

**AN APPLICATION OF REGRESSION ANALYSIS FOR MODELLING
OF THE FOREST FIRES**

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Abstract

20 years of environmental degradation, people gradually get used to the deterioration of nature and actually accept new conditions such as annual flood and drought. From an ecological point of view, fire is considered as a non-biotic factor which, in general, works within the ecosystem to decompose, recycle and select. For this aim we developed a modified method of regression analysis for modelling of the forest fires in the National Parks of Thailand and dynamic of the rate of spread of the Sundance fire. The method is distinguished from the conventional regression analysis of that the factors included in the regression dependence are time functions. Two type functions are tested: polynomial:

$x_i(t) = \sum_{i=0}^n a_i t_i^n$ and periodical from the type: $x_i(t) = A \sin(\pi(t - x_c)/w)$. The investigations show better results the periodical functions give. The comparison is made on Fisher function and correlation coefficient R^2 for each of the investigated functions. For aim of the regression analysis, an algorithm and program are developed for the experimental data processing. The results show the experimental data are stationary and it can be accepted they have normal distribution.

Keywords: regression analysis, forest fires, National parks of Thailand, Sundance fire.

1. INTRODUCTION

For our world the environmental changes caused by man during the last two decades are obviously terrible. Second only to deforestation, fire plays the most destructive role in the forest ecosystem which results in drastic deterioration of the environment as a whole. However, these changes over time seem slow to human eyes. As an agent of decomposition, fire releases, in the form of a heat, the chemical energy stored in the available fuel. Fire liberates, in slightly altered forms, many of the constituent bio-chemicals residing in the litter. Somehow an ecosystem must cope with this discharge of energy and chemicals, with the eradication of some organisms and the introduction of others, and with the simultaneous processes of selective destruction and selective enhancement. It is therefore, evident that fire is not a minor factor, but a major one. Fire is and has been, for centuries, a part of terrestrial environments of the world. Consequently biotic communities adapt and compensate for this factor just as they do for temperature or water. Yet, as with most environmental factors, man has greatly modified its effect, increasing its influence in many cases and decreasing it in others. Through careless behavior, man has often so increased the effect of fire that a productive environment, is destroyed or injured [20].

Forest fire is a physical and chemical response. Three major components form the "fire environment triangle": fuel, topography and weather. Without one of these, fire cannot occur. Heat transfer occurs in three ways: conduction, convection, and radiation [21].

The Sundance Fire on September 1, 1967, made a spectacular run of 16 miles in 9 hours and destroyed more than 50,000 acres. This run became the subject of a detailed research analysis of the environmental, topographic, and vegetation variables aimed at reconstructing and describing fire phenomena. This report details the fire's progress; discusses the fire's buildup in intensity, the fuel complex through which it traveled, the wind and other atmospheric variables affecting the fire's behavior; and describes the processes that probably account for the tree breakage and blowdown, the long-range spotting, and the subsidence of the fire's run [2].

There is a row models for description of the forest fires developed in USA, Germany, Russia and in other countries that are used in the research activity and in particular at the forest control.

The aim of this paper is application of a regression analysis for modelling of the forest fires in the National parks in Thailand and dynamic of the rate of spread of the Sundance fire.

2. MATERIALS AND METHODS

2.1. A modified method of a regression analysis for modelling of forest fires

The polynomial models from second order are some the most used in the practice. They allow the investigation phenomenon to be described in comparison a wide area of change of the input variables. In general type they have the type [11]:

$$\mathbf{y} = \mathbf{B}_0 + \sum_{i=1}^m \mathbf{B}_i x_i + \sum_{i=1}^m \mathbf{B}_{i,i} x_i^2 + \sum_{i=1}^m \sum_{j=i+1}^{m-1} \mathbf{B}_{i,j} x_i x_j \quad (1)$$

where: $\mathbf{B}_0 = \mathbf{B}_0[b_0^1, b_0^2, \dots, b_0^m; \mathbf{B}_{i,i} = \mathbf{B}_{i,i}[b_{i,i}^1, b_{i,i}^2, \dots, b_{i,i}^m; b_{1,1}^1, b_{2,2}^1, \dots, b_{m,m}^1; b_{1,1}^2, b_{2,2}^2, \dots, b_{m,m}^2; \dots, b_{1,1}^m, b_{2,2}^m, \dots, b_{m,m}^m];$
 $\mathbf{B}_{i,j} = \mathbf{B}_{i,j}[b_{i,j}^1, b_{i,j}^2, \dots, b_{i,j}^m; b_{i,j}^1, b_{i,j}^2, \dots, b_{i,j}^m; b_{i,j}^1, b_{i,j}^2, \dots, b_{i,j}^m], i = 1, \dots, m, j = i + 1, m - 1;$

$\mathbf{y}$ —vector of the investigated indexes, $\mathbf{y} = [y^1, y^2, \dots, y^m]^T$; $\mathbf{x}_i$ — the same investigated indexes.

In contrast to the conventional regression analysis, the factors participant in the regression dependence are the time functions. In the paper, the following models are investigated:

$$x_i(t) = \sum_{k=0}^r a_{i,k} t^k \quad (2)$$

or

$$x_i(t) = c_i \sin\left(\pi \frac{t - p_i}{q_i}\right) \quad (3)$$

where r is the polynomial degree, $a_{i,k}$ — the coefficients in the polynomial functions (2) of each index; c_i , p_i and q_i — the coefficients on each index for the periodical functions.

The choice of a suitable function from (2) and (3) is made based on the correlation coefficient.

The regression analysis requires some statistical verification of the experimental data to be made. The verification is based on the mathematical statistic methods, as far as the investigated indexes are shown chance quantities and chance processes.

2.2. Statistical treatment of the data

The forest indexes of the ecosystems are shown chance processes that allows at they treatment the mathematical statistical method to be used [1, 11, 14]. In practice we dispose with a final of duration realization of the measurement of the indexes for a given time period – T , for which the values $x_{i,j}$ are known, ($i=1, \dots, n$ – number observation; $j=1, \dots, m$ – number investigated indexes) in discrete time moments t_i . There where the measuring missing an approximation is made by cube spline [9] of the experimental data with an aim obtaining of an even time row distribution. The statistical treatment includes the following basic stages [11]:

1. The assessment of the average values $\bar{x}_j$ of each indexes is calculated:

$$\bar{x}_j = \frac{1}{n} \sum_{i=1}^n x_{i,j} \quad (4)$$

where: $n = T / \Delta t$; Δt – the discretisation step.

2. The assessment of the dispersion is calculated:

$$s_j^2 = \frac{1}{n-1} \sum_{i=1}^n (x_{i,j} - \bar{x}_j)^2 \quad (5)$$

3. Normalizing of the experimental data by the equation: $\tilde{x}_{i,j} = (x_{i,j} - \bar{x}_j) / \sqrt{s_j^2}$.
4. Check-up for *stationary* of the chance process is made. The interval T is divided in some subintervals p ($p \geq 2$), in each of them there is an equal number observations $n_1 = n / p$. The mathematical expectation and dispersion are calculated for each index j and for each subinterval:

$$\bar{x}_i = \frac{1}{n_1} \sum_{j=1}^{n_1} x_{i,j} \quad (6)$$

$$s_i^2 = \frac{1}{n_1-1} \sum_{j=1}^{n_1} (x_{i,j} - \bar{x}_i)^2, \quad i = 1, 2, \dots, p \quad (7)$$

- 4.1. The assessment for *reproducibility* is made by the *Kohren criterion*:

$$G_c = \frac{\max_i s_i^2}{\sum_{i=1}^p s_i^2} \quad (8)$$

The obtained value of $G_{c,j}$ is compared with the tabular value G_T at n_1-1 and p degrees of freedom and a level of significant $\alpha=0.05$. If $G_c < G_T$ then the process is considered for *reproducible*, i. e. the dispersions in the separate subintervals do not distinguish materially each other and they can be used for an assessment of the dispersions s_k^2 ($k=1, \dots, m$) of the chance processes of each investigated index:

$$s_k^2 = \frac{1}{p} \sum_{i=1}^p s_i^2 \quad (9)$$

4.2. A check-up for constancy of the mathematical expectation is made on each index by *dispersion analysis*:

$$F = s_{\bar{x}}^2 / s_{\kappa}^2 \quad (10)$$

where $s_{\bar{x}}^2 = \frac{n_1}{p-1} \sum_{i=1}^p (\bar{x}_i - \bar{x})^2$ is the dispersion of the average values in the subintervals toward the average value $\bar{x}$ for the entire interval, $\bar{x} = \frac{1}{p} \sum_{i=1}^p \bar{x}_i$, and s_{κ}^2 is calculated by (9).

For check-up of the notability, the Fisher criterion is used. The calculated F value is compared with the tabular value F_T for $p-1$ and $p(n_1-1)$ degrees of freedom. The mathematical expectation is taken for constant in the all interval if $F < F_T$.

All too often for check-up of the *stationary* of the processes only two intervals are used. In this case, instead on the *Kohren criterion*, the assessment can be made on the *Fisher criterion*, as the relation of the larger to the smaller dispersion is taken at degrees of freedom n_1-1 and n_1-1

$$F = s_1^2 / s_2^2 < F_T(n_1 - 1, n_1 - 1) \quad (11)$$

The given assessments for *stationary* of the processes are true in case of a normally density of the distribution of the investigated chance process. Therefore, it is useful a check-up for presence of a trend to be made.

5. A check-up for presence of a trend is made [18]

$$T'_j = \frac{n}{(n-1)} \frac{\sum_{i=1}^{n-1} (x_{i+1,j} - x_{i,j})^2}{\sum_{i=1}^n (x_{i,j} - \bar{x}_j)^2} > T = 2.0 - \frac{2.0 - \alpha Z(x)}{\sqrt{n}} \quad (12)$$

where: $Z(x)$ – diversion from the normally distribution; α – level of considerable, $\alpha=0.05$.

If the condition (12) is executed then it is accepted that we have presence of a trend.

6. An important characteristic of the chance process is its *autocorrelation function*. At an final length and discrete values the correlation is used [11]:

$$r_{xx}(k) = \frac{1}{n-k-1} \sum_{i=1}^n (x_{i,j} - \bar{x}_j)(x_{i+k,j} - \bar{x}_j) \quad (13)$$

where $k=\tau / \Delta t$ and accepts an integer value, $\tau=0, \dots, T-2$.

At $\tau = k = 0$ the expression for the *autocorrelation function* coincides with that for the dispersion, i. e. $r_{xx}(0) = s_j^2$. On the value of this function is judged for the frequency characteristic of the chance process also and for the dependence between the values in two time moments t_1 and t_2 .

The higher border of the interval between two observation Δt is determined by the expression $\Delta t = T / n$, where T is the time for that the characteristics of the object can be examined as stationary.

The normalized *autocorrelation function* is determined by:

$$\rho_{xx}(k) = \frac{1}{(n-k-1)s_j^2} \sum_{i=1}^n (x_{i,j} - \bar{x}_j)(x_{i+k,j} - \bar{x}_j) \quad (14)$$

that is characterised with $\rho(0)=1$.

On analogous way, the *correlation* and *normalized correlation function*:

$$r_{xy}(k) = \frac{1}{n-k-1} \sum_{i=1}^n (x_{i,j} - \bar{x}_j)(y_{i+k,j} - \bar{y}_j) \quad (15)$$

$$\rho_{xy}(k) = \frac{1}{(n-k-1)s_x s_y} \sum_{i=1}^n (x_{i,j} - \bar{x}_j)(y_{i+k,j} - \bar{y}_j) \quad (16)$$

The correlation coefficient is changed from -1 to + 1 and it is an index for the linearity and direction of the connection between the two chance quantities. Itself connection is called *correlation* or *statistical*.

7. The correlation matrix is constructed from (14) and (16). The correlation matrix gives the connection between the private correlation coefficients, between the exits and the respective entrances, also and the correlation coefficients between the separate entrances.
8. The check-up for considerable of the correlation coefficients on the Student criterion is made:

$$t = \frac{r_{i,j} \sqrt{n-2}}{1-r_{i,j}^2} \quad (17)$$

IF $t < t_{TAB}(0.95, n-2)$ then it is accepted that the correlation coefficient is not considerable.

2.3. A comparative analysis and check-up for adequate of the regression models

Often at examining of different approximations of real processes the question is manifested for criteria of that they can be objectively compared. According to the rule, the complicating of the dependence between the end and entrance of the object leads to approximation that is more precise. The comparing of two regression models is made with a help of the Fisher criterion. The dispersion relation is composed:

$$F = s_1^2 / s_2^2 \quad (18)$$

where s_1^2 and s_2^2 are accordingly the residual dispersion of the model 1 and 2, calculated by the equation:

$$s_i^2 = \frac{1}{n-k} \sum_{j=1}^n (y_{i,j} - \bar{y}_{i,j})^2, i = 1, 2 \quad (19)$$

and $s_1^2 > s_2^2$.

The obtained F is compared with the tabular value F_T for given level of residual α and degree of freedom $v_1 = n - m_1$ and $v_2 = n - m_2$, where m_1 and m_2 are the numbers of the members accordingly in the models 1 and 2. IF $F > F_T$, then we accept that the model 2 leads to materially decrease of the residual dispersion. Otherwise, the complicating of the dependence does not provoke materially improving of the model.

The assessment for the models adequate is made on the basis of the following statistical criteria [11, 16, 18]: Fisher function F , correlation coefficient R^2 , statistical index WRMSE (*the Weighted Root Mean Square Error*) applied from English Agency for Water Control and relative error S_L . The statistical index WRMSE is determined by the following dependence:

$$WRMSE_j = \sqrt{\frac{1}{n} \sum_{i=1}^n \frac{(x_{i,j} - y_{i,j})^2}{s_j^2}}, j = 1, \dots, m \quad (20)$$

where: $x_{i,j}$ – experimental values; $y_{i,j}$ – calculated by the model.

The relative error is determined by the relation [3-8, 15-20]

$$S_L^j = \sqrt{\frac{1}{(n-k)} \sum_{i=1}^n \left(1 - \frac{y_{i,j}}{x_{i,j}}\right)^2}, \quad (21)$$

Indexes values $WRMSE_j$ and s_L^j are in the interval from 0 to 1. As the indexes, values (23) and (24) are less as more the model validity for investigated index is increased.

An algorithm and program are developed for a statistical treatment of the experimental. The algorithm block scheme is shown in Figure 1, where: SPLINE is a procedure for extrapolation of the experimental data in the time [9]; STATIONARY is a procedure for check-up of the *stationary* of the experimental observations; TREND is a procedure for test for presence of a *trend* (check-up for normally distribution of the observations); CORR is a procedure for calculating of the auto- and correlation functions; STUDNT is a procedure for determining of the correlation coefficients.

The coefficients in the polynomial models from the type (2) are determined by the help of the polynomial regression subprogram from the library IMSL of FORTRAN 90 [7]. The program computes the correlation coefficient, Fisher function and standard error. In these criteria, easily and conveniently the polynomial degree r is determined. For determination of the coefficients in the periodical function from the type (2) the possibilities of the graphic package Origin 6.0 are used.

The coefficient in the regression models from type (1) is determined with the help of the plural regression subprogram from the same library of FORTRAN 90. The program computes also the basic statistical quantities on that are passed for the models adequate – correlation coefficient, Fisher function and standard error. Excepting these statistical indexes the program computes and t – *Student* distribution for each coefficient. In this way, the check-up for the coefficient considerable can made. If $t_i < t_T$ at degrees of freedom $n - k$ (k – number the model degrees of freedom) and a confidential interval $\alpha = \pm 5\%$, then the coefficient is not statistical considerable and the variable x_i can be expelled from the regression equation.

All programs are developed on COMPAQ Visual FORTRAN Pro [7].

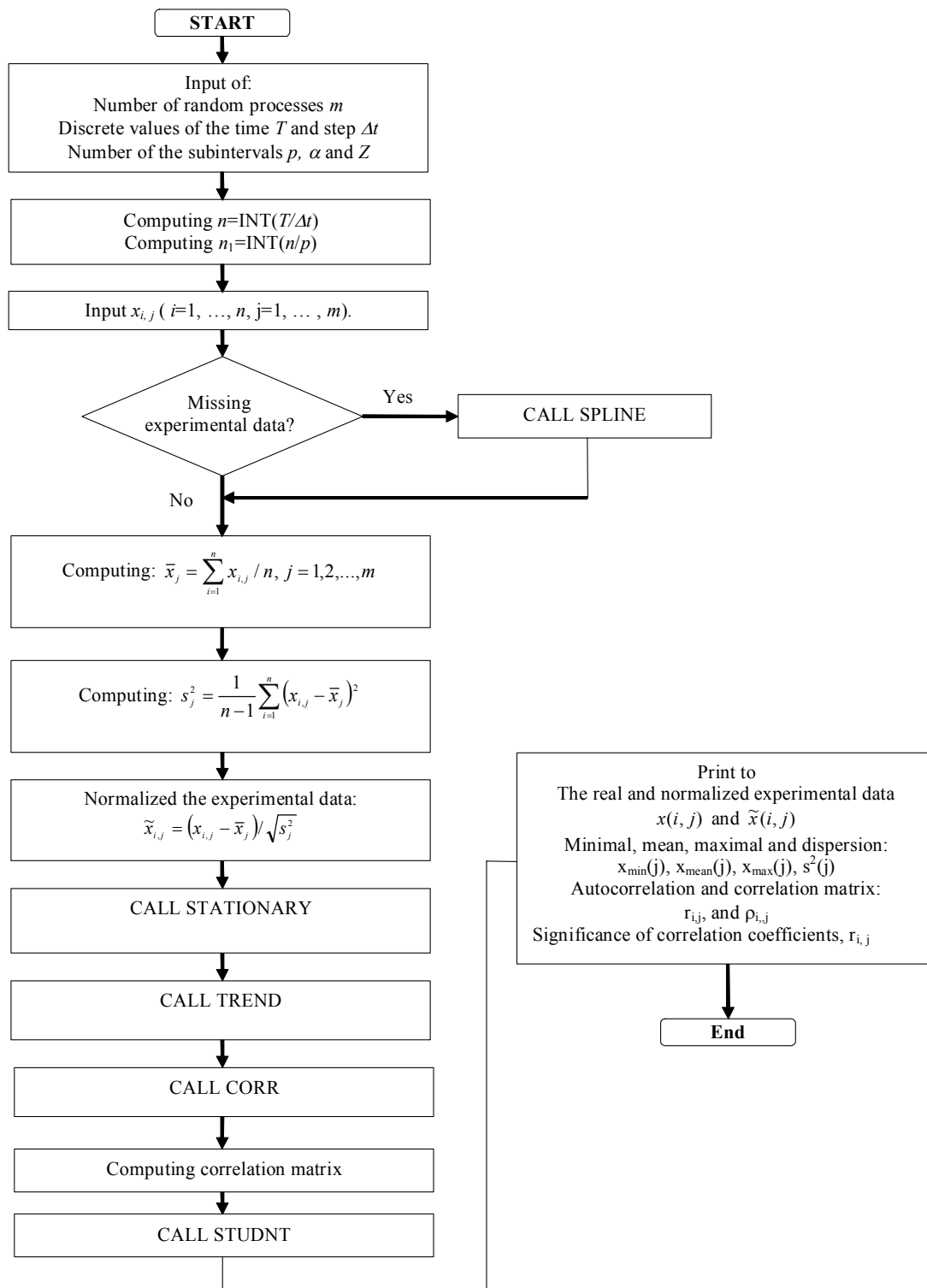


Figure 1. Block scheme of the algorithm

4. AN APPLICATION OF REGRESSION ANALYSIS FOR MODELLING OF FOREST FIRES

4.1. An application for annual burnt areas by forest fire in the National parks in Thailand

Fire is and has been, for centuries, a part of terrestrial environments of the world. Consequently biotic communities adapt and compensate for this factor just as they do for temperature or water. Yet, as with most environmental factors, man has greatly modified its effect, increasing its influence in many cases and decreasing it in others. Through careless behavior, man has often so increased the effect of fire that a productive environment, is destroyed or injured [20].

The parks in Thailand are administrated by the *National Park, Wildlife and Plant Conservation Department* (DNP), which is part of the *Ministry of Natural Resources and Environment* (MONRE). The department was newly created in 2002, and took over the national parks from the Royal Forest Department of the Ministry of Agriculture.

The used information received from the Forest Fire Control Division National Park, Wildlife and Plant Conservation Department in Thailand [20, 21].

Table 1 – Fire Statistics (Annual burnt areas by forest fire)

Year	1985	1986	1992	1993	1994	1995	1996
Area burnt by forest fire /ha	3535110.00	3797289.00	2030160.00	1459617.00	763648.0	643799.00	490303.00
Year	1997	1998	1999	2000	2001	2002	2003
Area burnt by forest fire/ha	660208.00	1145452.00	293480.00	93324.00	76189.00	139389.00	15763.68
Year	2004	2005	2006	2007	-	-	-
Area burnt by forest fire/ha	32281.28	30284.16	8621.60	18728.64	-	-	-

From 1999 to 2002 the assessment of Burned Forest Area were received using Remote Sensing and GIS. From 2003 to 2007 - Data from forest fire control station.

In Figure 2 annual burnt areas by forest fire are presented. In the figure we also present the regular trends, and model data developed by the modified method of regression analysis.

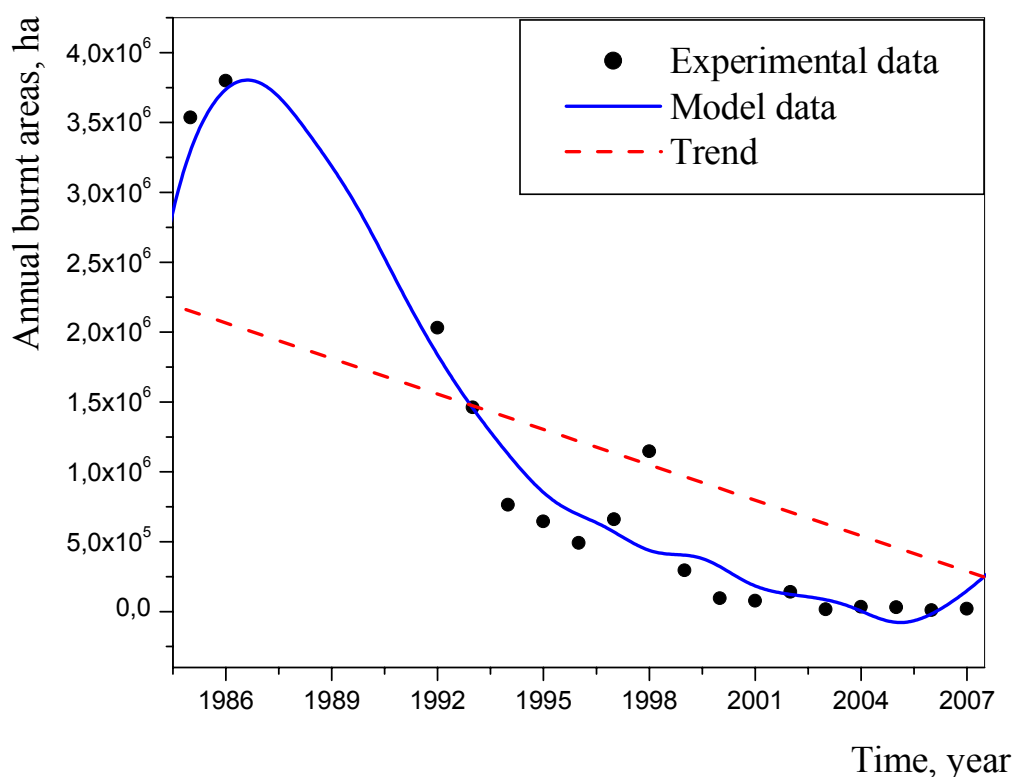


Figure 2. Dynamic of the annual burnt areas by forest fire in the National parks in Thailand

The figure shows tendencies to decrease of the burnt areas of the National parks in Thailand. This is a fact of both indexes: increase of ability to master the fires, and developing of the contemporary method for the forest fire prevention. Forest fire prevention and rescue job stresses the significance of fire prevention. Rescue plans are strong in advance to stronger various forest protection measures, maintain fire prevention and fire fighting facilities and equipment, properly train fire-fighting units, and increment mobilization activity.

4.2. An application for the rate of spread of the Sundance fire

The Selkirk Mountains still show scars from the devastating effects of the Sundance fire. The fire started on August 23, 1967 with a lightning strike on Sundance Mountain near the Sundance lookout tower in Bonner County. The mountain is 6,298' high and is located four miles east north east of Coolin on Priest Lake. The initial blaze was contained after burning 35 acres but it was not completely extinguished. One week after the initial blaze the winds increased and fanned the smoldering flames into action. The fire jumped the lines and burned two thousand acres by August 30. When things looked as bad as they could get the worst possible thing happened. The summer had been particularly hot and dry and there had been little or no rain. High winds hit the area and some observers said that it was as if the forest exploded in front of the wind driven flames. The fire moved with such force that on September 1 it traveled approximately sixteen miles in nine hours, destroying over 55 thousand acres of land and about 10 million board feet of lumber. In the Pack River Valley the fire created its

own winds causing an inferno known as a "fire storm." The winds were strong enough to snap large trees and enough heat was generated to split large granite boulders. At the time the Sundance fire was called the most destructive fire in Idaho in 50 years. There were reports that an even more dangerous fire had been avoided. At the same time the Sundance fire was burning there was a second fire burning out of control about 30 miles north of Trapper Peak. There was also a third blaze on Caribou Creek that had been confined to 30 acres. If the Caribou Creek fire had gotten out of control the three fires would most likely have merged and much of North Idaho would not be the place of beauty it is today [22].

Table 2 – Dynamic of the rate of spread of the Sundance fire (a wind-driven fire) in hours

Hour	0	1200	1400	1600	1700	1800	1900	2000	2050	2100	2200	2350	2400
Rate of spread	0.00	0.25	0.70	1.60	0.30	2.40	1.00	3.50	6.15	2.5	2.00	0.50	0.10

In Figure 3 Dynamic of the rate of spread of the Sundance fire (a wind-driven fire) in hours. In the figure we also present the regular trends, and model data developed by the modified method of regression analysis.

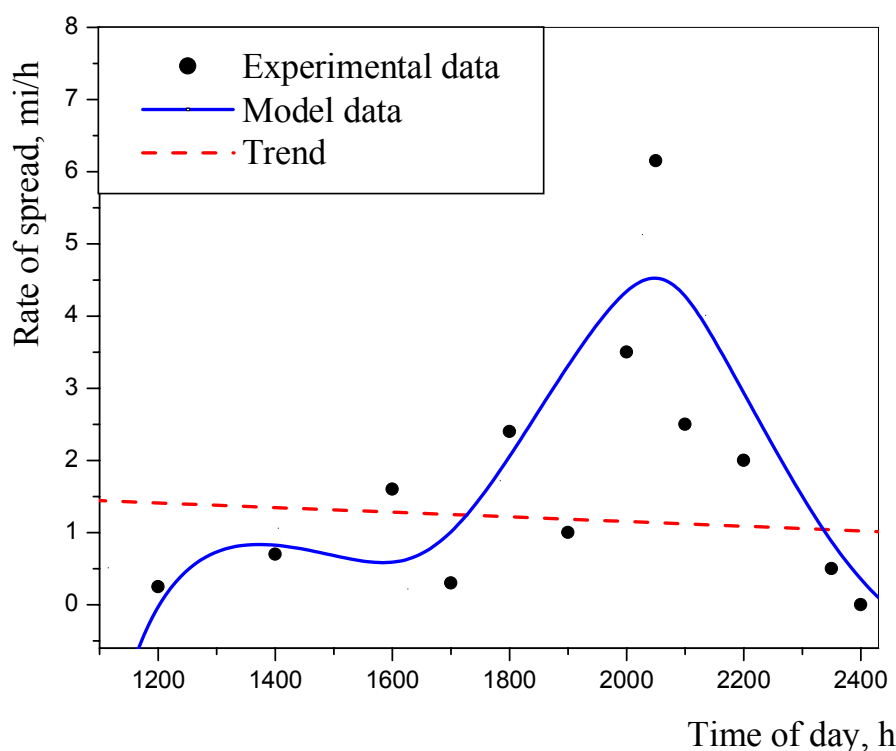


Figure 3. Dynamic of the rate of spread of the Sundance fire (a wind-driven fire) in hours

Figure 1 shows that the the rate of spread of the Sundance fire has tendencies to decrease in the time. At the 2000 hour there was a big pick, that was raise to 6 mi/h. After that the rate has a steadfast trend to decrease and the fire disappeared.

6. CONCLUSIONS

1. An algorithm and program for statistical treatment and analysis of experimental observation for the forest fires are developed. The statistical data treatment is used at modelling of the area burnt by forest fire in the national parks in Thailand. The program can be used at the statistical data treatment in other anagical problems.
2. From developed investigation it shown the offered regression model for the forest fires it can be shown they can be used for analysis of information, for analysis of the condition of the forest fires, for assessment of the anthropogenic impact, for assessment of risk situation etc. The offered regression models for the forest fires can be used for modelling of other ecosystems.
3. One from basic defects of the regression analysis is that it is rather sensitive toward the premises for its using. The mistakes in the input variables conduct to considerable mistakes in of the regression coefficients the determination as sometime can reach even sometimes change a sign of the coefficients. It must foresee the regression analysis decides the problem for *approximation* in the given area of the space of the input variables, definite from experimental take down points. Each effort *extrapolation* to be done out of this area is *ungrounded*. For this aim in the methods of *times series analysis* will be used.

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