3. Effect of water shortage on agriculture and natural areas

3.1. Severity of past and present droughts

Károly Fiala, Balázs Benyhe, Dragan Dolinaj, Imre Pálfai

Introduction

Meteorological factors play a significant role in the formation of drought, thus by their further assessment, drought severity can be quantified. It is of great importance to examine and study the phenomenon of drought on the study area due to the high ratio of agricultural areas. PAI (Pálfai Drought Index, Pálfai 1989) and the MAI (Moisture Anomaly Index, Hargreaves 1971) were used to describe droughts of the past decade for the right bank-side catchment of Tisza and in Vojvodina.

The indices are calculated as follows:

$$PAI = \frac{\left[\sum_{i=apr}^{aug} T_i\right] \qquad 5}{\sum_{i=oct}^{aug}\left(P_i * w_i\right)} * 100 * k_t * k_p * k_{gw}$$

where: T: temperature; P: precipitation
w_i: weighting factor
k: correction factors (temperature, precipitation, groundwater)

$$MAI = \frac{AE}{PE}$$

where: AE: actual evapotranspiration
PE: potential evapotranspiration

Analysis of Pálfai Drought Index in the Hungarian part of the study area

The calculated Pálfai Drought Indices for the stations on the right bank-side of the Tisza catchment are shown in Figure 3.1 (page 88). In the case of all stations a significant rise could be seen between the mean values of the two partial periods. Drought severity increased; mild and moderate drought characterised the first period, while mean drought was dominant in the second period. Although PAI values were around 5 for the period of 1961-1987, they reached the value of 7 for the next period!

Drought severity can be defined by the degree of water scarcity, though sometimes this parameter is not considered appropriate for the affected sectors. Agriculture, ecology, industry and society have completely different water needs. Because of these various needs this question can be approached with reference to the average precipitation of the affected area. Precipitation amounts compared to the long-term average are suitable to describe the water shortage. Several researchers dealt with this issue (Szalai 2009, Bartholy and Pongrácz 2005) and zonal maps of the areas with water deficiency were created. According to the studies, water deficiency is between 100 mm and 200 mm in drought periods on the catchment area, which could be even higher in extreme circumstances. The problem may culminate in cases (it has already happened) when drought occurs on the same area for consecutive years since water shortage (if there is no significant water refill) becomes worse.

Besides drought severity, frequency also has to be assessed, which shows how the different areas are affected. Fig. 3.2 (page 89) shows that not only severity, but frequency increased as well. A more considerable change could be observed after the 1990s. Prior to this, the annual drought index had reached the value of 8 in a few cases (moderate drought), then in the past two decades in several cases serious drought (in 5 cases) or extreme (in two cases) drought occurred. Data has pointed out that the area is affected at least by moderate drought in every 2 years, serious or extreme droughts are recorded for every 3 years, causing serious damages.

Besides temporal changes, considerable spatial differences can also be observed. Certain areas are more sensitive to drought. In the point of drought the geographical location of the study area is quite unfavourable. Of course, consecutive years differ from each other; therefore the rate of drought is different, too. It is really important to note that PAI values are much higher compared to the national average in case of the study area, furthermore the deviation of heavy droughts is remarkable.

The dry autumn and snowless winter of the year 1989 contributed to the formation of droughts for the next years. In 1990 the low level of groundwater, followed by a hot July and August with no rainfall, resulted in huge damages to the maize yield. The same causes could be determined for the development of drought in 1992 and 1993 with an extent similar to that of 1990.

Based on the air temperature data for 1992, the annual mean temperature for the April-August period was 18.8°C, which is not extraordinary. The mean monthly temperature in August exceeded 25 °C, which meant breaking the records of the last century. The number of heat days in the three summer months was over 37 days, which is twice as much as the average value. The last quarter of the previous year precipitation exceeded the long-term average. Following December, the monthly sums were below the long-term average with one exception, which is June. During the warmest period there was no precipitation, the affected area had more than 30 days without precipitation. The PAI values were between 11-14 °C/100 mm, whose spatial distribution is represented in Figure 3.3 (page 91). This year droughts of the same severity occurred in Vojvodina as well.

The drought in 2000 was preceded by huge inland excess water inundations as a result of the precipitation which fell in November and December in 1999, and was twice the amount of annual mean precipitation. January and February was characterised by few precipitation, and then March and April were slightly rainier. However, after 7 April, an extremely long, dry period started lasting until the first week of July then it went on after a short break. 216 mm precipitation was recorded for the whole calendar year in Szeged. Most stations in the Danube-Tisza Interfluve measured less than 300 mm. The precipitation did not reach 60 mm from April to August. The number of heat days was extremely high. These both contributed to severe drought. PAI values were between 12 and 14 (Fig. 3.3 on page 91). The drought affected the area of Vojvodina much more seriously.

Prior to the drought in 2007, the area was damaged largely by inland excess water inundations and a record-size flood in 2006. In 2007 spring water scarcity could be expected since a long arid period was experienced in the autumn and winter of 2006. The 3-month amount of precipitation reached only half of the long-term average. Besides these, winter months were unusually mild. The monthly mean temperature was around 4–5°C unlike the long-term average of -1-1.5°C. Accordingly, evaporation was higher, thus, the water shortage that had already developed further increased. An average amount of precipitation fallen at the beginning of spring, and then in April hardly any rain could be measured. The situation slightly moderated during the period starting in May defined by heavy rains, however, serious drought evolved as the summer heat arrived. The daily maximum temperature from mid-July exceeded 36°C. There were 50-60 heat days on the Great Hungarian Plain. The precipitation was half of the long-term average. Precipitation further dropped in August – one third of the amount typical for the area fell, which resulted in extreme drought (Fig. 3.4 on page 93). In 2007 moderate and mild drought could be observed in Vojvodina according to the values of Pálfai index.

The most severe drought of the past 50 years evolved in 2012. Considering the national average, scarcely more than 400 mm precipitation was measured in 2011, which is two-thirds of the multi-year average. The annual precipitation was 325-400 mm in the study area. It was the driest year since 1901 (Fig. 3.4 on page 93). The precipitation of 2010 and stored moisture in soil could somewhat compensate for the water deficit. The permanently dry period continued in the first half of 2012. The precipitation on the catchment area was 30% less, while at certain places there was a decrease of 50% compared to the long-term average. On average, 225 mm precipitation was recorded until August (only about 5 mm fell in August!), while the long-term average was 380 mm. The entire catchment area, especially Kecskemét area, was extremely dry (Fig. 3.5 on page 94). The extremely high temperature in July and August intensified the unusual aridity. The monthly mean temperature was 3-4°C over the long-term average. There were 60 days with daily extremes and heat days. Due to the superponation of the extreme weather elements, extreme and severe droughts developed on 80% of the catchment area

Drought severity in consecutive years can be significantly different, however, in many cases no drought develops in subsequent years. Based on the temporal changes of mean drought indices (Fig. 3.5 on page 94) it can be stated that drought severity considerably increased in the two studied periods. The figure reveals that the frequency of drought-affected years and the intensity of the effects also increased. There is a 40% rise between the mean values of both periods, which is mainly caused by the apparent temperature increase. If the tendency remains, the annual mean value of PAI index for the coming 30 years is likely to be around the value of 8. The reasons behind changes on the studied catchment are of natural and anthropogenic origin. Integrated intervention is necessary to prevent and mitigate the damages of drought. Further impacts of climate change could initiate irreversible processes, whose effective management is doubtful.

Further analysis of drought indices in the Vojvodina part of the study area

Dry years were particularly frequent in the last two decades of the 20th century in Serbia as well (Spasov et al. 2002, Gocic and Trajkovic 2013). Gocic and Trajkovic (2014) allocated North Serbia as a region with precipitation values under the average value of Serbia. In order to evaluate drought in this region, data analysis for 7 hydro-meteorological stations and 45 municipalities in Vojvodina was carried out. The presentation of the results was based on the meteorological station Rimski Sancevi, which is located 15 km from Novi Sad, because its statistics are exceedingly similar to the average meteorological values throughout Vojvodina. Measuring precipitation throughout critical months such as July and August for the period of 88 years (1924-2012) shows that 84.27% of the years July, and 84.27% of the years August were arid. The amount of the precipitation evidently was not sufficient to satisfy crop water requirements, which was above 100 mm from June to August (Table 3.1 on page 95). The moisture

Availability index (MAI) in the region very low, particularly in August (Table 3.2 on page 95), and there are some spatial differences (Table 3.3 on page 96). Regions where MAI index is under 0,33 are very deficient, 0,34-0,66 moderately deficient, 0,67-0,99 somewhat deficient, 1,0-1,33 adequate moisture and above 1,34 excessive moisture. According to analysis the climate circumstances in Vojvodina are semi arid, and semi humid.

The period 1924-2003 was analysed in terms of sufficient amount of water, specified by the precipitation that crops need for regular growth consistent with Hardgrave's' model and index. Model is based on the analysis of 75% precipitation (P) and potential evapotranspiration (ETo). Based on the assessment, the area of Vojvodina has semi arid or arid climate during summer, which is not favourable for successful crop production, thus irrigation has high importance int he region.

3.2 Effect of water shortage on agriculture and natural areas

Péter Szilassi, Károly Fiala, Zsuzsanna Ladányi, Viktória Blanka

Introduction

In spite of the dramatic technological development of agriculture (for example, irrigation systems, new seeds for sowing, genetic modification), environmental factors such as climate, ecology and soil attributes still substantially affect crop yields. The consequences of climate change appear in different forms all over the world, thus assessing local conditions is also important.

Climate change can have impact on agricultural production in many ways in the long run. Drought periods influence the yield and quality of crops, the application of agro-techniques by means of changes in water balance (for example, irrigation, chemical need). Furthermore, the choice of species, soil quality and soil erosion, and last but not least, the flora and fauna are also affected by drought. It is a key problem in the future to maintain food safety in the changing circumstances, therefore involvement and identification of areas affected by drought hazard and revealing steps of efficient adaptation are of vital importance.

Yield loss

The Hungarian Central Statistical Office has published the crop yields of the major field crops for all Hungarian counties since 2000. According to the yield data of wheat and maize, the most prevailing field crops, yields in 2000, 2002, 2003, 2007, 2009 and 2012 were below the average between 2000 and 2012, and maize showed the greatest deviation. The highest decrease of average crop yield was seen due to the drought in 2012 (Fig. 3.6 on page 98). It was a decrease of over 50% in Csongrád County, while in Bács-Kiskun County the crop yield dropped by 44% as compared to the long term average. There were some Hungarian counties where, in the same year, farmers could harvest maize with yield exceeding the long term average values. The crop yield map for 2012 in Figure 3.6 shows that the southern counties experienced the most substantial reduction, which areas are in parallel with the areas most exposed to drought hazard according to the Pálfai Drought Map.

In Vojvodina in 2012 remarkable yield loss could be observed, similarly to the southern Hungarian counties (Mészáros et al. 2013). There was a 50% decrease in maize yield in 2012 compared to 2011, furthermore reduced yields for less sensitive cereals were also observed (wheat: 8%, sugarbeet: 30%, sunflower: 11% , soy: 35%, potato: 30%, beans: 40%, clover: 30%, tobacco: 25%).

Figure 3.7 (page 99) illustrates the changes in maize yield, as the most drought sensitive plant in the region. The most remarkable decrease occurred in 2000, 2003 and 2007, while the best crop yields were recorded for the years 2004, 2005 and 2006 between 2000 and 2009. The yield loss in Vojvodina peaked in 2000 exceeding the discrepancies seen in the southern Hungarian counties. In the other years strongly affected by drought (2003, 2007) Bács-Kiskun County suffered the biggest damage owing to the sandy soils typical for this area (due to the better water retention capacity of chernozem, meadow and alluvial soils in Csongrád County and Vojvodina). The greatest changes both in positive and negative directions were found in Bács-Kiskun County.

Drought damages due to yield loss

The damages caused by drought could be depicted by the calculation of the rate of agricultural yield loss, as this section reflects the impact of this phenomenon most and at the earliest. Under such climatic conditions the damage is determined by the tolerance of plants grown, the water balance features of the soil, and the possible irrigation. The most sensitive plants are legume crops, vegetables and cereals. The damages for 1990 in Hungary were estimated to reach 50 billion HUF, for 1992 the damages arising from the drought may have been 30 billion HUF, due to the extreme drought in 1993 - based on approximate estimates – it was 50 billion HUF. In 2003 the damage due to drought was estimated at 40 billion HUF. Based on estimates by experts, the drought damages were 18 billion HUF for 2000, and 25 billion HUF for the year 2007. Yield loss as a result of drought in 2012 reached 400 billion HUF (Fiala 2013). However, it has to be emphasized that the real value of previous damages has changed by now. As there are considerable spatial deviations in the appearance of drought, the damages are distributed unevenly. The intensifying damages are demonstrated by Figure 3.8 (page 101), which shows that, as a result of the more frequent droughts following the 1990s, the yield loss was up to 50% in several years! In Serbia the damages resulting from yield loss reached 600 million EUR in 2007 (Popov and Frank 2013), and in 2012 damage at 2000 million EUR was reported (Mészáros et al. 2013). The drought also led to damages in forestry. In Serbia in Tara National Park about 25000 damaged trees had to be cut down due to desiccation. Forest fire depleted 10000 hectares of forest in 2012 (there were more than 10 large fires with the biggest one in Tara National Park damaging 300 hectares of pinewood) (Mészáros et al. 2013).

In Hungary in the Danube-Tisza Interfluve, considering that the groundwater level had considerably sunk, the damages caused by yield loss due water shortage reached 11 billion HUF in the right hand side sub catchment of Lower-Tisza in the Great Plain (almost 5000 km^2) on average. At various sites of the catchment area, studies were conducted to reveal yield loss and yield decrease. On the study areas of Kecskemét, Kiskőrös, Tiszaalpár, Csongrád and Szeged, yield loss related to certain sector groups, cultivation sectors were determined (Table 3.4 on page 102). The data clearly shows that water shortage has an impact on all cultivated plants. The financial value of lost yield is incredibly high where the added work is substantial, thus the damages of the given sector are especially severe. A special feature of the study area is the important tradition of vegetable and fruit cultivation that makes it sensitive to water deficit and drought. It is also important to mention that the mostly affected sectors are linked to smallholders, whose financial stability is much worse than that of large agricultural farms, where cereal production is typical. Consequently, damage can be expressed in numbers but has a lot more serious long-term impact on the intention to farm; therefore the conditions need to be improved.

3.3. Relationship of drought and biomass production

Zsuzsanna Ladányi, Viktória Blanka

Introduction

The more and more frequent and severe droughts in the Carpathian Basin in the past decades have caused significant ecological and agricultural damage in the vegetation. For example, the reduction of biodiversity and wetland habitats, and the transformation of habitats have been observed in a lot of places, in addition, agriculture faced serious yield loss in drought years. The environmental changes also influence the phenology, the spatial pattern and the distribution of vegetation. The observation of vegetation by remote sensing methods have significantly sped up obtaining spatial information, its scale provides us with the possibility of regional and global research, and it has made possible the observation of areas that could not be investigated due to their location or inaccessible (Ladányi and Kovács 2009). Another important advantage of these methods can be that higher temporal resolution can be achieved, and the fast processing of real time data makes the operation of monitoring and early warning systems possible, as well. The development of drought can be inferred by changes in the intensity of vegetation patterns using remote sensing.

The observation of drought requires high temporal resolution data sets about vegetation. The vegetation indices are the most frequent remote sensing data, which help us draw conclusions on vegetation cover, the state of vegetation, its ongoing biophysical processes and changes. This type of data has been at our disposal for more than two decades with increasing spatial resolution, and due to the uniform character of its calculation method and scale, it makes the cross-border analysis possible.

The vegetation indices of MODIS are used in several fields of scientific research (e.g. desertification, forest fires, ecosystem development, spread of invasive species, and yield) because daily data with 250-metre spatial resolution can be accessible, thus, regional changes can be assessed easily. Composite pictures are made from daily data to avoid default data originating from cloud cover. Vegetation intensity between 2000 and 2013 was assessed using biomass production index in the study area of the project (South-Hungary and Vojvodina). The severity and patterns of drought were assessed with the help of Pálfai Drought Index (PaDI) (Pálfai and Herceg 2011). The correlation between drought years and the areas showing decreasing biomass production were also analysed, with which we tried to draw attention to the drought sensitivity of the region.

Methods

Biomass production index was calculated by 16-day-composite images of Enhanced Vegetation Index (EVI) (Huete 2002) of MODIS sensor aboard NASA's Terra satellite. The biomass production index (Ladányi et al. 2011) was calculated for the vegetation period (from April to September) of every year, and its difference from the average was assessed. The anomaly of biomass production was calculated in the following way:

$\text{BP anomaly} = (\text{Xt} - \text{Xmean})/\sigma$

where: Xt: annual biomass production index
Xmean: average of biomass production index between 2000 and 2013
σ: standard deviation

We described the biomass production anomaly on the basis of land cover categories (Corine 2000) in the separate years. The correlations of drought and biomass production were evaluated in agricultural areas in examples of a few years. Climate change is classified as one of the major factors influencing biodiversity patterns in the future. The increase of climatic extremities has been projected in the Carpathian Basin for the next century, thus it is especially important to monitor the spatial and temporal aspects of the ongoing processes in the landscape, and to observe the formation and the effects of drought.

Results

The vegetation of the sample area clearly shows a significant negative anomaly in four out of the fourteen years (2000, 2002, 2003, 2012) compared to the average of the period (2000-2013) (Fig. 3.9 on page 104). These years were very dry according to the Pálfai Drought Index (PaDI). In another two years (2007 and 2009) a minor negative biomass production anomaly can be observed; these were moderate drought years according to the PaDI index values. Drought did not characterise the years when a positive biomass production anomaly could be shown according to PaDI (PaDI<6). The connection between biomass production and the severity of drought is strong, since PaDI index values and the averages of biomass production anomalies show a highly significant coincidence.

Each of the most severe droughts (2000, 2003, 2012) of the period are reflected in the values of the biomass production anomaly; the differences seen are due to the differences between the hydrological features of drought periods and the periods preceding them (e.g. stronger biomass production anomaly in 2013 compared to PaDI). Although, among the driest years, the spring of 2000 was characterized by excess inland water inundations (due to the highly humid autumn-winter of 1999), total precipitation was only 200-250 mm in the rest of the year in the sample area. The significant drought damage in 2003 was also influenced by the negative biomass anomaly and reduced water reserves of 2002, and precipitation was around 300-350 mm. The region faced the highest drought of the decade in 2012 even if precipitation was average, 400 mm.

A significant proportion of the study area is used as arable land, where the plant species changed from year to year. The alternation of plant species in itself influences the calculated biomass production anomaly; nevertheless, the effects of drought can be clearly detected: the coincidence of the biomass production anomaly and the drought index is 100% (Fig. 3.10 on page 107). Differences can also be seen among arable lands, between soils formed on sand and those formed on loess. The range of biomass production anomaly is wider in arable lands on loess, but even less severe droughts cause a more significant negative biomass production anomaly in sandy areas. The reason for this is the differences in water balance and fertility.

The proportion of forests is significantly lower in the area. Forests are mainly situated on sandy soil, where planted pine and acacia forests are predominant, and there are alluvial forests on alluvial and meadow soils along the rivers. There are only smaller forest patches on good-quality chernozem soils. The anomalies in the case of forests are not as strong as in the case of arable lands, since in the forest the plant population is of the same type for decades, and the positive, as well as the negative effects are less strong due to less intense cultivation (Fig. 3.11 on page 107). If we examine the forests in blown sand soil and the alluvial forests separately, we can see anomalies of different scales and direction. This can have various reasons. For example, trees on soil with better water supply and water retention capacity could store more water from the very wet year of 1999 than trees on sandy soil, and they disposed of slightly more positive anomalies compared to the average, even if precipitation was scarce in 2000, while the forests of sandy soils had a negative biomass production anomaly compared to the average at the end of 2000. This difference can also be seen in the cases of 2003 and 2007. All the forests reacted with biomass production decrease to the drought of 2012. Among the wet years, 2006 is interesting, because a significant biomass production increase was experienced in forests on sandy soils (same as in 2010), but there is a negative anomaly in the case of alluvial forests. The flood waves going through floodplains and the long-lasting water cover can cause negative biomass production compared to the average (Fig. 3.12 on page 109). It is worth looking separately at the forests around Fruska Gora, where we can see more significant anomalies due to the smaller thickness of the fertile topsoil layer, and to the different climatic effect.

If we compare the spatial distribution of biomass production anomaly and of drought calculated on the basis of PaDI in the sample area, we can conclude that the spatial pattern of the two parameters show a very high similarity. For example, in 2000 we can see that Csongrád County and Vojvodina were exposed to significant drought, and as a result, more significant biomass production anomalies could be detected (Fig. 3.13 on page 109). The least exposed areas were the north-northwest of the sample area, and the smallest values of negative biomass production characterize them. The spatial pattern of drought in 2003 is highly similar to that of 2000; however, it is worth highlighting the increased involvement of the eastern part of Csongrád County, and the appearance of this involvement in the negative anomaly of biomass production.

The spatial differences are better shown by the years when the severity of drought did not have such extreme values. Such was, for example, 2002, when the eastern part of Csongrád County, the border of Csongrád and Bács-Kiskun counties, and the south-east of Vojvodina were more affected. This pattern can be clearly identified in biomass production, too.

The connection between the reduction of biomass production identifiable by GIS methods and the drought indices can be identified in the sample area, in space and time, as well. These data support that drought has a significant effect on the intensity of vegetation in the cases of all vegetation types, and this can be detected by GIS methods, as well. The results confirm that droughts have had a highly significant effect on the vegetation in the sample area in recent times. Preparation, management, and proper water management measures will be very important, and not only for agriculture, but for water management and conservation, as well.

3.4. Effect of water shortage on groundwater level

János Rakonczai, Zsolt Fehér, Károly Fiala

Introduction

Soil has a huge water storing capacity: even half of the total annual precipitation in Hungary can be stored in it. Water infiltrating into deeper levels increases the groundwater resources. Alterations of the water resources moderately reflect the changes of the meteorological parameters (mainly precipitation and evapotranspiration). Therefore, the long-term changes in water resources are an important indicator of climate trends and human impacts.

Temporal changes of groundwater resources in the Danube-Tisza Interfluve

The drier period from the beginning of the 1980s until the mid-1990s caused significant decline of groundwater resources mainly in the Danube-Tisza Interfluve. Scientific debate was formed over the reasons behind the decrease in the Hungarian literature (Pálfai 1994). The geoinformatical assessment of changes (Fig. 3.14 on page 111) shows that the precipitation deficit in the above mentioned period can be felt up to today. There could be an argument about the underlying causes, but it can also be seen that the remarkable change in water resources is mainly determined by the quantity of precipitation. A humid year could temporarily contribute to the decrease of water scarcity, but overall, an increasing shortage in groundwater resource can be experienced (a deficit of 6-9 km^3 in the first decades of the 2000s with reference to the 1950s, 1960s).

In previous studies (Rakonczai 2013) it was revealed that the sinking of groundwater largely depends on relief conditions; more substantial decline can be observed on highly elevated areas (Fig. 3.15 on page 112). It is due to the fact that the only water source in this area is precipitation, and due to Darcy's law and the sub-surface seepage, spatial arrangement of water resources also occurs (the higher areas are affected by further decrease as a result of seepage). The figure shows that specific resource change (for an area of 1km^2) is more balanced at lower elevated areas. It can also be observed that the drier period for one and a half decades as mentioned above, resulted in the formation of specific water shortage on higher elevated areas.

Quantitative assessment of the changing water resources was carried out for the study area (Fig. 3.16 on page 113). It is clearly visible that the changes are similar to the values for the Danube-Tisza Interfluve. Humid years resulted in an increase of water resources for the second half of the 1960s and the beginning of the 1970s, followed by years with precipitation around and below average, contributing to a slow decrease. This decline speeded up from the second half of the 1980s and it did not change remarkably due to the humid period in the mid 1990s, either. The year of 1999 with inland excess water inundations (extending up to the beginning of 2000) could slightly reduce water shortage. The next 4-5 years experienced a drop in the resources exceeding the previous ones, which in the last years of the decade – halted by a shorter period with higher precipitation – further intensified. The data also suggest that the precipitation reduction in the past 15-20 years itself would not explain the decrease of resources. Presumably the more intensive irrigation in Serbian areas may partially be the reason for the groundwater changes as indicated by the maps on groundwater changes. Even during the humid year of 2010, the remarkable groundwater level reduction in the south-eastern part of the Danube-Tisza Interfluve is clearly visible, which is not justified by the precipitation and hydrological forms. Fig. 3.16 (page 113) also reveals that the specific water resources during some humid years on areas below 120 m can be replenished, which means that more drought-affected years did not result in permanent groundwater deficit (precipitation and sub-surface groundwater flows may have role in this process).

Temporal changes and spatial differences of groundwater level on the right catchment-side of River Tisza

Based on the groundwater-table map series, which have regularly been published monthly since the beginning of the 1960s, it was published in the 1980s that in the higher elevated area of the Danube-Tisza Interfluve unfavourable processes could be observed in the groundwater level change (Major and Neppel, 1988). By the mid-1990s an average groundwater level decrease of 250-300 cm, and a decrease of 600-800 cm in the northern and south-western parts developed. Changes closer to the rivers on the edges were substantially less, and in certain areas they could not be regarded considerable (VITUKI 2001-2002, Szalai 2004.).

The following years indicated high groundwater levels within the studied period: 1965-1967, 1970, 1975, 1999–2000, 2006, 2010–2011, that is 10 years altogether. It can be seen from the list that years with above the average groundwater level are present unequally in time. Their frequency of occurrence for certain longer periods is various. Years with high groundwater level typical for the 1960s and 1970s were followed by low water periods, which reached their minimum in the 1990s. Following this, years with higher groundwater level became more frequent again: there were 5 out of 13 years for the period of 1999-2011 (with the highest water level in 2000 and 2010).

Years with below the average groundwater level are as follows: 1960–1962, 1968, 1983–1995, 2000–2003 and 2007–2009. That is 24 years (!) altogether, which is 50% of the studied period. It exceeds much the years with high groundwater level. The list shows that the year 2000 has been indicated for both among the years with high and low groundwater level. The reason for this is that high water developed at the beginning of 2000 (as a result of the high precipitation in 1999), while low water developed towards the end of the year 2000 due to the lack of precipitation. The succession and the length of such periods in case of years with extremely low groundwater is more prominent The longest period of 13 years (!) is for 1983-1993.The lowest water level measured at several wells evolved in 1995. One of the reasons for the low groundwater level for this period is that precipitation was below the average, but the effects of different human activities (groundwater irrigation) also play an important role.

Temperature change also has an impact on groundwater changes, which determines evaporation. Since the end of the 1980s the temperature has been increasing. There is a strong connection between temperature and years of low groundwater level. The effect of high temperature has substantial role in the development of minimum values as it could be seen in the first half of the 1990s.

The year 2012 demonstrates the effect of extremely dry years (Fig. 3.17 on page 116). The declined groundwater-resources continue decreasing under such hydrological conditions. The piezometric groundwater level on the western, higher elevated parts of the catchment has dropped to 4-6 metres, whereas areas located closer to the River Tisza have also decreased to 2-4 metres. The groundwater level was 0.5-2 m lower compared to the multiyear average. The upwelling experienced around Pusztaszer both in dry and wet years is prominent, which can cause positive anomaly mainly in periods with water shortage.

Thus, a permanent decline of groundwater on the catchment in the studied period can be stated. Previously the average groundwater level was 2 metres below the terrain. Spatial differences could be observed; by now the water table is situated 1-1.5 metres deeper. If the change is projected to the 5300 m^2 of the catchment area, and porosity (0.5) is taken into account, the resource decrease is as follows:

0.5 m decrease of groundwater	1.32 km^3 decrease of water resources
1 m decrease of groundwater	2.6 km^3 decrease of water resources

One, but rather two years' total precipitation has been 'consumed' from the sub-surface water resources in the past 40 years during the groundwater level decline, based on the precipitation multiyear averages, Considering the infiltration rate, approximately the same time would be necessary to refill the resources, supposing sustainable water usage. However, it is influenced by the decreasing precipitation, the unfavourable precipitation distribution (fast runoff), the increasing evaporation, and the improper water usage. It is inevitable to make efficient use of excess water inundations characteristically occurring in spring and to change the practice of national water management aiming at drainage for the increasing trend of the groundwater resources.

3.5. The potential pedological effects of aridification due to climate change

Andrea Farsang

Introduction

The climate change related scenarios of the IPCC (2007) project a rise in temperature, a change in the amount of precipitation, plus a more frequent occurrence of extreme weather conditions (drought, flood, extreme amount of precipitation). According to projections water is likely to be the most limiting factor in agriculture in the Carpathian Basin in the future. Climate change has both long- and short-term influence on the physical and chemical parameters of the soil, therefore research on the protection and monitoring of soil is becoming increasingly relevant, since its effects are present in the changes of the physical, chemical and biological characteristics of our soils (Sisák et al. 2007, Faragó et al. 2010, Puskás and Farsang 2012).

Among the features defining and describing soil quality, climate change has effects primarily on organic matter content, carbon and nitrogen cycles, microbial biomass production, flora and fauna diversity, as well as on physical characteristics of soils (e.g. soil structure). Thus, one parameter is not sufficient to define the pedological consequences of aridification. Biological, chemical and physical examinations are also necessary to provide the indicator parameters characteristic of the given soil type (Karlen et al. 2003).

Amongst the applicable indicators soil pH is a very dominant chemical indicator, which is a determinant factor of several other soil parameters (e.g. adicification, sodification, nutrition cycle, biological activity etc.). Brinkman and Sombroek (1999) found that the pH of most soils does not change significantly due to climate change, but climate change itself has such significant effects on other parameters that causes the modification of pH (Reth et al. 2005).

According to Várallyay (2005) the alteration in climate elements results changes in soil water balance. However, climate change, fauna change and the timescale of soil formation processes are very different in time and space. The speed of changes is hard to estimate, as human activities might both enhance and slow them down. Therefore the constant monitoring of the changes is an important task.

As a result of climate change, the alteration of the seasonal dynamics of weather elements, and the changing ratio of Continental, Atlantic and Mediterranean effects, carry the possibility of the shift of natural-geographical zones in our country (Máté et al. 2009). A pedological consequence of the serious weakening of continentality may appear for example in the processes of chernozems (Farkas et al. 2011). In chernozem soil the calcareous chernozem feature may strengthen, whereas in the south Transdanubian areas the strengthening of Mediterranean soil formation and the shift towards brown forest soils can be foreseen (Máté et al. 2009). Owing to rising temperature and the decreasing amount of precipitation various changes might begin in the soil processes (Fig. 3.18 on page 119). Due to the rising temperature evaporation of the soil increases, infiltration decreases, just as the amount of water stored in the soil, increasing the area's drought sensitivity. Thus, the changes of climate and flora influence soil water balance, which influences soil air and temperature management, the biological activities, and the soil nutrient management.

Organic matter content – as the most complex and most heterogeneous soil component – is a very relevant, soil quality indicator, since it can modify the character and direction of several features, soil functions and transformation processes. Due to the less water the quantity of produced biomass decreases, which results in lower crop yields and less plant residues in the soil. Under drier circumstances, dominated by aerobic processes, the residue decays more quickly, decreasing soil organic matter content (Tóth et al. 2009). Due to the rising temperature the speed of decomposition and soil airing is more intensive, which then further enhances the decrease in the carbon supply. The effect of climate change on this parameter is worth examining on a long-time scale, although organic matter change due to a rise in temperatures is still strongly debated today.

Due to less precipitation and rising night-time temperature, the formation of dew becomes more limited, while evaporation intensifies. These changes affect decomposition processes in the soil, its nutrient circulation and soil airing (Tóth et al., 2009). Due to the complexity of the process and the spatial differences of influencing factors, the effect of the parallel change in moisture and temperature on carbon content of the soil cannot definitely be forecasted yet.

An important question affecting great territories is the effect of climate change on salt regime of soils. Under drier and hotter conditions evaporation increases resulting in concentration of soil solution, thus, increased salt concentration. Due to less precipitation infiltration and its leaching effect decrease. These two processes may increase the intensity of salt accumulation in certain areas (Blaskó et al. 1996). Decreasing precipitation increases sodification hazard not only by moderating leaching and accelerating upwards water- and soil movement, but also by creating greater irrigation demand, thus generating the possibility of secondary sodification. At the same time opposing processes may also happen, as, for example, the sinking of groundwater works against sodification. Due to sinking groundwater the capillary rise, as well as the height of the capillary zone decrease, and so do the sodification hazard and the risk of salt accumulation. This raises the exciting question of what type and what extent of soil properity changes can be detected as a result of these opposing effects. Aridification processes experienced in the Southern Great Hungarian Plain carry the hazard of secondary sodification for several reasons, e.g. intensified evaporation and increased irrigation demand. Nowadays, owing to the strategic importance of water, the quality of water used for irrigation may also generate problems (Gál and Farsang 2013).

Investigation of soil structure in the case of chernozems on the Southern Great Hungarian Plain related to climate sensitivity

The extent of long-term effects of climate change on soil structure depends on the vulnerability of the soil. Chan (2011) differentiates between three aspects of soil structure regarding soil quality: structural form, stability and resiliency. Stability means the ability of the soil to maintain its structure and its solid phase-pore distribution against different types of stress; while resiliency means the ability of the soil to re-establish itself after the stress to its previous state before the degradation. Stability and resiliency together define vulnerability to outer stress factors. The effect-specific natural sensitivity of soil reactions to stress factors caused by anomalies, mainly of temperature and precipitation conditions, is the "climate sensitivity" of soils (Birkás et al. 2007), which can also be characterised by the quality of soil structure. The condition of soil agronomical structure, i.e. the proportion of clod (>10mm), crumb (0.25-10mm) and dust (<0.25mm) describe the characteristic processes of regularly cultivated soils (crumbling, clodding, or dusting) (Buzás 1993). When the proportion of dust is more than 25-30%, the soil is sensitive and degraded. 75-80% crumb proportion indicates good climate stress endurance. Increasing proportion of dust and clod (e.g. from 10 to 30-40-50%) and decreasing proportion of crumb (e.g. from 70 to 50-40%) mean risk, or high risk in quality (Birkás et al. 2010).

Wind erosion mostly affects the sandy type soils, but at the same time degraded, dusty-structured chernozems are also becoming more endangered, due to intensive cultivation (Birkás et al. 2010, Farsang et al. 2011). The deflation sensitivity of the soil in connection with its structural characteristics was examined on the loess plateau of North Bačka, and chernozems in the South Tisza Valley (Fig. 3.19 on page 122). Taking into consideration the genetic type of soil, the fields used as arable land, and the prevailing wind direction, 21 parcels were separated on the loess plateau, and 16 in the South Tisza Valley. Average samples were collected from the topsoil of the plots to identify the structural characteristics.

Determination of aggregate-stability from the 37 soil samples was carried out by using the method Sekera's qualitative estimation (Buzás 1993). Agronomical structure and distribution of aggregates were defined by separating soil structure elements with dry sifting (sifter's hole being 10; 5; 1; 0.5; 0.25; 0.1 mm) (Buzás 1993). The crumb composition of the soil according to Stefanovits (1999) was calculated, expressing the quantities belonging to the given clod, crumb and dust fractions in mass percentage of the sample. The aggregate composition of soils can be defined with the help of GMD (geometric diameter). The basis of calculation is the following (Kemper and Rosenau 1986):

$$GMD = \exp\left(\frac{\sum_{i=1}^{n} w_{i*l} * \log x_i}{\sum_{i=1}^{n} w_i} \right)$$

w_i mass of aggregate in a given xi average diameter particle size fraction

$\sum_{i=1}^{n} w_i$ total mass of samples

The degradation pace of the structure primarily depends on the water resistance of the soil crumbs, measured under air-dry conditions (di Gléria et al. 1957). It can be estimated from the measured stability values whether degradation has or will become faster and have a greater extent on the monitored chernozems. In the case of chernozems in Bačka, 19% of the samples was slightly degraded, 47.6% degraded and 33.4% extremely degraded in structure; i.e. the aggravates were not resistant enough to water effects, and under the effects of external forces the coherency of structural elements loosened easily. In the case of the South Tisza Valley chernozems the proportions were quite the same: 12.5% of samples were slightly degraded, 50% degraded and 37.5% extremely degraded.

The crumby genetic soil structure is a characteristic of healthy chernozems, ideally with the dominance of 1-3 mm diameter crumbs. The agronomical structure of the cultivated surface soil could be deduced from the aggregate distribution deriving from dry sifting. In the light of this we daresay that the crumby structure, characteristic of the lime-covered chernozems in the Great Hungarian Plain, could not be detected in all cases; several samples proved the dusting of surface soil. Climate stress resistance among the Bačka loess plateau samples was found to be rather good only in one case, which has the necessary ability to moderate and muffle harmful climate effects (Fig. 3.20 on page 124). Six further examples have appropriate climate stress resistance. These soils are located on the northern part of the separated areas. 14 samples proved to be sensitive, degraded soils; 5 samples out of these do not have appropriate climate stress resistance. In these cases the proportion of dust, plus in one case the proportion of clod was above 25-30%. Soils being of very risky quality are located on the southern and eastern parts of the sample area. The longitudinal axis of parcels with a degraded structure mostly runs parallel with the region's prevailing wind, which increases deflation sensitivity. In the South Tisza Valley parcels the structure is less dusty, the proportion of dust exceeded 30% only on two sample areas.

Condition assessment of structural elements was carried out by comparing their GMD. First GMD of a virtual sample was calculated, which optimally has 80% of crumb fraction and an optimal particle diameter of 3 mm. In this virtual sample case GMD would be 1.4. Later the GMD values of the examined soil samples were compared to this value. Values of both examined areas, calculated on the basis of the sifting report, are rather small (Fig. 3.21 on page 125). The GMD value of analysed soil samples on the Bačka area did not reach the optimal value in any case; the average value of samples was 0.89. The South Tisza Valley chernozem areas have a better soil structure: 3 samples reached the optimal 1.4 value, and the average GMD value of samples was 1.28.

Such rate of dusting of chernozems is a significant problem, because the fertility of good quality chernozem decreases. Besides, the degree of deflation is also substantial in the case of chernozems. Even at relatively low wind speed (50-60 km/h) and short-time wind event (10 min), the transported soil matter is 1-1.2 ton/hectare (Farsang et al. 2011). Due to a 15 m/s, 10-minute-long wind activity (measured at 20 cm high) the chernozem aggregate structure modifies significantly: based on our wind-channel experiments, due to the shift of dust fraction, the proportion of 1-4 mm crumbs increases by 10% in the surface soil (Farsang et al. 2011). Moreover, dust in the air causes indirect problems (e.g. in traffic). It may have health effects as well, since if the transported air is inhaled, it harms people and animals. Damage can be detected in accumulating areas, too; since soil matter covers plants influencing their development and causing damages. By examining the surface soil structure of cultivated chernozems, and by revealing the regularity of nutrient and organic matter movement via wind erosion, we can gather ideas about what risks our arable lands, having the greatest economic potential, are exposed to, and what nutrient loss of deflation damage can experienced caused by structure degradation (dusting) if cultivation is done at the wrong time and under inappropriate moisture conditions.