

Adaptation Measures for Climate Change in the Process of Land Consolidation

František PAVLÍK, Arnošt MÜLLER, Svatava MARADOVÁ and Michal GEBHART,
Czech Republic

Key words: Land consolidation process, climate change, adaptation measures, common facility plan

SUMMARY

There have been increasing hydrological extremes in the Czech Republic during the last years. Drought periods are often alternated by flood events including flash floods. According to predictions of global climate models for the Czech Republic these phenomena will be more likely in the future. These facts cause higher demand on the land consolidation process and introduce new challenges especially in the design of adaptation measures through the Common Facilities Plan as an important part of land consolidation process.

The Common Facilities Plan proposes a new structure (infrastructure), in which new plots (parcels) are situated. Adaptation measures are designed using a complex multifunctional system: organizational (the shape and size of plots, direction of farming), agro-technical (seeding, leaving harvest residue) and technical (ditches, retention basins) measures.

The State Land Office is currently participating in the project, which is focused on conceptual modification of landscape with respect to impacts associated with climate change. This project from the agricultural practice aims to define most vulnerable areas of the Czech Republic and develop adaptation measures to mitigate negative effects, especially floods and droughts. Proposed measures need to be acceptable by farmers. The project responds to the priorities of the Government in the food self-sufficiency, increasing flood protection, and increasing protection of soil and landscape. State Land Office was delegated by the Czech Republic's Government in 2015 to be responsible within the Ministry of Agriculture for the development and maintenance of the national agricultural drought monitoring and early warning system.

The Common Facilities Plan as a part of Land Consolidation process it is one of the tools for implementation of new findings from the present project or monitoring of drought into practice of designing adaptation measures.

State Land Office try to be ready for new challenges in process of Land Consolidation.

The decisive factor in adapting to climate change remains the political will to implement the proposed measures.

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1. INTRODUCTION

Present day landscape of the Czech Republic faces multiple challenges including the ongoing climate change that is at many locations combined with soil degradation. At the same time, erosion risks and the rate of the soil degradation are still deemed as unsustainable in some areas despite a number of existing measures being taken (Vopravil et al. 2012). The deterioration of the soil properties through unsustainable agricultural practices and changing climate could lead to fall in the productivity beyond the point of no return with devastating effect on the ecosystem services in large area (Trnka et al., 2016). With that closely related increasing hydrological extremes in the Czech Republic during the last years, drought periods are often alternated by flood events including flash floods. According to predictions of global climate models for the Czech Republic these phenomena will be more likely in the future. This also realized the Agrarian Chamber (representing the great majority of farmers in Czech Republic) and State Land Office that major revisions of the existing policies related to the management of soil degradation frequently associated with intensive rains and the increased drought risks due to climate change are needed. Therefore multidisciplinary task force was formed and supported through so called “Master Plan of Landscape Water Management of the Czech Republic”.

The ultimate goal of the whole procedure is the quantification of these risks, putting into place policies and measures leading to risk reduction and ensuring their adoption in practice through the use of demonstration areas, as well as through technical and financial assistance. This may be achieved only when hazards, vulnerability and exposure are known, allowing for the calculation of the expected damages related to the risks associated with different hazardous scenarios. This study uses concept of more-than-one-hazard and focuses on drought and soil degradation hazard assessments for the agricultural landscape of the Czech Republic. While according to Kappes (2012) the multi-hazard assessment maybe understood as assessment of „the totality of relevant hazards in a defined area”.

For the suppression of hydrological extremes is possible to use the process of Land Consolidation which can propound and then implement water management, erosion control, ecological and land accessibility measures and so the measures to reduce the effects of drought. Nevertheless the expected climate change cause higher demand on the land consolidation process and introduce new challenges especially in the design of adaptation measures through the Common Facilities Plan. In this process is therefore essential to use latest scientific knowledge and respond to the economic and political development. Very important is also to choose the right measures for the specific area of the Czech Republic in the current and expected future climate.

2. MATERIAL AND METHODS

2.1 Common Facilities Plan

Common Facilities Plan is an elementary document of the whole Land Consolidation because it allows propound many elements and measures which fulfill public interest (Figure 1). These measures we divide into measures for land accessibility, for erosion control, water management measures and ecological measures.

Common Facilities Plan (CFP) must tally to the Urban Planning Documentation (UPD), otherwise the CFP represents a propound for actualization or a change in UPD. If it is necessary to provide an area of land fund for common facilities, firstly is used land in ownership of state and then in the ownership of municipality. Finished CFP has to be passed by the municipality council and other involved authorities are expected to apply their objections. Municipality council also defines the priorities in implementation of realizations of the proposed measures.



Figure 1. Example of Common Facilities Plan

In CFP there are often combinations of various types of measures to complement each other. An example can be a field road with tree alley and dike alongside (Fig. 2).



Figure 2. Erosion control belt with a planting

2.1.1 Measures for land accessibility

These measures are trying to solve the principles of the proposed concept of the transport system and in the same time it includes relations with the transport system network with the higher order. The proposed transport system and its technical parameters must be in accordance with the valid technical standards and regulations. This transport system also has to fulfill the requirements for the movement of the agricultural vehicles, enable the rational agriculture and other use out of agricultural transport. Measures which provide land accessibility include field or forest roads (Fig. 3), small bridges, fords, railroad crossings etc.



Figure 3. Example of measures for land accessibility

2.1.2 Ecological measures

Proposals of these measures have to document the process for maintaining and improving the ecological stability of land after the Land Consolidation Process. It also has to document the relations with the areas out of bounds of the land consolidations and functional relations with the transport, erosion control and water management parts of the CFP.

To this category belong measures like local system of ecological stability (biocenters, biocorridors), interaction elements, small water pools, wetlands (Fig.4) etc.



Figure 4. Example of ecological measure

2.1.3 Soil erosion control measures

To prevent soil erosion CFP often designs a complex of organizational, agronomic and technical measures which complement each other to reach the highest efficiency. These measures are aimed at protecting watercourses, water pools and urban areas against the negative effects of soil erosion, retarding surface runoff and supporting water retention in the landscape, all with taking under consideration requirements and abilities of the agriculture. The enforceability of the measures, especially the “soft” ones (organizational and agrotechnical), largely depends on the willingness (or its lack) of agricultural subjects to implement these measures. Therefore is essential to consult the planned measures with these subjects.

Soil erosion control measures are divided into three groups:

- 1) Organizational measures – grassing, foresting, shape and size of the parcels, rotation of crops on the soil, change of land use (Fig. 5) etc.



Figure 5. Change of land use (arable / vineyard with anti-erosion function)

- 2) Agrotechnical measures – growing measures, grassing between fields, seeding into protective crop (Fig. 6), leaving crop residues etc.



Figure 6. Seeding into protective crop

- 3) Technical measures – sedimentation reservoirs, ditches, stabilization of the paths of runoff (Fig. 7), infiltration zones, terraces, windbreaks etc.



Figure 7. Stabilization of the paths of runoff

2.1.4 Water management measures

These measures deal with the water management with particular attention to the relations in the watershed (which means also outside the border of the land consolidation). The principles of these measures are based on legal obligations consisted of improving water conditions, drainage of surface water, flood protection, water resources protection, surface and groundwater protection, measures for water works and the elimination of the drought. These measures are projected primarily to eliminate negative hydrological conditions (floods, droughts) and they include reservoirs, revitalizations of water streams, ponds, dams, stream adjustments etc.

2.2 Master Plan of Landscape Water Management of the Czech Republic

Master Plan of Landscape Water Management of the Czech Republic is a project which is focused on conceptual modification of landscape with respect to impacts associated with climate change. The project tries to find new legislative, economical and technical solutions which can be enforced by the process of Land Consolidations (CFP). The main institutions involved under the rule of State Land Office are Czech Agrarian Chamber, universities (Mendel University in Brno, Brno University of Technology), Research Institute for Soil and Water Conservation, T. G. Masaryk Water Research Institute and Global Change Research Institute. This project from the agricultural practice aims to define most vulnerable areas of the Czech Republic and develop adaptation measures to mitigate negative effects, especially floods and droughts. Proposed measures need to be acceptable by farmers. The project responds to the priorities of the Government in the food self-sufficiency, increasing flood protection, and increasing protection of soil and landscape.

2.2.1 Description of the solution

First step of the solution was to describe the current situation (studies, legislation, foreign experience, etc.) and evaluation of available data sources.

The second step towards the implementation of the proposed framework is the identification regions with the highest hazards so that the next steps of risk assessment (vulnerability and exposure assessments) and policy application can be targeted to these regions.

The potential indicators that could be used to for the assessment of hazards are numerous.

Because the focus of this study was on assessing combined hazards for agricultural land, we focused on the indicators that in our view can best be used to quantify these hazards.

Towards the assessment of the combined hazard (Fig. 8) for the agricultural lands analyzed, we identified the following hazards as being the most critical ones:

- Agricultural drought during the growing season
- Pre-existing poor soil conditions decreasing the ability of the soil to hold water (quickly drying soils)
- Increased susceptibility to water erosion, including the occurrence of concentrated runoff pathways
- Pre-existent infrastructure and/or settlements in the path of the concentrated runoff pathways

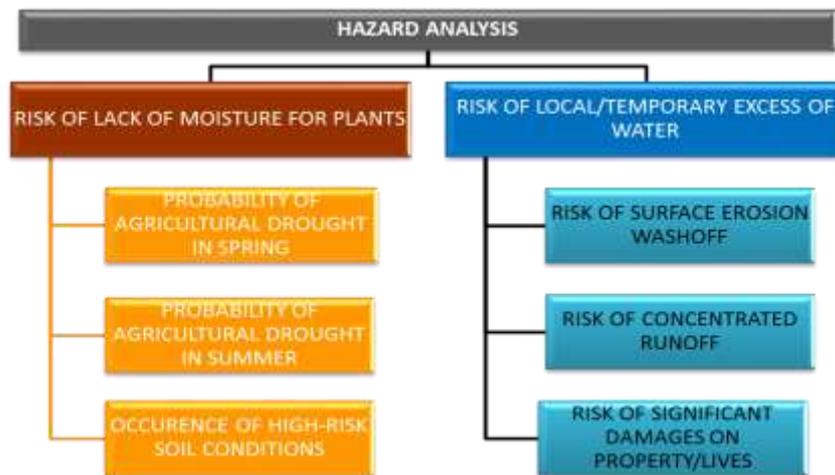


Figure 8. Overview of the individual hazard indicators with arrows showing their interactions
 2.2.2 Individual hazard indicators

Agricultural drought during the growing season

As the indicator of drought hazard, we selected the median number of days per season (based on 1991-2014 data) with a saturation of the surface soil layer below 30 % of the relative soil water content (i.e., the percentage up to which water fills the soil pores between the so-called wilting point and field capacity) in the topsoil. In general, this value could be considered as the level below which the physiological processes of the plant begin to be significantly limited by a lack of water (e.g., Larcher 2003). The calculations were performed in 500 m grid covering the whole Czech Republic (Trnka et al., 2015b). Based on the drought-yield relationship, we divided the growing season into two parts: April-June and July-September. The former, mostly spring- and winter-sown cereals (usually harvested in July) are known to be affected the most (e.g., Hlavinka et al., 2009), while the latter season represents the time period in which latter-maturing crops (e.g., maize, potatoes or sugar beets) can be negatively affected.

Quickly drying soils

In Czech Republic, this issue is of concern in the northwestern and southeastern parts of the country. The expansion of fast drying soils is driven by erosion, and many areas with very fertile soils less than 100 years ago (e.g., chernozems) are presently fast drying soils consisting of an underlying loess or sand from the original bottom of the sea. The process is accelerated by ongoing climate change connected with the increasingly frequent occurrence of long periods of drought and also by unsuitable tillage practices with a low re-supply rate of organic matter to the soil. Determining the occurrence of fast drying soils was performed through the evaluation of a high resolution (5x5 m grid) map of the soil conditions based on the information obtained from the soil database that is maintained and permanently updated by the Research Institute for Soil and Water Conservation

Sheet, interrill and rill soil erosion

The first indicator of an erosion hazard for agricultural land focuses predominantly on so-called sheet erosion (i.e., the transport of loosened soil particles by overland flow). In this study was used an approach based on the universal soil loss equation USLE (Wischmeier & Smith 1978). The topography factors were estimated according to the modified equation of

Desmet & Govers (Desmet & Govers 1996) using a 5x5 m grid digital elevation model. The efficiency factor of erosive rainfall was set to $R = 40 \text{ MJ}\cdot\text{ha}^{-1}\cdot\text{cm}\cdot\text{h}^{-1}$ (Janeček et al. 2012), and the C factor was based on the actual crop proportions at the same resolution as the slope and length estimates. After estimating annual soil loss, those 5x5 m grids showing the annual potential loss higher than 4 tons per ha (i.e. nationally enforced limit) were marked as those with a significantly higher than permissible erosion rate.

Rill and ephemeral gully erosion

In addition to the classic erosion furrows on the surface slopes of arable land, there are also so-called “rills” and “ephemeral gullies” present, which differ from the classic erosion furrows because of their cross-sectional area (larger than 1 square foot) (Morgan, 2005).

For the analysis of ephemeral gully erosion hazards, the method of plotting potential paths of runoff concentration at the spatial resolution of 5 m was used. This method is based on the modeling of flow accumulation from drainage areas, the interpretation of the nature of the terrain and the visual interpretation of aerial photos of the affected land blocks. Contributing areas were used to automatically generate the direction and accumulation of runoff over a digital terrain model with manual correction using raster topographic maps and aerial orthophotos (Dumbrovský et al. 2011).

Localized floods originating from agricultural land

Drbal & Dumbrovský (2009) reported that even a contributing area of 5 ha is sufficient to generate a flow that can cause severe damage to property. The causal factors critical for the formation of a concentrated runoff were determined based on the number of recent flood events from torrential rainfall, and parameters were set to estimate so-called “critical points”. Critical point (CP) was defined as the point where the trajectory of the concentrated runoff penetrates into the municipality. CPs were thus determined based on the intersection of a municipality (urban) boundary with concentric lines of a track drainage area with the contributing to a region $\geq 0.3 \text{ km}^2$. As the area affected by torrential rainfall tends to be limited, the contributing area was also limited to 10 km^2 . In this analysis we assumed that torrential rain could occur at any location in the Czech Republic.

2.2.3 Multiple hazard analysis

The original quantification of the indicators was based on different resolutions, with data on drought occurrence being available as a 500 x 500 m grid and the remaining indicators being calculated at 5 m resolution due to the importance of the local terrain conditions. As the study aimed at identifying the areas with the highest hazard level for policy making purposes, the indicators were aggregated at the level of the cadaster unit, which is the smallest administrative unit in the Czech administrative division system. For each cadaster unit, the value of each indicator was calculated. All indicators were normalized using a z-score approach. It is one of the most commonly used normalization procedures in which all indicators are converted into a common scale with an average of zero and the standard deviation of one.

Value of Z-score was calculated as:

$$z = \frac{x - \mu}{\sigma}$$

where:

x - parameter value in the cadastral; μ - average value for all cadastral; σ – standard deviation for all cadastral

Hazard of solved area was classified according to the value of Z-scores as show Table 1.

Table 1: Z-score table used to interpret the standardized values of the indicators

| Indicator interpretation | z-score range |
|---------------------------|----------------|
| Above average | 0-0.5 |
| Markedly above average | >0.5 and < 1.0 |
| Highly above average | 1.0-1.5 |
| Very highly above average | >1.5 and < 2.0 |
| Extremely above average | 2.0 and higher |

2.2.4 Results of Multiple hazard analysis

Spatial distribution of multiple hazard analysis is shown in Fig. 9. The percentage of territory at where the hazard level is highly above average or worse is 8% (Fig. 9a). Within the multi-criteria analysis, was simultaneously examined how a large part of the territory of Czech Republic meets at least one of the criteria for an extreme degree of risk (Fig. 9b). This combined approach provides a good overview of the areas where the hazard level is significantly higher than the rest of the territory. The last step of this analysis was to define the territory that may be considered to be at a particularly high risk. As such, was considered a territory where the average value of the z-scores was higher than 1.5 and/or where at least two criteria had z-scores above 2.0 to be at a high risk. These criteria are met by 4.5% of the territory of Czech Republic. As Fig. 9c shows, two areas can be pinpointed as the most at risk. These most vulnerable regions constitute areas where attention and resources should be given the highest priority.

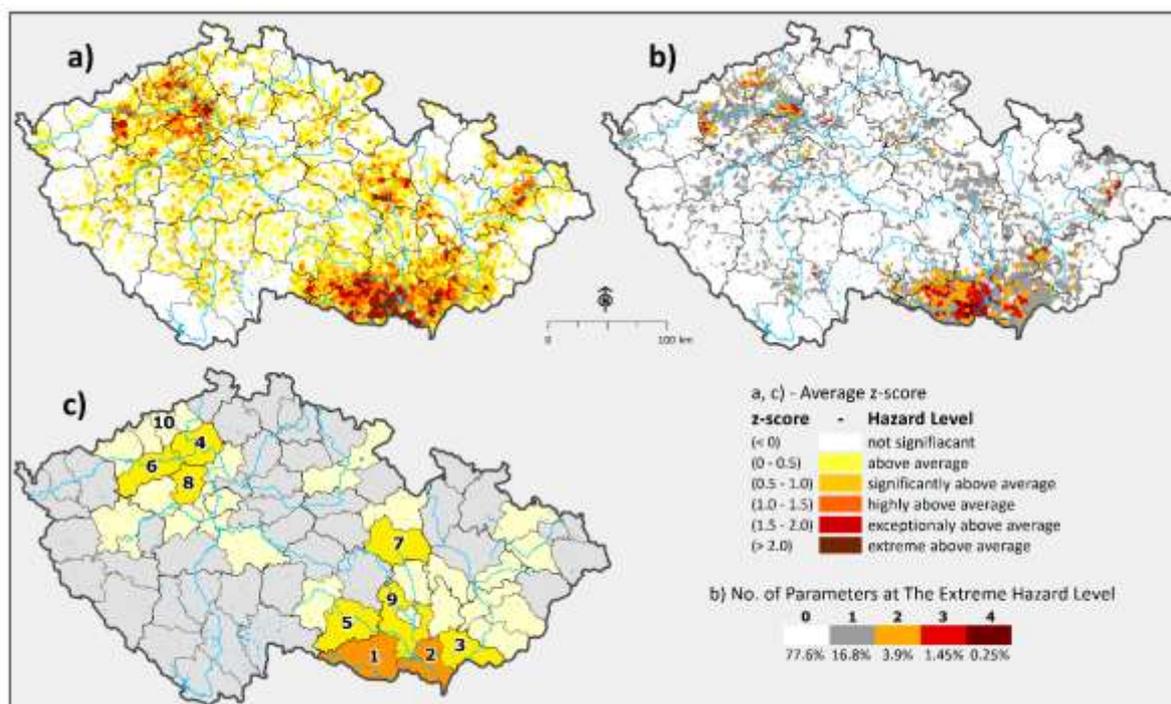


Figure 9. The result of the multiple-hazard analysis at the cadastre (a-b) and district (c) level: a) mean z-score of all six individual hazards, b) number of individual hazards per cadastre unit in the worst category, and c) the districts with the highest combined hazard level within the country. The top 10 regions according to hazard level are numbered.

3. CONCLUSION

The mapping of multiple hazards for agricultural land is intended as an important step in the assessment of the vulnerability of the agricultural sector to the occurrence of drought and extreme precipitation events under the present conditions and under the predicted future climate conditions in Czech Republic. The map presented here synthesizes a variety of data and serves as an indicator of areas deserving more detailed attention. Regions with highest hazard level are concentrated in the southeastern and northwestern lowland areas. As typical areas with the highest hazard levels, we can identify regions with below average precipitation and a high proportion of soils with a degraded or naturally occurring low water-holding capacity, and those with steeper than average slopes and terrain configurations in relatively large catchment areas that have urbanized landscapes located at their lower elevations. The identification of the most vulnerable areas in the Czech Republic through a multi-hazard analysis is an important source of information in guiding the prioritization of the land consolidation process and its spatial targeting for the State Land Office. In this way, the State Land Office receives unique material that can be used to improve their ability to mitigate the impacts of climate change. In addition, it will be able to effectively participate in the establishment of a legislative and economic framework that could possibly realize adaptation measures acceptable to agricultural entities.

As the next step in the search of new measures (technical, economic and legislative) and their efficient spatial targeting will be analyzed in detail farms from areas with the highest hazard

levels. It will also made a detailed proposal of adaptation measures that will be acceptable to farms under the current (climate, economical, legislative) and future (climate) conditions. Experiences from the pilot farms will help indicate the necessary adaptation measures for the future. An important question is the political will and ability to enforce the necessary adaptation measures at national and international level.

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BIOGRAPHICAL NOTES

Ing. František Pavlík, Ph.D. is a Head of department at State Land Office of the Czech Republic and works in the field of land consolidations, soil conservation, and geoinformatics. He studied at Brno University of Technology where he obtained PhD Degree with his thesis “Quantification of Natural Water Retention Capacity in Selected Watersheds” (2014). After graduation he works as a researcher at Palacký University Olomouc and T. G. Masaryk Water Research Institute. He published in Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, in Fresenius Environmental Bulletin and he also contributed as an author to a books about degradation and regeneration of soils and landscape. He also works on research projects during his studies and further career in field of water retention, erosion, land consolidation and soil degradation.

CONTACTS

Ing. František Pavlík, Ph.D.
State Land Office
Husinecká 1024/11a
Prague
CZECH REPUBLIC
Tel. +420 729 922 528
Email: f.pavlik@spucr.cz
Web site: www.spucr.cz