of the landslides. Thus, early-stage vegetation, such as primitive mosses or lichens, could indicate recent landslide formation on this surface, while distribution of meadow and willow shrubs with high canopy points to the final stage of the landslide activities. Besides type and age of vegetation coverage, the salinity of ground waters as well as sediment chemical content indicates the relative age of the landslides.

The sustainable functioning of such unique ecosystems is highly adjusted towards climatic-environmental settings. Recent changes in the climate patterns may result in serious alterations in the structure of tundra ecosystems. The environment in the Kara Sea area is mostly influenced by the Arctic climate conditions, which had several fluctuating changes since past time [1], [20]. Nowadays, the processes of global climate warming have severe threats to the tundra environment [6], [7]. Since early 1980s the processes of Arctic warming activated and included meteorological changes (precipitation level, permafrost and snow cover depth) and increase of greenhouse gases percentage in the atmosphere [16]. This naturally triggered certain changes in the vegetation coverage. Namely, climate change causes "greening" effect in Arctic, i.e. unnatural increase in vegetation growth, primarily of willow (Salix lanata L.) [31]. The significant increase in willow growth, height, cover, abundance and shrub ring width is detected in the last 60 years, which perfectly correlates to the overall increase in summer temperatures for the same period [14]. Similar results are reported by [26], demonstrating that growth of the willow shrubs and air temperatures are closely connected, so that the shrub growth serves as a good indicator of the climate change in Russian Arctic.

Besides natural factors, the anthropogenic activities, mostly connected with exploration of hydrocarbons [21], contribute to changes in tundra ecosystems. The continental shelf of Kara Sea is the largest Russian national reserve of hydrocarbons, primarily oil and gas [19]. Therefore, the anthropogenic pressure on this region is high, and Arctic complex ecosystems are highly susceptible to the industrial and technological impacts, as well as to the climate change. At the same time, the environment of the high north has high environmental vulnerability, low resilience towards external impacts, as well as low capacity to respond to the external environmental impacts [15]. Namely, specifically for the Arctic region, the natural recovery of the damaged landscapes becomes a very slow and difficult

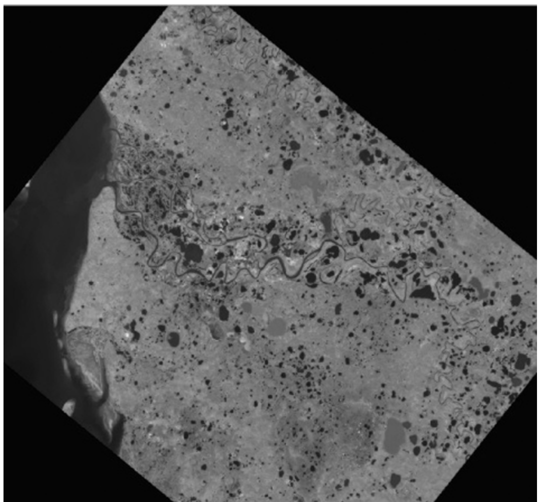

Figure 2 – Illustration of the tundra wetlands: a view from space (Landsat TM scene)

process, due to the above mentioned climate factors. Thus, seasonal thawing of the permafrost triggers dangerous geomorphological processes, e.g. thermokarst, thermoerosion, solifluxion and erosion [30]. As a result, the impacts of socio-technological negative processes on the Yamal landscapes become reinforced by the natural factors in Arctic climate, which finally leads to the drastic changes of tundra landscapes. Consequently, it may have serious consequences for the overall sustainability of polar tundra ecosystems. Needless to say that careful, recovering and responsible use of natural resources in the Russian Arctic tundra should be the priority way of anthropogenic activities in this unique region of our Earth.

Vulnerability is a multidisciplinary concept, broadly used in various scientific branches. As defined by [18], "the vulnerability is a function of the sensitivity of a system to changes in climate (…) adaptive capacity (…) and the degree of exposure of the system to climate hazards". Thus, the vulnerability is composed of three main components: the risky event, the risk responses and losses. The concept of vulnerability is the basis in studies of natural hazards risk assessment. Thus, since late 1960s the studies on risk assessment show that destructions and devastation caused by the hazardous events are a function of socio-economic vulnerability. Consequently, the events of natural hazards are not necessarily hazardous if the social vulnerability is low. Conversely, when natural event affects and threaten infrastructure and human lives, it becomes more or less hazardous [34]. People may also create hazardous circumstances when transforming the environment into natural resources for economic and social purposes [12]. Another point in the vulnerability evaluation is the concept of risk perception. Depending on the variety of factors, people sharing the same threat may perceive the same risk in a different way [34]. In summary, the impact of the hazardous event on the elements at risk can vary from slightly damaged to partially destroyed and totally lost. The variation of the expose of the elements at risk can be expressed as their vulnerability, which is a degree to which a system or a part of a system may react adversely to the occurrence of the hazardous event. The factors determining vulnerability in the context of landslide hazards are volume of slide, type of landslide, mechanism of slide initiation and velocity of sliding [2].

The methods of vulnerability assessment include estimation of the vulnerability degree at accepted scale "0-1" where most resistible elements receive "0- vulnerability", and the elements which collapse during the hazard are classified as "1-vulnerability". Environmental vulnerability has implications for the vulnerability of inhabitants and population and can also affect agricultural production and lead to serious changes in the land use types. Thus, vegetation destroyed by the natural hazards, such as landslides, may expose soils to erosion. Excessive use of firewood for fuel may lead to desertification and over-intense land-use and intensifies soil erosion [24].

Although the vulnerability of the elements at risk is important characteristics for the comprehensive risk assessment, and the overall risk can be sharply mitigated by reducing the vulnerability, the assessment of the vulnerability of elements at risk towards landslide risk has been done in very few works previously [3], [13], [27], [4]. The main reasons for this are complexity of the vulnerability assessment, as well as data availability. It is often difficult to analyze vulnerability objectively, as landslides vary in origin, structure, size and speed, and consequently, may cause various levels of damages, from insignificant to devastating. Therefore, the vulnerability assessment contains many uncertainties and current research focuses on GIS based spatial analysis of landscape changes, caused by landslides hazard disaster.

Impacts from climate change and anthropogenic activities may lead to changes in land cover types and degradation in vegetation coverage in Yamal. For example, there is a considerable increase in the tundra shrubs including willows [28], [29]. The northern ecosystems, such as Yamal, have low resilience and capacity to respond to external environmental impacts [15], because the processes of the natural recovery of the damaged landscapes are slow down under conditions of northern climate. As a result, the negative impacts on the northern environment may become reinforced.

The concept of hazard has been first mentioned in works on social and human ecology in 1920, so that the history of its development goes back to 1940s in the U.S. Now it is accepted that hazard is an interaction between two systems – environment and human society with their belongings as seen from the human point of view. According to the definition [32], hazard is a "potentially damaging physical event… that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation”. Comparing to other types of natural hazards, such as earthquakes and floods, landslides are often underestimated [4]. However, landslides may lead to serious damage of the infrastructure and the environment. Landslides are hazardous and detrimental natural phenomena, which occurrence is difficult to predict and map, due to the uncertainty, caused by many factors, e.g. types of movements, forms and shape, etc. Landslides negatively affect surrounding landscapes and cause changes in vegetation coverage [30]. Different types of landslide movements exist, varying in origins and types. Landslides may differ in age, size and ground material [8]. The great variety of landslide types is caused by different environmental conditions of their formation. Thus, there are four defined general types of landslide movements [23]: pre-failure movements, or small displacements including progressive creep of soils, failure, post-failure movements, i.e. the remaining movements after the event and the reactivation of the landslide. Respectively, four types of hazards are specified [22], according to their types of movements: 1) Hazards associated with pre-failure movements; 2) Hazards caused by the main phase of movements; 3) Secondary hazards generated as a consequence of movements; and 4) Hazards associated with subsequent movements (i.e. reactivation). The landslide hazard zones are identified as areas where landslides occur with high frequency and low magnitude, medium hazard zones have low frequency of landslides, and the least hazardous zones have low frequency and magnitude of landslides [33]. In this study effects of cryogenic landslides on the environment are analyzed. Landslide hazards, including cryogenic, are associated with variety of types, caused by various triggers and differing in age, size, speed and material.

It is accepted [9] to classify the mechanisms of the landslides into five various types: falling, the detachment of soil from a steep cliff with material falling down through the air, toppling, a forward rotation of a material out of a slope, spreading, the extension of a cohesive soil into softer underlying material, flowing, the turbulent movement of a fluidized mass over a rigid bed, and sliding, a downslope movement of a soil on surfaces of intense shear strain.

The assessment of the areas of all land cover classes shows following results. Willows covers 2750,57 ha in 2011, which is more than in 1988, when it covered 1547,52 ha (both ’tall willows’ and ’willows’ classes). Noticeable is increase in tundra vegetation: ’short shrub tundra’, ’sparse short shrub tundra’ and ’dry short shrub tundra’ have more areas covered in 2011 comparing to 1988: almost 5442,00 ha vs 1823,00 ha. Increase of wooden vegetation class goes along with shrunk of grass and heath areas: ’dry grass heath’ occupied area of 3335.39 ha in 1988, while currently it covers 1204.94 ha. Slight decrease can be noticed in the ’peatlands’ and ’wet peatlands’ classes: 3958.40 ha against 2765.41 ha in 2011 by ’wet peatlands’, and 625.71 ha in 1988 versus 488.69 ha by ’peatland (sphagnum)’ class. Resuming this work, the following conclusion should be done. First, landslides affect environment, cause negative impacts on the ecosystems and make changes in vegetation coverage. Second, climate change also affect land cover types, since there is a trend towards increase of woody vegetation, which is not typical for high latitudes.

The material involved in landslides can be rock, debris and soil. Various geological units have different susceptibility towards landslides formation. The landslide types, velocity, size and material characteristics directly determine its kinetic energy parameter, which characterizes devastating force of the landslide, i.e. destructive potential. Among all landslide types, slides and flows are considered as the most devastating [22]. Falls often serve as an initiative, triggering event which generate slides and flows of enormous destructive force and devastating consequences. The problem of landslide risk assessment has complex character with some points of uncertainties: it includes investigation of landslide origin, type and triggers, geological and geomorphic settings, defining potentially unstable areas, landslides propagation zones, vulnerability assessment for infrastructure and people, and monetary estimation of the potential losses. Besides, landslides include a wide variety of materials and involve different types of movements, such as topples, falls, slides and spreads [11], which increases difficulties in the landslides risk assessment.

Technically, current study is focused on the GIS approach of raster data processing. There are numerous classification algorithms and techniques that determine natural spectral groups from the initial pixels sets. For instance, the most well-known are Parallelepiped classification, Neural Nets, Decision Trees, Mahalanobis Distance, Minimum Distance, and Maximum Likelihood classifiers, ISOCLUST, K-means, and so on. Usually, it is not easy to decide, which classifier method is a priori the best cartographic solution for actual research problem, due to different factors that vary significantly: characteristics of raster images, mapping scales, specific situation of the study area, reflectance properties of the local land cover types, landscape structure and heterogeneity, etc. Current study objective is to apply segmentation technique for clustering image into thematic areas. The data used in this research included Landsat TM and ETM+ multi-band imagery covering chosen research area in Izmir, western Turkey. The image processing was performed using supervised classification in Erdas Imagine software. The general aim of the research is image classification which consists in automatic assignation of all pixels on an image into land cover classes that are typical for this study area. The logical algorithmic approach of clustering segmentation was applied to identify clusters for thematic mapping of land cover types in the selected study area. Classification was done on the basis of the multispectral data, spectral pattern, or signatures, of the pixels that represent each land cover class. Different land cover types and landscape features are detected using individual properties of digital numbers (DNs) of the pixels. The DNs showed values of the spectral reflectance of the land cover features, and individual properties of the objects. The used algorithm principle consists in merging pixels on the images into clusters, which is based on the assessment of their homogeneity and distinguishability from the neighboring pixel elements.

The results of the GIS based analysis of the land cover types which reflects landslide processes in the study area. The working process includes following research workflow. First research steps consists in data capture and pre-processing. It has been performed by import of .img file into ASCII raster format (GDAL). After converting, each image contained collection of 7 Landsat raster bands. Afterwards, visual color and contrast enhancement were performed. Geographic referencing of Landsat scenes included setting of UTM projection (Universal Transverse Mercator), Eastern Zone 42, Northern Zone W, WGS 1984 datum (Georeference Corner Editor, ILWIS). After that the research area was selected. The area of interest was identified and cropped on the raw images. This area shows region in a large scale which best represents typical tundra landscapes. Then the images were classified by supervised classification (Minimal Distance). This method is based on the spatial analysis of spectral signatures of object variables, i.e. vegetation types at various landscapes.

Current research details changes in land cover types in a selected region of Yamal Peninsula, which are caused by the landslide hazards and overall climate changes. These results are received as a result of the spatial analysis of classified images. The GIS mapping is based on the results of the image classification. The research results, presented in the current work, illustrate spatial distribution of land cover types in the selected areas and demonstrate changes that were caused by the landslides.

Analysis of the results shows noticeable overall increase of woody vegetation (willows and shrubs) and decrease of peatlands, grass and heath areas. This illustrates both environmental and climatic factors affecting landscapes. Environmental factors include active cryogenic landsliding, typical for this area. Climatic factor includes increase of annual average temperatures, which leads to permafrost thawing and process of greening in Arctic, i.e. the unnatural increase of woody plants. Gradual changes in plant species patterns and distribution affect landscape structure in Yamal ecosystems. Triggering factors for these processes could be complex climatic-environmental changes in Arctic, as well as local cryogenic processes (e.g. successive change in vegetation recovering after cryogenic landslides).

This work demonstrated how the GIS methods and tools can be effectively applied for environmental analysis and monitoring. Special advantage of the use of GIS in combination with remote sensing data consist in specific location of the study area, Yamal Peninsula, which is very difficult to access. In such cases using of GIS is an indispensable and incomparable tool for studies of distantly located areas. Remote sensing data (Landsat TM satellite images) can be visualized using GIS and spatial analysis can be performed using available tools. Since ILWIS GIS is an open source software, it can be effectively applied for students education. The GIS-based mapping of the northern ecosystems is important tool for the landscape monitoring and management. GIS can assist in analysis of how landslides impact local landscapes: changes in vegetation coverage and land cover structure. Processing of remote sensing data (e.g. Landsat TM scenes) by means of GIS (e.g. ILWIS) improves technical aspects of the landscape studies, since it enables assessment of spatio-temporal changes in vegetation coverage. Spatial analysis of land cover types in northern landscapes can help to detect local environmental changes in Arctic regions.

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ФИТОПЛАНКТОН НЕКОТОРЫХ ОЗЕР ГИДРОЛОГИЧЕСКИХ ЗАКАЗНИКОВ ВОЛОГОДСКОЙ ОБЛАСТИ

Н.Н. Макаренкова

Вологодская лаборатория ФГБНУ «ГосНИОРХ», г. Вологда, Россия, mackarenckowa@yandex.ru

Статья содержит сведения структуре фитопланктона озер гидрологических заказников на территории Вологодской области. Приведены данные об интенсивности развития фитопланктона изученных озер в летний период 2015 г. Дана оценка качества воды водоемов по наиболее распространенным альгологическим характеристикам.

Ключевые слова: фитопланктон, озеро, гидрологический заказник, качество воды, структура

На территории Вологодской области находятся 5 пять гидрологических заказников, из которых 4 озерных. Они располагаются в северо-западной части региона. В 2015 г. в летний период был исследован фитопланктон трех озер, входящих в Лухтозерский (оз. Лухтозеро и оз. Ундозеро) и Ежозерский (оз. Ежозеро) гидрологические заказники. Оз. Лухтозеро (496 га) вместе с оз. Ундозером и оз. Качозером (235 га) образует единую систему водоемов с подземным стоком. Оз. Ежозеро (230 га) принадлежит к системе р. Мегры и типично для Мегорско-Андомского ландшафта.

В соответствии с методикой гидробиологических исследований пробы объемом 0,5 л, зафиксированные люголь-формалиновой смесью, сгущали до 25 мл и обрабатывали счетно-камерным методом с использованием камеры Нажотта (0,01 мл) [3, 8]. Идентификацию водорослей проводили под световым микроскопом ЛОМО Микмед-6 по общепринятым методикам с помощью определителей [2, 4, 5].

В фитопланктоне исследуемых озер отмечено 88 видов и подвидовых таксонов водорослей из 7 отделов, 10 классов, 16 порядков, 52 родов. Наибольшую видовую насыщенность имеют 5 родов, включающих по 3-4 вида, к ним относятся 26 % всех видов. Это роды *Aulacoseira* Thw. – из диатомовых, *Dolichospermum* Ralfs ex Born. et Flah. – из синезеленых, *Pediastrum* Meyen - из зеленых, *Cryptomonas* Ehr.– из криптофитовых и из эвгленовых – *Trachelomonas* Ehr. В сообществе преобладают одновидовые роды – 77 % от всего числа родов. Видовым богатством отличаются зеленые водоросли, в частности порядок Chroococcales.

В фитопланктоне оз. Ежозера встречаются водоросли из 6 отделов: Bacillariophyta – 41 %; Cyanophyta – 16 %; Chlorophyta – 22 %; Chrysophyta – 5 %; Cryptophyta – 5 %; Euglenophyta – 11 % от общего количества видовых и внутривидовых таксонов. Основу флористического списка составляют диатомовые и зеленые водоросли.