Analysis of evaporation from water surface measured automatically by the EWM evaporimeter at the weather station in Ústí nad Orlicí between 2001 and 2014

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Abstract: Evaporation from water surface at the station in Ústí nad Orlicí was measured using an automatic EWM evaporimeter. The analysed period was from May 1st to September 30th in the years 2001 to 2014. Statistical analysis of the daily evaporation showed that the values ranged between 0.0 mm and 7.3 mm (July 17, 2007). This maximum value was analysed in detail and considered to be realistic based on the unusual weather conditions on that day. The highest average daily evaporation was observed in July (2.8 mm), followed by August (2.5 mm). On the other hand the lowest average daily evaporation was found to be in September (1.6 mm). Average monthly evaporation totals in the analysed period (2001–2014) ranged from 49.1 mm (September) to 86.1 mm (July). The absolute lowest monthly evaporation total in the analysed period was measured in September 2002 (34.4 mm), on the other end of the scale, the absolute highest monthly evaporation in the period of interest was measured in August 2003 (114.5 mm). Statistics of annual data show that out of the 14 years analysed, the lowest evaporation was observed in 2005 (263.5 mm), while the highest in 2007 (426.1 mm). Average annual (May-September) evaporation for the 14 years is 355.0 mm. The trend in evaporation for May and August is negative, in the other months it is positive. The largest change was seen in July, where the linear index value is +1.555. However, the trends in monthly values are not statistically significant.

Key words: evaporation, statistical analysis, trend in evaporation, Ústí nad Orlicí

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1. Introduction

Evaporation represents the outflow component within the water cycle in landscape. The amount of water in landscape is therefore determined not only by the amount of rainfall, but also by the level of evaporation (*Kohut, 2005*). Evaporation occurs from various surfaces and if the surface is not covered with vegetation it is referred to as evaporation, whereas if there is vegetation present, it is called the evapotranspiration (*Allen et al., 1998*). Evaporation is a meteorological variable which represents the amount of water, which evaporates into the air from water surface, soil and also plants (*Sobíšek et al., 1993*).

In nature, evaporation is a very complex physical process, which takes place at all moist surfaces depending on how much energy there is available for the actual evaporation (*Penman, 1948*). The intensity is influenced by the physical properties of the surface, solar radiation balance determined by its transformation at this surface, humidity and air flow, vegetation cover etc. Various methods are used for the quantification of plant transpiration in correlation to environmental conditions (*Klimešová et al., 2013*). Besides modelling based on meteorological variables, instrumental methods are utilized as well. It is this complexity of the evaporation process which makes it difficult to measure unlike many of the other meteorological parameters (*Brutsaert, 1982*).

Evaporation from a water surface is the simplest case of the evaporation process (*Novák, 1995*). Unlike evaporation from the other surfaces (bare soil, grass land, plant cover, agricultural crops), evaporation from water surface is not limited by the amount of available water and so it can be considered to be equal to the potential evaporation, namely the maximum possible evaporation, the intensity of which is only dependent on atmospheric conditions. This means that the amount of evaporation from a water surface in a given time span (day, month, year etc.) depends on the state and variability of the basic meteorological variables – the air temperature and humidity, global radiation (duration of sunlight) and wind speed (*Burman and Pochop, 1994*). It can also be said that the amount of evaporation from a water surface is quantitatively very similar to the values of potential evapotranspiration from grassland or reference evaporation from a hypothetical surface based on the FAO method (*Knozová et al., 2005*). Together with atmospheric precipitation and outflow, evaporation determines water balance in the landscape, where scenario calculations of potential evapotranspiration predict a significant increase in aridity of the climate in the Czech Republic (*Spáčilová et al., 2014*).

In the history of CHMI measurements, various instruments have been used to measure the evaporation from a water surface. This includes the Wild evaporimeter, Ron's evaporimeter (the so-called pan or difference evaporimeter), but also the Piche evaporimeter (*Kocourek, 1972*). The predecessor of the automatic evaporimeter EWM was the GGI 3000 evaporimeter.

Analysis of the measured values of evaporation was performed by Váša (*Váša, 1968*), data from Moravia and Silesia were also analysed by Kříž (*Kříž, 1966*) and data from Slovakia were processed by Lapin (*Lapin, 1977*). Analysis of the measured data, however, showed some imperfections in the case of all the instruments, which to a lesser or higher degree influenced the values of evaporation from the water surface, so the measurements were ended. Comparison of the measured values using several evaporimeters was performed at a station of the Water Research Institute Hlasivo (*Buchtela, 2005*).

The sum of evaporation and transpiration, namely the evapotranspiration, represents the total evaporation from the landscape and it is the basic phase of water outflow. When we subtract evaporation from the amount of rainfall we get the amount of available water in the soil, in other words the water balance (*Kohut et al., 2013*). Evaporation from water surface represents one of the main components of the hydrological balance and significantly influences various processes that take place in the lower levels of the atmosphere. Within the weather station network of the CHMI, evaporation is currently measured using the automatic EWM evaporimeter, in the case of the station in Ústí nad Orlicí, this instrument was installed in 2001 (*Bareš et al., 2006*).

The station in Ústí nad Orlicí is located in the Podorlická hilly area, 402 m above sea level. Based on Quitt classification it is found in a slightly warm area MW7, the Atlas of Czechoslovakian climate from 1958 assigns it to slightly warm area and slightly humid subregion B3 of slightly warm and humid hilly region with mild winter. Based on agroclimatic division it is a warm macroregion, relatively warm region, slightly dry subregion and area with relatively mild winters. Regular automatic measurements of evaporation from water surface have been performed here since the beginning of the vegetation period of 2001, this means data are available since May 15, 2001. Prior to that evaporation was measured using the manual GGI-3000 evaporimeter (*Fišák, 1994*). Results of the analysis of GGI-3000 measurements were published in a work by Kohut in 2014 (*Kohut et al., 2014*).

The aim of the presented study is to analyse daily, monthly and seasonal values of evaporation from water surface at the station in Ústí nad Orlicí.

2. Methods

The presented results were obtained from an analysis of measured values from an automatic evaporimeter EWM (technical specification of this instrument can be found in *Lipina et al. (2014)*).

Data from the station were analysed for a 14-year period between the years 2001 and 2014. Values of evaporation were assessed for each year between 1st May and 30th September. Before the actual assessment, the data were verified; any potential missing values were added and the likely incorrect values based on the comparison with values calculated by the AVISO model using meteorological variables, corrected (*Kohut et al., 2013*). Complete statistical analysis of the data set was performed for individual months, years and the overall period. Calculations were done using the climatological software ProClimDB (http://www.climahom.eu).

3. Results

The results of the statistical analysis of daily values of evaporation for the individual months and the whole period are summarized in Table 1. The daily evaporation amounts in the analysed period (2001–2014) ranged between 0.0 mm and 7.3 mm (July 17, 2007). The course of daily values for the entire period and the daily minimum and maximum values are shown in Fig. 1. The maximum average daily evaporation was in July (2.8 mm), followed by August (2.5 mm). Minimum average daily evaporation was observed in September (1.6 mm). When comparing the extreme values measured in the individual months, it can be seen that with the exception of June and July

Table 1. Statistics of the daily evaporation from water surface from automatic measurements from the station in Ústí nad Orlicí for the period between May and September 2001 to 2014.

Month	V	VI	VII	VIII	IX	V–IX
Day average	2.164	2.519	2.776	2.488	1.637	2.320
Standard deviation	0.985	1.042	1.076	1.032	0.829	1.070
Coefficient of variance	45.518	41.366	38.761	41.479	50.641	46.121
Skewedness	0.187	0.232	0.225	0.297	0.337	0.322
Kurtosis	−0.287	−0.068	0.450	0.060	−0.067	0.040
Day minimum	0.000	0.100	0.100	0.000	0.000	0.000
Day maximum	5.100	6.000	7.300	5.700	4.600	7.300
10^{th} percentile	0.800	1.200	1.400	1.300	0.500	1.000
25^{th} percentile	1.500	1.800	2.000	1.800	1.000	1.600
Median	2.100	2.500	2.800	2.500	1.600	2.300
75^{th} percentile	2.900	3.200	3.500	3.100	2.200	3.000
90^{th} percentile	3.400	3.900	4.100	3.910	2.700	3.700

(0.1 mm), the absolute minimum value for all the other months is equal to 0.0 mm, and the absolute maximum values in the individual months range from 4.6 mm (September) to 7.3 mm (July).

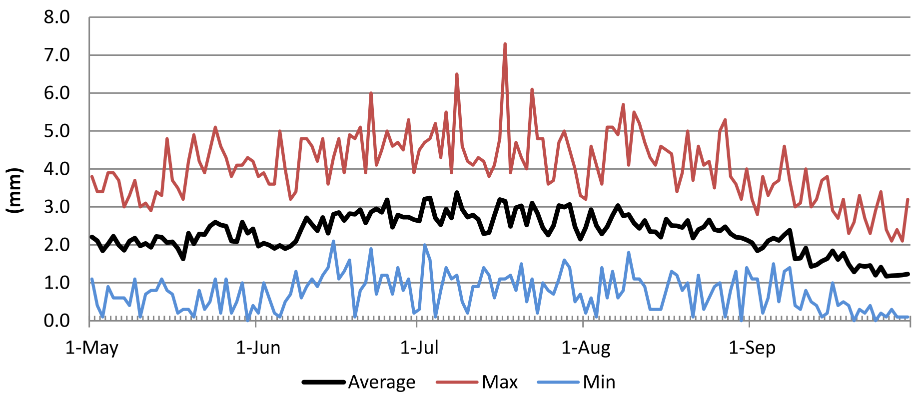

Fig. 1. Average, maximum and minimum values of daily evaporation from water surface from automatic measurements at the station in Ústí nad Orlicí in the period between May and September 2001 to 2014.

Fig. 2 shows the course of daily evaporation in 2005, when the overall total evaporation was the lowest out of all the years and 2007, when it was the highest. Both lines show the large variability in the meteorological variable of interest between the individual days. A very significant decrease in evaporation amount (2.4 mm) was observed from July 17th 2007 to July 18th 2007. This is the largest decrease observed in the above mentioned two years. Such changes are associated with changes in many other meteorological variables, which determine the evaporation process. A detailed analysis of the events on July 17th, 2007 is described in the next chapter.

The results also show that 50% of all the values lie in the interval between 1.6 mm and 3.0 mm. Frequency histogram (Fig. 3) and Table 1, which also includes the values of kurtosis and skewedness, show that the distribution curve is slightly shifted towards higher values (skewedness = 0.322). In comparison to measurements from this station from previous years, which were performed using the manual evaporimeter GGI-3000 (*Kohut et al., 2013*), the value of kurtosis is lower and the daily evaporation values are in general more concentrated around the mean. The median value (2.3 mm) is almost equal to the mean (2.32 mm). The variability in data was analysed by calculating the standard deviation and coefficient of variance. The coefficient of variance for the entire period analysed is 46.12.

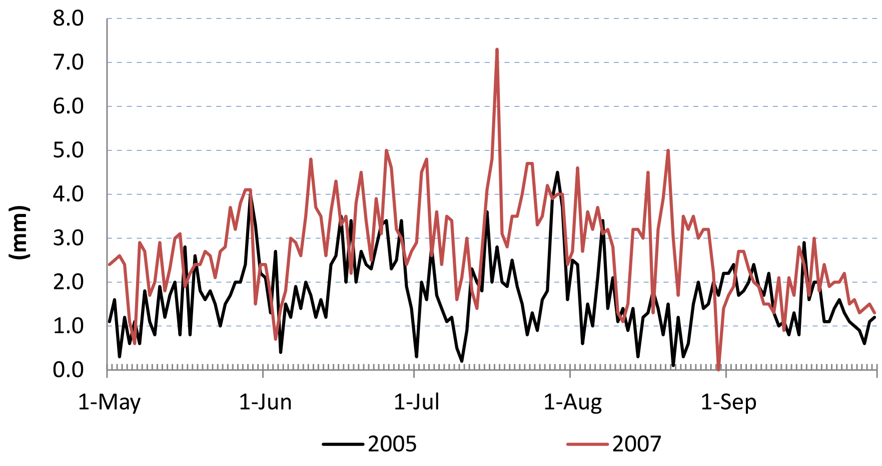

Fig. 2. Daily evaporation from water surface from automatic measurements at the station in Ústí nad Orlicí in the period between May and September 2001 to 2014.

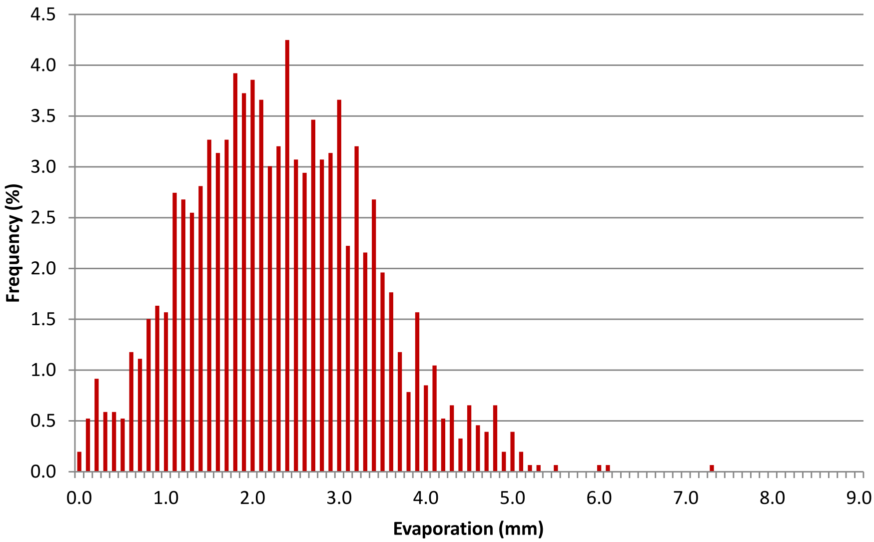

Fig. 3. Frequency histogram of daily evaporation from water surface from automatic measurements at the station in Ústí nad Orlicí in the period between May and September 2001 to 2014.

The highest values of standard deviation were observed during the summer months, which is due to the fact that the absolute highest values of daily evaporation occur in these months and so also the variability is greatest.

4. The extremely high evaporation value measured on July 17, 2007

When analysing the daily data, close attention was paid to the extreme values. Very low values of evaporation are actually quite common at the Ústí nad Orlicí station, 2.8% of days have a value of less than 0.5 mm. Values exceeding 6.0 mm, on the other hand, are relatively very rare and account for only 0.1% of all the monitored days. It must be said however, that even such high values of evaporation are realistic given the climate conditions in the Czech Republic and are also observed at other evaporation measuring stations within the CHMI network. In the past, when evaporation was measured using the manual evaporimeter GGI-3000, the proportion of days with evaporation over 6.0 mm measured at the station in Ústí nad Orlicí was 0.9% (*Kohut et al., 2013*), however, it must be noted that this analysis was from a 30-year period.

Extremely high evaporation is related to several factors. In order to find the relationships between the weather conditions and evaporation at this particular station, an in-depth analysis of the meteorological conditions during the day with highest evaporation measured was performed. On July 17, 2007, a cold front was slowly moving from the Western Europe towards the East, preceded by tropical air. It was sunny in the analysed location, mostly sunny or partly cloudy in the afternoon and thunderstorms and rain showers appeared occasionally, especially in the region of South Moravia. The course of the various meteorological variables on this day is shown in Fig. 4. The weather station in Ústí nad Orlicí had direct sun light for the whole day. The duration of sun light on this day was 13.5 hours. The air temperature exceeded 20 °C in the morning and kept on increasing until the afternoon when it reached the maximum of 33.9 °C. The average daily air temperature was 27.6 °C. This was also reflected in the air humidity, which was very low throughout the whole day and reached its minimum at 3 PM, with a value of 28% . The daily average humidity was only 45% . There was a very gentle wind during the whole day, with occasional fresh gusts. During

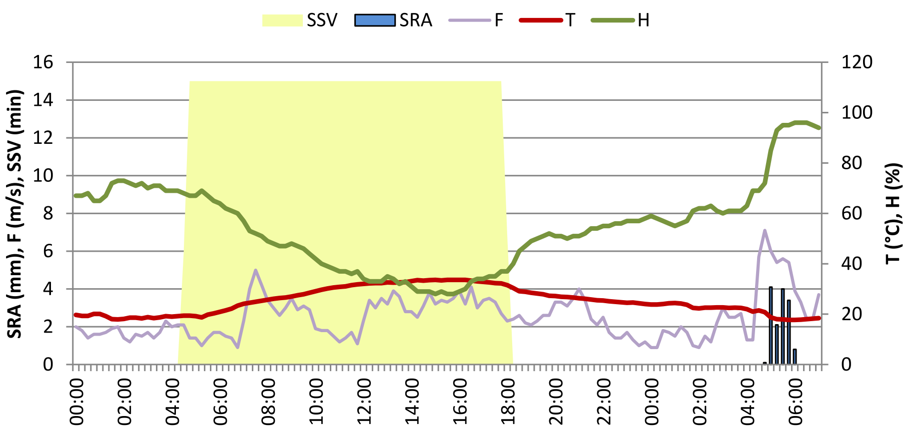

Fig. 4. Course of precipitation (SRA), wind speed (F), solar radiation (SSV), air temperature (T) and relative humidity (H) in 15-minute intervals on July 17, 2007 at the station in Ústí nad Orlicí.

the night of July 18, 2007, a large thunderstorm system formed in Bohemia, which subsequently moved towards the southwest. The thunderstorm in Ústí nad Orlicí was accompanied by intense rain and lasted from 4:30 AM to 6:05 AM CET. After that the rain intensity decreased and the thunderstorm moved towards the northeast. The above described conditions are ideal for very high values of evaporation.

5. Monthly statistics

Statistical analysis of monthly data was also performed and the results for the individual months given in Table 2. Average monthly evaporation sums in the analysed period from 2001 to 2014 ranged from 49.1 mm (September) to 86.1 mm (July). The month with the absolute lowest evaporation out of all the measured months was September 2002, with a value of only 34.4 mm. On the other side of the scale, the highest absolute monthly sum of evaporation was measured in August 2003 (114.5 mm). It can also be seen from the table (Table 3) that especially during the summer months, the variability of data is quite high, especially because the highest values of

Table 2. Statistics of monthly total evaporation from water surface from automatic measurements at the station in Ústí nad Orlicí from May to September 2001 to 2014.

Month	**V**	**VI**	**VII**	**VIII**	**IX**	**V–IX**
Average sum	67.079	75.579	86.071	77.121	49.121	70.994
Standard deviation	13.987	14.162	14.067	17.443	10.030	18.612
Coefficient of variance	20.852	18.738	16.343	22.618	20.419	26.216
Skewedness	−0.265	−0.019	−0.612	0.254	−0.154	0.000
Kurtosis	−1.332	−1.258	0.106	0.610	−1.058	−0.677
Monthly minimum	44.300	54.700	58.100	44.600	34.400	34.400
Monthly maximum	87.500	97.500	108.100	114.500	66.600	114.500
10th percentile	47.990	56.320	61.970	58.820	35.210	45.050
25th percentile	54.400	61.400	79.000	64.100	38.200	56.500
Median	69.250	78.300	88.050	76.650	52.550	73.300
75th percentile	78.600	86.300	93.800	89.500	56.400	86.300
90th percentile	82.190	93.990	101.080	94.250	58.410	93.500

Table 3. Monthly total evaporation from automatic measurements at the station in Ústí nad Orlicí from the period between May and September 2001 to 2014 in the individual years.

Month	**V**	**VI**	**VII**	**VIII**	**IX**	**V–IX**
2001	81.6	54.7	62.4	74.5	35.3	308.5
2002	78.4	81.5	89.3	64.1	34.4	347.7
2003	73.0	97.5	79.0	114.5	54.1	418.1
2004	48.4	61.3	82.0	89.5	53.9	335.1
2005	50.8	64.5	58.1	44.6	45.5	263.5
2006	57.4	61.4	100.3	61.5	66.6	347.2
2007	78.6	93.6	108.1	88.7	57.1	426.1
2008	65.5	86.3	86.8	92.0	51.2	381.8
2009	73.6	72.1	82.6	78.8	56.2	363.3
2010	44.3	78.6	93.8	60.4	44.5	321.6
2011	80.6	92.3	76.3	74.0	57.5	380.7
2012	87.5	78.0	93.4	90.1	56.4	405.4
2013	54.4	56.5	100.2	80.0	36.8	327.9
2014	65.0	79.8	92.7	67.0	38.2	342.7

evaporation are measured in these months due to the weather conditions common for this part of the year.

Monthly total evaporation over 100 mm was only measured three times during the analysed period and this was always during either July or August. This is then also reflected in the value of standard deviation. The lowest variability within one month is in September (standard deviation of 10.03), highest variability on the other hand was during August (standard deviation of 17.44). Table 2 also shows the overall variability in data. 50% of values of total monthly evaporation lie between 56.5 mm and 86.3 mm. The overall skewedness is exactly 0, which means that data is evenly distributed and deviations lie evenly on both sides of the mean.

It is also interesting to compare the average monthly values measured in this study from 2001 to 2014 using the automatic evaporimeter with the ones measured using the manual evaporimeter GGI-3000 in the years between 1971 and 2000. In general, the average of monthly total evaporation from water surface measured using the manual evaporimeter was higher in the case of all the months and thus also overall. The monthly average total evaporation measured between 1971 to 2000 was 76.2 mm, while in the case of the automatic measurements from 2001 to 2014 it was only 71.0 mm, which means approximately 7% less.

6. Annual statistics

Statistical analysis for the individual years in the analysed period is given in Table 4 and shown in Fig. 3. The highest total evaporation during one year (measured between May and September) in the analysed period from 2001 to 2014, was observed in 2007 (426.1 mm). The lowest overall value was observed in 2005 with just 263.5 mm. The overall average total evaporation from all the 14 years analysed is 355.0 mm.

Graph 3 clearly shows the variability of the data between the individual years. A numerical expression of this variability can be found in Table 4. 50 % of the average evaporation totals for one year (May to September) lie between 327.9 mm and 381.8 mm. The table (Table 4) also shows that the skewedness of data is slightly negative, which means that the data is concentrated a little bit more towards values below the mean.

Table 4. Statistics of total evaporation for the individual years (May-September) measured by automatic EWM evaporimeter at the station in Ústí nad Orlicí between 2001 and 2014.

Average annual (May-September) total	354.971
Standard deviation	44.782
Coefficient of variance	12.616
Skewedness	−0.157
Kurtosis	−0.021
Monthly minimum	263.5
Monthly maximum	426.1
10th percentile	304.0
25th percentile	327.9
Median	347.45
75th percentile	381.8
90th percentile	418.9

In general it can be said that during the analysed period between 2001 and 2014, there was one year with exceptionally low evaporation (263.5 mm, measured in 2005) and total evaporation over 400 mm was observed during three years (2003, 2007 and 2012) (see Table 3 and Fig. 5).

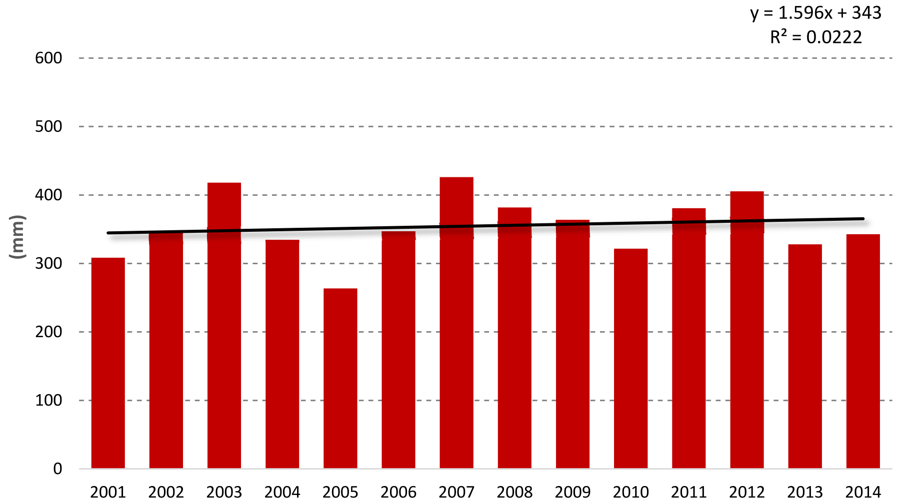

Fig. 5. Graph of total evaporation from water surface for the individual years between May and September 2001 to 2014 at the station in Ústí nad Orlicí. Line corresponds to the linear trend in data.

7. Trends

Linear trend was calculated for the individual years (Table 5), as well as for the particular months. The value of linear index of the annual values in the 14-year period is +1.596. This however, is not statistically significant. A negative trend was observed in May and August, in the other analysed months the trend was positive. The greatest change was observed in July,

Table 5. Linear trends in evaporation from water surface for the individual months and the whole analysed period between 2001 and 2014 at the station in Ústí nad Orlicí.

Month	**V**	**VI**	**VII**	**VIII**	**IX**	**V–IX**
Linear trend	−0.266	0.413	1.555	−0.256	0.149	1.596

for which the value of linear index is +1.555. The monthly trends, however, are also not statistically significant.

8. Conclusion

Statistical analysis of the values of evaporation from water surface during the vegetation period from May to September 2001 to 2014 at the station in Ústí nad Orlicí show, that daily evaporation sums in this 14-year period ranged between 0.0 and 7.3 mm. The daily average was 2.32 mm and standard deviation 1.070.

When comparing the values for the individual months it can be seen that the highest average monthly evaporation amount was during the summer months of July (86.1 mm) and August (77.1 mm), while the lowest values were observed in September (49.1 mm). The overall average monthly total was 71.0 mm.

The totals from the entire vegetation period for the individual years vary irregularly from 263.5 mm (2005) to 426.1 mm (2007). The linear trend of these values is slightly positive, but this increase is not statistically significant and also the trends in totals for the individual months are not statistically significant.

The fact that all the trends are not statistically significant is due to the fact that when comparing the trends in the individual meteorological variables, which determine evaporation (air temperature and humidity, wind speed, sun light duration) a slight decrease can be seen in all cases, but always statistically insignificant.

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