Combining of basic geomorphological monitoring and terrestrial laser scanning in evaluation of erosion within the tourist paths (Kasprowy Wierch peak, Tatra Mts.)

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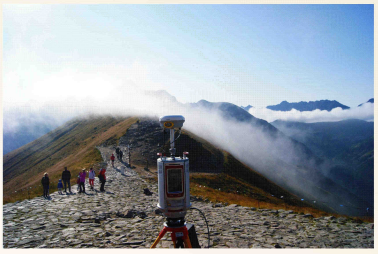
Introduction:

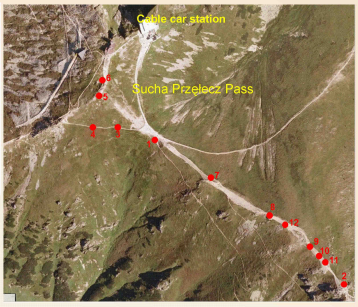
Mountain areas especially attractive to tourists, include the Tatras, are significantly exposed to degradation of the natural environment. 3 millions tourists visit Tatra during a year and 50% of them visited Tatra in summer season. The Kasprowy Wierch peak is among the three most affected area by tourists in the Tatras. One of the reasons is cable car there. The number of tourists continuously grows up, particularly since 2009 when capacity of the cable car increased after its renovation. For example about 200,000 peoples were transported in summer 2014 (June-September). The main goal of the study was evaluation of erosion on tourist path in surrounding of the Kasprowy Wierch peak.

Methods:

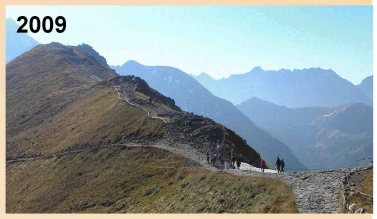
Monitoring of erosion within the tourist paths started in 2009, on 12 study sites located within the tourist path. Basic geomorphological methods like marked points, marked lines etc. are used in the studies. The study sites were checked two time every year, after winter and before winter.
Since 2014 terrestrial laser scanner Riegl Vz4000 was used in the studies. The paths were scanned once a year, in summer. The digital terrain models of tourist path surfaces in 2014 and 2015 were obtained as results.

Location of study area





Location of study sitesof tourist erosion



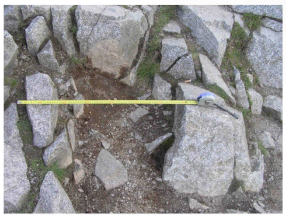
View of tourist path form the Sucha Przełęcz Pass to the Beskid peak. The bare rock within the path in 2009 is effect of tourist erosion

View of antropoghenic erosion on the Kasprowy Wierch peak.

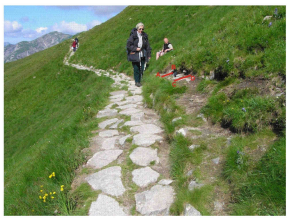
The results of geomorphological studies.

Sites no	Type of changes	Rates in cm
3	Widening	11-12
3	Deepening	10
4	Widening	10
5	Deepening,	1.4-6.8
8	Widening	2.0-2.5
10	Widening	20
10	Trampling	50
11	Erosion – lowering	Max 2.5
12	Widening	22
12	Trampling	40

Changes of the tourist paths in period 2009-2015

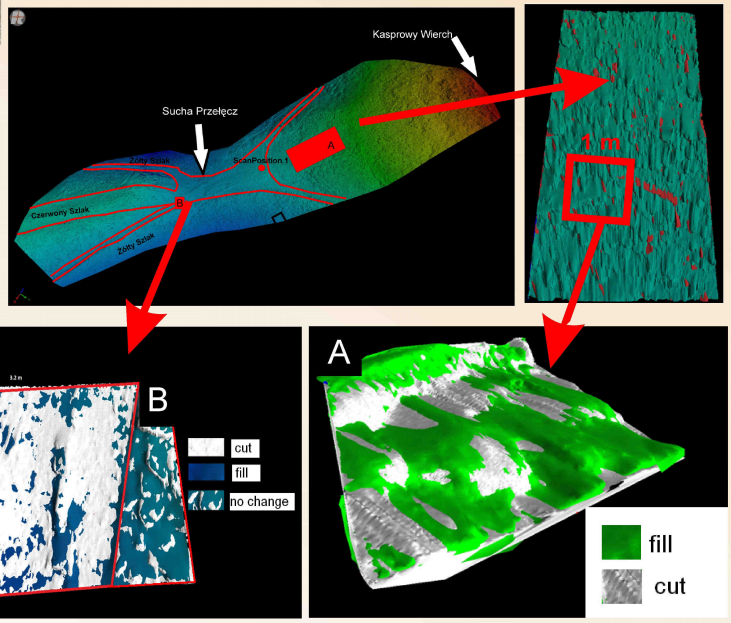



Tourist erosion on sites no 5, one of the most affected fragment of the studied paths




Widening of tourist path on sites no 3. The path is hardened and should be protected against erosion, but paths is too narrow

The results of terrestrial laser scanning



The results of terrestrial laser scanning measurements. I - Location of areas analysyed on fig B, C, D; B - The digital terrain models adjustment carried out 1.5 mm.

	Name of the analyzed surface	Study area [m²]	Fill [cm³/m²]	Cut [cm³/m²]	Average increase of surface	Average reduction of surface
A	Natural slope (Sucha Pass- Kasprowy Wierch peak)	1	9 239	3 033	1,847	0,607
B	Tourist path (surface artificially hardened by stone pavement)	1,3	180	2 190	0,036	0,438
C	Tourist path (natural surface)	7,6	3 725	4 726	0,745	0,945

Changes of tourist paths measured by terrestrial laser scaning

Summary:

Monitoring of study sites proved erosional changes within the tourist paths, which are spatially differentiated both horizontally and vertically. Erosion of the paths in size of 2 cm/year in average was found as well as their widening 20 cm during 5 years. The intensity of degradation of the paths surface differs belonging of type of paths surface (natural surface or surface artificially harden by stone pavement) and its inclination.
Difference in erosion between harden and not harden fragments of the paths was also confirmed by TLS measurement. The greatest erosional changes were found on not harden paths with large inclination. On flat (level) not harden path lowering 1 cm/year on average was found, while no changes were identified on paths with stone pavements. The size of erosion found by geomorphological monitoring is higher but it is related to measurement point only, while TLS results to larger fragment of the path.