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DEVELOPMENTS IN CLIMATE AND SOIL WATER STORAGE IN THE LOCALITY OF POIPLIE

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ABSTRACT

Climate change is one of the largest threats to the modern world. It is primarily experienced via changes and extreme weather events, including air temperature changes, the uneven distribution of precipitation and an increase in the alteration of torrential short-term precipitation and longer non-precipitation periods. However climate change is not only a change in the weather; it also has a much larger impact on an ecosystem. As a result of expected climate change, a lack of either surface water or groundwater could occur within wetlands; thus, the existence of wetlands and their flora and fauna could be threatened. This submitted work analyses the impact of climate change on the wetland ecosystems of Poiplie, which is situated in the south of Slovakia in the Ipel' river basin. The area is an important wetland biotope with rare plant and animal species, which mainly live in open water areas, marshes, wet meadows and alluvial forests. To evaluate any climate change, the CGCM 3.1 model, two emission scenarios, the A2 emission scenario (pessimistic) and the B1 emission scenario (optimistic), were used within the regionalization. For simulating the soil water storage, which is one of the components of a soil water regime, the GLOBAL mathematical model was used.

1. INTRODUCTION

Climate changes occur due to internal changes in a climatic system. They are primarily due to the net balance of solar radiation, but also are due to secondary influences, which are, e.g., natural factors (cloudiness, precipitation) and factors caused by human activity (increasing concentrations of greenhouse gases in the atmosphere). Ongoing climate change and its consequences nowadays represent some of the most serious global problems.

Increasing concentrations of greenhouse gases are causing an increase in the average global temperature, changes in rainfall regimes, rising sea levels, etc. Some effects of global warming are already visible today, e.g., through extreme weather events in the form of droughts, strong torrential rain and increases in the intensity of tropical cyclones and storms (IPCC, 1998, 2001).

Therefore, experts are trying to forecast meteorological elements in order to adapt to the anticipated changes. The largest expansion of the mathematical modeling of climate change occurred in the 1970s and 1980s, mainly due to the rapid development of computer technology. Many institutions are presently involved with General Circulation Models (GCMs) (Lapin et al., 2006; Stehlová, Štekauerová, 2008), which provide climate scenarios of various climate parameters.

The mathematical modeling of climate change includes physical and chemical processes in the atmosphere and oceans of the Earth and the physical processes associated with the cryosphere, biosphere and lithosphere if they have any significance for climate change.

KEY WORDS

- *Climate change,*
- *soil water storage,*
- *wetland,*
- *mathematical modeling.*

2. MATERIALS AND METHODS

The area of interest is Poiplie, which is one of the Ramsar sites in Slovakia declared by the Ramsar Convention (http://www.ramsar.org/cda/en/ramsar-home/main/ramsar/1_4000_0__); on 17 February 1998; it was officially registered on the list of wetlands of international importance specifically as a waterfowl habitat. The Poiplie Ramsar site is the last wetland ecosystem of the Ipeľ River Basin, which is located in the south of central Slovakia. It continues on extensive wetlands in Hungary, which are part of the Hungarian Dunaj-Ipoly National Park. The Poiplie Ramsar site is located southeast of the town of Šahy. It belongs to the cadastral of the two villages of Tešmak and Ipeľské Predmostie. The boundaries of two districts and regions, i.e., the Levice district, Nitra region, and the Veľký Krtíš district, Banská Bystrica region, pass through the centre of the site. This area represents a preserved part of the meandering Ipeľ River with its original composition of natural bank vegetation, various types of wetland habitats, floodplain forests, and alluvial grasslands (Pásztorová, 2009). In terms of geomorphic units, the Krupinská plateau covers the north and northwest parts of the Poiplie Ramsar site, while the Juhoslovenská basin covers the whole eastern part. The total area of the Poiplie site is 410.87 ha, and its altitude ranges from 124 m above sea level to 132 m above sea level. Therefore, the whole area can be characterized as a typical plain relief of a lowland river floodplain shaped by a terrain depression, with an average terrain slope of about 1°. The site is shown in Figure 1 (Ministry of the Environment of the Slovak Republic et al., 2002).

Fig. 1 Location of the Poiplie Ramsar site.

In terms of its climatic conditions the area of the Poiplie Ramsar site is a warm and dry climate area with mild winters. The temperature conditions are influenced by the latitude, altitude and orographic ratios. According to the measured values at the Dudince meteorological station (1977-2010) of the Slovak Hydrometeorological Institute (SHI), the average annual air temperature is about 9.6 °C and about 16.5 °C during the growing season (IV.-IX.). The range of the air temperatures is shown in Figure 2, where it is clearly seen that the trend lines document a slight increase in air temperatures during the reference period. The coldest month of the year is January, with an average air temperature of -1.9 °C, and the warmest month is July, with an average air temperature of 20.3 °C.

Fig. 2 Range of the average annual air temperatures and average air temperatures during the growing season at the SHI Dudince observation station for the period 1977-2010.

The Ipeľská basin, along with the Poiplie area, is relatively dry; the amount of annual precipitation is around 600 mm. In the average monthly precipitation totals from the SHI Dudince station for the period 1977-2010, the maximum precipitation is seen in the summer months, especially in the month of June, which is due to the influence of the tidal marine polar air from the Atlantic to the European hinterland. Another peak is generated in November, which can be explained by the influence of the Mediterranean Adriatic disorders. The lowest values of precipitation occur from January to March and in October. Figure 3 shows the increasing range of the annual precipitation totals and precipitation totals during the growing season for the years 1977-2010. The year 2010, which is considered to be one of the years of the last period with the highest precipitation, may have contributed to that increase.

Fig. 3 Range of the annual precipitation totals and precipitation totals during the growing season at the SHI Dudince observation station for the period 1901-2010.

This contribution, which forecasts the development of water storage due to climate change, uses the CGCM 3.1 global mathematical model, which is the latest version of a Canadian interconnected model of the circulation of the atmosphere and oceans. This is the first version of the scenario based on the CGCM 3.1 model in Slovakia.

In regional modifications the A2 (pessimistic) and B1 (optimistic) emission scenarios were used. Emission scenarios are based on a wide range of assumptions of future developments mutually affecting and affected by economic, demographic and political factors. Group A2 corresponds to the idea of a very heterogeneous world. The basic idea is to rely on itself, preserve a local identity and respect local traditions. The population in the 21st century is continuously growing; economic development is strongly regionally oriented; and technological changes and growth in the gross domestic product are slower than in other storylines. Group B1 corresponds to the idea of the convergence of the world with the same population as in A2, the rapid development of information technology and services, and the introduction of clean and efficient technologies that reduce material consumption. The emphasis is on a global solution of economic and social problems and environmental protection (Melo, 2004).

A simulation of the meteorological parameters for the SHI Dudince station for the period 2011-2100 for both emission scenarios

(A2 and B1) was performed using the CGCM 3.1 model. In this way the meteorological parameters were modified for the simulation of the soil water storage. As for the reference period, the period of 1977-2010 was chosen, and the evaluated time period was divided into 30-year time periods of the years 2011-2040, 2041-2070 and 2071-2100.

A simulation of the soil water storage using modified meteorological parameters was carried out using the GLOBAL mathematical model (Majerčák, Novák, 1994). It is a mathematical simulation model of the movement of water in soil, which allows for the calculation of the potential distribution of soil moisture over time based on the flow in the soil matrix. The principle of the model is a numerical solution of nonlinear partial differential equations of water movement in an unsaturated soil zone in the form:

$$\frac{\partial h_w}{\partial t} = \frac{1}{C(h_w)} \frac{\partial}{\partial z} \left[k(h_w) \frac{\partial h_w}{\partial z} + I \right] - \frac{S(z, t)}{C(h_w)} \quad (1)$$

where:

- h_w – soil water potential [cm],
- z – vertical coordination [cm],
- $k(h_w)$ – unsaturated soil hydraulic conductivity [$\text{cm} \cdot \text{s}^{-1}$],
- $S(z, t)$ – root extraction rate [$\text{cm} \cdot \text{s}^{-1}$],
- $C(h_w) = \partial \theta / \partial h_w$ – specific water capacity [cm^{-1}],
- θ – volumetric soil water content [$\text{cm}^3 \cdot \text{cm}^{-3}$],
- t – time [s].

The upper boundary condition at the interface between the soil surface and the atmosphere is determined by modified meteorological elements for the SHI Dudince station for the period 2011-2100. The meteorological data entered in the modeling included the daily precipitation total Z [mm], the daily average of the air temperature T [$^{\circ}\text{C}$], the daily total of the duration of sunshine S [h], the daily average of the atmospheric partial water vapor pressure p [hPa], and the average daily wind speed v_w [$\text{m} \cdot \text{s}^{-1}$] for each day of the modeled period. The lower boundary condition is the position of the groundwater level [cm] below the surface level, which in this contribution is considered to have a constant value of 67.5 cm below the surface level. The initial condition was entered into the model as a distribution of the moisture according to the depth of the soil profile modeled.

The hydrophysical soil characteristics entered in the GLOBAL model were expressed by the parameters of the water retention curve (WRC) according to van Genuchten (1980): $\alpha=1.0685$, $N=0.0901$, the value of the saturated hydraulic conductivity of the soil $K=1.34 \text{ cm} \cdot \text{day}^{-1}$, the hydrolimits, and major soil physical properties (porosity, specific and bulk density, saturated soil moisture). For the purposes of this analysis, the soil layer 0-20 cm below the surface level was emphasized.

The input parameters characterizing the vegetation include the leaf area index LAI [-], the evaporating surface roughness z_0 [-], the albedo of the evaporating surface α [-], and the root zone depth z_r [cm]. Within the simulation a vegetation cover of soft mead with a predominance of poplars, which occur in Poiplie, was considered.

3. RESULTS AND DISCUSSION

Using modified meteorological parameters, the impact of climate change on the Poiplie area of interest was evaluated. The evaluated time period was divided into 30-year time periods of the years 2011-2040, 2041-2070 and 2071-2100, while the period of 1977-2010 was selected for the reference period.

The outputs of the model were the daily data, which was then converted to the average monthly and annual data for a better visual understanding of the impact imposed by the modified meteorological parameters. In the first part of the analysis, the courses of the modified meteorological parameters were compared with the real measured values for the period 2000-2010. Subsequently, the modified meteorological parameters for the time periods of 2011-2040, 2041-2070 and 2071-2100 were compared with the reference period of 1977-2010.

In the next part of the contribution, the impact of climate change on the soil water storage was evaluated with the GLOBAL model, which was used to model the soil water regime. As upper boundary conditions, modified meteorological parameters were used according to the two emission scenarios of A2 (pessimistic) and B1 (optimistic). As the soil water regime and its changes could be well characterized by the soil water storage and an assessment of the impact of climate change on the soil water regime, this way of expressing the soil water regime was emphasized.

3.1 Comparison of the modified meteorological parameters with the real measured values for the period 2000 – 2010

In Figure 4 the range of the average annual air temperatures modified by the A2 and B1 scenarios and the range of the real measured values for the period 2000-2010 at the SHI Dudince observation station, are plotted. Based on the graph, a clear position on the development of the air temperature cannot be taken, because the modified data according to the scenarios variously fluctuate around the real measured values. However, if we look at the average values calculated for the whole period of 2000-2010, the predicted values of the scenarios compared with the real measured values are lower. It is necessary to realize that the climate change forecasts indicate significant increases in air temperature until the end of the 21st century.

Fig. 4 Range of the annual average air temperatures modified by the A2 and B1 scenarios and the real measured values for the period of 2000-2010 at the SHI Dudince observation station.

In Figure 5 we can see the trends of the average monthly air temperatures modified by the A2 and B1 scenarios and the trends of the real measured values for the period of 2000-2010 at the SHI Dudince observation station. The graph shows that, according to the scenarios, the coldest months are the months of January and December, which also agree with the real measured values. The warmest month is the month of July, which is confirmed not only by both scenarios, but also by the real measured values.

Fig. 5 Range of the monthly average air temperatures modified by the A2 and B1 scenarios and the real measured values for the period of 2000-2010 at the SHI Dudince observation station.

In Figure 6 we can see the trends in the annual precipitation totals modified by the A2 and B1 scenarios and the course of the real measured values for the period 2000-2010 at the SHI Dudince observation station. The graph shows a considerable lack of coherence between the scenarios and the real measured values in the amounts of precipitation. The biggest difference between the real measured data and the modified data is in 2010, when more than 1000mm of precipitation actually fell. However, if we examine the average precipitation totals for the entire period of 2000-2010, the A2 and B1 scenarios forecasted lower precipitation totals than what actually occurred.

Fig. 6 Range of the annual precipitation totals modified by the A2 and B1 scenarios and the real measured values for the period of 2000-2010 at the SHI Dudince observation station.

In Figure 7 we can see the trends in the average monthly precipitation totals modified by the A2 and B1 scenarios and the range of the real measured values for the period of 2000-2010 at the SHI Dudince observation station. At first glance it is clear that there is

a higher discrepancy in the values between the real measured and modified data, especially in the last part of the year. The months of June, August and September are notable, as the values obtained by the scenarios are lower than the actual measured data.

Fig. 7 Range of the average monthly precipitation totals modified by the A2 and B1 scenarios and the real measured values for the period of 2000-2010 at the SHI Dudince observation station.

3.2 Evaluation of the development of air temperature and precipitation totals until 2100

According to the A2 pessimistic scenario in the time periods of 2011-2040, 2041-2070 and 2071-2100 in Figure 8, the course of the average monthly air temperatures for the area of Poiplie are compared with the course of the average monthly air temperatures during the reference period of 1977-2010. The figure shows that compared with the reference period of 1977-2010, the A2 pessimistic scenario gives a higher average monthly air temperature in each term, except for the month of November, where during the time period of 2011-2040, the average value is lower than during the reference period. At the end of the century a gradual increase in air temperature is expected to occur in each month by more than 4 °C, and this increase is manifested mostly in the months of January, February and April. On the other hand, the smallest amount of warming of just over 2 °C is expected in the months of June and July. According to the pes-

Fig. 8 Range of the average monthly air temperatures modified by the A2 pessimistic scenario for the time periods of 2011-2040, 2041-2070 and 2071-2100 and the reference period of 1977-2010.

simistic scenario, it is predicted that at the end of the 21st century, the average increase in monthly air temperature compared with the reference period will be up to 3.43 °C.

According to the B1 optimistic scenario for the Poiplie area, the courses of the average monthly air temperatures are presented in Figure 9 for the time periods of 2011-2040, 2041-2070 and 2071-2100 and the reference period of 1977-2010. Compared to the reference period of 1977-2010, the B1 optimistic scenario for each time horizon represents a higher average monthly air temperature, except for the months of June and November, where the average values in the period of 2011-2040 are lower compared to the reference period. Compared to the reference period of 1977-2010, warming of about 2.90 °C will occur at the end of the century, most notably in the month of February, and a minimum temperature increase of only about 0.28 °C is expected in November. According to this scenario, an average monthly air temperature increase of 1.65 °C compared to the reference period is predicted by the end of the century.

Fig. 9 Range of the average monthly air temperatures modified by the B1 optimistic scenario for the time periods of 2011-2040, 2041-2070 and 2071-2100 and the reference period of 1977-2010.

The courses of the average monthly precipitation totals for the area of Poiplie, which were calculated from the daily data modified by the A2 pessimistic scenario for the time periods of 2011-2040, 2041-2070 and 2071-2100, are compared with the course during the reference period of 1977-2010 in Figure 10. The figure shows that compared to the reference period of 1977-2010, the A2 pessimistic scenario indicates an increase in precipitation in most parts of the year. The only exceptions are the months of August, September and November, where a significant decrease in precipitation compared to the reference period is expected, with the greatest decrease in the month of August. The largest increase in precipitation compared to the reference period of 1977-2010 is expected during the time period of 2071-2100 for April (31.52 mm) and May (35.78 mm), but also in the month of December (27.30 mm). According to the pessimistic scenario, the predicted total annual increase in precipitation totals compared to the reference period and to the end of the century will be up to 157.75 mm.

Fig. 10 Range of the average monthly precipitation totals modified by the A2 pessimistic scenario for the time periods of 2011-2040, 2041-2070 and 2071-2100 and the reference period of 1977-2010.

In Figure 11 the courses of the average monthly precipitation totals for the area of Poiplie, which were calculated from the daily data modified by the B1 optimistic scenario for the time periods 2011-2040, 2041-2070 and 2071-2100, and the measured data for the reference period of 1977-2010, are illustrated. Particularly interesting is the significant increase in precipitation totals during the time period of 2071-2100 compared to the reference period in January (18.15 mm), April (20.94 mm) and May (22.45 mm), and a decrease in the precipitation totals in August (11.59 mm). In comparison with the reference period an increase in the annual precipitation totals of up to 88.33 mm will occur at the end of the century.

Fig. 11 Range of the average monthly precipitation totals modified by the B1 optimistic scenario for the time periods of 2011-2040, 2041-2070 and 2071-2100 and the reference period of 1977-2010.

3.3 Evaluation of the development of soil water storage due to climate change

Figure 12 shows the average monthly water storage in the soil to a depth of 20 cm below the surface level according to the A2 pessimistic scenario for the different time periods of the years 2011-2040,

2041-2070 and 2071-2100 compared with the reference period of 1977-2010. It can be seen that the soil water storage begins to increase in the winter season from November, whereas the highest increase is in the months of March and April, which have the highest precipitation totals. Consequently, the soil water storage decreases and reaches its minimum in September and October, due to the drier summer season. Within the comparison of the reference period with the different time periods, we can see that the soil water storage during the reference period was higher than the predicted water storage in most parts of the year until 2100. The greatest variation is in November. Also, we can see that the soil water storage at different time periods until 2100 increases slightly, which is confirmed by the forecast of increasing precipitation until 2100.

Figure 13 shows the average monthly water storage in the soil to a depth of 20 cm below the surface level according to the B1 optimistic scenario for different time periods of the years 2011-2040,

Fig. 12 The average monthly water storage in the soil layer 0-20 cm below the ground surface according to the A2 pessimistic scenario for the time periods of 2011-2040, 2041-2070 and 2071-2100, compared with the reference period of 1977-2010.

Fig. 13 The average monthly water storage in the soil layer 0-20 cm below the ground surface according to the B1 optimistic scenario for the time periods of 2011-2040, 2041-2070 and 2071-2100, compared with the reference period of 1977-2010.

2041-2070 and 2071-2100 compared with the reference period of 1977-2007. From the graph it can be seen that the course of the soil water storage is the same as for the A2 pessimistic scenario. Within the comparison of the reference period with different time periods, we can see that according to this scenario, the soil water storage also has a lower value until 2100 compared to the reference period, but also is gradually increasing towards the end of the century.

4. CONCLUSIONS

The Poiplie area is a wetland ecosystem, where water is one of the decisive factors for its existence. It is an ecosystem which is sensitive to any changes, including climate change. The basic parameters through which climate change can be evaluated, and which have a great impact on any changes in the water regime, are the air temperature and precipitation totals.

For evaluating the climate change, two emission scenarios, i.e., an A2 pessimistic and a B1 optimistic scenario, were used. Using the modified meteorological data, the development of the air temperature and precipitation totals were evaluated during the time periods of 2011-2040, 2041-2070 and 2071-2100, compared with the reference period of 1977-2010, while the modified data according to the scenarios for the period of 2000-2010 were compared with the real measured data.

From the results obtained it can be stated that the analysis of the air temperature developments reveals notable contrasts in the A2 pessimistic scenario and B1 optimistic scenario. Although the A2 pessimistic scenario predicts an increase in the air temperature by

3.43 °C until 2100 compared to the reference period of 1977-2010, an increase of only 1.65 °C is forecast according to the B1 optimistic scenario. To evaluate the development of the precipitation totals according to those two scenarios, it can be said that the higher increase in precipitation totals of up to an additional 157.75 mm until 2100 is assumed by the A2 pessimistic scenario, while the B1 optimistic scenario assumes an increase of 88.33 mm in annual precipitation totals.

An evaluation of the impact of climate change on the water storage in the soil was also examined. For the assessment, the GLOBAL mathematical model was used, where the modified meteorological elements served as the upper boundary condition. Based on the results obtained, it can be seen that climate change would not cause significant changes in the water storage in the soil until 2100.

To conclude, it can be said that according to both emission scenarios, an overall increase in air temperature and also an increase in precipitation totals until 2100 are expected. The water storage in the soil should not be too compromised, which means that, in the case of sufficient precipitation totals, the existence of the Poiplie wetland ecosystem will be preserved.

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