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APPLICATIONS OF INFORMATICS IN ENVIRONMENT ENGINEERING AND MEDICINE

Editors:
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Olgierd Hryniewicz

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CHAPTER 2

Mathematical Modeling in Environment Engineering

IDENTIFICATION OF MONTHLY PRECIPITATION PATTERNS IN POLAND BY MEANS OF SELF-ORGANIZING FEATURE MAPS[1]

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Identification of monthly precipitation patterns is an importance issue for climate studies. It is also necessary for development of rainfall erosivity factor annual distribution curves. Establishing of monthly precipitation distributions for different Polish gauging stations by means of Self-Organizing Feature Maps (SOFM) was the first study aim. The attempt to use SOFM for classification of analyzed stations into typical precipitation regions was the second study aim. The research was based on database consisted of monthly precipitation totals from years 1961-1980 for a total number of 103 gauging stations located in the whole country. For needs of local monthly precipitation patterns identification SOFM networks of simple architecture 12:12-4:1 were used. Additional SOFM network of 12:12-10:1 architecture was developed for classification of local average monthly precipitation patterns into 10 separate classes. SFOM networks proved to be useful for calculation of average monthly precipitation distributions on the network of gauging stations. It was observed that implementation of SFOMs instead simple average value calculation made the data processing less sensitive for extreme events. Also topological map developed for classification of analyzed gauging station with respect to their previously calculated average monthly precipitation distributions into precipitation regions performed well. It was able to divide logically stations into groups of similar precipitation patterns having an explanation in local climate conditions. Moreover the arrangement of topological map nodes was generally clear and understandable due to neighbourhood of identified precipitation regions. All this suggests that SFOM networks could find practical implementations for climate precipitation studies, optimization of the gauging station networks and development of R-factor annual distributions in Poland.

Keywords: Identification, monthly precipitation pattern, rainfall erosivity factor, Self-Organizing Feature Maps.

1. Introduction

Identification of precipitation patterns has a significant importance for our understanding of climatic parameters controlling biological life of our planet. Since

[1] Project of the Ministra of Scence and Information Society Technologies No. 3P04G08425.

the water inflow in a form of liquid or solid precipitation is one of the most important controlling factors of plants growth, identification of precipitation patterns at different time and spatial scales was urged primary by the needs of agriculture production intensification. Precipitation measurements were undertaken as a first step to realize this aim. According to Arthastr's manuscript early measurements of precipitation by means of simple raingauge were undertaken more or less 400 B.C. for needs of proper rice planting planning. In Europe simple raingauges were constructed and introduced into practice in the XVII century. In Poland first raingauge was installed probably in Wrocław and was a part of the first international meteorological network, called Florence's network, established in 1654 (Licznar, et al. 2005).

Presently precipitation characteristics are being measured permanently on a network of gauging stations aided by the radar and remote sensing techniques. It supplies us with the vast of information that needs to be properly processed and analyzed (Licznar et al. 2005). Until know a wide range of techniques mostly based on simple statistical methods was introduced for needs of precipitation patterns identification at different time and spatial scales. However in some cases statistical data processing with the use of simple static tools as: average, mean, standard deviation, etc. proved to be unsatisfactory and extremely sensitive for improper data inputs. At the same time advances at the field of modern computing techniques and their wide implementations in user-friendly computer software give the possibility for amelioration of precipitation data processing.

Monthly precipitation patterns recognition is one of the important goals of the Polish State Committee for Scientific Research Project 3P04G08425: "Geostatistical methods application for environmental monitoring data processing." Development of new updated isoerodents map of Poland based on monthly precipitation totals is foreseen as one of the final outcomes of the project. The isoerodents map has to be however associated with annual distributions of rainfall-runoff erosivity factor (R-factor). Wide introduction of USLE (Universal Soil Loss Equation) into soil conservation service in the USA was possible mainly after publishing by Wischmeier and Smith (1972; 1978) isoerodent map with the set of R-factor annual distributions for different precipitation regions. In Poland soil erosion by water USLE model prediction capability studies conducted by Licznar (2003) at the catchment scale proved the importance of annual R-factor distribution for proper phenomena modeling. The annual soil erosion yield was stronger determined by R-factor value monthly distribution then by its annual value. For years with small and moderate annual R-factor values big soil erosion yields were modeled and observed in the reality in case of strong erosive rainfalls concentration during months of weak soil cover by crops, like: April, September or October.

It was assumed that recognition of annual R-factor distributions in Poland should be followed by identification of monthly precipitation distributions for a network of meteorological stations and delineation of typical precipitation regions. This assumption was made on the basis of the fact, that there was observed good relation between monthly precipitation totals and R-factor values (Licznar, 2004a; 2004b; 2005a; 2005b). To some precision rainfall erosivity factor value can be even estimated on the base of the sole annual precipitation total and its monthly distribution according to Fournier's formula (Licznar, 2003; Renard and Freimund, 1994):

$$R_r = \sum_{i=1}^{12} \frac{p_i^2}{P}$$

where:

R_r – annual rainfall erosivity factor value [$MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$],
p_i – precipitation total for the i-th month of the year [mm],
P – annual precipitation total [mm].

This study had two main aims. Establishing of monthly precipitation distributions for different gauging stations by means of Self-Organizing Feature Maps (SOFM) was the first of them. The attempt to use SOFM for classification of analyzed gauging station with respect to their previously calculated monthly precipitation distributions into typical precipitation regions was the second study aim.

2. Material and methods

Database consisted of monthly precipitation totals from years 1961-1980 for a total number of 103 gauging stations in Poland was used as the base for the study. Stations were selected to cover the whole country with the quite smooth distribution. A bigger density of stations was taken into consideration only for mountainous areas of the south Poland since the orography effect usually contributes to precipitation pattern complication. The database in question was prepared at the frame of previously mentioned project no. 3P04G08425 in order to develop the new updated isoerodents map of Poland. Names of the stations present at the database with their brief localization characteristics: geographical coordinates and elevation above see level can be found at table 1.

Since the study was dedicated to exploratory precipitation data analysis it was decided to use Self Organizing Feature Map (SOFM), often called Kohonen networks. SOFM networks are designed primarily for unsupervised learning during which they can learn to recognize clusters of data, and can also relate similar classes to each other. It allows for build up an understanding of the data, which is used to refine the network. Moreover as classes of data are recognized, they can be labeled, so that the SOFM network becomes capable of classification tasks.

The architecture of SOFM networks is inspired by some known properties of the human brain. The cerebral cortex is actually a large flat sheet with known topological properties (for example, the area corresponding to the hand is next to the arm, and a distorted human frame can be topologically mapped out in two dimensions on its surface) (STATISTICA Elect. Man.). A SOFM networks have only two layers: the input layer, and an output layer of radial units (also known as the topological map layer). The units in the topological map layer are laid out in space - typically in two dimensions (Tadeusiewicz, 1993; Osowski, 2000).

The above mentioned SOFM networks unsupervised learning is executed using an iterative algorithm. Starting with an initially-random set of radial centers, the algorithm gradually adjusts them to reflect the clustering of the training data. At the same time the iterative training procedure arranges the network so that units representing centers close together in the input space are also situated close together on the topological map. For all SOFMs developed for the study simple and popular Kohonen training algorithm was used. This basic iterative algorithm runs through a number of epochs, on each epoch executing each training case and applying the following algorithm (STATISTICA Elect. Man.):

- Select the winning neuron (the one who's center is nearest to the input case);
- Adjust the winning neuron to be more like the input case (a weighted sum of the old neuron center and the training case).

The Kohonen algorithm uses a time-decaying learning rate. At the beginning the network develops only a crude topological ordering, with similar cases activating clumps of neurons in the topological map. As epochs pass the learning rate and neighborhood both decrease, so that finer distinctions within areas of the map can be drawn, ultimately resulting in fine-tuning of individual neurons. Very often, as it was made in case of this study, training is conducted in two distinct phases: a relatively short phase with high learning rates and neighborhood, and a long phase with low learning rate and zero or near-zero neighborhood (STATISTICA Elect. Man.). More detailed information concerning SOFM networks, their training algorithms and fields of possible practical introduction can be found in the following sources: Tadeusiewicz (1993), Osowski (2000), STATISTICA Elect. Man.

Practically all computations for the study realization and SOFMs development were made with the use of Statistica 6,0 software and its Neural Networks application.

3. Results and discussion

For needs of the specific local monthly precipitation patterns identification for analyzed meteorological stations SOFMs of identical simple architecture 12:12-4:1, with 4 neurons in an output layer, were developed. As the input for them presented were 20 data vectors (from years 1961-1980) for each station, consisted of 12 following months' contributions into the annual precipitation total, calculated previously according to the formula:

$$x_i = \frac{p_i}{P}$$

where:

x_i – contribution of the i-th month of the year for annual precipitation total [-],

p_i – precipitation total for the i-th month of the year [mm],
P – annual precipitation total [mm].

An example of SOFM 12:12-4:1 architecture developed for Wrocław-Strachowice meteorological station is present on figure 1. Moreover on figure 1 presented is the graph showing monthly precipitation distribution curve developed by means of established SOFM (calculated on the base of all neurons weights vectors and their wins frequencies) versus the similar curve calculated as the statistical average. In general both curves are identical which was also the case for distributions developed for other 102 stations. However more detailed inspection of curves on figure 2 displays some exceptions concerning summer months. The biggest differences were observed for July when suggested according statistical average and SFOM method percent of annual total precipitation equaled to 15,4% and 12,8% respectively. It was probably due to the fact that in case of year 1980 measured precipitation total was equal to 251 mm and was close to the 50% of total annual precipitation for this year (570 mm). For other years precipitation totals in July were usually lower then 100 mm. This yielded in elevated value of 15,4% in annual distribution for this month. However discussed above anomaly did not influence strongly results from SFOM network. It suggests that results from SFOM method were characterizing better really natural mean local monthly precipitation pattern then calculated simple average.

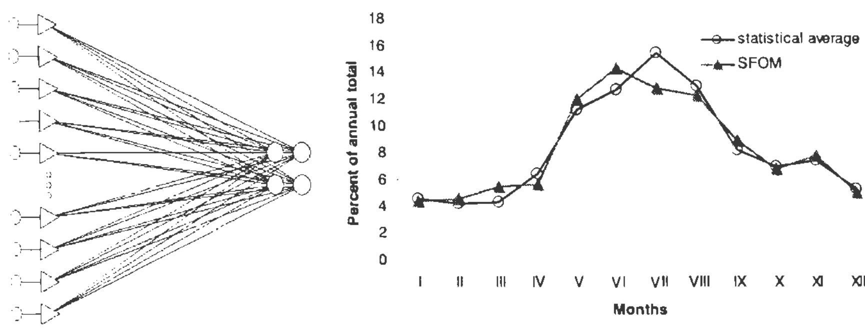

Figure 1. Constructed for Wrocław-Strachowice meteorological station SOFM 12:12-4:1 network architecture and monthly precipitation distribution curves developed by means of network and simple statistical average

Previously calculated local monthly precipitation distributions for 103 localizations were used for unsupervised learning of new SOFM network. This SOFM network of 12:12-10:1 architecture showed on figure 2 was designated for classification. The purpose of this network functioning was to assign each case of average local monthly precipitation pattern to one of 10 classes defined by output layer neurons weights vectors. The number of output layer neurons equal to 10 and their arrangement in 2 by 5 matrix at the final SOFM network were selected after other combinations of topological maps and their classification capabilities studies.

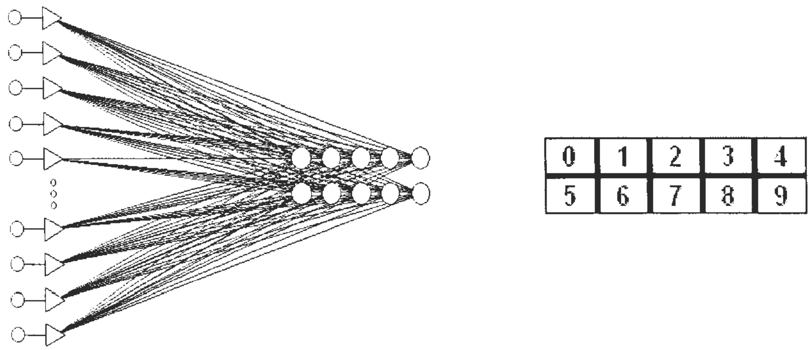

Figure 2. Developed for classification of gauging station into precipitation regions SOFM 12:12-10:1 network architecture and its topological map layer nodes numbers

In a SOFM network, the winning node in the topological map (output) layer is the one with the lowest activation level (which measures the distance of the input case from the point stored by the unit) (STATISTICA Elect. Man.). Classification of analyzed gauging stations according winning nodes (neurons) of topological group is presented at tables 1&2. Patterns of monthly precipitations represented by weights vectors of SFOM 12:12-10:1 network output layer neurons are showed on figures 1&2.

Analysis of the data present at table 1&2 leads to very interesting observations. For example gauging stations located on the western costal area of the Baltic See, like: Kołobrzeg, Koszalin, Łeba, Rozewie, Ustka and Lębork were put into one class, according to the winning neuron 9. Similarly stations from the area of eastern costal area were classified into other single class of winning neuron 4. Both classes had monthly precipitation distribution curves of quite similar shapes with low percent of annual precipitation in winter and spring months and high one in summer and autumn months. Especially high percent of annual precipitation in comparison to other neurons distributions was observed for months of October and November (at the range from 8,9% to 10,7%). This phenomenon can be naturally explained by the influence of marine climate and was already reported by other authors (Dębski, 1959). At the same time from the point of SFOM usability for precipitation patterns recognition and gauging stations classification analysis it is worth to mention that neurons 9 and 4 were neighbors at the right end of topological map. Observed here concept of topological map neurons neighborhood was also clear in case of next two nodes: 3 and 8. All the stations of Polish western border area, like: Gubin, Kostrzyń nad Odrą, Słubice, Zgorzelec, etc. were among class of wining neuron 3 being a neighbor of nodes 4 and 9. Stations located at the western part of Poland, however generally closer to the central part of the country, like: Poznań-Ławica, Piła, Leszno-Strzyżewice, etc. were in class of winning neuron 8. Stations located both close to the western border and the Baltic See cost, like: Świnoujście, Dziwnów and Szczecin-Dąbie were also found in discussed classes.

Table 1. Analyzed stations classified according to winning neurons 0÷3 of SOFM 12:12-10:1

Station	N	E	Elevation [m a.s.l.]	Station	N	E	Elevation [m a.s.l.]
Winning neuron 0							
Baborów	50°09'	18°00'	251	Kraków-Balice	50°05'	19°08'	237
Białobrzegi	51°39'	20°57'	119	Legnica	51°13'	16°10'	122
Bystrzyca Kłodzka	50° 18'	16°39'	365	Wrocław-Strachowice	51°06'	16°53'	120
Dobrogoszcz	50°46'	17°01'	175	Popiołówka	53°24'	23°07'	150
Głuchołazy	50°18'	17°23'	350	Porąbka	49°49'	19°13'	310
Grabowiec	51°06'	21°23'	210	Sulejów	51°21'	19°52'	188
Jelenia Góra	50°54'	15°48'	342	Szczucin	50°19'	21°04'	170
Kłodzko	50°26'	16°39'	316	Ochaby	49°51'	18°46'	270
Winning neuron 1							
Częstochowa	50°49'	19°06'	293	Sandomierz	50°42'	21°43'	217
Dubienka	51°03'	23°53'	179	Terespol	52°04'	23°37'	133
Jastrzębie-Zdrój	49°57'	18°34'	282	Turbacz	49°33'	20°07'	1240
Katowice	50°14'	19°02'	317	Włodawa	51°33'	23°33'	175
Kolbuszowa	50°14'	21°48'	204	Wysowa	49°26'	21°11'	517
Opole	50°40'	17°58'	176	Zawoja	49°37'	19°31'	670
Polanica Zdrój	50°24'	16°30'	385	Zwolaki	50°30'	22°20'	168
Racibórz	50°05'	18°13'	190				
Winning neuron 2							
Bydgoszcz	53°06'	17°58'	70	Mikołajki	53°47'	21°35'	127
Chojnice	53°42'	17°33'	172	Mława	53°06'	20°21'	147
Elbląg	54°10'	19°26'	38	Olsztyn-Dajtki	53°46'	20°25'	133
Kalisz	51°44'	18°05'	140	Radostowo	53°59'	18°45'	40
Kętrzyn	54°05'	21°22'	108	Suwałki	54°08'	22°57'	184
Kolo	52°12'	18°40'	116	Szelejewo	52°44'	17°45'	100
Łódź -Lublinek	51°44'	19°24'	187	Warszawa-Okęcie	52°09'	20°58'	106
Winning neuron 3							
Bogatynia	50°54'	14°59'	280	Szczecin-Dąbie	53°24'	14°37'	1
Gorzów Wielkopolski	52°44'	15°15'	72	Świeradów-Zdrój	50°54'	15°20'	543
Kostrzyn nad Odrą	52°35'	14°40'	15	Zielona Góra	51°56'	15°32'	180
Gubin	51°57'	14°46'	76	Słubice	52°21'	14°36'	21
Zgorzelec	51°08'	15°02'	203				

Table 2. Analyzed stations classified according to winning neurons 4÷9 of SOFM 12:12-10:1

Station	N	E	Elevation [m a.s.l.]	Station	N	E	Elevation [m a.s.l.]
Winning neuron 4							
Gdańsk-Wrzeszcz	54°23'	18°36'	13	Kościerzyna	54°08'	17°58'	190
Gorowo Iławieckie	54°17'	20°30'	130	Rudzienice	53°38'	19°40'	102
				Hel	54°36'	18°49'	1
Winning neuron 5							
Brzegi Dolne	49°27'	22°37'	438	Rzeszów-Jasionka	50°06'	22°03'	200
Lesko	49°28'	22°20'	386				
Limanowa	49°42'	20°26'	414	Stróża	49°48'	19°56'	307
Nowy Sącz	49°37'	20°42'	292	Tarnów	50°02'	20°59'	209
Piwniczna	49°26'	20°42'	379	Zakopane	49°18'	19-57'	857
Przemyśl	49°48'	22°46'	279	Zamość	50°42'	23°15'	212
Winning neuron 6							
Białowieża	52°42'	23°51'	164	Płock-Radziwie	52°32'	19°40'	63
Białystok	53°06'	23 10'	148	Puławy	51°25'	21°58'	142
Lublin	51°14'	22°34'	238	Siedlce	52°11'	22°16'	146
Mieroszów	50°40'	16°11'	510	Wieluń	51°13'	18°35'	195
Ostrołęka	53°05'	21°34'	95	Wińsko	51°28'	16°37'	180
Winning neuron 7							
Bełżec	50°23'	23°26'	266	Piekło	49°31'	19°00'	605
Kasprowy Wierch	49° 14'	19°59'	1991	Skrzyczne	49°41'	19°02'	1230
Kielce	50°51'	20°37'	268	Śnieżka	50°44'	15°44'	1603
Międzylesie	50°09'	16°40'	440	Wetlina	49°09'	22°27'	700
Winning neuron 8							
Choszczno	53°10'	15°25'	55	Poznań-Ławica	52°25'	16°50'	86
Dziwnów	54°01'	14°44'	7	Resko	53°46'	15°25'	52
Gorzyń	52°34'	15°54'	65	Szczecinek	53°43'	16°41'	137
Leszno-Strzyżewice	51°50'	16°32'	90	Świnoujście	53°55'	14°14'	6
				Piła	53°08'	16°45'	72
Winning neuron 9							
Kołobrzeg	54°15'	15°35'	3	Łeba	54°45'	17°32'	2
Koszalin	54°12'	16°09'	33	Rozewie	54°50'	18°20'	54
Lębork	54°33'	17°45'	17	Ustka	54°35'	16°52'	6

It confirms the proper recognition of neighborhood by developed SOFM network. At the same time precipitation distributions for western regions were visually different from other ones. Low percent of annual precipitation in July (only 10,5%) was especially visible in case of winning neuron 3 curve. Delineation of separate precipitation regions for western part of Poland is also in a good agreement with previous climate studies proving the visible influence of the Atlantic Ocean for this country area local climate conditions (Dębski, 1959). Among locations of winning neuron 2 class were stations of central Poland, like: Kalisz, Łódź-Lublinek, Warszawa-Okęcie, Bydgoszcz, etc. Also in this case geographical neighborhood with previously discussed regions was in good agreement with topological map arrangement.

Above mentioned clear arrangement of topological map was not so visible in case of its left side nodes. Almost all stations in class of winning neuron 7, with exceptions of Kielce and Bełżec were located in high mountains or even on their tops, like: Kasprowy Wierch, Śnieżka. The elevations of stations were high, at the range of 440-1991 m a.s.l. (with exception of Kielce and Bełżec, 268 and 266 m a.s.l. respectively). Probably the precipitation pattern for this group was mainly determined by the orography effect. Very characteristic was high share of winter and early spring precipitation in the annual total. Percent of total annual precipitation for months from January to March was at the range from 6,2% to 6,5%. Other stations from mountains areas, however located mostly in the valleys, not on the hilltops, like for example: Zakopane, Nowy Sącz, Limanowa, etc. were classified to another class of winning neuron 5. Elevations of this class stations were much lower at range from 200 m to 857 m a.s.l. The shape of their average monthly precipitation distribution was very distinctive because of high accumulation of rainfalls during months of June and July: 15,4% and 14,9% of annual total respectively. Located between nodes 7 and 5 neuron 6 was assigned to the group of stations mainly from the area of eastern border of Poland. Gauging stations from other geographical locations: Mieroszów, Płock-Radziwie, Wieluń and Wińsko were classified to this group probably accidentally. Precipitation pattern of this border region was probably resulting from the influence of eastern continental climate and almost ideally equal percent of precipitation was observed in summer months of June, July and August: (12,4%; 12,5% and 12,5% respectively).

Interpretation of stations' lists obtained for wining neurons 0 and 1 can lead to some confusion. Gauging stations in both lists are somehow mixed together and SOFM functioning seems to be out of the order. Existence of station Polanica Zdrój at the class of winning neuron 1 and closely located and situated on the comparable elevations stations: Kłodzko and Bystrzyca Kłodzka at the class of winning neuron 0 is a good example of it. This phenomenon can be however at least partly explained after examination of precipitation distribution curves of both classes. They are very similar and probably both classes should be consider as the one joined precipitation region of the southern Poland, covering areas of highlands and low mountains. This is somehow confirmed by the close neighborhood of nodes 0 and 1 on the topological map.

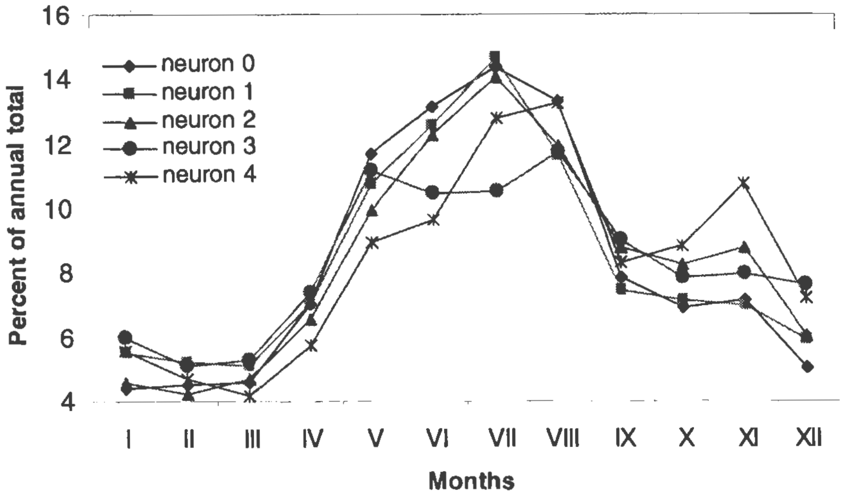

Figure 3. Monthly precipitation distribution curves for wining neurons 0÷4 of SOFM 12:12-10:1

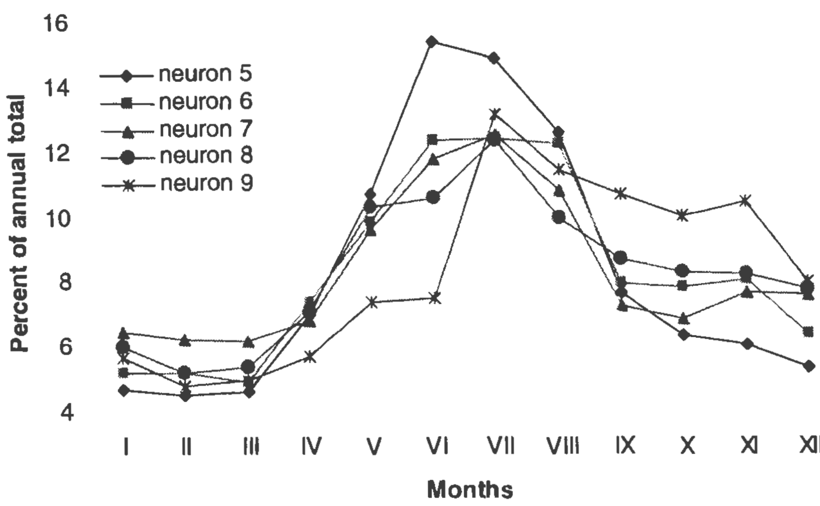

Figure 4. Monthly precipitation distribution curves for wining neurons 5÷9 of SOFM 12:12-10:1

4. Conclusions

On the base of conducted research based on the monthly precipitation totals from years 1961-1980 from 103 gauging stations in Poland the following conclusions were formulated:

1) SFOM network of very simple architecture can be practically used for calculation of average monthly precipitation distributions for specific location on the base of archive records. Implementation of SFOM networks instead simple average value calculation makes the data processing less sensitive for extreme events.

2) SFOM network can be also used for classification of analyzed gauging station with respect to their previously calculated average monthly precipitation distributions into precipitation regions. Developed topological map was able to divide logically stations into groups of similar precipitation patterns. Proposed classification seemed to have an explanation in local climate conditions. Also the arrangement of topological map nodes was generally clear and had an understandable explanation in neighborhood of identified precipitation regions. This suggests that SFOM networks could find practical implementations for climate precipitation studies, optimization of the gauging station networks and development of R-factor annual distributions in Poland.

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(Editors)

APPLICATIONS OF INFORMATICS IN ENVIRONMENT ENGINEERING AND MEDICINE

The purpose of the present publication is to popularize applications of informatics in environment and health engineering and protection. Runned papers are thematically chosen from the works presented during the conference *Multiaccessible Computer Systems* (*Komputerowe Systemy Wielodostępne*) that has been organized by the Systems Research Institute and University of Technology and Agriculture of Bydgoszcz for several years in Ciechocinek. Problems described in the papers concern quality management of the surface waters and the atmosphere, application of the mathematical modelling in environmental engineering, and development of computer systems in health and environmental protection. In several papers results of the research projects financed by the Polish Ministry of Science and Information Society Technologies are presented.

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