Research Article

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Forestry Aridity Index in Vojvodina, North Serbia

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Abstract: In investigating aridity in Vojvodina (a region in the northern part of Serbia), the Forestry Aridity Index (*FAI*) was used. This index was chosen due to being one of the most suitable indices for the analysis of the interaction of climate and vegetative processes, especially in forestry. The spatial distribution of the *FAI* for annual and decennial periods, as well as its annual trend, is analysed. Satisfactory compatibility between the low (forest) and high (steppe) *FAI* values with the forest and steppe vegetation on the Vojvodina terrains was obtained. The calculated values of the *FAI* showed that there was no particular annual trend. These results correspond to the earlier calculated values of the De Martonne aridity index and the Pinna combinative index. Therefore, it can be concluded that there were no recent changes in aridity during the observed period. Results of the correlation indicate weak linearity between the *FAI*, and the North Atlantic Oscillation and El-Niño South Oscillation.

Keywords: aridity in Vojvodina, aridity trend, aridity climate classification, climatological hazard, NAO, ENSO

1 Introduction

In recent decades, the issues of climate variability and climate change have been at the center of many scientific studies. Global climate change, caused by natural processes as well as anthropogenic factors, is a major 21st century environmental issue [1–4]. Governments, the scientific community, as well as the media and its consumers all over the world, have been paying increasingly more attention to the recent trends regarding global climate change [5]. Temperature change [6], precipitation change [7], and the rate of these changes are the most important variables in determining the possible effects of climate change. However, sometimes it is more useful to analyze temperature and precipitation together. Parameters in which there is a mathematical quotient/ratio between precipitation and some air humidity and temperature values are known as the aridity indices and are used to measure aridity. According to the American Meteorological Society [8], aridity is the degree to which a climate lacks effective, life-promoting moisture. It is the opposite of humidity, in the climate studies usage of the term. Furthermore, the higher the values of the aridity indices in a region, the greater the water resource variability [9]. Aridity indices are not only important indicators for the potential growth and development of plants, but could be good indicators of climate changes, be used to estimate change in runoff [10], and also be a factor in explaining the meteorological/climatological characteristics of a landscape. Also, it is the aridity indices that can help in the recognition and classification of slow climatological natural hazards [11], such as droughts.

Famous aridity parameters that include both temperature and precipitation are the De Martonne [12] aridity index and the Pinna [13] combinative index. The first index can be calculated for different time scales, such as years, seasons and months, while the second of them is calculated only for years. Both aridity indices are used worldwide in order to identify the dry/humid climate conditions of different regions *e.g.* [9, 14–18]. They describe the climate in specified regions as well as any climate changes, on the territory of Serbia from 1949 to 2015 [19–21]. However, some scientists prefer to characterize aridity conditions by using indices based on (potential or reference) evapotranspiration, calculated by using different formulas [22–27]. Then, for the classification of continental and oceanic climates, the Johansson [28] continentality index and the Kerner [29] oceanity index are used, *e.g.* [9, 14, 17]. Also, there is class of the aridity indices that are based on relevant data associated with the vegetation process. One of the oldest is the Emberger [30] index, obtained from the mean annual precipitation and the mean temperature of both the coldest and hottest months. The Food and Agri-

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culture Organization (FAO) [31] aridity index is the ratio between total annual precipitation and potential evapotranspiration.

In this paper, the focus will be to research the recently defined Forestry Aridity Index (*FAI*) published by Führer [32]. The calculation of the *FAI* takes into account the ratio of the average temperature of the critical months (July to August), the precipitation sums in the main growth cycle of the forest (May to July), and the precipitation sums in the critical months (from July to August). This index can be classified as vegetative because the *FAI* climatic categories are defined according to the types of forest and steppe vegetation. In order to forecast the future impact of climate variability on the forest vegetation in Vojvodina (North Serbia) usage of climate projections together with forest aridity index would be appropriate approach. Raising questions regarding variability of aridity in the region due to climate change can be focused on obtaining an insight about how these conditions will influence European forest vegetation and how to prepare adequate adaptation and mitigation strategies. Therefore, the *FAI* is defined for the conditions that exist in Hungary, but due to climatic similarities of the regions, it appears to be applicable to the region of Vojvodina in Northern Serbia as well. Both regions belong to the Carpathian (Pannonian) Basin, making them very similar in their climatic, environmental, and vegetative conditions. The *FAI* results will also be useful in comparing the results of both the De Martonne and Pinna combinative indices [19], as all three indices were calculated for the same period, from 1949 to 2006, yielding data containing nearly two 30-year climatic cycles. Therefore, the results could act as efficient indicators for recent interpretations of climate. To investigate a possible aridity connection with the North Atlantic Oscillation (NAO) [33] and the El-Niño Southern Oscillation (ENSO) [34], the correlations between the NAO and ENSO indices as well as the *FAI*, are calculated. Finally, the characteristics of recent aridity are interpreted in the context of paleoclimatic and paleoenvironmental phenomena during the Late Pleistocene.

2 Data and methods

2.1 Study Area

Vojvodina is a region in northern Serbia, located in the southeastern part of the Carpathian (Pannonian) Basin, encompassing the confluence area of the Danube, Sava and Tisa rivers with an area of 21,506 km^2 (Figure 1). More than 60% of this lowland area is covered by loess and loess-like sediments [35, 36]. The loess–paleosol sequences, situated in the Vojvodina region, represent the most detailed archive of climatic and environmental fluctuations during the Middle and Late Pleistocene on the European continent [37–39]. The most distinctive landforms of the Vojvodina region are two mountains: Fruška Gora Mountain, which is situated between the Danube and Sava rivers, and Vršac Mountain, which is located in southeastern part of the region [40]. Sandy areas (Deliblato Sands and Subotica-Horgoš Sand), lower terrains, and alluvial plains are also located in the Vojvodina region [41]. Forests comprise only about 7% of Vojvodina and mainly occur in the mountains and terrains along the banks of rivers, while the agriculture land occupies about 84% [41].

The climate of Vojvodina is moderate continental, with cold winters, and hot and humid summers, with huge range of extreme temperatures and a very irregular distribution of rainfall per month, which lead to different values in calculating aridity types. The diversity of the climate of Vojvodina is influenced by surface wind, which blows from two prevailing opposite directions; from NW when it is cold and humid, and from SE when it is warm and dry [41, 42]. The mean annual surface air temperature is about 11°C [43, 44] and the annual amount of precipitation is approximately 600 mm [45].

2.2 Data

The aridity indices were calculated from 1949 to 2006 for 10 meteorological stations across the territory of Vojvodina (Table 1). These stations are operated by the Republic Hydrometeorological Service of Serbia [46]. Data sets for each of the stations were analysed and processed for the calculation of the mean monthly values of surface air temperature and monthly amount of precipitation. Thus, a database was created with a time series of temperatures and precipitation values, for the purpose of creating a calculation of aridity indices. Before this analysis, the homogeneity of the precipitation and temperature series was examined, according to the Alexandersson test [47]. This test is based on the assumption that the difference/ratio between temperature and precipitation amounts at the station being tested and the reference series is fairly constant over time. The correlation coefficients between the candidate stations and the reference stations were above 0.7 because of the relatively low and uniformly flat terrain of Vojvodina. The homogeneity analysis showed that the time series of the data for all the stations are homogeneous. It should be noted that the same set of data was used in [19, 48] for

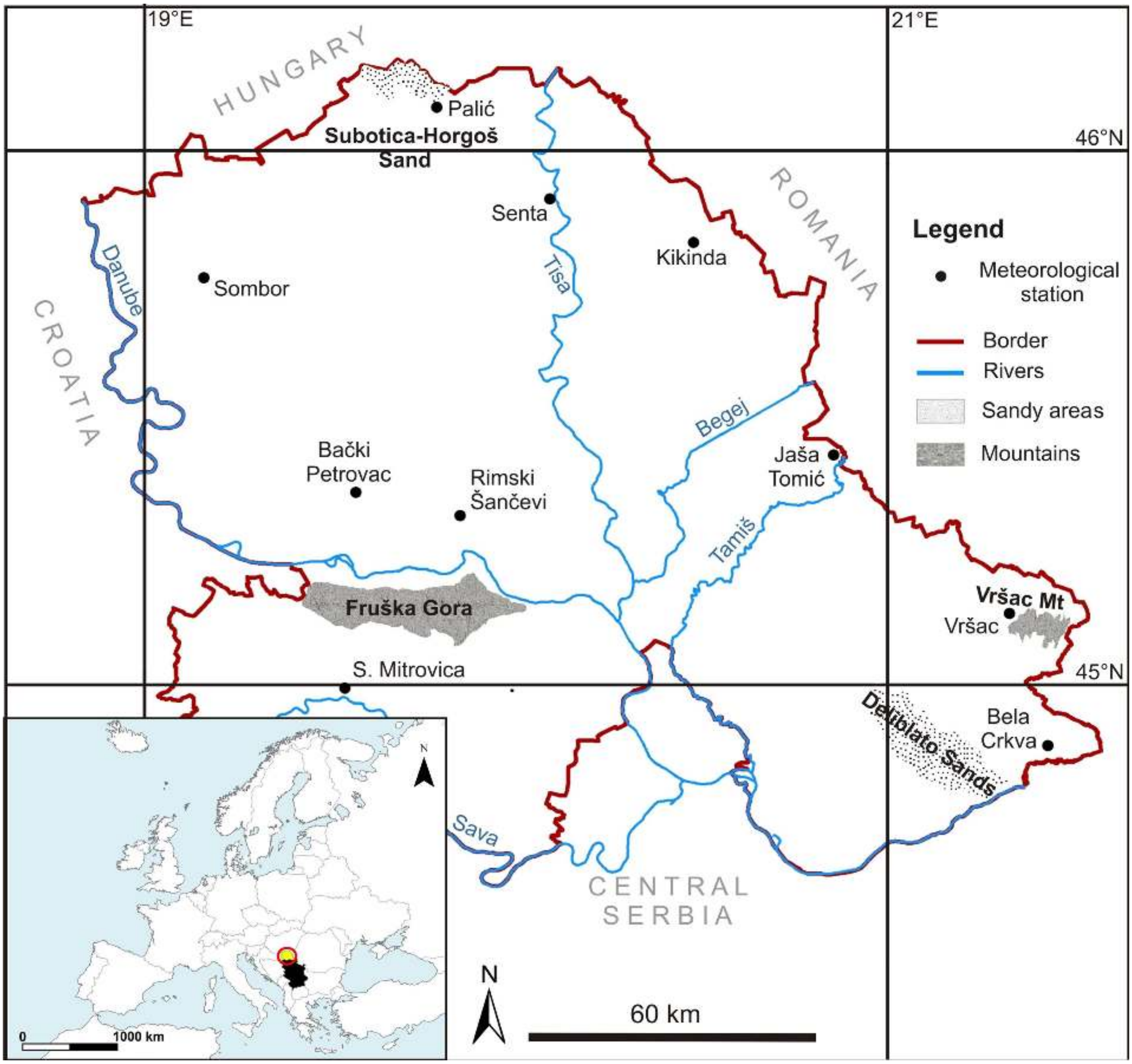

Figure 1: Geographical location of meteorological stations in Vojvodina region ([19], modified)

Table 1: List of meteorological stations and their geographical coordinates and altitudes

Number	Meteorological station	Latitude (N)	Longitude (E)	Altitude (m)
1	Bački Petrovac	45°22′12″	19°34′12″	85
2	Bela Crkva	44°54′00″	21°25′12″	90
3	Jaša Tomić	45°27′00″	20°51′00″	80
4	Kikinda	45°51′00″	20°28′12″	81
5	Palić	46°06′00″	19°46′12″	102
6	Rimski Šančevi	45°19′48″	19°51′00″	86
7	Senta	45°55′48″	20°04′48″	80
8	Sombor	45°46′12″	19°09′00″	87
9	Sremska Mitrovica	45°03′00″	19°33′00″	82
10	Vršac	45°09′00″	21°19′12″	83

calculating the De Martonne aridity index and Pinna combinative index.

In order to examine the relationship between the *FAI* and potential large scale climate drivers NAO and ENSO, linear correlations were utilized. The station based NAO time series for calculating correlation from 1949 to 2006 [49] was downloaded from Climatic Research Unit [50], while the ENSO record was represented by the NINO3 time series for the same time period National Oceanic and Atmospheric Administration [51].

2.2.1 Forestry Aridity Index

The original Forestry Aridity Index [32] is defined as,

$$FAI = C_g \times \frac{T_{VII-VIII}}{(P_{V-VII} + P_{VII-VIII})}, \quad (1)$$

where $T_{VII-VIII}$ is the average temperature in July and August in °C, P_{V-VII} is the precipitation sum in the period from May to July, $P_{VII-VIII}$ is the precipitation sum in the period from July to August, all in mm, and C_g=100 is constant. By introducing the constant with dimensions, C_g=100 mm/°C, instead of the previous constant without dimensions, but with the same numerical value, *FAI* lost its dimensions and became a "true" index, that is, the non-dimensional number. With this modification, the *FAI* has got a better physical basis, and the interpretation of results will not change.

Thus, the *FAI* can be a very good tool for presenting climate conditions during the yearly forests' growth, which is very important for forestry and agriculture. With the *FAI*, the average weather conditions of different climate categories applied in forestry practice are shown in Table 2.

Table 2: Meteorological features of forestry climate categories [32]

FAI value	Forestry climate category
less than 4.75	beech climate
4.75-6.00	hornbeam-oak climate
6.00-7.25	the sessile oak / Turkey oak climate
more than 7.25	forest-steppe climate

2.2.2 Aridity Trend

Two statistical approaches are used to investigate the aridity trend. The first approach is to calculate the tendency (trend) equation of the aridity by fitting the linear trend of the forestry aridity index's mean values, *FAI*, per year for the entire territory of Vojvodina. Tendency equation (linear trend) is graphically shown with the mean values of the aridity indices per year. In the second statistical approach, the Mann-Kendall (MK) test [52–55] is used for estimating the significance of the aridity trend which was obtained from the tendency (trend) equation. According to the MK test, two hypotheses were tested: the null hypothesis, H_0, that *there is no trend* in the *FAI* aridity time series; and the alternative hypothesis, H_a, that *there is a significant trend* in the series, for a given α significance level [56]. Probability, p, in percent was calculated [43, 44, 57, 58] to determine the level of confidence in the hypothesis. If the computed value p is lower than the chosen significance level α (*e.g.*, α=5%), H_0 (*there is no trend*) should be rejected, and H_a (*there is a significant trend*) should be accepted. In case p is greater than the significance level α, the H_0 (*there is no trend*) cannot be rejected. MK tests are widely used in environmental sciences, for example: temperature, precipitation, sunshine hours, cloud cover, relative humidity and wind speed [59]; temperature and precipitation [57]; precipitation [60]; extreme temperatures [43, 44, 58, 61]; hail [62–64]; aridity [19, 21, 65]; evapotranspiration [66]; and atmospheric deposition [67]; because it is simple, robust, and can cope with missing values.

2.2.3 Software

In order to calculate the forestry aridity index, *FAI*, special software using C Sharp programming language was created [68]. This paper uses numerical approaches for interpolating aridity indices, for the spatial representation and visualization by applying ArcMap software [69]. For calculating the probability, p, and hypothesis testing, XLSTAT's [70], statistical analysis software was employed.

3 Results and discussion

3.1 Distribution of aridity

The spatial distribution of *FAI* from 1949 to 2006 is shown in Figure 2. On the basis of the mean of the 58-year long measurement record, it can be concluded that there are only two meteorological stations (Bela Crkva and Vršac) in the sessile oak (*Quercus petraea*) / Turkey oak (*Quercus cerris*) climate zone and that the remaining eight stations belong to a forest-steppe climate (Table 2). Aridity is inversely

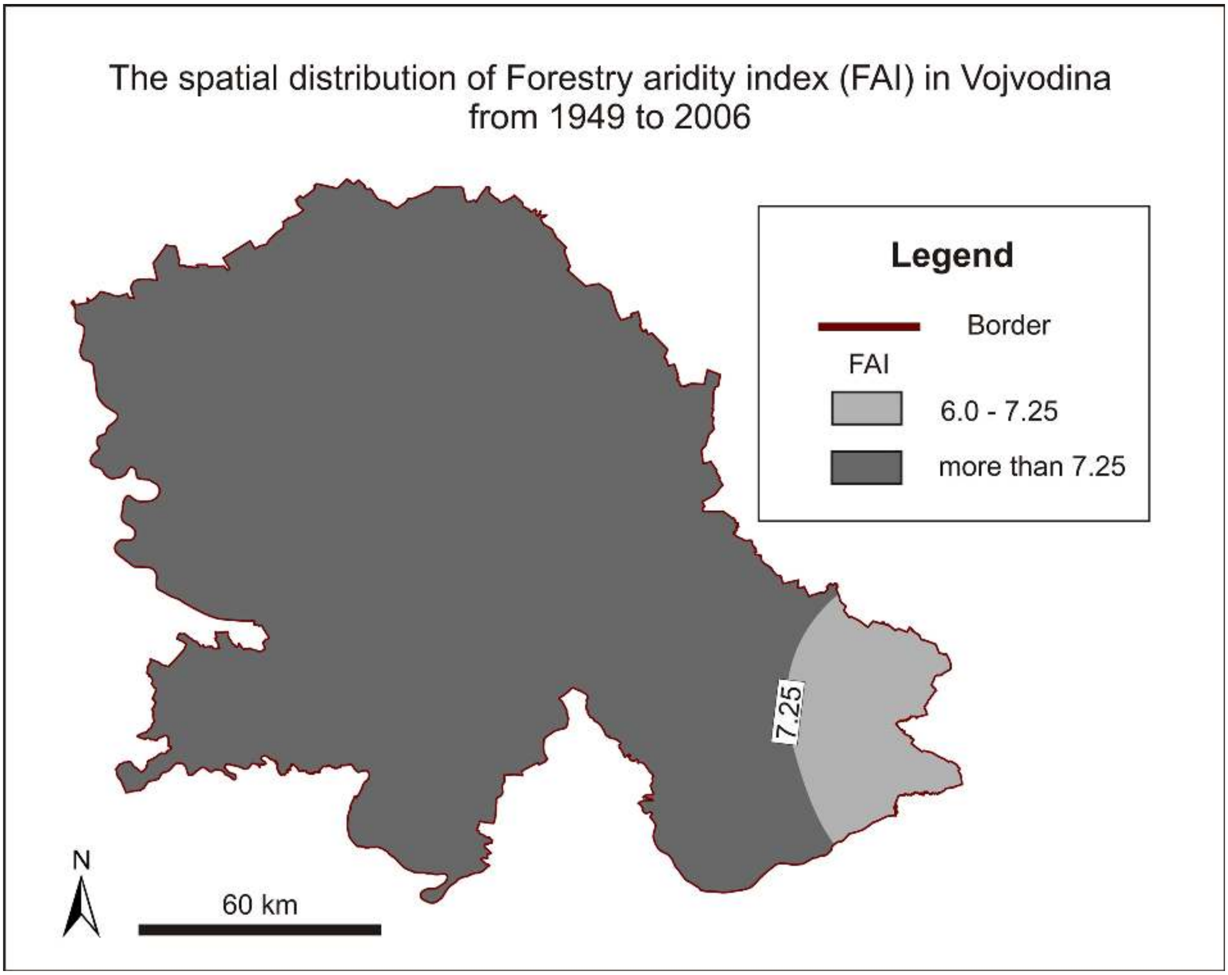

Figure 2: The spatial distribution of the mean forestry aridity index, *FAI*, from 1949 to 2006 in Vojvodina

proportional to the values of *FAI*, *i.e.*, if the values of *FAI* are higher, aridity is lower. Also, lower values of *FAI* correspond to higher values of De Martonne index and Pinna combinative index [19] and vice versa, which can be concluded on the basis of climate forestry categories. This is contrary to the statement that the higher the values of the aridity indices in a region, the greater the water resource variability [9], which is the consequence of the *FAI* definition (1), where is sought the ratio between the temperature and the precipitation, while for De Martonne and Pinna combinative indices the reverse is required, the ratio between precipitation and temperature. Since this contradiction has no effect on the results obtained here, it will be ignored, and potential harmonization of the *FAI* with the previous statement can be left for future research.

The lowest values of *FAI*, from 6.95 to 7.25, were found in the southeast Vojvodina region, while in the rest of the region values were higher than 7.25. This means that, according to *FAI* values, a sessile oak / Turkey oak climate is present in the southeast part of Vojvodina. These results correspond to the values of Pinna combinative index and De Martonne index, characterized by humid climate, according to De Martonne climate classification. It is interesting to note that low values of *FAI* (6.95–7.25) in the southeast part of Vojvodina are more favorable to forest vegetation, which occupies about 20% of the southeast part of the region [71].

Values of the *FAI* increase to the north, where its values vary from 7.40 to 8.56, and where a forest-steppe climate can be found. It can also be correlated with lower values of the De Martonne and Pinna indices, which indicate semi-humid conditions or semi-dry Mediterranean climate, respectively. Thus, higher values of *FAI* or forest-steppe climate in the north of Vojvodina correspond to lower values of Pinna combinative index, which is caused by a lower level of precipitation.

The spatial distribution of the *FAI* for decennial periods is shown in Figure 3 on six maps.

For the first eight-year period from 1949 to 1956, conditions were very similar to those conditions specific to the

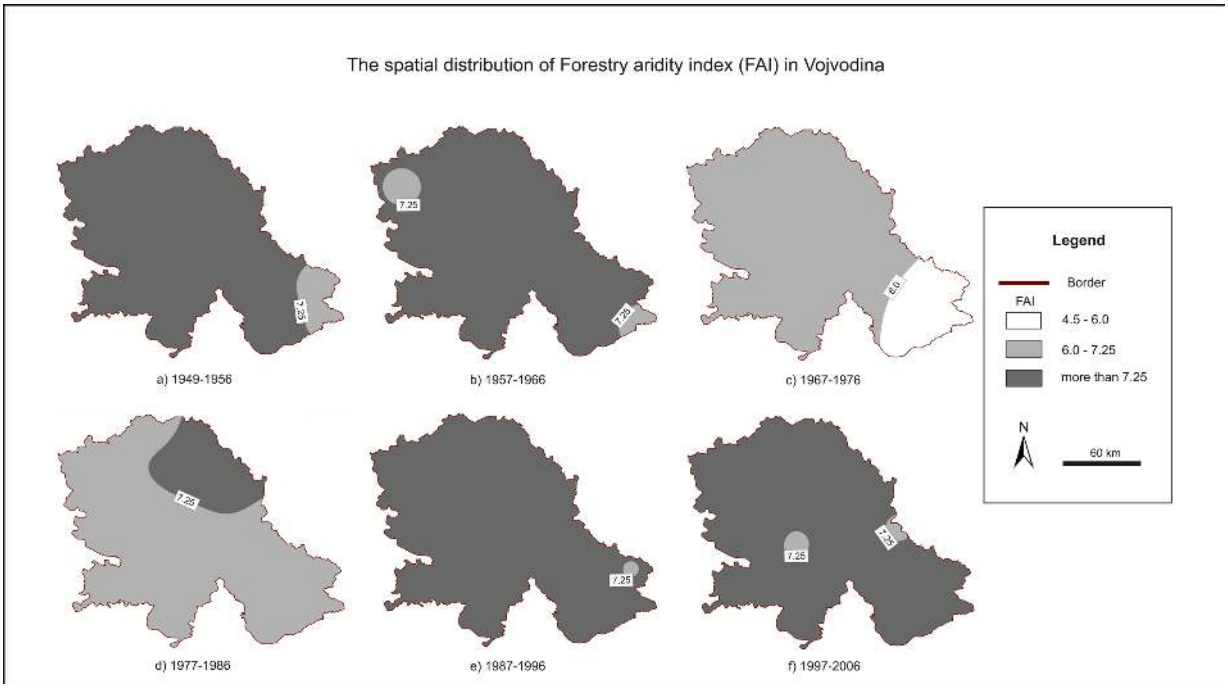

Figure 3: The spatial distribution of the mean forestry aridity index, *FAI*, per decennial periods from 1949 to 2006 in Vojvodina

annual values in the entire period, shown in Figure 2, and they are characterized by a sessile oak / Turkey oak climate and forest-steppe climate.

The decennial period from 1957 to 1966 is mostly dominated by forest-steppe climate; only small parts of southeastern Vojvodina and northwestern Vojvodina had sessile oak / Turkey oak climate recording values of *FAI* lower than 7.25.

For the decennial period from 1967 to 1976 values of *FAI* are significantly lower, indicating the hornbeam-oak (*Carpinus betulus*) climate in southeastern part of Vojvodina, and sessile oak / Turkey oak climate in the rest of the territory.

Values of the *FAI*, from 1977 to 1986, show that about 75% of the territory of Vojvodina is dominated by a sessile oak / Turkey oak climate, while a forest-steppe climate is present at only two stations (Kikinda and Senta) in the northeastern region of investigated area, with the highest *FAI* value being 8.06.

From 1987 to 1996 the forest-steppe climate dominated at nine stations, but the *FAI* values were very high with a value of 10.75, while only the station at Vršac, in the southeast, had recorded a sessile oak / Turkey oak climate.

Compared to the previous period, from 1997 to 2006, the forest-steppe climate again dominates, now at 8 stations, with the *FAI* recording the greatest value at 9.21, while a sessile oak / Turkey oak climate is present at only two stations (Jaša Tomić and Rimski Šančevi).

It appears that the obtained results show a significant diversity, since three types of climate aridity have been identified out of a total of four types. This can be considered a significant result, as Vojvodina is a relatively small territory with, at first glance, uniform geophysical characteristics [35, 41], therefore the climate would be expected to be uniform. Also, decennial results show significant mutual differences that quasi periodically alternate, which is very similar to climate variability. For decennial periods, the situation is not so distinctive when compared to the entire period from 1949 until 2006, except for two periods: 1967–1976 and 1977–1986, where calculated *FAI* values are lower.

3.2 Trend

By calculating the trend from the available mean annual values of the forestry aridity index, the following tendency equation (linear trend curve) is obtained:

$$y = 0.002\,x + 7.672, p = 77.8, \qquad (2)$$

where y represents the mean annual values of the aridity index, x is the time in years, p is the probability in percent to determine level of confidence in the hypothesis, and the significance level α=5%.

Figure 4 as well as Equation (2) show that there is no trend. Testing the hypothesis will prove whether this state-

Table 3: Seasonal and annual correlation coefficients (*Cors.) with p-values (pvs) between FAI and NAO*

Meteorological station and region	Winter NAO		Spring NAO		Summer NAO		Autumn NAO		Annual NAO	
	pvs	*Cors.*	*pvs*	*Cors.*	*pvs*	*Cors.*	*pvs*	*Cors.*	*pvs*	*Cors.*
Bački Petrovac	0.26	0.14	0.48	−0.04	0.69	−0.05	0.50	0.08	0.71	0.05
Bela Crkva	**0.09***	**0.23***	0.77	−0.04	0.66	−0.06	0.12	0.2	0.24	0.16
Jaša Tomić	0.24	0.16	0.43	−0.11	0.78	0.04	0.87	−0.02	0.74	0.04
Kikinda	**0.06***	**0.25***	0.90	−0.02	0.54	0.08	0.98	0.00	0.43	0.11
Palić	0.48	0.26	0.75	−0.04	0.95	0.01	0.97	0.00	0.52	0.09
Rimski Šančevi	**0.10***	**0.21***	0.83	−0.03	0.72	−0.05	0.66	−0.06	0.86	0.02
Senta	**0.01****	**0.33****	0.90	0.07	0.80	0.03	0.78	−0.04	0.28	0.15
Sombor	0.18	0.18	0.42	0.11	0.87	−0.02	0.65	−0.06	0.90	0.00
Sremska Mitrovica	0.49	0.09	0.35	−0.12	0.28	−0.14	0.96	0.007	0.70	−0.05
Vršac	0.60	0.07	0.50	−0.10	0.87	0.02	0.61	0.07	0.73	0.04
Vojvodina	0.16	0.18	0.60	−0.07	0.08	−0.02	0.84	0.03	0.59	0.07

**90 % significance; **99 % significance*

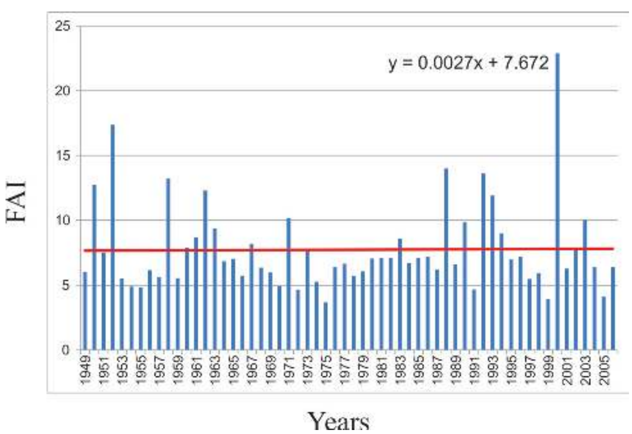

Figure 4: The mean annual values of the forestry aridity index, *FAI*, and linear trend curve of aridity from 1949 to 2006 in Vojvodina

ment is true. As the computed *p*-value in (2) is greater than the significance level (α=5%), one cannot reject the null hypothesis, H_0 (*there is no trend*). The risk to reject H_0 while it is true is 77.8%.

Taking into account Equation (2), its coefficients of linear regression, and the MK test result, it can be concluded that the trend of the *FAI* is negligibly small, recording almost the value of zero, showcasing that there are basically no trends. Viewing the *FAI* in this way, it seems that there is no change in aridity in Vojvodina from 1949 to 2006. In [19] very similar results of the aridity trends for De Martonne aridity and Pinna combinative indices for the territory of Vojvodina in the same period from 1949 to 2006 were obtained. It seems that aridity trend in Vojvodina really did not change in the long interval of 58 years, which is opposite to trends in temperature [43, 44], precipitation [45], and hail [63], which are very variable. Very similar results of aridity trends have been obtained for the rest of Serbia's territory; for Kosovo and Metohija [20] and Central Serbia [21], where it is also found that there is no trend.

Thus, it seems that there is no aridity change in Serbia in this recent period, and perhaps this holds even wider in the Carpathian Basin. It is likely to be the consequence of the conservative nature of aridity, when compared to temperature and/or precipitation, that yields the mathematical definition of aridity as being the quotient/ratio between precipitation and some values of air humidity and temperature. As there is plenty of water on Earth, any increase in the temperature of the atmosphere, generally, causes humidity to rise in the atmosphere and vice versa. That is why aridity is a less variable parameter of climate than the others. In general, it seems that greater conservative nature of aridity provides a greater reliability in its calculation, in the assessment of climate and environmental change.

3.3 Correlation

Correlation coefficients between the NAO and ENSO indices, and the *FAI* were determined in order to investigate the possible relationships between forest aridity and atmospheric variability. Results are shown in Tables 3 and 4. The correlation between the *FAI* and the NAO index is significant (at a 90% and 99% level of significance) only in winter. Stations like Bela Crkva, Kikinda, and Rimski Šančevi have significant correlation with values varying between 0.21 and 0.25 at the 90% level of significance, while meteorological station Senta has a significant correlation of 0.33 at the 99% level of significance. On the other hand, no significant correlations were observed between

Table 4: Seasonal and annual correlation coefficients (*Cors.*) with *p*-values (*pvs*) between *FAI* and ENSO

Meteorological Station and region	Winter NINO3		Spring NINO3		Summer NINO3		Autumn NINO3		Annual NINO3	
	pvs	*Cors.*	*pvs*	*Cors.*	*pvs*	*Cors.*	*pvs*	*Cors.*	*pvs*	*Cors.*
Bački Petrovac	0.79	−0.35	0.90	−0.02	0.32	−0.13	0.50	−0.09	0.47	−0.09
Bela Crkva	0.87	−0.02	0.65	0.06	0.23	−0.15	0.41	−0.11	0.48	−0.09
Jaša Tomić	0.75	0.04	0.70	0.04	0.32	−0.13	0.54	−0.08	0.66	−0.06
Kikinda	0.4	0.11	0.19	0.17	0.65	−0.06	0.50	−0.08	0.96	0.01
Palić	0.46	0.10	0.57	0.07	0.30	−0.14	0.35	−0.12	0.63	−0.06
Rimski Šančevi	0.90	0.02	0.80	−0.03	0.22	−0.16	0.31	−0.13	0.36	−0.12
Senta	0.20	0.17	0.14	0.19	0.33	−0.13	0.32	−0.13	0.86	−0.02
Sombor	0.92	−0.01	0.70	−0.05	0.19	−0.17	0.39	−0.11	0.34	−0.13
Sremska Mitrovica	0.25	−0.15	0.48	−0.09	0.40	−0.11	0.54	−0.08	0.31	−0.13
Vršac	0.83	0.03	0.81	−0.03	0.16	−0.19	0.22	−0.16	0.27	−0.14
Vojvodina	0.86	0.02	0.78	0.04	0.23	−0.15	0.35	−0.12	0.47	−0.10

the ENSO and *FAI*, thus generally indicating the absence of strong linearity between the *FAI*, and the NAO and ENSO.

4 Conclusion

With the help of the *FAI*, we are able to classify the average climate of a particular small area, or even a region, from a forestry viewpoint. For the territory of Vojvodina, which is situated in the southeastern part of the Pannonian Basin, with its rich and widespread loess and loess-like sediments, aridity was investigated from 1949 to 2006. For this entire period, all the temperature and precipitation data was available for 10 meteorological stations that were evenly distributed throughout Vojvodina. Meteorological data was used to determine the forestry aridity index, *FAI*, as the most suitable for the description of aridity and climate in Vojvodina as a forest area. The values of *FAI* have been calculated for the entire recent period and six deccenial periods.

Of the four types of climate that the *FAI* recognizes, there are two types: the sessile oak (Quercus petraea) / Turkey oak climate and the forest-steppe climate, over the course of 58 years; and in the decades periods there are three types of climate, which all together can be considered to be significant climate diversity for a relatively small territory such as Vojvodina. *FAI* climatic diversity might have shown more varied values if there were meteorological data for mountainous locations in Fruška Gora Mountain and Vršac Mountain, both of which are very rich in forests. On the other hand, there is a significant overlap of the southeast part of Vojvodina as the area with the richest forests (20%) and low *FAI* values. This seems to indicate that the *FAI* can be considered as a good indicator of climate interaction and forest vegetation.

The *FAI* aridity trend was calculated and tested recently, over a period of 58 years. The conclusion is clear: there is no detectable aridity trend, confirming the results of the aridity trends for the De Martonne and Pinna aridity indices, for the same territory and time period. The similar behavior of aridity trends were present in the rest of Serbia; in the territories of Central Serbia as well as Kosovo and Metohija, between 1949–2015. Unlike the temperature and the precipitation, which show variability of trends, aridity does not show any change in trend. Therefore, aridity can be considered a stable climate parameter and indicator, which should be used more frequently in the interpretation of climate change, in order to avoid any hasty conclusions.

As the correlation coefficients calculated between the *FAI*, the NAO, and the ENSO very small, one can see that these two large-scale processes of climate variability do not have any significant influence on the *FAI*.

Similar stable semi-arid conditions have been discovered to have occurred in the Late Pleistocene paleoclimatic and paleoenvironmental records in the region of Vojvodina [72]. The last glacial loess snail fauna in the investigated area, which is characterized by a complete absence of any cold-resistant species, suggests a stable, dry, and relatively warm glacial summer climate, when compared to other European loess provinces [35, 73–75]. Two independent, environmental pieces of evidence from this loess-paleosol section, novel n-alkane biomarkers and traditional land snail assemblages, independently confirm a relatively stable paleoenvironment during the past 150 kyr. One characterized by the continuous dominance of grassland vegetation, with periodic intervals involving forest elements [72]. Using stable carbon isotopes (δ13C) of organic matter in reconstructing Quaternary climate variability based on loess are widely used methods and the most important factors controlling the isotopic signal in soils and sediments implying the changes in the photosynthetic pathway (shifts from C3 to C4 vegetation), physiological water stress, and changes in the atmospheric CO_2 concentration. On the other hand, the isotopic signature of vegetation provides information on photosynthetic pathways (C3 versus C4) and, thus, on environmental changes that are a prelude to the replacement of one vegetation type by another. Nevertheless, and in contrast to all European loess sequences that were recorded along the last climatic cycle with large C3 plant dominance, the organic δ13C record of the Surduk section was, until now, only a glacial record with evidence of several arid periods associated with the presence of C4 plants [76, 77].

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