Combining Different Data Types for Evaluation of the Soils Passability

Martin Hubáček, Lucie Almášiová, Karel Dejmal and Eva Mertová

Abstract The soils, as one of the basic landscape components, influence directly or indirectly almost all human activities. They have radical influence on a food production, environment formation, water regime and many other aspects. Besides that, they are one of the dominant landscape components, which influences significantly passability of the off-road movement. The knowledge of this influence is necessary especially for farmers, foresters, soldiers and rescuers. Farmers and foresters have an opportunity to postpone their work when the conditions are inconvenient. But rescuers and soldiers must accomplish their tasks immediately. So it is very important for them to know how they can move and which vehicle they can use in the required area. The big amount of data is necessary to evaluate the soil. Except for own soil databases there are mainly meteorological information, because weather has significant influence on the behaviour of the particular soil. Precipitations are the most fundamental of all the meteorological components or phenomena. Except for weather, there are also other components of landscape influencing the soil characteristics, such as vegetation, drainage and especially relief, which affect significantly drain and accumulation of water in soils. The main goal of the undergoing investigation is to predict the influence of soils on vehicle movement in dependence on soil characteristics, weather information and modelled drain conditions. The actual modelling employs digital soil database, detailed elevation models, radar images of precipitations, meteorological information from stationary stations and penetrometric measurement realized in different soil conditions. This modelling will be implemented to the cross-country movement model,

M. Hubáček (✉) · L. Almášiová · K. Dejmal · E. Mertová
Department of Military Geography and Meteorology, Faculty of Military Technologies,
University of Defence, Kounicova 65, 662 10 Brno, Czech Republic
e-mail: martin.hubacek@unob.cz

L. Almášiová
e-mail: lucie.almasiova@unob.cz

K. Dejmal
e-mail: karel.dejmal@unob.cz

E. Mertová
e-mail: eva.mertova@unob.cz

which caused improvement to the older version of the model of cross-country movement and makes the model more accurate.

Keywords Geographic data · Meteorological data · Soils · Precipitation · DEM · Vehicle movement

1   Introduction

Soil is the outermost layer of the Earth crust. It represents a part of landscape, where its other components are meeting (Monkhouse 1970; Collins 1998). Soils have a very important role in the civilization development and influence both directly and indirectly most of human activities. In ancient times, the soil fertility influenced an existence of the human civilization in a particular area (Hillel 1991). Today, in time of the globalization and technological progress, it is possible to colonize in fact any part of the Earth.

Nevertheless, the soil will affect human activities at each location. One of these activities is movement. The man transforms landscape and creates various traffic infrastructures to make movement easier. But there are cases, when choosing an off-road movement for various activities is necessary. That kind of activities are for example agricultural and forest works. Most of them take place in an open countryside where agriculture and forest machinery moves not only on unpaved and forest roads, but also on fields, meadows and in forests. In such cases, the machinery movement is significantly influenced by soil conditions, which depends considerably on meteorological conditions. It is possible to postpone this type of works until suitable conditions occur, therefore to avoid situations, when vehicles sink or move with large difficulty throughout the area. But there are situations, when vehicles must go to the field regardless of any conditions, such as during military or non-military crisis situations. The aim of the research is to refine and modify existing simple and not very accurate algorithm for calculating soils passability. The new algorithm will be subsequently implemented into a comprehensive model for calculating of cross-country movement.

2   Initial Assumptions

Every vehicle movement is tied to the Earth's surface. The movement possibilities are affected by the whole range of parameters. The technical specifications of a vehicle, terrain, where vehicle moves, weather at the location and also driver´s skills of the vehicle belong among the most basic parameters (Rybanský and Vala 2009; Rybansky et al. 2015; Cibulova and Sobotkova 2006; Cibulova et al. 2015). The most important terrain components are relief, soil, drainage and vegetation cover, which influence movement during the off-road driving. The influence of

terrain relief, drainage and vegetation can be relatively well parametrized and evaluated (Manual 1998; Rybansky 2009). For assessing the effect of the terrain there are known technical parameters of vehicles, such as maximal climbing capability, maximal transversal inclination, maximum width of trench, maximum climbing capability up to rigid step and others. Then it is possible to evaluate area of interest for a particular type or category of vehicles and to determine impassable terrain or terrain passable with restrictions using precise digital model of the terrain.

The similar attitude can be used for vegetation and drainage. The following parameters can be assessed: type of trees, spacing between stems, stem diameter, tree height, depth and width of rivers, flow speed, characteristics of bottom and others. Based on this knowledge, it is possible to make decision when planning vehicle movement through a particular area. However, such parametrization is more difficult in case of soils. It is especially caused the following:

- less quality data displaying soils,
- considerable dependence of soil behaviour on meteorological conditions,
- usually unclear boundaries between different soil types,
- affecting soils by water infiltration from rivers and lakes and by accumulation of precipitations in low lying locations.

The problem of the influence of soils on vehicle movement is relatively complex and cannot be solved using a simple analysis like in case of other landscape components. In addition to soil data and vehicle parameters, it is necessary to consider also other phenomena in calculation. Principally, it is the influence of meteorological conditions, especially precipitations, as well as terrain relief, which affects drain conditions in a given area. The research team at the Department of Military Geography and Meteorology has been dealing with problems of cross-country movement for a relatively long time.

In addressing the issue of cross-country movement, the requirement for solving the influence of the dominant soils on movement of military and rescue vehicles in the territory of the Czech Republic was considered. Total of 12 locations representing main soil types and soil textures for the entire territory of the Czech Republic was selected in collaboration with soil scientists from the Mendel University in Brno. The soil sampling was carried out within these locations for the comparison with data sources of soils (Specialized military database of soils—SMDoS) being used in the Army. Also the penetrometric measurements were performed for dry, humid and wet seasons according to the NATO classification (Manual 1994).

These penetrometric measurements showed that these soils are passable or passable with restrictions in most of the year regardless of the weather conditions (Hubacek et al. 2014). Any of the selected locations were impassable for monitored categories and vehicle types. The problem emerging from the comparison of soil analysis and values shown in the SMDoS was that this database is not convenient for evaluating soils from the point of view of its cross-country movement with
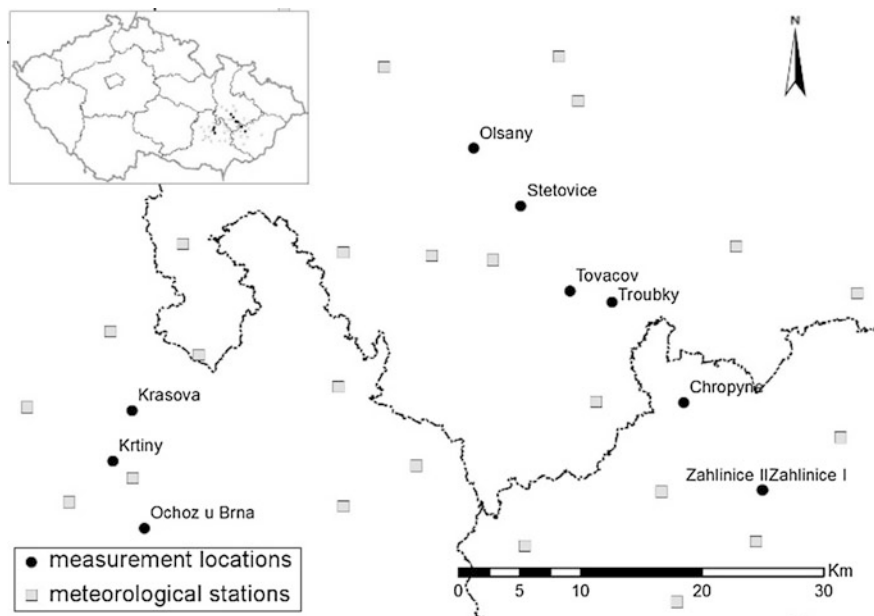
Fig. 1 The localization of measurement locations and using meteorological stations

respect to its quality, which comes out of the way of the classification and of the scale original maps used for creation of SMDoS (Technical Report 2000).

Considering these results, the second phase has been started in 2014. This was focused on soils, which have prerequisite for significantly greater impact on vehicle movement and which change their own characteristics significantly according to the amount of water. During this phase it was chosen nine appropriate locations (Fig. 1) situated in the area of south and middle Moravia. The locations were selected with regard to the time accessibility from Brno. It is suitable for opportunity to organize measurements flexibly with respect to meteorological situation. The next task of this phase was searching for convenient digital data describing soils.

3 Tested Area and Used Data Sources

The area of penetrometric measurements is relatively extensive. It occupies an area of approximately 3000 km^2 and it is relatively varied in terms of orography. There it is possible to find lowlands, such as the Hornomoravský Valley, highlands, such as the Drahanská Upland, or karst area, such as Moravian Karst. There is a variety of soils, such as gley, pseudogley, gleyic, organogenic, but also chernozem or phaeozem occuring on loessic sward. They are mostly sandy-loam and loam soils

Fig. 2 Measurement locations **a** agriculuture land, **b** wasteland (reed-mace)

from the perspective of soil texture. The test locations are situated out of forest areas usually at the agriculture land (meadows, fields) (Fig. 2a) or at wasteland with low vegetation (grass, reed-mace, bush) (Fig. 2b).

In addition to the penetrometric measurements the appropriate data are needed for the analysis. These are the soil data, meteorological data (precipitations) and elevation data. The main information about soils, which are necessary for calculating, are the information about the soil texture and the soil type. Both these attributes are contained in the SMDoS. Comparison of information from the database and information obtained from the soil samples revealed considerable unreliability of data, especially the soil type classification. Therefore, the digital soil map at scale 1:50,000 (DSM 50) was chosen as the main information source and was compared with the SMDoS and the terrain samples. Despite the fact that even this source is not 100 % reliable in terms of drawing accuracy, it is still noticeably more accurate in comparison with the SMDoS (Hubacek et al. 2015a). One disadvantage of DSM 50 is missing information about soil texture (soil granularity). This information is thus taken from SMDoS, where reliability of soil textures was more than twice higher to taken soil samples in comparison with information about soil type. Currently, there is no other suitable digital data source of required information from the territory of the Czech Republic. The compilation manuscript

drafts from the time of the Complex soil mapping (Prax et al. 2008; Research Institute for Soil and Water Conservation 2015) could serve as the alternative source, however these materials exist in an analogue form only and they do not have any digital equivalent, be it the vector form or the raster form. Employing these manuscripts would require extensive amount of the manual work in terms of vectorization. The territory of the Czech Republic is situated on more than 16,000 map sheets and vectorization would thus one thousand hours of work.

Precise mapping of soil boundaries is very difficult. Border areas of soils in principle are not as sharp as in other geographical objects. In most cases, there is a gradual change in soil properties, which reflected the influence of soil on movement of vehicles. For this reason, in the calculation expressed by the uncertainty boundaries soils using fuzzy logic tools.

The main source of meteorological data is represented by data from meteorological stations of the Czech Hydrometeorological Institute. There are total of 39 stations of different categories in the area of interest. Varying amount of meteorological elements is collected at the stations according to station category (i.e. meteorological, climatic, precipitation gauged). The only precipitations, which are available from all stations of the area, are included to the processing in a case of the first investigation of the research currently. It is possible to use compound radar images from the radars Skalky u Protivanova and Brdy-Praha in addition to data from individual meteorological station. The compound radar images are being acquired every 5 min. They are then post-processed to generate the compound information of the total estimates of the precipitations of the duration of 1 h. The pixel's information of the compound radar image gives an intensity of precipitation in millimetres per hour on the base of the total estimates of the precipitations. The values of radar image pixels represent the intensity of precipitations according to the classes in Table 1.

The last source of data is represented by the digital elevation model (DEM). Several DEM types of various accuracy exist in the Czech Republic. Currently, the most accurate elevation model is the DEM 4, which was created using the Airborne Laser Scanning method. This model contains elevation points in a grid of 5 by 5 m and its accuracy is expressed by 0.3 m mean error in the open terrain and 1.0 m mean error in the areas covered by vegetation (Brazdil et al. 2012). The results of

Table 1 The classes of radar intensity of the precipitations

Class	Intensity of precipitations (mm/h)	Class	Intensity of precipitations (mm/h)
0	0	8	3.65
1	0.6	9	6.48
2	0.12	10	11.53
3	0.21	11	20.50
4	0.36	12	36.46
5	0.65	13	64.84
6	1.15	14	115.31
7	2.05		

independent accuracy testing show that its accuracy is usually twice than is declared, despite systematic errors, which model contains (Silhavy and Cada 2015; Hubacek et al. 2015b). The most accurate available model is the most appropriate data source, because during own analysis cross-country movement the drainage ratio and the capabilities of water accumulation in landscape are monitored.

4   Methodology

A big variety of geographic data is being employed during solving of this problem. They have different structure and they are primarily in different coordinate systems. Therefore, it is necessary to transform all data to the same coordinate system before the processing. The SMDoS and DEM 4 data produced by the Military Geographic and Hydrometeorological Office (MGHMO) use the WGS84 coordinate system and the UTM projection. The DSM uses the S-JTSK national coordinate system of the Czech Republic. The data transformation between these coordinate systems is described very well and the most of data analyst tools can execute transformation easily.

Meteorological data from meteorological stations represent the discrete point set. Their coordinate system can be transformed into the selected system. The situation with radar image is a little bit complicated, even though it is possible to execute data transformation only with knowledge of the projection parameters of the compound radar image. In this case, it relates to a set of data (report), which are transformed to raster image of the size 256 × 356 pixels, where one pixel has size 2 × 2 km. The images are in gnomonic projection in universal position, where the middle of projection is situated at the Prague Libuš station, which has geographic coordinates 14.45° east longitude and 50.01° north latitude.

After transforming data into the same coordinate system, it is necessary to execute the following steps:

- to analyse precipitations in previous season;
- to calculate drainage ratio and accumulation polygons at the area using DEM data;
- to express uncertainty in location of soil polygons using fuzzy logic tools;
- to estimate the water amount in soil on the basis of overlap function with usage precipitation and elevation data;
- to calculate bearing capacity of soils.

The first three tasks are currently tested and verified. They proceed from own experiments as well as from generally known principles of modelling of geographic reality. The estimate of the water amount in soil is problem, to which the main attention is paid at the moment and its solution will noticeably make calculation of cross-country movement more accurate. Current calculation of cross-country movement is based on the application of previously implemented procedures using

the SMDoS database with using newly collected precipitation data, relief characteristics with regard to its ability to drain water, and the DSM soil types.

4.1 Precipitation Modelling

Although there are 39 meteorological stations in the monitoring area and its vicinity, where data are collected, their distribution is not optimal with respect to locations of penetrometric measurements (Table 2). It is evident that minimum distance between the measurement location and the nearest meteorological station is 2.2 km. Maximum distance is 9.3 km and the average distance is 5.7 km. Therefore it is not possible to consider the precipitation value at the nearest station as coincident with the precipitations amount falling down at location of measurement for calibration of calculation (Salek 2012). It is necessary to compute the precipitation amount for the locations of the measurement. Except for values at the locations of the measurement, it is necessary to have the precipitation values from the entire area. To extrapolate data to entire area, it is possible to use some of the interpolation algorithms, such as Spline, IDW, Kriging and so on (Childs 2004; Myers 1994). However, the precipitation course in the real world has usually the arrangement not corresponding to any commonly used interpolation (Fig. 3).

Therefore different method was chosen for gaining the overview of precipitation amount over the selected area and that is usage radar data and their rectification due to data from meteorological stations. The rectification of radar data is executed because radar data give only estimates of precipitations. The attenuation in the precipitations is very important phenomenon whose value depends mostly on precipitation intensity. In case of heavy precipitations it could become considerably underestimated due to noticeable shading of distant precipitations (Salek 2012; Andersson and Ivarsson 1991; Almasiova 2015).

Table 2 Distance between the measurement location and the nearest meteorological station

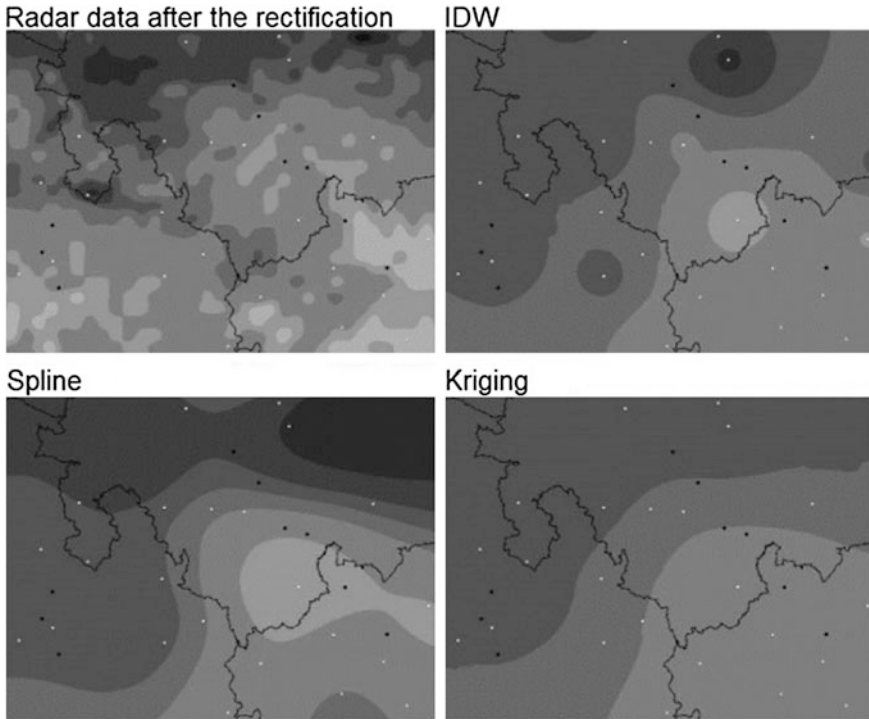| Measurement locations	Meteorological stations	Distance (km)
Zahlinice I	Kvasice	4.3
Zahlinice II	Kvasice	4.3
Troubky	Kojetin	8.3
Tovacov	Kralice na Hane	6.8
Stetovice	Kralice na Hane	5.0
Krasova	Bukovina	5.7
Olsany	Kralice na Hane	9.3
Krtiny	Bukovina	2.2
Ochoz u Brna	Bukovina	4.2
Chropyne	Kojetin	7.2
Mean		5.7

Fig. 3 The comparison of the precipitation distribution to different interpolation algorithms

There were determined errors on the basis of the comparison between the values of 24 h precipitation totals at meteorological stations to the 24 h precipitation totals gaining from radar data during the second half of March 2015. These were used afterwards for executing the radar image rectification and its accuracy improvement in the way that values express real precipitation total. The mentioned season was chosen on the basis of data availability, precipitation intensity and the term of the executed penetrometric measurement in the terrain. This method is not optimal, but it seems to be more accurate. To verify the method, the four precipitation different days we chosen, when precipitation totals were within the interval of 5–20 mm at least at half of the monitoring stations. In this case only half of stations regularly located at the whole area were used for rectification of the radar data. The second half was used as control points. The precipitation estimates were created from the same data by interpolation methods. The results from these control stations are better in comparison to the interpolation methods such as IDW, Spline and Kriging, which were used for generating continuous distribution of the precipitations. The mean error and RMSE for each method are showed in Table 3.

The noises represent a problem of radar data and it has different causes—both meteorological and non-meteorological. The most common non-meteorological error is the interference with other source, especially with Wi-Fi networks.

Table 3 The accuracy comparison of the interpolation algorithms

Interpolation algorithm	Mean error (mm)	RMSE (mm)
Radar data after the rectification	1.7	0.9
Spline	2.2	1.7
IDW	2.0	1.8
Kriging	2.0	1.9

The right band effect, influence of droplet size, rise and evaporation of droplets below cloudiness belong among often meteorological errors. Reduction of these noises is problem, which has not been solved yet. It could be expected, that data quality is improved after installation of the new radars. The data are already available, but currently we do not use data from precipitation stations for their rectification.

4.2 Expressing Uncertainty in Location of Soil Polygon

The expression of a border between the two soil polygons is generally quite difficult in comparison to other geographical phenomena. It is caused by two factors. First of them is the creation method of the most of soil maps, which is built of the sampling soils probe. In this method, it is necessary to define a shape of boundary between each soil polygons on the basis of knowledge of the soils characteristics in location of the soil probe, of the landscape configuration and of the knowledge of the soil forming processes. This method, however, shows a considerable uncertainty in definition of soils polygons. The second factor, which affects the soil characteristics, is the change soil types from one to the other, which can be more or less continuous. It is possible to say, that boundaries of the two adjacent soil polygons are significantly uncertain and that soil characteristics will be overlapping. It is necessary to express this uncertainty in location of soil polygons for modelling purposes. The fuzzy logic tools are thus employed (Ross 2009). Fuzzy sets are characterized by the membership function or the characteristic function. This is a functional dependency, where each element of the universal set has one exactly specific value of a degree of belonging to the fuzzy set. However, it is necessary that the functional values are just within the interval <0; 1>. Similarly to mathematical functions, fuzzy function can be linear, sinusoidal, discrete and continuous or in the shape of the Gaussian curve (Kainz 2008; Hofmann et al. 2013). Linear function of distance was selected for fuzzification of transition of individual soil types.

It is very important to choose the correct overlapping distance especially for the calculation of the uncertainty in location of soil polygons, which have different shape and size. It was taken 13 soil probes in Zastávka-Rosice terrain profile for boundary determination. There was found out the soil parameters by analysis in the laboratory. Afterward, they were compared in location in the soil maps. The three

distances were defined on the basis of this analysis and of the particular soil polygons size in database. They are applied for the creation of the uncertainty layer of soil boundaries. The distances are the following: 250 m for large polygons, 125 m for medium-size polygons and 10 m for very narrow polygons adjoining to the rivers. The influence of uncertainty can be expressed for each soil area as follows (formula 1 sample for 250 m the distance):

$$\mu_S(x) = \begin{cases} 1, & x \leq -250 \\ \frac{x-250}{-500}, \ldots & -250 < x < 250 \\ 0, & x \geq 250 \end{cases}$$

where:

μs the degree of conformity of the type soils with the reality;
x distance from the interface of soils in database.

These modified soil layers serve as the additional data source for final modelling of soil impact to vehicle movement.

4.3 Calculating Drainage Ratio

Hydrological modelling tools, which enable the calculation of drainage ratio at a given area, are currently intergraded in the most of GIS tools. Their workings principle is very well described in a whole range of publications (Beven 1996; Vieux 2001). Their usage ranges from modelling of drainage ratio in drainage basin, flash floods simulation, searching slopes in danger of landslide, to calculation of erosion or pollution spreading by surface or underground waters (Kubíček et al. 2011; Gritzner et al. 2001; Vranka and Svatonova 2006). The final goal is usage of these tools to making precipitation-drainage ratio more accurate in the monitoring area.

The layers of slope, flow direction and flow accumulation are generated from DEM data. The last two generated layers are not used in the simplified form of the calculation. They are expected to enter the phase of the calculation of the water amount in soil, of the determination of the ratio between precipitation amount, which soaks into the ground and which flows away. Currently only the layer of slope is used in calculation. It is classified for two basic values, which come from the definition of the plain terrain of the NATO standards. When slope exceeds 5° value, it is expected, that drainage speed on the surface in noticeably higher than in case of plain surface. From this reason there is lower probability of absorption at these locations than on plain surface. The slope layer is classified in the way, that plain surface has value 1 and terrain with slopes exceeding limit has value 0.8. This value determination was counted on the basis penetrometric measurements of the soil resistance in season of recent rainy days. This value is determined by only two different soil types measurement currently. In future, it is expected to improve the

accuracy of that value or to define more values in dependence on different soil characteristics.

4.4 Soil Passability Modelling

The bearing capacity of soils in most cases depends on meteorological conditions, especially on amount of precipitations, which influences soil saturation by water. This soil characteristic is defined particularly by vertical soil permeability, which is basically a function of soil texture (granularity). Light soils are good permeable, heavy soils are permeable with restrictions or impermeable. Further important characteristic, that affects the bearing capacity, is drainage speed depending on slope. The lower bearing capacity occurs at soils with permanent high water table or at soils, where water accumulates or where drainage is difficult. These locations are determined by the terrain relief which is tied to the presence of specific soil types (Novak et al. 1991). These attributes and dependencies emphasize the proposed approach to the passability modelling.

The problem of its adequate implementation is a correct expression of soil saturation and amount of precipitation, which flows away from the area without any distinct impact on soils. Until satisfying solution of the problem is reached, modified process determined during the SMDoS formation for soil impact modelling on vehicle passability will be applied. This procedure was designed by experts from the Research Institute of Amelioration and Soil Protection depending on the knowledge of the behaviour of soils. Influence of soil was generalized regardless of the specific type of vehicles that should be in the area (User Manual 2000). It is possible to create a map of soil influence on the movement of vehicles (Fig. 4). Individual soils polygons depending on the parameter soil type and soil texture represent the following parameters:

- GO in all weather conditions (light grey);
- SLOW GO in wet season (grey);
- NO GO in wet season (dark grey);
- NO GO throughout the year (black).

The wet season is defined as follows: rainfall in a liquid state greater than 40 mm during 3 days in the period from October to April and rainfall greater than 70 mm during 3 days in the period from May to September.

This relatively simple process is modified and it is applied in the following way with combining created data layers:

1. Creation of layer from the combination of data from precipitation-measured stations and from meteorological radars;
2. Calculation of the area slope and reclassification into defined categories;
3. Creation of modified precipitation layer by multiplying precipitation layer with reclassified slope;
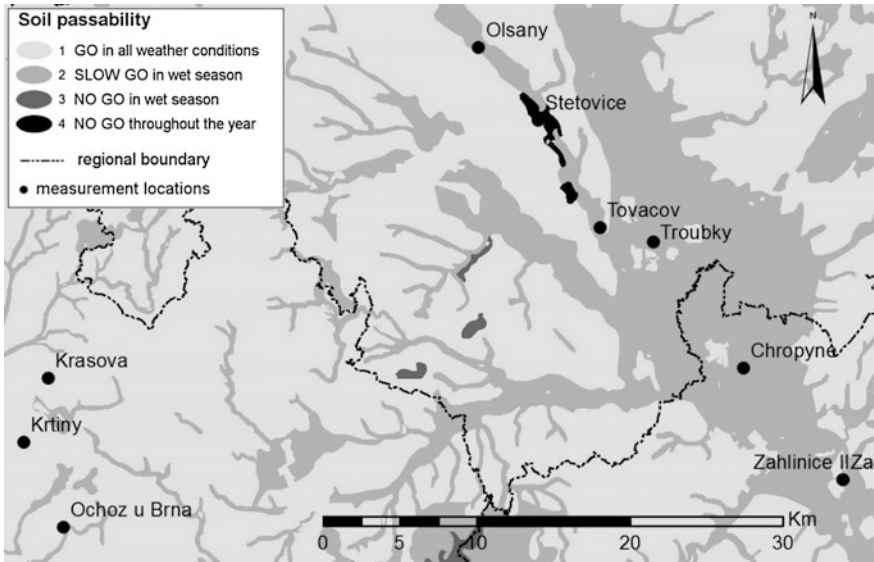
Fig. 4 The map section of soil passability created by the original algorithm for all vehicle types

4. Adaptation of soil texture and soil type layers using fuzzy logic;
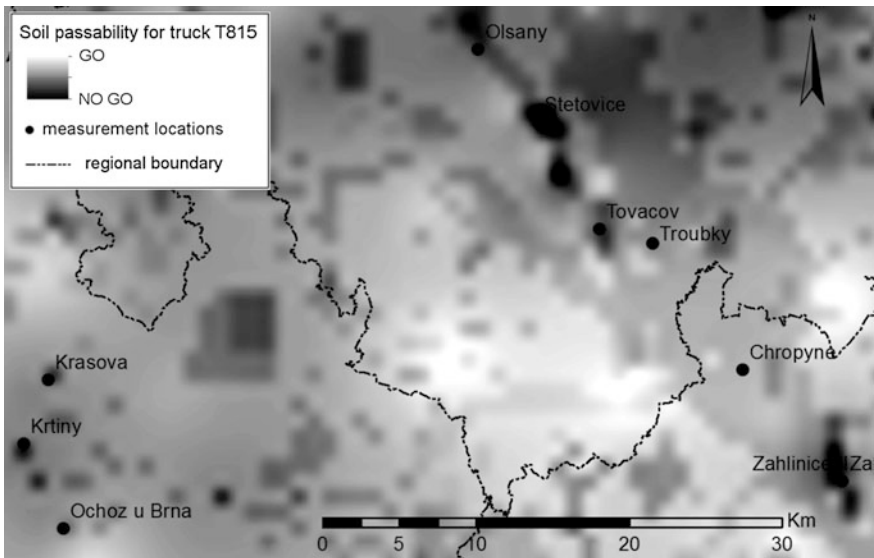5. Calculation of passability using the algorithm defined for SMDoS;

Fig. 5 The map section of soil passability created by the new algorithm for truck T815

6. Multiplication of final soil passability layer by coefficients of a particular vehicle type collected during terrain research.

It is possible to create a soil passability map by modifying the original algorithm and by processing further input data. The resulting map could express the soil impact to the possibility of movement depending on used vehicle type (Fig. 5).

5 Discussion and Conclusion

The creation of geographic data and making them available are very useful activities. It enables their wide usage in many disciplines. The usage of pedological and meteorological data together with accurate relief model for soil impact modelling to the vehicle movement can serve as the example. The proposed process uses already existing method of evaluating soil polygons depending on the precipitation amount and it extends the method with new possibilities. It evaluates precipitation amount in landscape by relatively reliable method and uses more than 1 year executing penetrometric measurement of bearing capacity at localities with soils which are passable with restrictions. Although the process is not capable of considering ratio between absorption and rain precipitations drainage and other meteorological influences as a temperature, time of sunshine, wind speed and others, the proposed solution is more accurate than the present method. Its improvement depends on a way of determination of precipitation distribution in landscape and combination various pedologic data including expression uncertainty in location of soil polygons. Modelled values of passability are not 100 % reliable, but their accuracy reaches approx. 65–87 % of values measured in terrain depending on soil characteristics in the area of measuring and on vehicle type.

Results that were achieved, are influenced to a considerable extent by climatically non-typical year 2015, when the precipitations in the Czech Republic did not reach even one half of annual mean at some places. Almost half of locations, where measurements were performed, are still insufficiently saturated (Global Change Research Institute of the Czech Academy of Sciences 2015). It is expected on the basis of recent autumn and winter months course, that situation will be improved during spring season. It will enable further measurement and checking of proposed procedures. It is planned to select and verify other locations with regard to soils showing lower reliability of results, besides continuation in measurement at present localities. The next step is to solve the problem of absorption and precipitation drainage.

At present, the results are being applied to the complex model of cross-country movement, which is being developed by the Department of Military Geography and Meteorology (Rybansky and Vala 2009; Rybansky et al. 2015; Rybansky 2009; Hubacek et al. 2015a, b; Hofmann et al. 2014). After its completion, this model could be implemented to the systems of provision of the geographic and

hydrometeorological support for the benefit of Czech Republic Army's units and the agencies of the Integrated Rescue System.

References

Almasiova L (2015) A relationship between radar reflectivity and rainfalls recorded by the ground gauges. In: International conference on military technologies (ICMT), IEEE, Brno, May 2015, pp 285–288

Andersson T, Ivarsson K (1991) A model for probability nowcasts of accumulated precipitation using radar. J Appl Meteorol 30:135–141

Beven KJ (1996) A discussion of distributed hydrological modelling. Springer, Netherlands, pp 255–278

Brazdil K et al (2012) Technical report to the digital terrain model DTM 4th generation. Pardubice, Dobruska, Czech Republic (in Czech)

Childs C (2004) Interpolating surfaces in ArcGIS spatial analyst. ArcUser, July–September, pp 32–35

Cibulova K, Sobotkova S (2006) Different ways of judging trafficability. Adv Military Technol 1 (2):77–88

Cibulova K, Hejmal Z, Vala M (2015) The influence of the tires on the trafficability. In: International conference on military technologies (ICMT), IEEE, Brno, May 2015, pp 1–4

Collins JM (1998) Military geography for professionals and the public. Potomac Books Inc, Sterling

Global Change Research Institute of the Czech Academy of Sciences (2015) http://www.intersucho.cz. Accessed 12 Dec 2015 (in Czech)

Gritzner ML et al (2001) Assessing landslide potential using GIS, soil wetness modeling and topographic attributes, Payette River, Idaho. Geomorphology 37(1):149–165

Hillel D (1991) Out of the earth: civilization and the life of the soil. University of California Press, Berkeley

Hofmann A et al (2014) Creation of models for calculation of coefficients of terrain passability. Qual Quant 49(4):1679–1691.

Hofmann A, Mayerova S, Talhofer V (2013) Usage of fuzzy spatial theory for modelling of terrain passability. Adv Fuzzy Syst 2013:1–7

Hubacek M et al (2014) The soil trafficability measurement in the Czech republic for military and civil use. In: 18th international conference of the ISTVS, September 2014, Seoul

Hubacek M et al (2015a) Assessing quality of soil maps and possibilities of their use for computing vehicle mobility. In: 23rd central European geographic conference, Masaryk University, Brno, October 2015 (in print)

Hubacek M et al (2015b) Accuracy of the new generation elevation models. In: International conference on military technologies (ICMT), IEEE, Brno, May 2015, pp 1–6

Kainz W (2008) Fuzzy logic and GIS. University of Vienna, Vienna

Kubíček P et al (2011) Flood management and geoinformation support within the emergency cycle (EU example). In: Environmental software systems. Frameworks of environment, Berlin, pp 77–86

Manual (1994) Field. Manual 5-430 planning and design of roads, airfields and heliports in the theatre operations. Washington, DC, USA

Manual (1998) Field. Manual 5-33, Terrain analysis. Washington, DC, USA

Monkhouse FJ (1970) Principles of physical geography. American Elsevier, New York

Myers DE (1994) Spatial interpolation: an overview. Geoderma 62(1):17–28

Novak P et al (1991) Synteticka pudni mapa Ceske republiky 1:200000. VÚMOP Praha (in Czech)

Prax A, Hrasko J, Nemecek J (2008) The importance of comprehensive agricultural soil survey in the former Czechoslovakia and processing the result thereof. In: 2008 soil in modern information society: 1st conference of the Czech Society of Soil Science and Societas Pedologica Slovaca. Bratislava, pp 22–28

Research Institute for Soil and Water Conservation (2015) http://wakpp.vumop.cz/. Accessed 12 Dec 2015 (in Czech)

Ross TJ (2009) Fuzzy logic with engineering applications. John Wiley & Sons, London

Rybansky M (2009) The cross-country movement—the impact and evaluation of geographic factors. CERM, Brno

Rybansky M, Vala M (2009) Analysis of relief impact on transport during crisis situations. Morav Geogr Rep 17(3):19–26

Rybansky M et al (2015) Modelling of cross-country transport in raster format. Environ Earth Sci 74(10):7049–7058

Salek M (2012) Analysis of rainfall intensities using very dense network measurements and radar information for the Brno area during the period 2003–2009. Meteorol Z 21:29–35

Silhavy J, Cada V (2015) New automatic accuracy evaluation of altimetry data: DTM 5G compared with ZABAGED® altimetry. Lecture notes in geoinformation and cartography. Springer, Berlin, pp 225–236

Technical Report (2000) UDB Pudy. Vojenský zeměpisný ústav Praha. Czech Republic (in Czech)

User Manual (2000) UDB Pudy. Vojenský zeměpisný ústav, Praha, Czech Republic (in Czech)

Vieux BE (2001) Distributed hydrologic modeling using GIS. Springer, Netherlands, pp 1–17

Vranka P, Svatonova H (2006) Continuous soil lost modeling in the Haraska watershed—an application of 4D digital landscape model. Morav Geogr Rep 14(1):38–45