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STATISTICAL MODEL OF THE INTENSITY OF THE RAINFALL IN SHUMEN REGION

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Abstract: *The report justifies the view that despite the apparent trend of warming and drought in recent years, there is an increasing frequency of extreme weather and climatic events (rainfall), which cause extensive damage to infrastructure and high costs to the economy and society. Therefore, to improve the performance and effectiveness of State bodies engaged in the prevention or eradication of harmful effects in emergency situations, it is necessary to make scientifically sound estimates of the frequency of intense precipitation over the next few years. Solving this important practical tasks is possible through the development of a statistical model of the intensity of the precipitation.*

Key words: *statistical model, floods, crisis situations*

Introduction

The dependence of humans from the natural environment and natural phenomena could be crucial for their existence, especially when watching the big deviations from the normal range of weather elements, especially temperature and rainfall. Therefore essential in the work of the organs of executive power is the rapid and timely response to heavy snowfalls, floods, earthquakes, landslides, fires and storms, which cause significant damage to commercial, residential and infrastructure.Some of them cover a significant area of the country, continue days, occurring repeatedly commit significant human, material and financial resources.

In this connection, the objectives of the report are:

1. To explore the tendency of increasing the number of days with intense rainfall for 1 year in Shumen region;
2. To justify measures to improve work of State bodies involved in the prevention or eradication of the harmful consequences of emergencies.

The report justifies the view that despite the apparent trend of warming and drought in recent years, there is an increasing frequency of extreme weather and climatic events (rainfall), which in combination with other factors – clogged river beds, inadequate care for the dams and sewage systems, cause flooding or crisis situations with significant material and financial damage, and sometimes human victims.

The hypothesis is justified by developing a statistical model of the intensity of rainfall for the period 2000 – 2012 on the territory of Shumen region.

Presentation

Floods are common natural disaster on the territory of the Republic of Bulgaria. They inflict massive damage, since populated areas, industrial areas and productive agricultural lands are affected. The reason for the floods is the intensity of precipitation, regardless of the status of the water flow in the river network. Torrential rainfall and outdated infrastructure of drainage systems have caused floods many times in the last decade.

In recent years, there is an increase of the frequency of extreme weather and climatic phenomena [2]:

- There is a significant increase in the average number of days with daily precipitation amounts over 100 mm-with about 30% in the period 1991-2007 compared to the base period 1961-1990;
- There is an increase of registered at the weather service cases with heavy rainfall;
- In recent years, there is a trend to frequent cases with typical spring-summer type convective cloudiness with showers of rain, thunderstorms and sometimes hailstorms during winter months such as January and February;
- There is an increased frequency of the average number of days with thunderstorms and hail in April and September 1961 -2006 in comparison to the same base period 1961 -1990.
- Annual amplitude between the maximum and minimum air temperature decreases-the minimum temperature is rising faster than the maximum.
- The snowy months in the mountains shorten and the thickness of the snow cover shows a sustained trend toward thinning.
- Phenology data observations show the overtaking in development with 7-15 days in different climatic regions, which unambiguously attests to the warming of the climate over the past 30 years, compared with previous periods.

According to the data of one of the Bulgarian insurance companies, applications for damage from heavy rain for the region of Shumen have risen for the past five years. According to the terms and conditions of the company, drenching (intense precipitation) is considered as dropping of large quantities of precipitation for a short time within the indicators in table 1.

Table 2 summarises the damage from intense rainfall for the area of Shumen according to data from an insurance company for the period: January 2008 – July 2013. It is apparent from the table that until mid -2013, the number of damages exceeds over 70% the maximum in 2010.

Table 1. Metrics indicating intense rainfall

Time (min.)	**Precipitation (l/sq.m.)**	**Time (min.)**	**Precipitation (l/sq.m.)**
5	2	35	9
10	4	40	10
15	6	50	11
20	8	60	12
Time (h)	**Precipitation (l/sq.m.)**	**Time (h)**	**Precipitation (l/sq.m.)**
2	18	12	45
4	27	18	52
8	35	24	60

Table 2. Damages from intense rainfall for the region of Shumen

year	2008	2009	2010	2011	2012	2013
Intense damage count. rainfall	5	7	15	9	12	11

In table 3 is summarized data for the rainfall in the region for the period January 2000-July 2013, published on the Internet from the National Institute of meteorology and hydrology at the Bulgarian Academy of Sciences (NIMHBAN) [3].

Table 3. Rainfall and rainfall days in months, and total annual quantity for the territory of Shumen region (rainfall values / rainfall days)

No.	**year**	**elem.**	**(I)**	**(II)**	**(III)**	**(IV)**	**(V)**	**(VI)**	**(VII)**	**(VIII)**	**(IX)**	**X**	**XI**	**XII**	**yr.**
1	**2000**	Rainfall v.	55.8	41.3	26.9	66.3	44.2	54.3	0	0	103.2	4.4	25.0	3	**456**
		Rainfall d.	5	5	6	10	3	3	2	1	9	2	3	2	**51**
2	**2001**	Rainfall v.	17.9	49.1	45.2	66.8	31.7	66,9	84.5	5.2	28.4	0	23.9	69.6	**533.2**
		Rainfall d.	4	7	6	8	8	6	3	2	7	1	6	7	**65**
3	**2002**	Rainfall v.	34	16.8	82	41.3	44	41	122.6	127.3	92	78.8	31.9	41.4	**753.1**
		Rainfall d.	4	2	10	7	5	7	10	6	12	7	6	9	**85**
4	**2003**	Rainfall v.	65.5	25.9	13.7	34	55.9	3.2	26	29.5	137.2	124	25.0	34.0	**648.8**
		Rainfall d.	9	6	6	6	4	2	7	4	6	11	5	6	**72**
5	**2004**	Rainfall v.	67	20.3	19.1	8.2	76.6	70.3	73	116.1	51.8	24.1	43.6	52.2	**632.1**
		Rainfall d.	12	5	8	4	10	14	9	5	5	8	4	9	**93**
6	**2005**	Rainfall v.	82.4	53	26.3	43.4	58.2	45.5	63.2	82.3	145.2	42.7	50.6	56.2	**765.1**
		Rainfall d.	13	13	12	6	12	10	11	11	13	6	16	9	**132**
7	**2006**	Rainfall v.	48.3	26.3	89	58	23	79.5	28.9	63.5	65.5	12.9	40.6	23.2	**592.3**
		Rainfall d.	13	8	10	7	4	9	4	6	9	7	7	5	**89**
8	**2007**	Rainfall v.	58.4	16.4	22.8	3	48.4	26.8	4	52.3	98.7	87.2	155.2	81.8	**685.3**
		Rainfall d.	7	8	5	1	8	9	1	4	10	13	15	9	**90**
9	**2008**	Rainfall v.	34	5.6	30.4	57.2	40.6	64.2	39.5	7.2	110.8	28	18.6	70.2	**517.6**
		Rainfall d.	8	5	6	13	10	7	7	2	9	3	5	13	**88**
10	**2009**	Rainfall v.	73.8	39.9	64.5	26	26.5	8.3	123.5	31.5	59	108.5	44	114	**735.7**
		Rainfall d.	14	8	6	5	9	2	9	2	4	11	5	12	**87**
11	**2010**	Rainfall v.	115.7	116	64	42	131.5	205.7	91	18	74	93	24	78.5	**1053.4**
		Rainfall d.	13	15	13	10	10	15	10	2	5	8	5	12	**118**
12	**2011**	Rainfall v.	27.7	44.5	23	45	78.5	72.5	60.5	69	9	84.5	0	43	**574.1**
		Rainfall d.	8	6	5	8	7	9	6	3	1	8	0	5	**66**
13	**2012**	Rainfall v.	108	42	5	55	154	18	25	42	17	56	27	144.6	**693.6**
		Rainfall d.	11	10	2	9	16	3	3	5	4	6	4	12	**85**
14	**2013**	Rainfall v.	29.0	79.8	57.4	36.5	55.9	142.4	54						**472.6**
		Rainfall d.	12	15	9	8	9	9	7						**69**

Based on the analysis of the harmful effects it is assumed that precipitation intensity over 8 mm/24 h. is potentially dangerous. For this reason the available weather data is processed and table 4 shows the number of days with intense rainfall (over 8 mm/24 h) on the territory of Shumen region during 2000 – 2012.

Table 4. The number of days with intense rainfall recorded with accumulations

(mm/24h)/ year	8-10 mm	8-20 mm	8-30 mm	8-40 mm	8-50 mm	8-70 mm	8-100 mm
2000	11	17	18	18	18	19	19
2001	12	22	25	25	25	25	25
2002	15	25	30	31	32	33	34
2003	10	24	26	27	28	28	30
2004	8	10	16	17	18	19	19
2005	7	19	28	31	34	34	34
2006	6	20	28	28	28	28	28
2007	10	26	27	31	32	32	32
2008	3	14	17	18	19	19	19
2009	13	28	36	38	39	39	39
2010	8	32	42	44	46	47	47
2011	8	22	24	26	27	27	27
2012	0	26	30	31	33	33	33

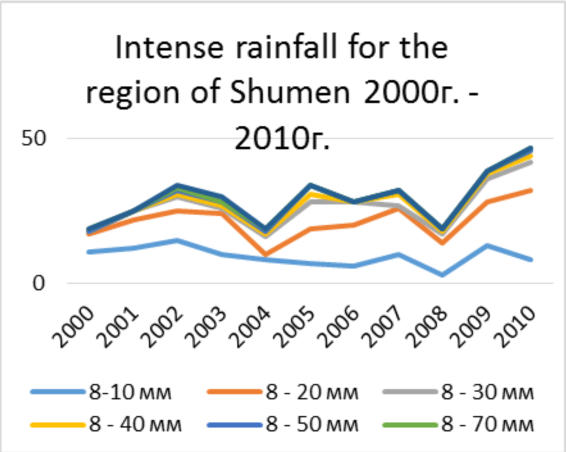

Fig. 1. Distribution of intense rainfall for the region of Shumen along the years

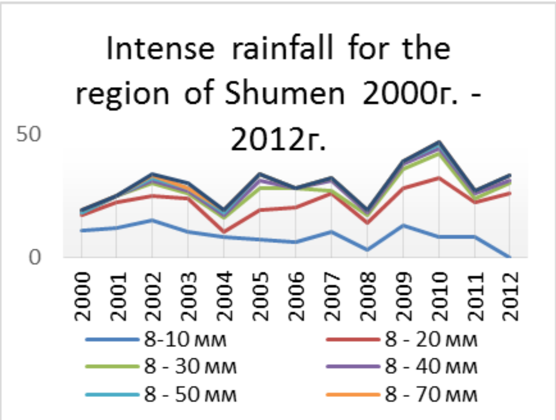

Fig.2. Distribution of intense rainfall for the region of Shumen along the years

To improve the performance of State bodies involved in the prevention or eradication of harmful effects in emergency situations, it is necessary to make scientifically sound estimates of the frequency of intense precipitation over the next few years. The solution of this important task is possible through the development of statistical model of the intensity of the rainfall in Shumen region.

It is known that [1], a basic statistical method for the study of dependancies, where the factor variables and result variables are quantitative indications, is the regression analysis. It says that the quantity to be estimated (extrapolated) for a future period of time, is presented with a mathematical function of time called the smoothing function which parameters are determined by point statistical estimates based on data in past moments of time. It is chosen frequently to be a polynomial function raised to the s-th degree. This assumption is justified by the fact that, under the famous calculus Bolzano-Weierstrass theorem, every smooth function can be represented by an arbitrarily high accuracy using polynomial.

In respect to the aforementioned, the quantity (number) of days $Дe(t)$ with intense rainfall (over 8 mm/24 h) for ***t***-th year shall submit by the following polynomial:

$$Дe(t) = d_0 + d_1.t + d_2.\frac{t^2}{2!} + ... + d_s.\frac{t^s}{s!}, \quad (1)$$

as the degree-s of polynomial depends on the physical nature of the quantity tested. The coefficients of the polynomial $d = \{d_0, d_1, d_2, ..., d_s\}$ have a starting value of the number of days with heavy precipitation for one year, the rate of increase (decrease) of the number of days with heavy rainfall, the acceleration of growth (decrease) of the number of days with intense rainfall, etc. As noted above, they are subject to statistical evaluation.

The evaluation of the coefficients of polynomial $d = \{d_0, d_1, d_2, ..., d_s\}$ is done by the method of maximum plausibility function while the role of interference play enumeration errors of days with intense rainfall for a year, which most often are distributed normally with zero average importance.

After the logarithming of $L(\vec{d})$ and determining of the private derivatives under each of the variables assessed $d_0, d_1, d_2, ..., d_s$, a system of plausibility equations shall be drawn up:

$$\begin{cases} \frac{\partial L(\vec{d})}{\partial d_0} = 0 \\ .... \\ \frac{\partial L(\vec{d})}{\partial d_s} = 0 \end{cases} \qquad (2)$$

After doing (2) the evaluation algorithms, we have:

$$\hat{d}_i = f(d_0, d_1, ..., d_s). \qquad (3)$$

The above data in table 2 by the insurance company give reason to believe that the degree of the polynomial (1) is at least ***s = 2***, i.e. the mathematical basis of the number of days with intense rainfall is nonlinear.

Taking ***s = 2***, from (1) $Дe(t)$, we get the following polynomial of the second degree:

$$Дe(t) = d_0 + d_1.t + d_2.\frac{t^2}{2!} \qquad (4)$$

The coefficients of polynomial (4) have the following physical meaning:

1) d_0 is the initial number of days with intense rainfall (for 1 year);

2) d_1 is the rate of increase of days with intense rainfall;

2) d_2 is the acceleration, by which the number of days with intense rainfall is changed.

In the Gaussian law of distribution of errors in counting the number of days with intense rainfall for 1 year, the system (2) is given by the so-called method of the smallest squares (MSS). In this method, the estimate of the quantities $d_0, d_1, d_2, ..., d_s$ is being calculated by finding the minimum total weighted quadratic deviation of the measured values of the leveled quantity (i.e. the number of days with intense rainfall for 1 year) relative to its model (1). In this particular case you need to find the minimum of the function:

$$L(d_0, d_1, d_2) = \sum_{i=0}^{n-1} w_i \left(d_0 + d_1.t_i + d_2.\frac{t_i^2}{2!} - r_i \right)^2 \qquad (5)$$

The following indications are used below:

1) $L(d_0, d_1, d_2)$ is the weighted quadratic deviation of the number of days with intense rainfall for 1 year relative to the model (4);

$t_0 = 2000 - 2000 = 0,$

2) $t_1 = 2001 - 2000 = 1, ...,$ are

$t_i = 200i - 2000 = i, ...$

discrete moments of time (years), during which measurements are taken (i.e. listed are the days with intense rainfall);

3) r_i is the number of days with heavy precipitation (from 8-100 mm) for the i-th year;

5) $w_i = \frac{1}{\sigma_{r_i}}$ is "gravity", by which is reported the number of days with intense rainfall (from 8 – 100 mm) in the i-th year;

6) σ_{r_i} is the average-quadratic error when determining the number of days with intense rainfall in ***the i***-th year.

7) ***n*** is the total number of years in which are recorded the days with intense rainfall.

The minimum of (5) is determined after you align of 0 the private derivatives of $L(d_0, d_1, d_2)$ in accordance with (2):

$$\begin{cases} \frac{\partial L(d_0,d_1,d_2)}{\partial d_0} = \sum_{i=0}^{n-1} w_i.2.\left(d_0 + d_1.t_i + d_2.\frac{t_i^2}{2!} - r_i\right) = 0 \\ \frac{\partial L(d_0,d_1,d_2)}{\partial d_1} = \sum_{i=0}^{n-1} w_i.2.\left(d_0 + d_1.t_i + d_2.\frac{t_i^2}{2!} - r_i\right).t_i = 0 \\ \frac{\partial L(d_0,d_1,d_2)}{\partial d_2} = \sum_{i=0}^{n-1} w_i.2.\left(d_0 + d_1.t_i + d_2.\frac{t_i^2}{2!} - r_i\right)\frac{t_i^2}{2!} = 0 \end{cases} \quad (6)$$

After revealing the brackets and shortening of 2 in (6), the result is:

$$\begin{cases} d_0 \sum_{i=0}^{n-1} w_i + d_1 \sum_{i=0}^{n-1} w_i.t_i + d_2.\frac{1}{2!} \sum_{i=0}^{n-1} w_i.t_i^2 = \sum_{i=0}^{n-1} w_i.r_i \\ d_0 \sum_{i=0}^{n-1} w_i.t_i + d_1 \sum_{i=0}^{n-1} w_i.t_i^2 + d_2.\frac{1}{2!} \sum_{i=0}^{n-1} w_i.t_i^3 = \sum_{i=0}^{n-1} w_i.r_i.t_i \\ d_0 \sum_{i=0}^{n-1} w_i.t_i^2 + d_1 \sum_{i=0}^{n-1} w_i.t_i^3 + d_2.\frac{1}{2!} \sum_{i=0}^{n-1} w_i.t_i^4 = \sum_{i=0}^{n-1} w_i.r_i.t_i^2 \end{cases} \quad (7)$$

The system of equations (7) is simplified in the following circumstances:

1) apparently the precision of the measurements in different years is the same, i.e. $\sigma_{r_i} = \sigma_0 = const$; This allows you, in (7), to shorten the constants $w_i = \frac{1}{\sigma_{r_i}} = \frac{1}{\sigma_0}$;

2) moments of measurements can be represented by integers $t_0 = 0, t_1 = 1, ..., t_i = i, ...$

After the consideration of these circumstances (7), were obtained and examined on two models – for an 11-year period, covering the years from 2000 to 2010 and a 13- year period – 2000 – 2012.

Model 1 : After replacing in (7) with the data of table 4 for the period 2000-2010, we get the following system of equations:

$$\begin{cases} 11.d_0 + 55.d_1 + \frac{1}{2}385 d_2 = 326 \\ 55.d_0 + 385.d_1 + \frac{1}{2}3025.d_2 = 1794 \\ 385.d_0 + 3025.d_1 + \frac{1}{2}25333 d_2 = 13236 \end{cases} \quad (8)$$

From (8) for the coefficients of the polynomial (4) we obtain:

$$d_0 = 25{,}43; \quad d_1 = -0{,}68; \quad d_2 = 0{,}43; \quad (9)$$

Therefore, the pattern of variation of the days with intense rainfall for 1 year as a function of time has the following form:

$$Де(t) = 25.43 - 0.68t + 0.43\frac{t^2}{2!} \quad (10)$$

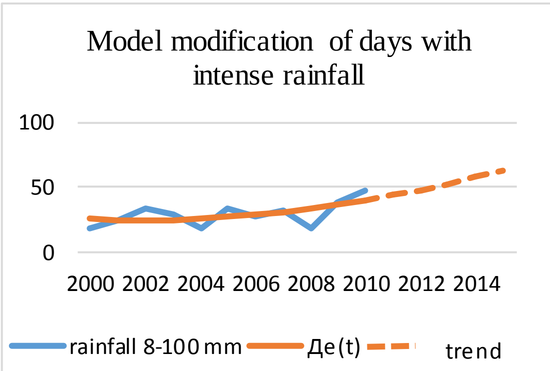

Fig.3. Model of the intensity of rainfall for the period 2000 – 2010 on the territory of Shumen region, and

the trend for the next 5 years precalculated.

The calculated values of $Де(t)$ for each of the years and the trend of development for the next five years are shown in table 5 as the trend is colored in green.

Table 5. Calculated values of De (t) for the period 2000 – 2015.

Years (t)	Numbers of rainfall 8-100 mm	**Де (t)**
2000	19	25.43
2001	25	24.97
2002	34	24.93
2003	30	25.33
2004	19	26.15
2005	34	27.41
2006	28	29.09
2007	32	31.21
2008	19	33.75
2009	39	36.73
2010	47	40.13
2011	_	43.97
2012	_	48.23
2013	_	52.93
2014	_	58.05
2015	_	63.61

The shape and the model calculations show that the trend of days with intense rainfall is rising.

Model 2 : After the replacement in (7) with the data from table 4 for the period of 2000 – 2012, we get:

$$\begin{cases} 13.d_0 + 78.d_1 + \frac{1}{2}650d_2 = 386 \\ 78.d_0 + 650.d_1 + \frac{1}{2}6084.d_2 = 2487 \\ 650.d_0 + 6084.d_1 + \frac{1}{2}60710d_2 = 21255 \end{cases} \qquad (11)$$

From (11) for the coefficients of the polynomial (4) we obtain:

$$d_0 = 22{,}989; \quad d_1 = 1{,}52; \quad d_2 = -0{,}097 \qquad (12)$$

Therefore, the model of the change of the days with intense rainfall for 1 year as a function of time has the following form:

$$Де(t) = 22.989 + 1.52.t - 0.097.\frac{t^2}{2!} \qquad (13)$$

The calculated values of $Де(t)$ for each of the years and the trend of development for the next five years are shown in table 6, the trend colored in green.

Table 6.Calculated values of $Де(t)$ for the period 2000 – 2017.

Years(t)	Numbers of rainfall 8-100 mm	**Де (t)**
2000	19	11.79
2001	25	24.46
2002	34	25.83
2003	30	27.12
2004	19	28.3
2005	34	29.38
2006	28	30.37
2007	32	31.26
2008	19	32.06
2009	39	32.75
2010	47	33.35
2011	27	33.86
2012	33	34.26
2013	_	34.57
2014	_	34.79
2015	_	34.9
2016	_	34.92
2017	_	34.84

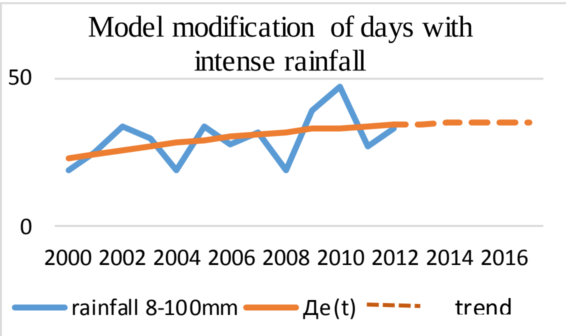

Fig.4. Model of the intensity of rainfall for the period 2000 – 2012 on the territory of Shumen region, and the trend for the next 5 years.

From Fig.4, illustrating the second model, we can see a trend of increasing the number of days with intense rainfall for a year, but it is more smooth.

Conclusion:

Extreme weather events such as heat waves and flooding pose a direct threat, because cause extensive damage to infrastructure and high costs to economy and society. The sectors whose development depends largely on the specific temperature and levels of waterfall, such as agriculture, forestry, energy and tourism, can be greatly affected.

From the studies of the two models for the change of number of days with heavy precipitation for one year in Shumen region it becomes obvious that despite the observed warming and drought on a global scale,in the short term, there is a tendency of increasing the number of days with heavy rainfall. In the first model (fig.3), covering the period 2000-2010, the curve is steeper. The second model (fig.4), including the period 2000 -2012 is more optimistic, the curve of growth of days with intense rainfall is more smooth and in the calculation of the trend for the next 5 years there has is a stabilisation of the number of days with heavy precipitation for one year. Data until July 2013, which is 70% (23) than for 2012, show, however, that the second model is probably optimistic and will need to be adjusted, taking account of the data for the following years.

Overall, the analysis of the substantiated in the report statistical models of the number of days with intense rainfall, shows a clear trend of increase in the medium term. Therefore, to address emergency situations such as floods, which are becoming more likely, action is needed at all levels-national, regional and local.These actions include a wide range of preventive, engineering-protective , zoning, legal-administrative, organizational, etc measures.

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References:

[1] Rumshiskij L. Z., Mathematical processing of experiment results, Moscow,1971.

[2] The third national plan for action on climate change for the period 2013-2020, MEW, Sofia, 2012

[3] www.stringmeteo.com