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ARIMA MODELLING OF ANNUAL RAINFALLS IN THE BREGALNICA RIVER BASIN

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A b s t r a c t: Changes in the hydrological characteristics have an impact on the environment. The reasons for negative impacts in the Bregalnica River basin are heavy rains and long droughts. Monitoring the understanding of hydrological impacts may provide useful assessment and forecast in several fields such as geology, mining, agriculture, civil engineering and management of water resources.

This paper is an analysis of hydrological processes (rainfalls) witch define the conditions for their occurrecne. The paper offers data processing of the monitoring.

Data visualization of hydrological processes of the basin makes possible assessment and forecast. Statistical models were applied to analyze time series of rainfalls.

The ARIMA modelling of the STATISTICA packet was used to analyze data for annual rainfalls. ARIMA models are good techniques for estimation forecast of the hydrological characteristics of the environment.

The models for analysis and forecast can be used in various fields (industry, investigation, production and monitoring). All we need is long time series of data.

Key words: rainfalls; forecast; ARIMA models

INTRODUCTION

The latest achievements in science are widely used in the study and modelling of hydrological events.

Over the past hydrology as a science followed the development of water supplied systems. Needs for water increase every day, whereas water and the environments are becoming contaminated. The need for clean water has increased, whereas its resources are in constant decrease.

Hence, the necessity of scientific approach in solving hydrological issues has become inevitable.

Planning and management of water resources require measurement of data. Many countries, including our country as well, have established nets of hydro-meteorological stations in which climatic and hydrological parameters are measured. The quality of forecast depends on the accuracy of measurements and length of the observation period. The Republic of Macedonia possesses data for hydrological parameters for a period of 35 to 40 years.

Hydrological process (HP) is a complex function (F) that depends on several parameters and can generally be expressed as:

$$HP = F(x, y, z, t, S_p, K_p, I_p), \qquad (1)$$

where:

x, y, z are coordinates;
T is the time;
S_P are parameters of environment;
K_P is climatic parameters;
I_P are infrastructure parameters.

The large number of parameters and their interdependence in describing of hydrological processes during modelling necessitates parameter stochastic model.

Up to date information hardware and software make possible successful analysis of such complex models.

The goal of this paper is the selection of adequate approach to define hydrologic models for the Bregalnica River basin.

Assessment of the quality of hydrological data, analysis of hydrological systems were used to define their components. Modelling of hydrological processes with right assessment of the parameters was carried out in order to obtain hydrological models.

Several authors point out that the deterministic and stochastic models forecast hydrological processes better e.g. rainfalls, water flows, runoff, temperature, evaporation, infiltration, index of droughts and prediction of future flows.

The paper explains ARIMA models used in the study and creation of descriptive model of rainfall in the river basin shown as annual rainfalls. These processes have been selected because they are measured and data are abundant. Time discrimination of one year, which is average of the hydrologic process, is regarded as optimal.

RAINFALLS

The Bregalnica River basin occupies an of 4270 km^2 in the eastern part of the Republic of Macedonia between 41° 30' and 42° 00' NGL and 21° 45' and 23° 00' EGL. The terrain is mostly mountainous except for the valleys of the Bregalnica, Zletovska, Kriva Lakavica, Kočani field and Ovče Pole. The Delčevo–Pehčevo valley with N/S strike is also part of the area.

The net of hydrological stations in the river basin consists of:

– the main hydro-meteorological station (Štip and Berovo);

– the climatological station (Kočani and Delčevo);

– rainfall measurement station (St. Nikole, Vinica, Probištip, Lesnovo, Zletovo, Puzderci, Nivičani, Sokolarci, Erdželija, G. Trogerci, D. Balvan, Ularci, Teranci, Radanje, Zrnovčki, N. Selo, Dolani, Dragoevo, Sasavarlija, Lakavica, Kosbunar, Kosevo, Parnalija, Piperovo, Dedino, Istibanja, Grljani, Grad, Blatec, Laki, Razlovci, Mirasinci, Pehčevo, Vladimirovo, Radanje and Miravci).

According to programs for operation the hydro meteorological stations are divided into:

– main synoptic station;
– main climatologic station;
– main agro-meteorological station;
– station for air quality;
– special station etc.

Hydro-meteorological stations monitor and measure:

– present and past time;
– atmospheric pressure;
– pressure and its characteristics;
– min. and max. temperature;
– air temperature;
– min. temperature at 5 cm;
– air humidity and soil moisture;
– direction, speed and strength of wind;
– cloudiness – amount, kind and height;
– visibility;
– soil condition;
– duration of sunshine;
– soil temperature at different depths;
– evaporation of water surface and land;
– intensity, duration and a mount of rainfalls;
– snow cover;
– phonologic observation:
– special occurrences.

Figure 1 presents a hydro-meteorological station in the Bregalnica River basin.

Of special importance is the quantity of annual precipitation (mm). The main hydro-meteorological and rainfall measurement stations provided the following results.

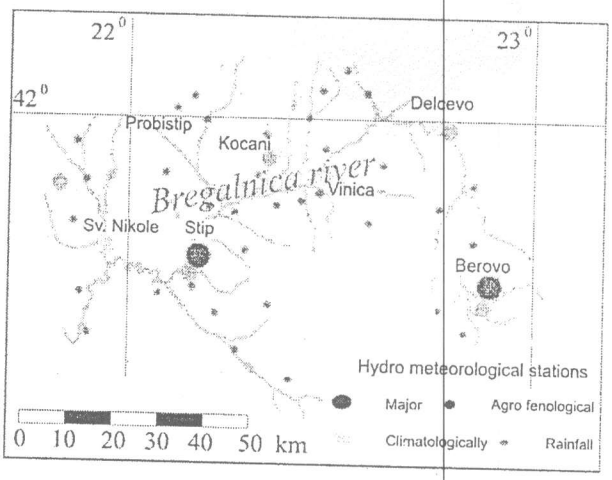

Fig. 1. Hydro meteorological stations in the Bregalnica River basin

Data presented in the Table 1 help created model for the total annual rainfalls in the river basin shown in the Figure 2.

Table 1

Annual rainfalls (mm) obtained by 40 rainfall measurement stations summarized and classified according to the position in the basin

Year	Annual rainfall (mm) in different parts in Bregalnica River basin						
	St. Nikole	Štip	Probištip	Kočani	Vinica	Delčevo	Berovo
1961	354.9	352.2		384.4			452.1
1962	655.5	641.0		692.8			822.3
1963	539.6	487.3		553.5			718.5
1964	468.8	529.3		560.7			642.5
1965	352.4	460.5		529.2			559.2
1966	378.6	477.2		560.6		621.1	664.7
1967	313.0	439.7		506.2		525.8	543.9
1968	458.6	513.6		448.1	402.0	558.4	571.8
1969	398.0	365.5	645.4	476.0	337.5	594.7	498.9
1970	402.9	422.4	636.9	545.3	237.8	602.4	498.1
1971	319.2	472.8	428.9	360.4	80.8	361.1	537.5
1972	591.6	596.8	778.4	609.2	281.7	544.1	630.8
1973	366.2	316.5	485.5	419.9	173.4	413.0	466.8
1974	513.2	726.0	682.4	492.6	203.5	624.1	648.8
1975	434.3	513.8	638.0	560.8	287.5	596.9	565.6
1976	494.2	440.4	762.9	589.4	406.3	637.9	593.5
1977	265.0	301.2	501.5	429.9	191.5	458.2	446.5
1978	484.3	364.5	675.6	509.3	211.9	650.9	686.8
1979	546.9	540.2	741.5	646.5	298.4	652.2	697.6
1980	556.4	537.8	869.4	546.9	457.7	546.2	766.3
1981	545.8	552.5	711.5	640.2	280.5	547.8	689.5
1982	507.4	392.7	570.8	517.8	427.0	506.2	634.5
1983	462.9	650.4	659.4	571.9	555.3	548.0	685.6
1984	456.9	365.3	468.3	436.8	349.3	348.1	477.1
1985	145.8	430.6	516.1	510.7	433.3	636.7	576.3
1986	288.1	327.9	457.6	285.8	266.3	303.0	388.8
1987	379.1	474.7	664.6	447.5	427.6	619.2	657.0
1988	372.4	323.8	552.3	410.0	399.7	473.2	520.2
1989	429.5	500.1	620.7	449.4	399.3	616.6	593.9
1990	256.6	295.1	452.0	426.6		439.1	460.1
1991	391.7	514.2	605.5	535.0		672.0	574.1
1992	312.5	366.4	442.7	330.8		387.2	431.2
1993	291.1	290.1	372.6	318.4		339.3	379.9
1994	312.6	315.9	451.1	356.5		407.5	486.2
1995	531.3	608.9	816.6	707.9			728.0

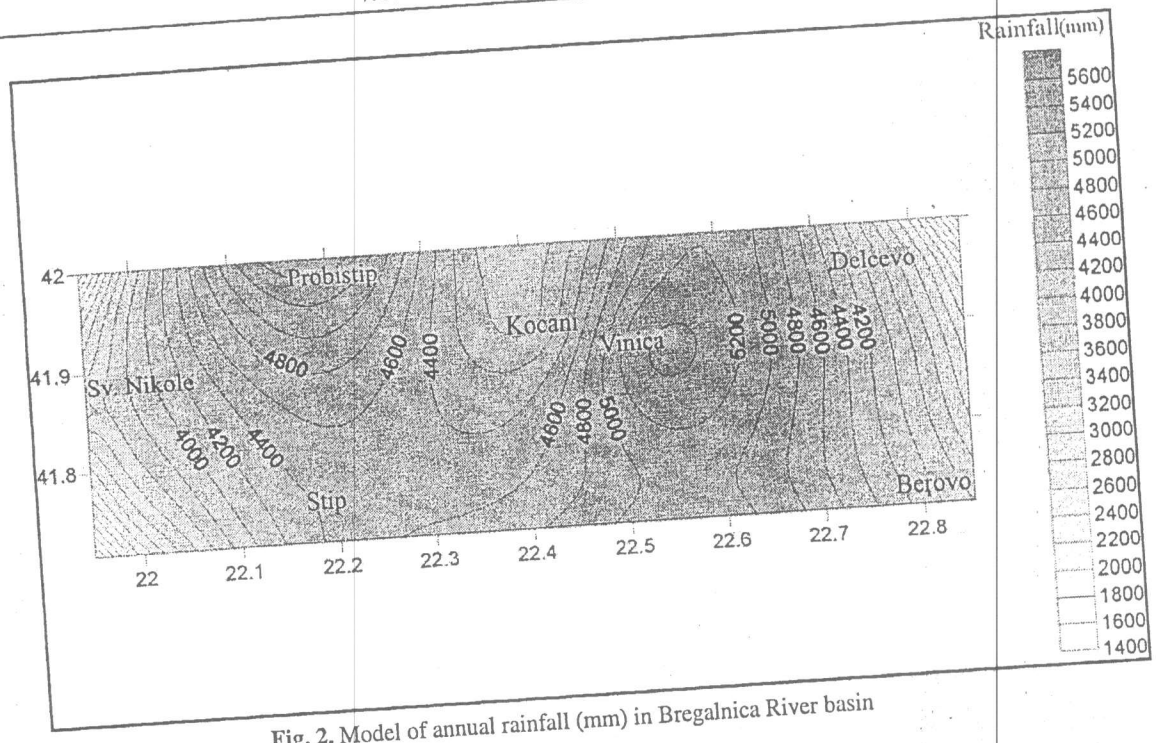

Fig. 2. Model of annual rainfall (mm) in Bregalnica River basin

ARIMA

ARIMA model is used to determine the data of hydrological processes obtained by analysis of historical series of data. ARIMA methodology was developed by Box and Jenkins (1976). It was widely used in research and justified its use and adaptability (Hoff, Pankrac, Vandaele, 1983). ARIMA is a complex technique, not easy to use, requires experience and offers good results that depend on the level of research skills (Baills and Paper, 1982).

The original projection for ARIMA time series modelling based on Box-Jenkins strategy is used in varies situations. This makes it possible to obtain system for data analysis and decides a good model that provide answers to questions related to the data.

1. Data preparation involves transformation and differentiation.

Data transformation makes possible variance stabilization in the series where there are changes. Then, data are differentiated until the model eliminates the trend and seasoning. Differentiation means defining of differences between observations of series or between observations for each year separately. Data differentiated are the easies way for original data modelling.

2. The selection of model is done with various diagrams based on transformed and differentiated data. They are used to determine the potential of ARIMA process used for data adjustment.

3. Change of parameters is a means which determines data models that make possible the best data adjustment.

4. Model check involves model testing in order to find the area where it does not meet the requirements. If we take that the model does not meet our needs, it is necessary to go two steps back and find a better model.

5. Sometimes the ultimate goal in data analysis is forecast. When a model is determined, assets and check as finale step in forecast can be made. This is often done with a computer.

FORECAST OF ANNUAL RAINFALLS IN THE BREGALNICA RIVER BASIN

ARIMA modelling is conducted with the single series ARIMA model used to carry out analysis and forecast time series and is part of statistical analysis of advanced linear and nonlinear models of STATISTICA software program. In this case the input series is series with annual rainfalls data (mm). Time series analysis with rainfall data as hydrological process in the river basin includes a

period of 36 years. Data for rainfalls for 365 days are editing and the average is estimated.

ARIMA modelling of time series and annual rainfalls consist of data presentation with annual rainfalls in the river basin.

Figure 4 is the total of annual rainfalls for the river basin for the same period.

Next step in ARIMA modelling is logarithmic transformation of the series $\ln(x)$ (Fig. 5).

The transformed series $\ln(x)$ is compared with original series or so called autocorrelation function (ACF) and used for estimation of standard error.

Figure 6 is autocorrelation function of time series $\ln(x)$ of rainfalls.

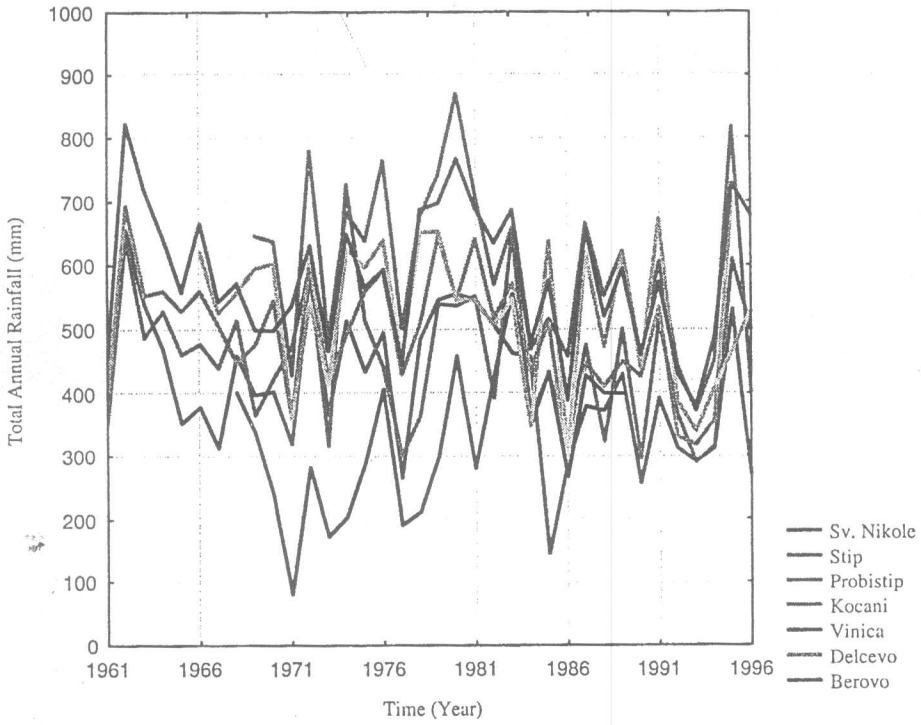

Fig. 3. Annual rainfalls from different parts in the Bregalnica River basin

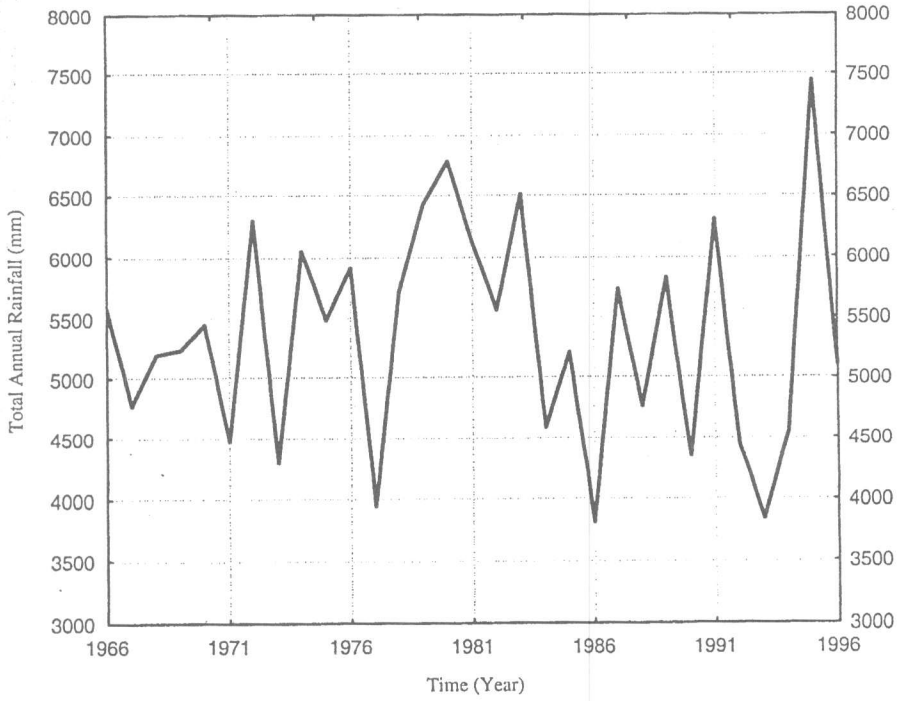

Fig. 4. Annual rainfalls in the Bregalnica River basin (summary)

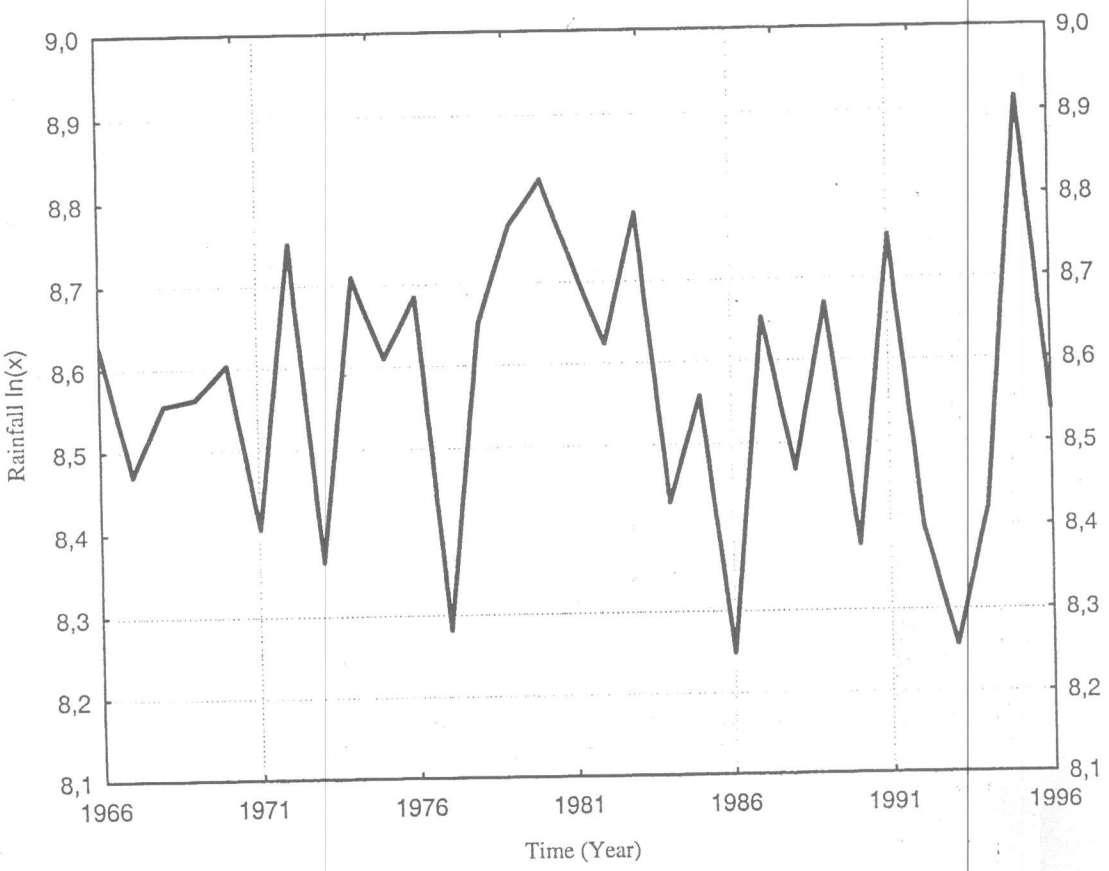

Fig. 5. Logarithmic transformation of input series

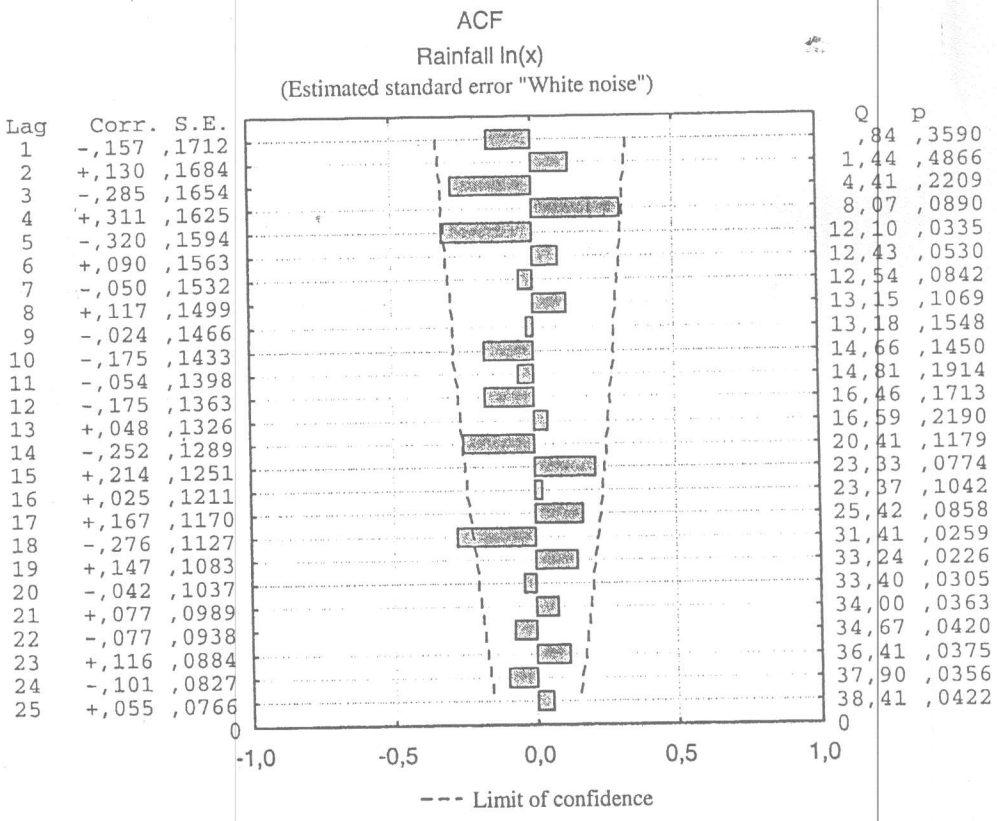

Fig. 6. Autocorrelation function (ACF) of annual rainfalls ln(x) and estimated standard error

Estimation and forecast are done based on data analysis with ARIMA models. Estimation of parameters is carried out with max increase of data probability giving advantage to parameter data.

Data obtained for estimation of ARIMA modelling parameters are shown in the Table 2.

Table 2 shows forecast until 2011. Data are given in Figure 9.

Table 2

Forecast of annual rainfalls (2007–2011)
ARIMA model: (0,1,1)(0,1,1); Season step: 10 (decade); Original series.

Year	Forecast	Lower limits	Upper limits
2007	6794,014	2343,542	19696,10
2008	3105,295	991,962	9720,99
2009	3708,246	864,396	15908,32
2010	6586,022	1400,526	30970,98
2011	3010,230	535,398	16924,77

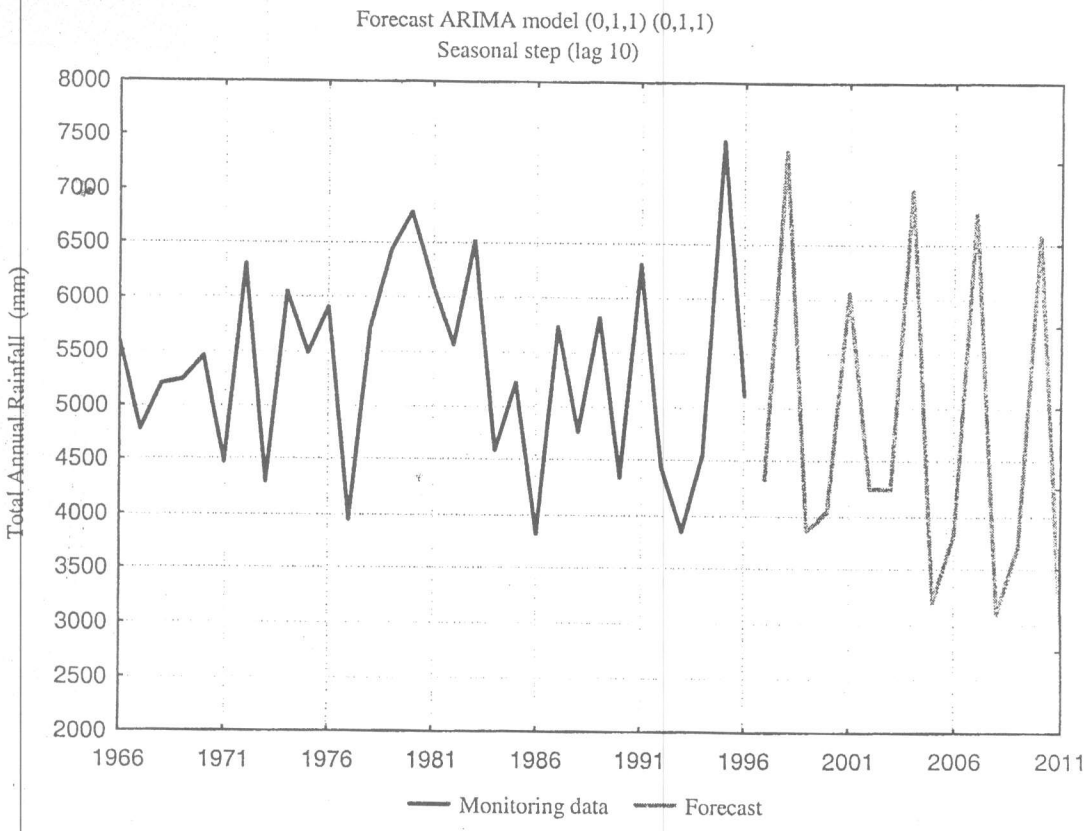

Fig. 9. Forecast of annual rainfalls until 2011 year

The diagram (histogram) of rainfalls indicates that the forecast model until 2001 year follows annual and decade changes as well. This is expected since accidental component with rainfalls is big. It can be concluded that the ARIMA model (0,1,1) (0,1,1) selected for modelling of annual series in the river basin fits well in to the hydrological process analyses.

Data made it possible to obtain a model for annual rainfalls in the river basin (Fig. 10).

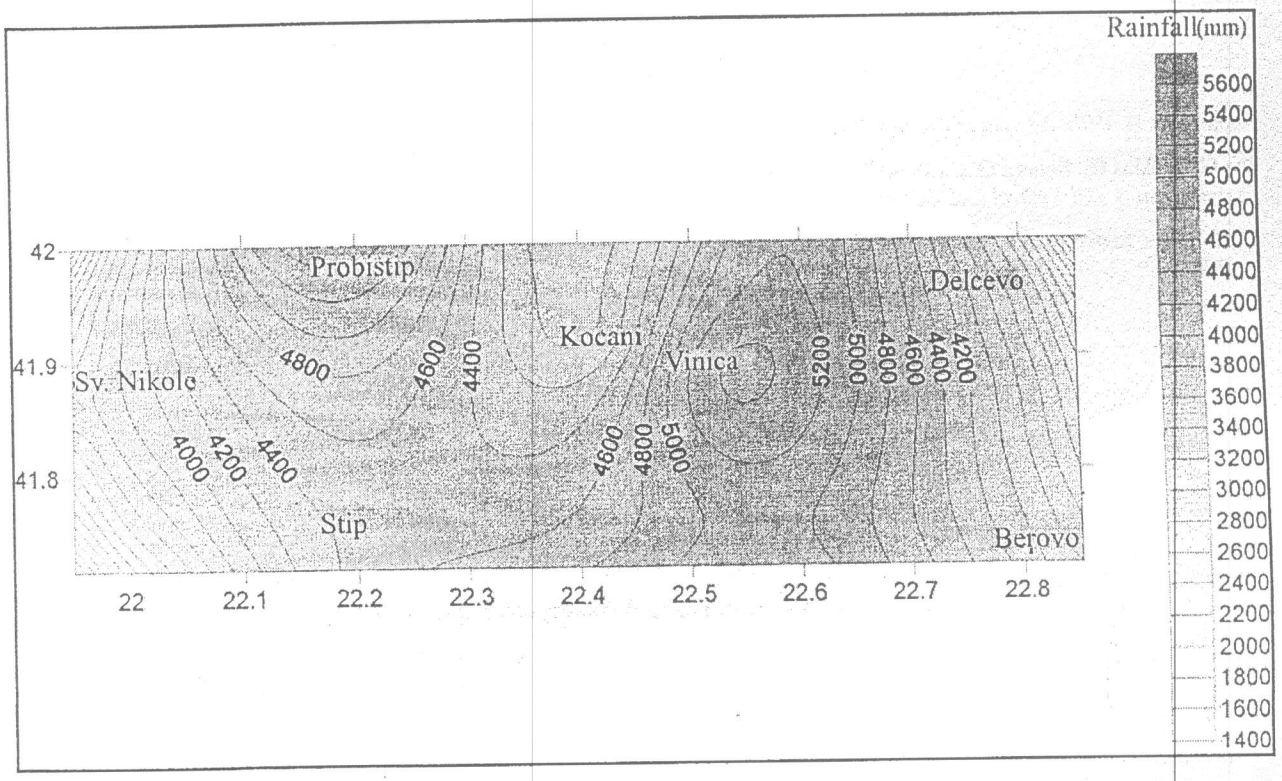

Fig. 10. Forecast model of annual rainfalls in the Bregalnica River basin until 2011

CONCLUSION

The processing of hydrological parameters is not based only on deterministic conclusions. The paper presents ARIMA models which are used for the study and creation of models for hydrological processes. The basic goal is study of the Bregalnica basin through non-seasonal ARIMA models of annual rainfalls for a period from 1961 to 1996. Data were used to create Box-Jenkins modelling with non-seasonal ARIMA models. Model selection was done with various diagrams based on transformed and differentiated data used to determine the ARIMA process.

Estimation of parameters made possible the determination of data model and better data adjustment.

Model check includes testing of model assumptions for possible determination of area where it does not meet the requirements. In places where the model did meet our needs, two steps back were necessary in order to define a better model.

The ultimate goal of data analysis with ARIMA models is to obtain a forecast model.

After determination, estimation and model check for each parameter as final step, forecast were carried out with a computer. In this case forecast for total annual rainfalls until 2001 was carried out.

The forecast model of hydrological parameters indicate that the ARIMA model selected (0,1,1)(0,1,1) for modelling of series of annual data in the Bregalnica basin adjusts best to hydrological processes analyzed. Forecast model until 2001 for the total rainfalls follows annual and decade changes the best. This was expected since accidental component with rainfalls is big.

Arima modelling of time series made possible data analysis of rainfalls and discovering a good model characterized by partial accuracy or knowing the probability of the hydrological process in fact we have a confidant result which is not totally accurate but can practically be used. All this provides a new quality which allows us to disregard formulas.

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Резиме

МОДЕЛИТЕ ARIMA ЗА ГОДИШНИТЕ ВРНЕЖИ ВО СЛИВНОТО ПОДРАЧЈЕ НА РЕКАТА БРЕГАЛНИЦА

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Промената на хидролошките карактеристики влијае на околната средина. Причини за проблемите во сливното подрачје на реката Брегалница се обилните дождови и долготрајните сушни периоди. Со следење и запознавање на хидролошките влијанија може да се даде корисна процена и прогноза во повеќе области (геологијата, рударството, земјоделството, градежништвото, менаџментот со водни ресурси).

Во овој труд е извршена анализа на хидролошките процеси (врнежи), при што се дефинираат условите за нивно настанување и се обработуваат податоците од набљудувањето.

Визуализацијата на податоците за хидролошките процеси во сливното подрачје на реката Брегалница овозможува процена и прогноза. Временските серии на врнежите се анализираат со стохастички модели.

Во овој труд е користен делот ARIMA од програмскиот пакет STATISTICA, кој врши анализа на податоците за годишните врнежи. Моделите ARIMA претставуваат корисна техника за процена и прогноза на хидролошките карактеристики на околната средина.

Моделите за анализа и прогноза можат да бидат применети во различни области (економијата, индустријата, истражувањето, производството, мониторингот). Единствено ни треба доволно долга временска низа со податоци.