1. Introduction

This thesis is a contribution to the multidisciplinary study of the arctic-alpine tundra of the Giant Mountains (a part of the arctic-alpine tundra of the High Sudetes), a unique environment in the context of the other central European mountains. In the Giant Mountains this environment occupies an area of about 47 km^2 (approximately 7.4 % of the total area of the Giant Mountains, with 32 km^2 on the Czech side and 15 km^2 on the Polish side). Within the framework of several research projects there are a number of studies carried out by Czech as well as foreign experts (Stursa 2002). The results of these studies are very important for a better understanding of the arctic-alpine tundra environment and its management.

In this thesis, three types of abiotic properties were studied: (1) the magnetic properties of the upper layers of the soil; (2) soil moisture properties in relation to vegetative cover (dwarf pine versus grassland stands); and (3) influence of wind-drifted snow on the water balance of small mountain catchments. In the case of (1) and (2), environmental geophysics methods (magnetic properties and TDR measurements) were used. In case of (3), a new method of snow-depth determination in the snowbed using a GPS system was developed.

2. Arctic-alpine tundra environment

The arctic-alpine tundra in the Giant Mountains is defined as a treeless area above 1250 m a.s.l. (approximately above the tree line). Because of snow avalanche activities on the avalanche tracks, the tundra environment locally encroaches below this tree line. But generally the area extends from 1250 m a.s.l. to 1602 m a.s.l. (the highest point of the Giant Mountains – Sněžka mountain). The tundra of the Giant ountains (developed mainly as a treeless districts throughout the Holocene) is represented by a number of physiographic components (patterned ground, late-lying snowbeds, avalanche tracks, intensive regelation and deflation) and relic populations and ecosystem types and has been divided into three zones (Soukupova et al. 1995): (1) cryo-aeolian zone mainly on fine-grained granites and quartzites, with prominent cryogenic processes and landforms and vegetation of the *Juncion trifidi*; (2) vegetated-cryogenic zone on deeply weathered mantles of plateaux and flat saddles, with vegetation of the *Nardo-Caricion rigidae*, krummholz and peat lands; and (3) niveo-glacigenic zone of the corries and nivation niches with a diversity of ecosystem types associated with rock faces, avalanche tracks, snowbeds and spring sites. The tundra ecosystem occupies two separate summit areas, one in the western and one in the eastern part of the Giant Mountains.

The natural conditions of the arctic-alpine tundra in the Giant Mountains have been strongly influenced by human activities (clear cutting, livestock grazing) from the 17th century to the present day (Stursa 2002). Today, the anthropogenic influence involves potential air, water and soil pollution, and the introduction of invasive plants and extensive dwarf pine plantations. Environmental protection and management of this area (including planned interventions to remove dwarf pine plantations, which should lead to restoration of this area to a condition more as it was before human intervention) should be based on sound objective knowledge of natural conditions and internal relationships within this ecosystem. That is why abiotic studies are also required.

3. Environmental magnetism

The magnetic properties of the upper part of the soil profile were studied in the whole arctic-alpine tundra area of the Giant Mountains and extended to include the tourist centers. The properties of ferrimagnetic minerals were used. Magnetic particles can originate from weathered bedrock, biogenic activity, volcanic ashes or extraterrestrial particles. Magnetic particles can also be of anthropogenic origin, mainly being produced by combustion processes and emitted together with pollutants such as heavy metals in industrial fly ashes. Among magnetic minerals, the most important are iron oxides such as magnetite, maghemite and hematite, and iron sulfides (Petrovský et al., 2000). The identification of magnetic minerals in a sample is possible by measuring their Curie (Neel) temperature. Magnetic methods also enable the determination of other physical properties of magnetic grains, such as magnetic anisotropy, distribution of grain size and shape, and eventually, magnetic interactions occurring between the grains (e.g. Dunlop and Özdemir 1997). Grain size and shape, which determine the domain state of the mineral, are of great importance. Domain is a term used to name a particle volume with uniform magnetization (SD – single domain, MD – multi domain or PSD – pseudo single domain, and SP - superparamagnetic particles). The concentration of especially MD particles, which are distributed by fly ashes, in the top soil layers, is not only an indicator but it represents a measure of anthropogenic pollution. The value of magnetic susceptibility (the measured magnetic parameter of the soil) is a proportion of the concentration of magnetic particles in the soils.

The occurence of mainly MD particles of anthropogenic origin (especially magnetite) in the top soil layers in the studied localities was confirmed by laboratory measurements (Curie temperature, SIRM, AC demagnetization, k_{FD}). The highest concentration of magnetic particles was in the depth from 4 to 6 cm below the soil surface. The value of low field magnetic susceptibility is very low in the whole arctic-alpine tundra area of the Giant Mountains (from 4 to 10 x 10^{-5} SI). The only places with some pollution were in the tourist centres (e.g. 10 - 20 x 10^{-5} SI in Pec pod Sněžkou, 40 - 60 x 10^{-5} SI in Svoboda nad Úpou). The value of magnetic susceptibility rapidly decreased away from tourist centres. In the tundra area the places of strong increase of magnetic susceptibility values were found on some tourist paths in the arctic-alpine tundra area. Using of unoriginal material is the main reason of this increase.The stability and vertical dynamics of fly ash pollutants in the soil profile in natural conditions were also studied. The experimental plot (1 x 1 m in size) with artifitial pollution by fly ash was set up in Modry dul valley. The time series data in soil profile were measured with result of maximum 1 cm of downward vertical movement during 3 years (2003 to 2006).

4. Soil moisture properties in relation to vegetative cover

Soil moisture properties in relation to vegetative cover (dwarf pine versus grassland stands) were studied in several plots. One of the aim was to get a set of reference data by TDR (Time Domain Reflectometry) measurements. These data were compared with data which were obtained by soil moisture sensors WIRRIB (Phase Transmition) during vegetation seasons (from 2001 to 2004). To know more about the soil environment in the studied area particle-size analysis and retention curves for depths of 15, 30, 45 and 60 cm were done. In addition every plot was arranged by automatic station for continual soil moisture measurements by WIRRIB sensors (in depth of 15 and 45 cm), tensiometer suction presure (in depth of 15, 30, 45 and 60 cm) and temperature of soil and air. Three plots were also arranged for precipitation measurements during the vegetation season.

Four groups of three rod probes (0.3, 0.6 and 0.9 m) for TDR soil moisture measurements for seven plots were installed. The irregular measurements were done during 2000, 2001, 2002 and 2003 vegetation seasons. The values of soil moisture for depth intervals of 0-30 cm, 30-60 cm and 60-90 cm were computed for each plot. For computation of soil moisture the equation $\theta_v = -5{,}3*10^{-2}+2{,}92*10^{-2}*\varepsilon_r-5{,}5*10^{-4}*\varepsilon_r^2+4{,}3*10^{-6}*\varepsilon_r^3$ (Topp, Zegelin & White 1994) was used. The results were compared with the data obtained from VIRRIB sensors.

The TDR values of soil moisture are generally lower than the results obtained from VIRRIB sensors. In the depth interval of 0-30 cm there were 43 % TDR values higher and 57 % lower than VIRRIB data. In the interval of 30-60 cm there were 18 % of TDR values of soil moisture higher and 82 % lower than the VIRRIB data. The explanation of this fact should be that the TDR method involves bigger interval of soil profile than VIRRIB sensor which measures smaller area of soil. The other reason could be the different way of probe installation for each method. The TDR measurements are more closer to natural conditions of intact soil environment. Significant influence of different vegetative cover on water regime in soils of tundra area of the Giant Mountains was not determined yet.

5. Influence of wind-drifted snow on water balance in the catchment Modry potok

There are very specific components of the water balance in the mountain headwater regions. Besides the points of cloud- and fog-water deposition, the accumulation of water in the snow cover drifted in the watershed by the wind is particularly important. The objectives of this part of the study were to highlight water storage in the snowbeds and to show how GPS kinematic measurements can contribute to better understanding of snow accumulation and melting processes in the Modry potok basin (2,62 km^2, 1010 - 1554 m a.s.l.).

Uneven distribution of the snow cover over the mountainous terrain is a well-known phenomenon in all alpine and arctic areas. The result of this variability is a mosaic of micro-habitats associated with various snow depths, different melting dates and snow-free periods. Sites with a deep snow pack and, subsequently, with a short snow-free period are called snowbeds. Snow pack in snowbeds varies from several meters to 20 meters and more (Wijk 1986, Stursa et al. 1973, Kudo 1991).

Wire probes can be reliably used up to snow depths of 3 m only. To get more realistic data, two digital models using kinematic carrier phase–based GPS measurements were developed: (1) a model for snow surface data, applied at the end of five winter seasons from 2000 to 2005; and (2) a model for the underlying snow-free ground surface, applied after the snow melt in August 2000. These two models, overlaid in the GIS environment, were used to identify snow depths.

The kinematic carrier phase–based GPS measurements with TRIMBLE Pathfinder ProXR and Pathfinder Power receivers were conducted in periods of the highest snow accumulation. For the greater part of a snowbed with potential high snow accumulation, relevant data were collected by measurements along parallel lines 5 - 10 m apart (by walking, slow skiing or pulling a rope-driven sledge with a GPS receiver across the snowbed), combined with a ''stop and go method'' (walking followed by a stop for measurement, collection of point data) Complete data for the whole snow patch were collected in a regular network by the ''stop and go method'' in a later period of spring when the snow cover was safe enough for surveying. Subsequent construction of the snow surface model was performed for data sets from each year. Data for the construction of the snow-free ground surface model were collected after the snow melting in mid-August 2000. The line measurements were used in a plot 400 m x 250 m in size, which covered the entire snowbed area. For the creation of digital elevation models (DEMs), the TOPOGRID command in ArcGis 8.3 (ArcInfo) was used, which generated a grid of elevations from 3-D point, line, and polygon data. This interpolation method, specifically designed for the creation of a hydrologically correct DEM, was based on the ANUDEM program developed by Hutchinson (1988, 1989) for hydrological research. The snow depths were obtained and snow maps constructed accordingly. These "snow" results can be used for more realistic estimation of water content of snow in the watershed, distribution of snow depth during the winter season and to define the water balance more precisely.

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