Estimation of the time dependence of fires quantity in Russia

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Abstract. Using correlation analysis of the statistical data for 2001-2016, the fact of strong dependence between the number of fires in the regions of the Russian Federation and the number per year was established. It has been established that Kabardino-Balkaria republic is an exception to this dependence. A hypothesis test of the relevance of the correlation coefficient found that the correlation coefficient between the number of fires and the number of years was 0.99.

1. Introduction

At present, there is a significant amount of data on fire statistics for the period 2001-2016 [1-4]. Based on this data, several investigations have attempted to predict the number of fires [5-7], for example, using time series theory [5-9]. In this case, it was originally assumed that the factor being investigated was time-dependent. The time factor was considered as a variable of order (number of year). This raises the question of the validity of the theoretical time series application to fire statistics. If there was a dependence of fire statistics on the number of years, the application of time series theory is correct. Otherwise, if there is no such dependence, some other mathematical technique should be applied. The dependences between the number of fires, an extent of material losses, the death toll, number of the injured, amount of the destructed buildings and number of the year previously were found [1-7].

For the rural areas of Russian Federation it was determined the presence of a strong dependence of the fires amount, extent of the material loss, death toll on the number of a year. Therefore, the utilization of the time series theory for prediction of the number of fires, extent of material losses, death toll and the number of the injured accomplished for the Russian Federation proved to substantiate. However, it is yet unclear if there is a dependence of the amount of fires on the number of a year in the regions of Russia. Therefore, validity of the use of time series theory for the prediction of the number of fires in the regions of Russia will be dependent on time that considered by assigning of the number of the year.

2. Results and discussion

In order to determine if the dependence of the fires amount in the regions of Russian Federation on the number of a year really observed let us accomplish correlation analysis.
The presence or absence of a relationship between the statistics was determined by calculating the Pearson linear correlation coefficient [8]:

\[ R = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \] (1)

Where \( Y_i \) - is the amount of fires for the i-th year, \( \bar{Y} \) - is a mean amount of dfires for the period of 2001-2016, \( X_i \) is a number of the year, \( \bar{X} \) - is the mean value.

Due to a small amount of data (n<100) let us recalculate Pearson’s coefficient of linear correlation (1) for a small sample range [8]:

\[ R' = R \left[ 1 + \frac{1-R^2}{2(n-3)} \right] \] (2)

Coefficient \( R' \) will take the values within the range from –1 to 1.

If \( |R'| = 1 \), then the values are related with a linear functional dependence. In case of \( 0.95 \leq |R'| < 1 \) the relation between the values is very strong. For \( 0.75 \leq |R'| < 0.95 \) a tight relation is present. If \( 0.5 \leq |R'| < 0.75 \) then the relation is an average one. For \( 0.2 \leq |R'| < 0.5 \) the relation is weak. In case of \( 0 \leq |R'| < 0.2 \) the relation is in fact absent.

Sample coefficient in the linear Pearson correlation depends on the amount of sampling. Sampling involves data on the amount of fires. These values are random variables. Therefore, correlation coefficient is also a random variable. Hence, validity test of the sample correlation coefficient is accomplished. So, two hypotheses formulated.

Hypothesis H0 – there is no any relation between the studied variables X and Y (\( R'=0 \)). An alternative hypothesis H1 – the relation exists (\( R' \neq 0 \)). Test for null hypothesis performed with the use of Fisher transform [25]:

\[ u = \frac{1}{2} \ln \frac{1+R'}{1-R'} \] (3)

After calculation of the value for \( u \) it compared with the critical one

\[ u_{\alpha} (n) = z_{\frac{1}{2}} \frac{1}{\sqrt{n-3}} \] (4)

Where \( z_{\frac{1}{2}} \) - are the normal distribution fractiles, \( z_{\frac{1}{2},\alpha} =1.96 \) for \( \alpha = 0.05 \) and \( z_{\frac{1}{2},\alpha} =2.576 \) for \( \alpha = 0.01 \).

If \( |u| \leq u_{\alpha} (n) \) then hypothesis H0 is adopted. Then there is no linear correlation link between the considered values. In case of \( |u| > u_{\alpha} (n) \) hypothesis, H1 adopted.

In addition to the point estimate of the correlation coefficient (2), one more estimate with the help of a confidence level is considered.

\[ R'_H < R' < R'_B \] (5)

The lower \( R'_H \) and upper \( R'_B \) bounds of the confidence level for the linear correlation coefficient calculated by the formulas presented in [8]:

\[ R'_H = \frac{\exp(2[u-u_{\alpha}(n)])-1}{\exp(2[u-u_{\alpha}(n)])+1}, \quad R'_B = \frac{\exp(2[u+u_{\alpha}(n)])-1}{\exp(2[u+u_{\alpha}(n)])+1} \] (6)

Results of the calculations demonstrated a very strong dependence of the fires amount on the number of the year in the regions of Russian Federation (table 1).

| Region of the Russian Federation | Y | S | R’ | u | Hypothesis | R'_H | R'_B |
|---------------------------------|---|---|----|---|-------------|------|------|
| Central Federal District        |   |   |    |   |             |      |      |
| Region                        | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | H1   | H2   |
|-------------------------------|---------|---------|---------|---------|---------|------|------|
| Belgorod Region               | 775     | 257     | -0.878  | -1.367  | H1      | -0.969| -0.574|
| Bryanskaya Region             | 1168    | 273     | -0.928  | -1.645  | H1      | -0.982| -0.731|
| Vladimir Region               | 1297    | 433     | -0.967  | -2.045  | H1      | -0.992| -0.869|
| Voronezh Region               | 1435    | 314     | -0.992  | -2.779  | H1      | -0.998| -0.968|
| Ivanovskaya Region            | 1145    | 439     | -0.959  | -1.934  | H1      | -0.990| -0.839|
| Kaluzhskaya Region            | 619     | 146     | -0.984  | -2.419  | H1      | -0.996| -0.936|
| Kostrama Region               | 553     | 181     | -0.966  | -2.030  | H1      | -0.992| -0.866|
| Kursk Region                  | 475     | 259     | -0.951  | -1.842  | H1      | -0.988| -0.810|
| Lipetskaya Region             | 740     | 190     | -0.951  | -1.840  | H1      | -0.988| -0.810|
| Moscow                        | 9330    | 2471    | -0.986  | -2.490  | H1      | -0.997| -0.944|
| Moscow Region                 | 4911    | 924     | -0.940  | -1.742  | H1      | -0.985| -0.773|
| Oryol Region                  | 411     | 103     | -0.959  | -1.932  | H1      | -0.990| -0.839|
| Ryazan Region                 | 730     | 238     | -0.953  | -1.863  | H1      | -0.989| -0.817|
| Smolensk Region               | 1069    | 406     | -0.962  | -1.977  | H1      | -0.991| -0.852|
| Tambov Region                 | 558     | 134     | -0.961  | -1.957  | H1      | -0.990| -0.846|
| Tver Region                   | 934     | 208     | -0.995  | -3.003  | H1      | -0.999| -0.980|
| Tula Region                   | 1223    | 430     | -0.989  | -2.600  | H1      | -0.997| -0.955|
| Yaroslav Region               | 1257    | 319     | -0.949  | -1.823  | H1      | -0.988| -0.804|

**Northwestern Federal District**

| Region                        | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | H1   | H2   |
|-------------------------------|---------|---------|---------|---------|---------|------|------|
| Archangel Region              | 1402    | 252     | -0.976  | -2.197  | H1      | -0.994| -0.902|
| Vologda Region                | 872     | 258     | -0.988  | -2.559  | H1      | -0.997| -0.951|
| Kaliningrad Region            | 1256    | 282     | -0.940  | -1.737  | H1      | -0.985| -0.771|
| Republic of Karelia           | 997     | 160     | -0.965  | -2.009  | H1      | -0.991| -0.860|
| Komi Republic                 | 1071    | 423     | -0.985  | -2.427  | H1      | -0.996| -0.937|
| Leningrad Region              | 1758    | 639     | -0.977  | -2.238  | H1      | -0.995| -0.909|
| Murmansk Region               | 1449    | 493     | -0.974  | -2.158  | H1      | -0.994| -0.894|
| Nenets Autonomous District    | 608     | 88      | -0.983  | -2.365  |         |      |      |

**Southern Federal District**

| Region                        | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | H1   | H2   |
|-------------------------------|---------|---------|---------|---------|---------|------|------|
| Republic of Adygea             | 154     | 51      | -0.948  | -1.812  | H1      | -0.987| -0.800|
| Astrakhan Region               | 718     | 92      | -0.953  | -1.866  | H1      | -0.989| -0.818|
| Volgograd Region               | 2261    | 395     | -0.990  | -2.644  | H1      | -0.998| -0.959|
| Republic of Kalmykia           | 104     | 13      | -0.558  | -0.630  | H1      | -0.873| 0.084|
| Krasnodar Territory            | 2377    | 388     | -0.989  | -2.590  | H1      | -0.997| -0.954|
| Rostov Region                  | 2485    | 759     | -0.960  | -1.948  | H1      | -0.990| -0.844|

**North Caucasian Federal District**

| Region                        | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | H1   | H2   |
|-------------------------------|---------|---------|---------|---------|---------|------|------|
| Republic of Dagestan           | 465     | 121     | -0.971  | -2.101  | H1      | -0.993| -0.882|
| Republic of Ingushetia         | 107     | 25      | -0.735  | -0.940  | H1      | -0.930| -0.222|
| Kabardino-Balkar Republic      | 361     | 68      | -0.336  | -0.350  | H0      | -0.787| 0.349|
| Karachai-Circassian Republic   | 160     | 43      | -0.893  | -1.436  |         | -0.973| 0.618|
| Republic.                      |         |         |         |         |         | H1   |      |
| Republic. North Ossetia-Alania | 276     | 68      | -0.983  | -2.391  | H1      | -0.996| -0.932|
| Stavropol Krai                 | 1087    | 276     | -0.932  | -1.670  | H1      | -0.983| -0.742|
| Chechen Republic.              | 127     | 81      | 0.511   | 0.564   | H1      | -0.149| 0.856|

**Volga Federal District**

| Region                        | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | H1   | H2   |
|-------------------------------|---------|---------|---------|---------|---------|------|------|
| Republic of Bashkortostan      | 2235    | 282     | -0.927  | -1.639  | H1      | -0.982| -0.728|

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The number of fires are present only for 2015 and 2016 years. Statistical data for the period of

| Region                  | Fires 2015 | Fires 2016 | Correlation Coefficient |
|------------------------|------------|------------|-------------------------|
| Kirovskaya Region      | 1453       | 219        | -0.968                  |
| Republic of Mari El    | 605        | 142        | -0.966                  |
| Republic of Mordovia   | 574        | 301        | -0.973                  |
| Nizhny Novgorod Region| 2483       | 547        | -0.971                  |
| Orenburg Region        | 1495       | 404        | -0.926                  |
| Penza Region           | 940        | 257        | -0.983                  |
| Perm Krai              | 2233       | 834        | -0.971                  |
| Samara Region          | 2741       | 550        | -0.973                  |
| Saratov Region         | 1717       | 218        | -0.869                  |
| Republic. Tatarstan    | 2292       | 300        | -0.949                  |
| Udmurt Republic.       | 969        | 462        | -0.961                  |
| Ulyanska Region        | 948        | 233        | -0.919                  |
| Chuvash Republic.      | 651        | 207        | -0.977                  |
| Ural Federal District  |            |            |                         |
| Kurgan Region          | 878        | 229        | -0.951                  |
| Sverdlovsk Region      | 4265       | 1237       | -0.965                  |
| Tyumen Region          | 1153       | 234        | -0.917                  |
| Khanty-Mansi Autonomous| 2224       | 483        | -0.956                  |
| District - Ugra        |            |            |                         |
| Chelyabinsk Region     | 3437       | 467        | -0.969                  |
| Yamalo - Nenets Auto   | 608        | 88         | -0.983                  |
| Siberian Federal District|         |            |                         |
| Republic of Altai      | 103        | 21         | -0.910                  |
| Altai Territory        | 2107       | 539        | -0.984                  |
| Irkutsk Region         | 3218       | 990        | -0.983                  |
| Kemerovo Region        | 3651       | 1072       | -0.978                  |
| Krasnoyarsk Krai       | 3126       | 640        | -0.943                  |
| Novosibirsk Region     | 2692       | 601        | -0.985                  |
| Omskaya Region         | 2155.75    | 711        | -0.976                  |
| Tomskaya Region        | 761        | 202        | -0.956                  |
| Republic of Tyva       | 360        | 46         | -0.864                  |
| Republic of Hakassia   | 525        | 142        | -0.951                  |
| Far Eastern Federal District|      |            |                         |
| Amurskaya Region       | 1324       | 331        | -0.986                  |
| Republic of Buryatia   | 923        | 307        | -0.931                  |
| Jewish Car Region      | 372        | 129        | -0.946                  |
| Transbaikal Krai       | 1138       | 206        | -0.992                  |
| Kamchatsky Krai        | 488        | 152        | -0.956                  |
| Magadan Region         | 520        | 204        | -0.986                  |
| Primorsky Krai         | 5271       | 1389       | -0.901                  |
| Republic of Saha (Yakutia)| 1393      | 476        | -0.994                  |
| Sakhalin Region        | 1072       | 463        | -0.978                  |
| Khabarovsk Krai        | 3478       | 663        | -0.962                  |
| Chukot Autonomous District| 75         | 44         | -0.965                  |

Republic of Kabardino-Balkaria is an exception from this observation, where R = -0.309. The amount of fires in this republic does not depend on the number of the year. Statistical data for the period of 2001-2016 years utilized. Crimea and the city of Sevastopol were not included in the table since the data on the number of fires are present only for 2015 and 2016 years. This amount of the statistical data is insufficient for the correlation analysis. Moreover, these data for trans-Baikal territory presented only
for the period from 2006 to 2016. It should be noted that the minimum value of $R'$ is equal to -0.996 (Yamal-Nenets Autonomous Area), while the maximum value of 0.638 (at Chechen Republic).

Let us make a test for validity of the sample correlation coefficient. For the significance point of $\alpha = 0.01$ the critical value is $u_\alpha(11) = 0.714$. Therefore, for the majority of the Russian Federation regions with $|u| > u_{0.01}(16)$, hypothesis H1 is true. So it was found with the probability of $P = 0.99$ that the correlation coefficient between the amount of fires and the number of a year differs from zero. It means that there is a relation between the amount of fires and number of the year. Republic of Kabardino-Balkaria is an exception – with a validity level of $\alpha = 0.01$ hypothesis H0 proved to be correct. The amount of fires in this region does not depend on the number of a year.

For trans-Baikal territory $n = 11$, the critical value $u_{0.01}(11) = 0.911$. Condition of $|u| > u_{0.01}(11)$ is satisfied, thus hypothesis H1 is true.

Calculations of the correlation coefficient between the mean amount of fires for the period of 2001-2016 and $R'$ resulted in the value of -0.139. For $R'$ and a standard deviation in the number of fires for the period of 2001-2016 we obtained correlation coefficient equal to $\mu = -0.153$. Therefore, between $R'$ and the mean and standard characteristics of the distribution (mean and standard deviation) for the amount of the fires in the Russian Federation regions there is no any valid relation.

An estimate of the confidence interval for the correlation coefficient of the amount of fires with the number of a year in the regions of Russian Federation was made at the significance level of $\alpha = 0.01$ (table 1). The lower boundary for the coefficient of $R'$ in the Republic of Kabardino-Balkaria was of -0.775. It means that one can anticipate the relation between the amount of the fires and the number of a year. For Kalmykia Republic, the upper boundary is equal to $-0.134$, for the Republic of Bashkortostan it is of $-0.114$, while in Republic of Tyva it is of $-0.294$. In this case, a situation can realized when there is no any relation between the amount of fires and the number of a year.

In order to explain the reasons for the absence of dependence in the amount of fires in the Republic of Kabardino-Balkaria on the number of a year let us compare corresponding indicators in the North Caucasian Federal District. First, it should note that the largest number of the fires occurred in the Stavropol territory [1-4]. Therefore, this region will excluded from the following analysis. Comparison with the situation in the Adyge Republic revealed a sharp peak for the period of 2005-2010 years. Beginning from 2011 the situation with the fires in the Republic of Kabardino-Balkaria demonstrated a downtrend. Note that the line of trend is in fact parallel to the similar trend line for the Republic of Adygei.

Comparison of the situation of the Republic of Kabardino-Balkaria, Ingush Republic, and Republic of North Ossetia-Alania revealed the presence of a strong peak. For the Republic of Kabardino-Balkaria, this peak coincided with the period of 2005-2010 years. In the Republic of North Ossetia-Alania and Ingush Republic, such peak observed in 2006.

Similar peak observed for the Chechen Republic. It occurred in 2006-2010 years.

3. Conclusions
The fact that the amount of the fires in the Republic of Kabardino-Balkaria, Republic of North Ossetia-Alania, Ingush Republic, Chechen Republic show rather similar peaks coinciding for the period of 2006-2010 years, results in a conclusion that the most probable reason of their occurrence is a set of climatic conditions. This peak mostly expressed for the Republic of Kabardino-Balkaria. The latter circumstance resulted in the fact that the dependence of the amount of fires in the Republic of Kabardino-Balkaria on the number of a year not observed.

Finally, because of the performed investigations correlation coefficients between the amount of fires in the regions of Russian Federation and the number of a year calculated according to the data for 2001-2016 years. The presence of a strong correlation between these indicators found (except for the Republic of Kabardino-Balkaria). Hypothesis on the equality of the correlation coefficient between the amount of fires and the number of a year was tested. As a result, it was found that for the significance level of 0.01 (with a probability of 0.99) correlation coefficient proved to be non-zero (except for the Republic of Kabardino-Balkaria). Upper and lower bounds for the correlation coefficient calculated as well.
The approved fact of the presence of a strong dependence between the amount of fires and the number of a year for the regions of Russian Federation makes it reasonable application of techniques utilized in the theory of time series for the mathematical predicting of the number of fires.

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