A FORECASTING METHOD FOR FOREST FIRES BASED ON THE TOPOGRAPHICAL CLASSIFICATION SYSTEM AND SPREADING SPEED OF FIRE

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Abstract:

On April 27,1993, a forest fire occurred in Morito-area, Manba-city, Gunma-prefecture Japan. Under the prevailing strong winds, the fire spread and extended to the largest scale ever in Gunma-prefecture.

The author chartered a helicopter on May 5, one week after the fire was extinguished, and took aerial photos of the damaged area, and investigated the condition of the fire through field survey and data collection. The burnt area extended over about 100 hectares, and the damage amounted to about 190 million yen (about two million dollar). The fire occurred at a steep mountainous area and under strong winds, therefore, wind and topography strongly facilitated the spreading.

It is the purpose of this paper to report a damage investigation of the fire and to develop the forecasting method of forest fires based on the topographical analysis and spreading speed of fire. In the first place, I analyze the topographical structure of the regions which became the object of this study with some topographical factors, and construct a land form classification map. Secondly, I decide the dangerous condition of each region in the land form classification map according to the direction of the wind and spreading speed of fire. In the present paper, I try to forecast forest fires in Morito area, and the basic results for the forecasting method of forest fires were obtained with the topographical classification system and spreading speed of fire.

1.Introduction

There are a lot of forest fires every year in Japan. To prevent forest fires is very important in terms of defense of personal property, preservation of forest and earth environment etc. There are two methods for the prevention of forest fires. One is to stop an outbreak of fire, and the other is the prevention of fire spread. This paper focuses on the prevention of fire spread.

The fire spread of forest fires is strongly influenced by topography and wind. It is the purpose of this paper to develop the forecasting method of fire spread, based on the topographical analysis and spreading speed of fire. In the case study, this paper treated the forest fire in Manba-city, Japan.

2.Outline of the forest fire and Manba-city

(1)Outline of Manba-city

Manba-city has forestry as the chief industry. There are a lot of artificial sugis and hinokis. Topography in the fire damaged area is a steep mountainous region with a hight about 1,000m.

(2)Outline of the forest fire

-Time of fire outbreak:11:35,April 27,1993

-Time of extinguishing of fire:13:40,April 28,1993

-Forest type:Sugi(20 ~ 45 years of growth), hybrid trees(30 ~ 45 years of growth), natural forest 30%, artificial forest 70%

-Burnt area: About 100 ha

-Damage amounted: About two million dollars

-Outline of the fire fighting actions

Fire fighting actions were done by the fire brigade on the ground and in the air

(3)Weather observation information at fire time

There is Manba Meteorological Observatory near the burnt area ;however it is in a bad position because it is enclosed by high mountains and buildings. So this paper shows weather observation data of Shimokubo-dam Meteorological Observatory and Fujioka Meteorological Observatory in Table 1. Shimokubo-dam Meteorological Observatory is about 10 km from the burnt area and Fujioka Meteorological Observatory is about 23 km from the burnt area. From information of Table 1, the wind suddenly became strong from a few minutes before the time of fire outbreak and the wind direction changed from north to west. Most strong wind blowed from about 8m/s to 9m/s of northwesterly and westerly wind from about 12:00 to 14:00. Between about 12:00 and 14:00, wind velocity became a little weakly.

Between about 18:00 and 9:00 of next day, wind velocity became windless.

Table 1 Wind direction and wind velocity at fire time

	Wind direction (16 direction)			Wind velocity (m/s)		
Time	Manba	Shimokubo	Fujioka	Manba	Shimokubo	Fujioka
April 27						
8	NE	NNW	WSW	1	1	0
9	E	ENE	SE	1	5	0
10	SW	ENE	SSE	2	3.5	1
11	WSW	NW	NW	4	7	6
12	WSW	NW	W	6	10	7
13	WSW	NW	NW	5	8	4.5
14	WSW	NW	WNW	5	7.5	7
15	WSW	WNW	NNW	4	6.5	6.5
16	WSW	NE	NE	4	4	4.5
17	WSW	ENE	NNE	4	4	4
18	W	W	NNE	1	1	4
19	ESE	N	NNE	3	2	6.5
20	ENE	SE	NNE	2	1	5
21	E	SSW	NNE	2	2	3.5
22	···	W	N	0	1	3.5
23	···	NW	NW	0	1	2
24	···	WNW	NNW	0	2	3
April 28						
1	···	NW	NNW	0	1	3.5
2	···	NW	NW	0	2	3
3	SW	NE	WNW	1	1	2
4	···	NW	W	0	0	3
5	···	NE	WNW	0	0	2.5
6	WSW	SE	NW	1	0	2
7	WSW	ENE	NNW	2	0	2
8	···	E	SW	0	2	0
9	E	ENE	E	3	1	1
10	E	ENE	W	5	2	1.5
11	E	NE	NE	4	1	2.5
12	E	NEN	E	4	2	1
13	E	E	SE	2	4	3.5
14	ESE	ENE	SE	4	8	4

(4)Figure of the burnt area

The group of home forestry administrative office, village office,firehouse,police and myself did a field survey at the burnt area. Fig. 1 shows the burnt area that was made by the home forestry administrative office.

(5)Circumstances of the spread of the fire

From my own on-site inspection and movement figure of the fire that was made by the Fujioka firehouse(Fig. 1), circumstances of the spread of the fire are shown as follows.

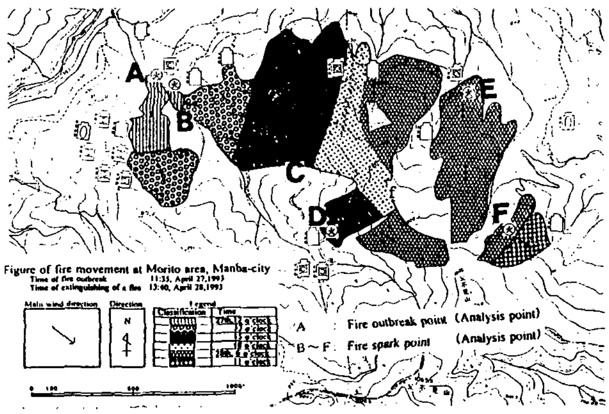


Fig.1 Burnt area, figure of fire movement

The fire that broke out at point a spread and extended to southwest direction. The fire leaped to point b, but the fire was put out at once. The fire that spread to southwest direction extended to the ridge and strongly burned in the slope east of the mountain at about one o'clock pm. The fire that arrived in this side of the ridge leaped to the mountain on the east side across a valley by strong wind. During this time, the fire leaped to the mountain of east. The fire which had leaped had burned down the whole slope of west of the mountain on the east side and leaped to point e and spread to the east direction. At this time from time of fire outbreak was best burning. At the time that fire arrived at the ridge of east side mountain, the wind velocity became weak and the fire certainly did not reach the slope of east of the ridge. Sparks of fire must have been carried by the wind to the ridge.

3.Forecast method of forest fire damaged area based on the topographical classification system

It is the purpose of this chapter to develop the forecast method of forest fire damaged area based on the topographical analysis. In the first place, this paper analyzed the topographical structure of the regions which became the object of this study with some topographical factors, and contracted the land form classification map. Secondly, this paper decided the dangerous condition of each region in the land form classification map according to the direction of the wind.

(1)Sampling of topographic factors

This paper sampled six topographic factors as follows. The analyzed area is within a radius of about five kilometers including the damaged area. The sampling area for sampling of topographic factors is a rectangular area of a radius of 2,250 meters around a center of given measurement point. The value of 2,250 meters is decided by growth curve.

-Slope form: this factor separates even slope form, dent slope form, protrude slope form.
-Angle of inclination: the greatest angle of inclination in the rectangular area.
-Direction of slope: this factor separates eight directions.
-Relief amount: Difference of highest elevation and lowest elevation.
-Elevation
-Existed direction of highland: this factor separates eight directions.

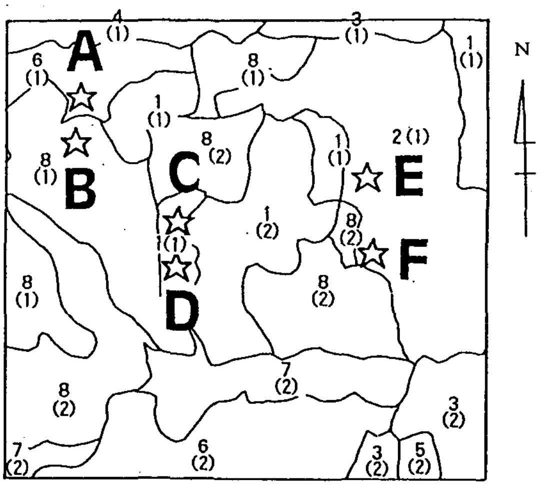
(2)Method of the topographical classification system

This paper did quantification 3 to analyze the principal components of the six topographic

Table 2 The characteristic quantities of topographic factors in the first principal component

	Elevation	Slope form	Elevation	Relief amount	Angle of inclination	Relief amount	Elevation	Angle of inclination	Slope form	Relief amount	Angle of inclination	Relief amount	Slope form	Elevation
Characteristic	0 · 450	凸	450 · 590	611 · 5000	7.6 · 15.0	560 · 611	590 · 780	1.4 · 3.0	⊿	515 · 560	3.1 · 7.5	0 · 515	凹	780 · 5000
Characteristic quantities	1.54	1.15	1.02	0.43	0.41	0.28	0	- 0.10	- 0.21	- 0.33	- 0.90	- 1.02	- 1.39	- 1.85

factors. In this place, this paper used the hypothesis that principal components of topography which influence wind distribution are: a principal component of gentle rise and fall or not "principal component of land form" ,and a principal component of inclination direction of land by quote from my study results on this subject. Table. 2 shows the characteristic quantities of topographical factors as regards land, that is to say slope form, angle of inclination, relief amount, elevation in first principal component arranged in order of size. From this result, the relief amount becomes small value as the elevation increased; that is to say, become land of gentle rise and fall. In this paper, the first principal component is principal component of land form, and the second principal components and the fourth principal component are principal components of inclination direction of land. This paper made a land form classification map for wind force of Manba-city (See Fig. 2). In this figure, a figure in parenthesis, (1) is a steep topography and (2) is gentle topography and a figure in not parenthesis, and 1 is north, 2 is northeast, 3 is east, 4 is southeast, 5 is south, 6 is southwest, 7 is west, 8 is northwest direction inclination topography.



Legend
Inclination direction of land :
1 North, 2 Northeast, 3 East, 4 Southeast, 5 South, 6 Southwest, 7 West, 8 Northwest
land form :
(1) Steep Topography, (2) Gentle Topography
☆ A Fire outbreak point (Analysis point)
☆ B ~ F Fire spark point (Analysis point)

Fig.2 Land form classification map for wind force, points of fire outbreak and spark of a fire

(3)Making forest fire risk district sectional map drawn by analyzing topography

Fire risk on each district sectional areas in the land form classification map for wind force were analyzed based on the wind direction at the fire. Intention of the risk judgment are shown as follows and the risk judgment is shown in Table 3.

(a) Relative degree of wind force based on the inclination direction of land were judged by conical land form model shown in Fig.3, that is to say land form was separated by eight

inclination directions and the relative fire risk of each districts were judged .
(b)Gentle topography region is more dangerous than steep topography region, because gentle topography region is more likely to catch fire than steep topography region.
(c)From combination of (a) and (b), relative fire risk judgment was made.
(d)Fire risk showed six grades.
Fig. 4 shows fire risk district sectional map drawn by analyzing Fig.2 based on the southwest wind direction. This method can draw fire risk district sectional map for any wind direction.

4.Forecasting method for forest fire damage forecast district

This paper made the sectional map of fire spread forecast district by analyzing fire spread direction, spread speed, spread times and spread distance based on the fire risk district sectional map analyzed based on the topography.

(1)Calculation of fire spread direction, spread speed, spread times and spread distance.
This paper calculated fire spread direction, spread speed, spread times and spread distance. The results are shown in Table.4.

(2)Making of sectional map of fire spread forecast district.
Sectional maps of fire spread forecast district were made for fire outbreak point and on each fire spark point. The area was decided by main fire spread distance, side fire spread distance and opposite fire spread distance. By way of example, a sectional map of fire spread forecast district for point C is shown in Fig.5. Fig.6 shows a sectional map of fire spread that combine map from

Table 3 Fire risk judgment analyzed based on the topography

Fire risk	Characteristic of district
1	There are highlands on the main wind direction side to the measurement point, and a steep topography area.
2	There are highlands on the main wind direction side to the measurement point and a gentle topography area, as well as highlands on the main wind direction on the opposite side to the measurement point and a steep topography area.
3	There are highlands on the main wind direction opposite side to the measurement point and a gentle topography area, as well as highlands on the main wind direction diagonal opposite side to the measurement point and a steep topography area beyond which there are not highlands.
4	There are highlands on the main wind direction diagonal opposite side to the measurement point and a gentle topography area, as well as highlands on the main wind direction diagonal side to the measurement point and a steep topography area.
5	There are highlands on the main wind direction diagonal side to the measurement point and a gentle topography area, as well as highlands at right angles to the main wind direction to the measurement point and a steep topography area.
6	There are highlands at right angles to the main wind direction to the measurement point and a gentle topography area.

Note: Area of large numerical value of fire risk is more dangerous than area of small numerical value of fire risk.

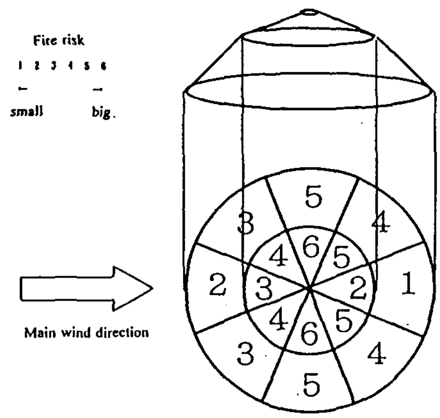


Fig.3 Fire risk judgement analyzed based on the topography (schematic diagram)

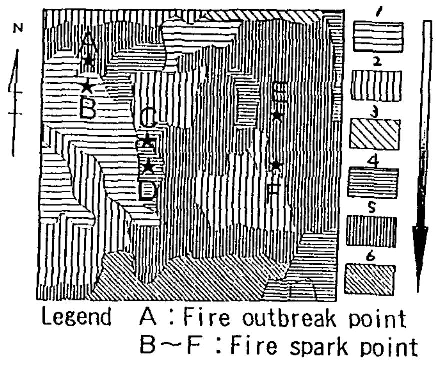


Fig.4 Fire risk district sectional map analyzed based on the topography (wind direction: south west)

Table 4 Fire spread direction, velocity, times and distance

	Fire outbreak date	Fire spark time(o'clock)	Wind directiom	Main fire spread direction(deg)	Main fire spread velocity(m/h)	Side fire spreading speed(m/h)	Opposite fire spread velocity(m/h)	Fire spread time(h)	Main fire spread distance(m)	Side fire spread distance(m)	Opposite fire spread distance(m)
A	Apr. 27 '93	12	NW	142	498	55	10	4	1992	220	40
B	Apr. 27 '93	13	NW	143	462	62	13	3	1386	186	39
C	Apr. 27 '93	18	W→NW	137	134	91	67	9	1206	819	603
D	Apr. 27 '93	15	W	137	208	79	37	5	1040	395	185
E	Apr. 28 '93	6	SE	223	79	43	27	9	711	387	243
F	Apr. 28 '93	11	NE	217	273	96	42	4	1092	384	168

A~F : Fire outbreak and fire spark points(Analysis points)

point A to point F.

(3) Making of sectional map of fire damage forecast district.

This paper made a map that combines sectional map of fire spread forecast district and fire risk district sectional map, analyzed based on the topography of each wind direction at the time of fire outbreak and spark from point A to point F. Fig.7 shows the map on point C.

This paper assumed that the fire at the fire outbreak point and fire spark points will spread to areas of more fire risk than area of the point. For example in point C, The area that has a high fire risk area than area of point C and area that borders on area of point C exist on the east of point C in Fig.7, so the fire should spread the area east of point C. Fig.8 shows the sectional map of fire damage forecast district at the point C. Fig.9 shows the sectional map of fire damage forecast district that combined the point A to point F into one. Furthermore, there is figure of burnt area in Fig.9.

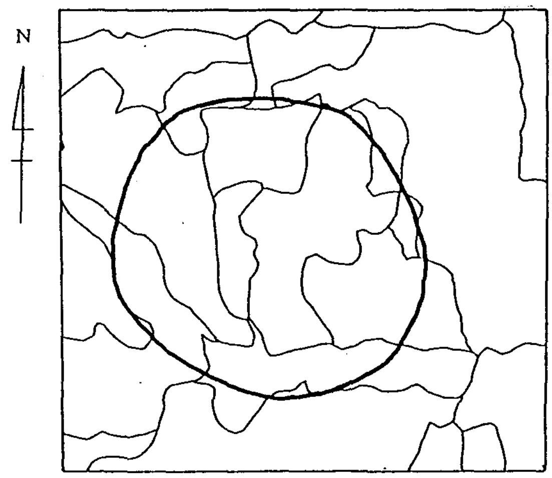


Fig.5 Sectional map of fire spread forecast district (point C)

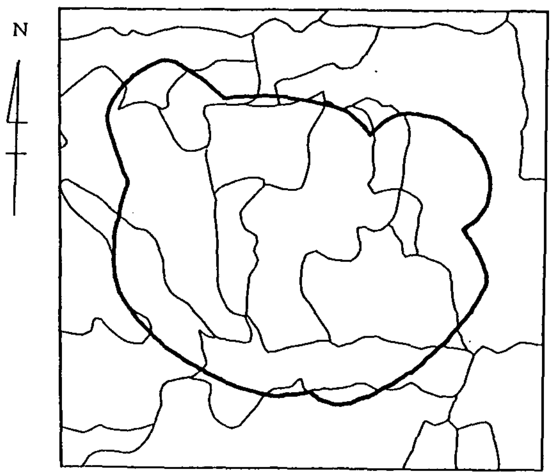


Fig.6 Sectional map of fire spread forecast district (whole area)

(4) Discussion and making of sectional map of the final fire damage forecast district.

In the Fig.9, the burnt area is in a sectional map of the fire damage forecast district, but the accuracy is not sufficient. The cause of this error will be the error of establishment of wind direction and to the lack of careful consideration to the fire actions. In this paper, wind direction was established by the wind direction at the fire spark time of the point, but the wind direction changed every moment. Especially, Wind direction changed remarkably after the fire spark time of point C. Then, this paper investigated for the second time about the wind direction at point C. As a result, just fire spark time at point C is the west wind, but after that wind direction can be seen changed from the west wind to the north west wind. So this paper corrected the west wind to the north west wind at the point C. The result is shown in Fig.10. Furthermore, fire of fire spark point B was got under control at once. So This paper thinked that the area of point B was damaged only just the circumference of point B and corrected Fig.10 to Fig.11. Fig.11 shows the sectional map of the final fire damage forecast district.

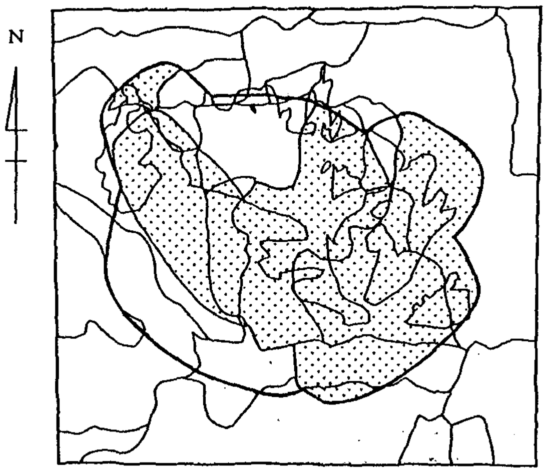


Fig.9 Sectional map of fire damage forecast district (whole area)

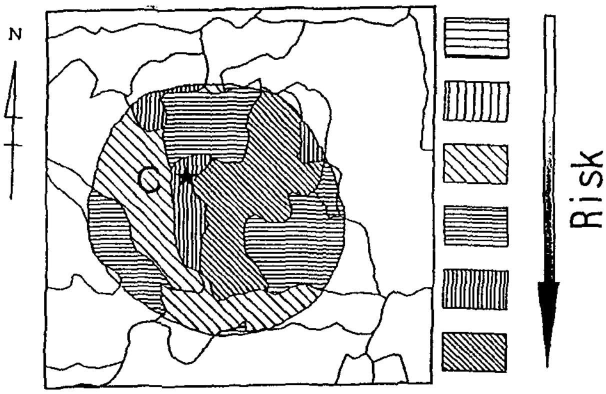


Fig.7 Combined map of sectional map of fire spread forecast district and sectional map of fire risk district (point C , wind direction: west)

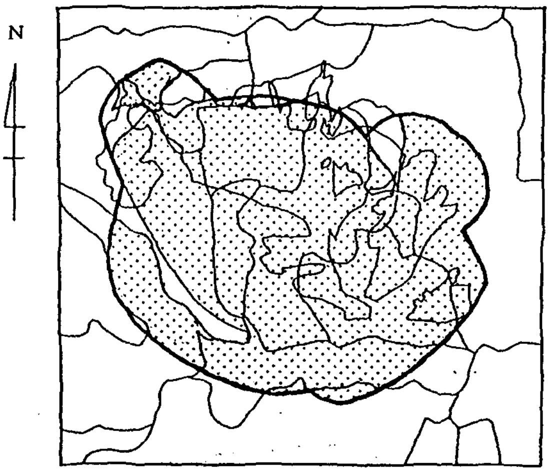


Fig.10 Sectional map of fire damage forecast district (whole area)

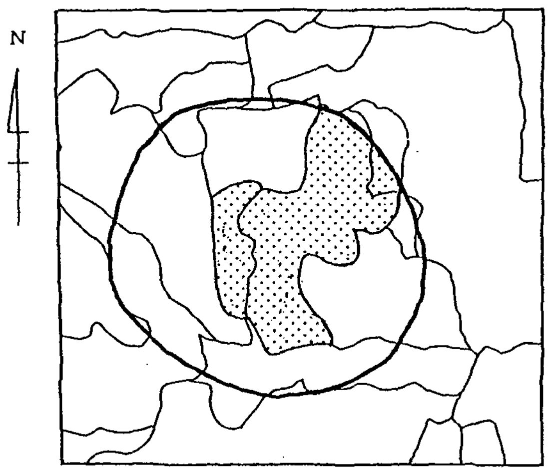


Fig.8 Sectional map of fire damage forecast district (point C)

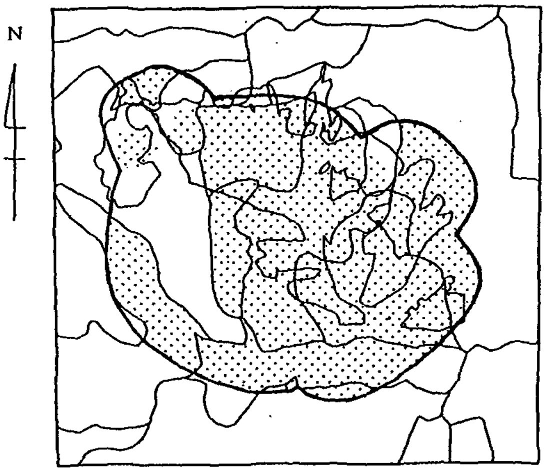


Fig.11 Sectional map of the final fire spread damage district, with consideration to action of fire fighting at point B (whole area)

5. Conclusion and consideration

The results of this paper are as follows:

① Although there are some problems, validity for the forecast method of forest fires in this paper could be confirmed. Especially this method can be use for all wind directions.

② One of the useful methods to get more high accuracy should establish exact wind direction and exact elements of fire fighting action.

③ This paper did not give consideration to differences of vegetation. After this ,difference of vegetation should give consideration in analysis.

④ A study of a spread forecast method of forest fires is very difficult because there are many complicated elements. However, the method of this paper will apply to another forest fire and improve.