RESEARCH BASED ON GEOGRAPHICAL AND WIND FEATURES WHICH RELATE TO THE FORECAST OF THE SPREADING SPEED OF FOREST AND FIELD FIRES

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ABSTRACT

There are many forest fires every year in Japan. The prevention of forest fires is very important in terms of defense of personal property, preservation of forest and protection of the environment. 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 spread of forest fires is strongly influenced by topography and wind. It is the purpose of this paper to develop a forecasting method for forest fires based on the topographical analysis system and spreading speed of fire. In the case study, this paper treated the forest fire in Manba City and Takehara City, Japan.

Keywords: Forest fires, topography, disaster, wind, GIS.

INTRODUCTION

Severe forest fires occurred at Manba City, Gunma Prefecture, Japan in April and at Takehara City, Hirosima Prefecture in August 1994. Fanned by strong winds, leaping flames spread and expanded in both areas, the damages amounted to the highest ever recorded in the respective prefectures. In Takehara City, the loss caused by the fire ran into approximately 500 million yen (about 4.2 million dollars), one of the severest forest fires in Japan. In the forest fire at Manba City, the author chartered a helicopter to take aerial photographs of the stricken areas and to perform an on-the-spot survey and data collection. Also carried out was a minute site survey of the forest fire at Takehara City. The results of these surveys and investigations suggested that there was a great topographic influence on the wind direction and velocity contributing to the spread and expansion of fire. This paper describes what topographies have impacts and how they exert certain influences on the spread and expansion of forest fire, and submits a report on the method of topographic classification that was developed based on the present results. The analysis began with the preparation of a detailed map of disaster areas based on aerial photographs and site surveys. Six topographic factors are then extracted from the numerical topographic maps such as altitude, slant and relief in the regions forming the subject of study including the disaster areas. The quantification theory type III, one of the statistical techniques, is employed to analyze the topographic structure of the regions and to prepare a wind force/topographic classification map. Lastly, the spreading direction, velocity and distance are calculated on the basis of the wind direction and velocity as collected to evaluate the potential risk of the respective regions in the wind force/topography classification map. Application of the techniques described in this paper to the forest fires in Takehara City and Manba-Machi gave satisfactory results. The topographical features are shown to have great impact on the spread of forest fire. This paper confirms that the most important information is the topographic geometries, representing how steep or moderate the topographies are and in which directions the topographies are slanted. This topographic information, together with the wind direction and velocity turned out to allow the prediction of disaster zones of forest fires.

Outline of the forest fire

Outline of Manba City and Takehara City[1,2,3]

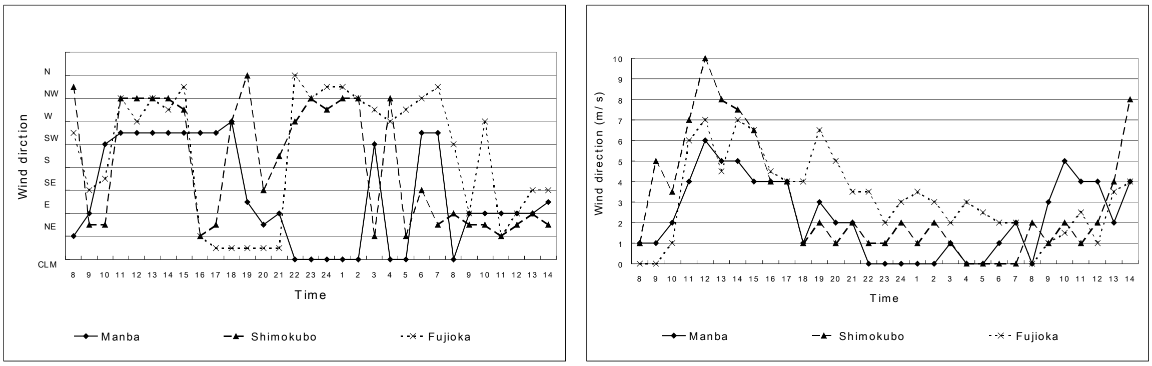
Manba City has forestry as the chief industry, with many sugis and hinokis (Japanese cedar and cypress) plantations. Topography in the fire damaged area consisted of a steep mountainous region with a height about 1,000 m in Manba-city. Takehara City is enclosed by the bay on one side and three sides are enclosed by the mountains of height from 200 to 300 m. Table 1 shows the outline of the forest fire.

Table 1: Outline of the forest fire.

	Manba	Takehara
Topography in the fire damaged area	Steep mountainous region with a height about 1,000 m	Three ways are enclosed by the mountain of height from 200 to 300m and is enclosed by the bay on the inside
Time of fire outbreak	11:35, April 27, 1993	15:33, August 11, 1994
Time of extinguishing of fire	13:40, April 28, 1993	14:00, August 20, 1994
Forest type	Sugi (20~45 years of growth) Hybrid (30~45 years of growth) Natural forest 30% Managed forest 70%	Coniferous forest 17% Hybrid forest 83% Natural forest 82% Managed forest 12%
Burnt area	About 100 ha	About 378 ha
Damage amount	About two million dollars	About 4.2 million dollars
Outline of the fire fighting actions	Fire fighting actions were done by the fire brigade on the ground and in the air	Fire fighting actions were done by the fire brigade on the ground and in the air

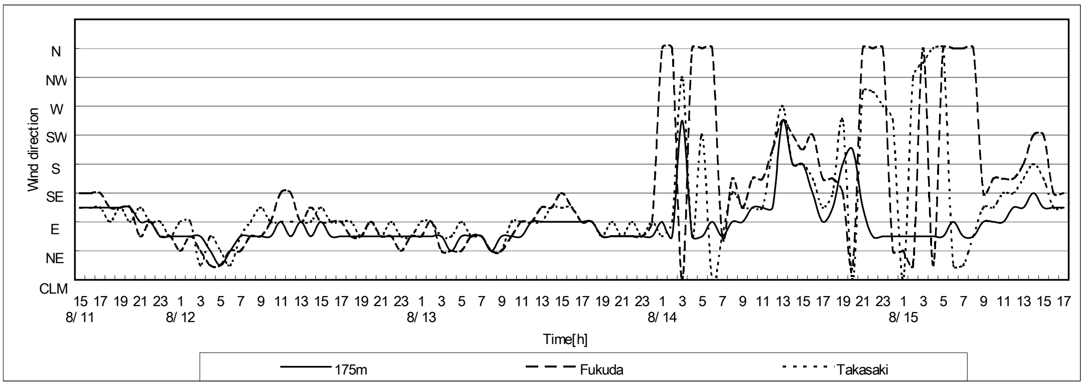
Weather observation information at fire time

Figure 1 and Figure 2 show the data of the wind direction and the velocity of wind in Manba and Takehara.

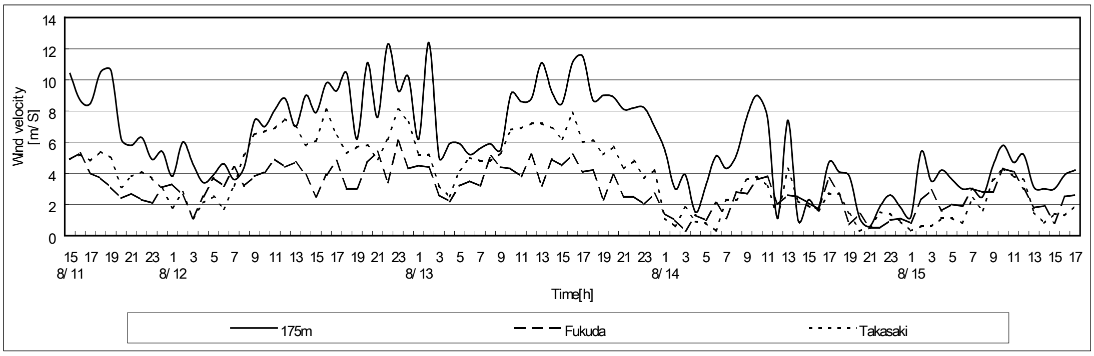


(a) Wind direction (b) Wind velocity

Figure 1: Time change in wind direction and wind velocity of the forest fire of Manba.



(a) Wnd direction



(b) Wind velocity

Figure 2: Time change in wind direction and wind velocity of the forest fire of Takehara.

Figure of the burnt areas

Figure 3 is a sketch of the burnt area prepared by the Home Forestry Administrative Office in Manba. Figure 4 is a sketch of the burnt area prepared by The Takehara Firehouse.

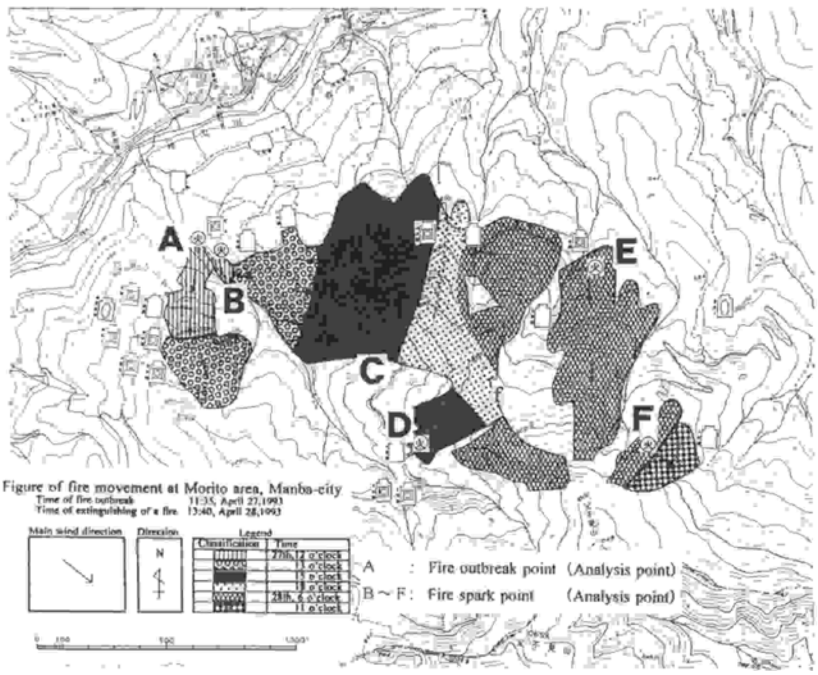


Figure 3: The burnt areas at Manba.

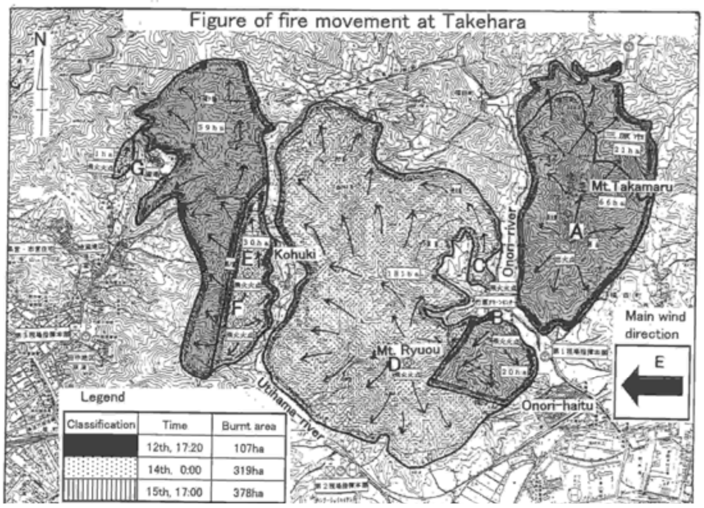


Figure 4: Fire movement at Takehara.

Circumstances of the spread of the fire

Manba

Figure 3 and Table 2 show the circumstances of the spread of the fire. The fire that broke out at point A spread and extended to the southwest. The fire leapt to point B, but the fire was put out at once. The fire that spread to the southwest extended to the ridge and strongly burned in the slope east of the mountain at about 13:00. The fire that arrived on this side of the ridge leapt to the mountain on the east side across a valley, driven by strong winds. During this time, the fire leapt to the mountain in the east. The fire which had leapt had burned down the whole slope west of the mountain on the east side and leapt to point E and spread to the east. At this time the fire outbreak was at its worst. At the time that fire arrived at the ridge of the east side mountain, the wind velocity became weak and the fire certainly did not reach the slope east of the ridge. Sparks of fire must have been carried by the wind to the ridge.

Table 2: Spreading situation of the forest fire of Manba.

Point	Fire outbreak date	Wind direction	Wind velocity (m/s?	Spread time (h)	Repressed time	Note
A	April 27 11:35	NW	8.0	4.0	Time that all fires were repressed. 28th 13:40	Fire outbreak
B	April 27 13:00	NW	7.3	3.0		spark
C	April 27 18:00	W	1.4	9.0		spark
D	April 27 15:00	W	3.5	5.0		spark
E	April 28 6:00	SE	2.2	9.0		spark
F	April 28 11:00	NE	3.8	4.0		spark

Takehara

Figure 4 and Table 3 show the circumstances of the spread of the fire. The fire broke out from Mt. Takamaru (point A) on August 11, 1994 at 15:33, and leapt to the east side slope of Mt. Ryuou (point B) before the wind from the east reached about 10 m/s. The fire would burn 86 ha on the Takehara-city side and 21 ha on the Mihara-city side by 17:20 on the 12th, and be repressed temporarily. However, the fire which remained under the grass was fanned by strong winds, and the fire rekindled from two places at about 23:30 on the 12th. Afterwards,the fire leapt to the west side of Mt. Ryuou (points E,F,G). The fire burnt 212 ha by midnight on the 14th. 59 ha was burnt down by 17:00 on the 15th.

Table 3: Spreading situation of the forest fire of Takehara.

Fire outbreak date	Wind direction	Wind velocity (m/s)	Spread time (h)	Change in wind direction (1)	Wind direction	Wind velocity (m/s)	Spread time (h)	Change in wind direction (2)	Wind direction	Wind velocity (m/s)	Spread time (h)	Repressed time	Note
August 11 15:33	E	6.8	11.5	12th3?00	NE	4	4	12th 7?00	E	5.6	2.9	12th 9?55	Fire outbreak
August 11 23:27	E	4.9	3.6	12th 3?00	NE	4	4	12th 7?00	E	5.6	2.9	12th 9?55	Spark
August 12 23:26	E	8.2	24.6	NO change in the wind direction								14th 0?00	Spark
August 13 1:00	E	8.1	23	NO change in the wind direction								14th 0?00	Spark
August 13 16:00	E	6.7	17	14th 9?00	SE	4.3	11	14th 20?00	E	2.8	13	15th 9?00	Spark
August 13 16:00	E	6.7	17	14th 9?00	SE	4.3	11	14th 20?00	E	2.8	13	15th 9?00	Spark
August 13 17:10	E	8.7	6.8	NO change in the wind direction									Spark

The topographical classification system for the forecast method of forest fire damage

In this chapter, a topographical classification system for the forecast method of forest fire damaged areas is developed. Firstly, the topographical structure of the regions were analysed, identifying important topographical factors, and allowing a land-form classification map to be drawn. Secondly, the dangerous conditions of each region in the land-form classification map were identified according to the direction of the wind.

Sampling of topographic factors

Six topographic factors were sampled as follows. The analysed areas were within radii of about 5 km and 7 km including the damaged area in Manba and Takehara. The area for sampling of topographic factors were rectangular areas of a radii of 2,250 m and 1,750 m around a center of a given measurement point in Manba and Takehara. These values were decided by a growth curve.

- Slope form: this factor separates even slope form, dent slope form, and 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.

Method of the topographical classification system

Table 4: The characteristic quantities of topographic factors in the principal component

(Takehara).

	Relief amount	Elevation	Angle of inclination	Slope form	Relief amount	Elevation	Slope form	Elevation	Elevation	Relief amount	Slope form	Angle of inclination	Relief amount	Angle of inclination
Characteristic	0 ? 180	0 ? 25	1.4 ? 3	flat	180 ? 260	25 ? 64	Convex	64 ? 160	160 ? 5000	260 ? 320	Concave	3.1 ? 7.5	320 ? 5000	7.6 ? 15
Characteristic quantities	2.59	1.87	1.53	0.47	-0.49	-0.60	-0.87	-0.88	-0.98	-1.03	-1.04	-1.07	-1.20	-1.27

Quantification type III was used to analyse the principal components of the six topographic factors. This study used the hypothesis that principal components of topography which influence wind distribution are: a component of gentle rise and fall; a component of land form; and a component of inclination direction of land derived from earlier work[4]. Table 4 shows the characteristic quantities of topographical factors as regards land, including slope form, angle of inclination, relief amount, and elevation with first principal components arranged in order of size in Takehara. From this result, the relief amount becomes smaller as the elevation increases. In Takehara, the first principal component is the principal component of land form, and the second principal component and the fourth principal component are principal components of inclination direction of the land. Figure 5 shows the land form classification map for wind force of Takehara.

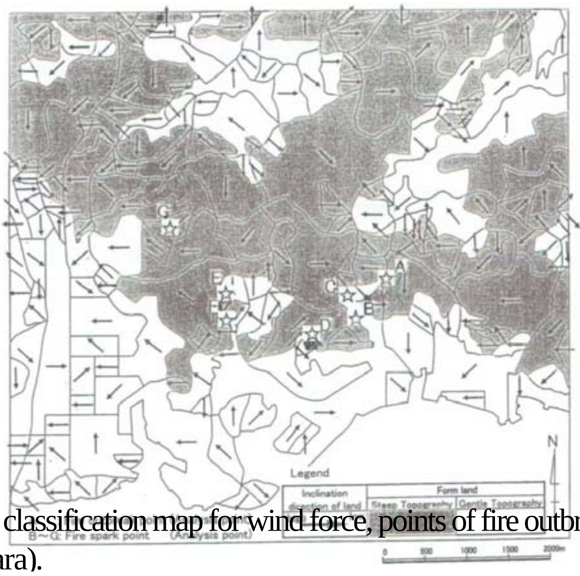


Figure 5: Land form classification map for wind force, points of fire outbreak and spark of a fire (Takehara).

Making a forest fire risk district sectional map drawn by analysing topography

Fire risk on each district sectional area in the land form classification map for wind force were analysed based on the wind direction at the fire. Intention of the risk judgment are shown as follows and the risk judgment in Takehara is shown in Table 5.

(a) Relative degree of wind force based on the inclination direction of land were judged by a conical land form model shown in Figure 6, that is to say land form was separated by eight inclination directions and the relative fire risk of each district was judged.

(b) Figure 7 shows the relationship between the inclination and the velocity of the wind of geographical features concerning the fire spreading velocity of a fire. It was assumed that the risk of steep geographical features was higher in Takehara where the velocity of the wind was small based on this figure. Alternatively, it was assumed that the risk of gentle geographical features was higher in Manba where the velocity of wind was large.

Table 5: Fire risk judgement 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 gentle topography area.
2	There are highlands on the main wind direction side to the measurement point and a steep topography area, as well as highlands on the main wind direction on the opposite side to the measurement point and a gentle topography area .
3	There are highlands on the main wind direction opposite side to the measurement point and a steep topography area, as well as highlands on the main wind direction diagonal opposite side to the measurement point and a gentle 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 steep topography area, as well as highlands on the main wind direction diagonal side to the measurement point and a gentle topography area.
5	There are highlands on the main wind direction diagonal side to the measurement point and a steep topography area, as well as highlands at right angles to the main wind direction to the measurement point and a gentle topography area.
6	There are highlands at right angles to the main wind direction to the measurement point and a steep topography area.

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

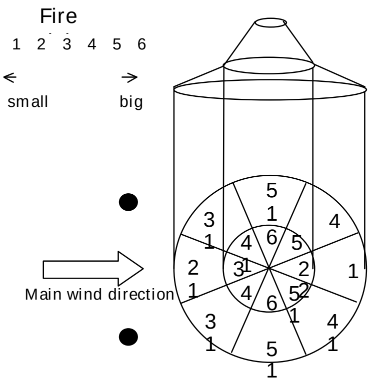


Figure 5: Fire risk judgment analysis based on the schematic diagram topography In (Takehara).

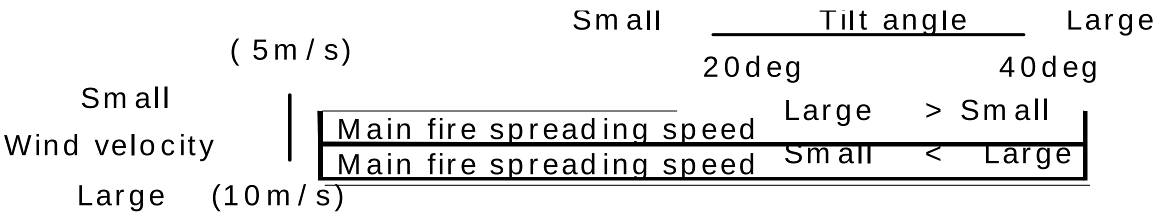


Figure 7: Relationship between tilt angle and wind velocity for main fire spreading speed.

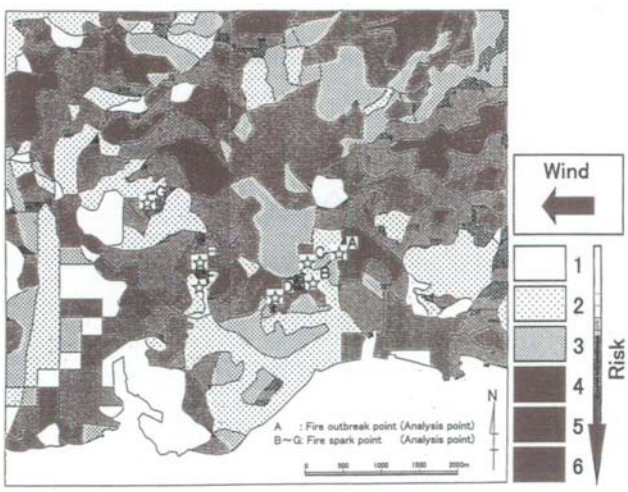


Figure 8: Fire risk district sectional map analysed according to the topography (wind direction-east).

(c) From combination of (a) and (b), relative fire risk judgment was made.

(d) Fire risk showed six grades.

Figure 8 shows the fire risk district sectional map drawn by analysing Figure 5 based on the east wind direction in Takehara. This method can draw fire risk district sectional maps for any wind direction.

Forecasting method for forest fire damage forecast district

The sectional map of fire damage forecast district was made by analysing fire spread direction, spread speed, spread times and spread distance, based on the fire risk district sectional map based on the topography. The example of Takehara is explained as follows.

(1) Calculation of fire spread direction, spread speed, spread times and spread distance[5,6]. This paper calculated fire spread direction, spread speed, spread times and spread distance. The results are shown in Table 6.

Table 6: Fire spread direction, spread speed, spread times and spread distance.

	Fire outbreak date	**Fire spark time**	**Fire spreading time (h)**	**Wind velocity (m/s)**	**Max. inclination direction θ_s (deg)**	**Tilt angle of max. inclination direction S (deg)**	**Wind direction θ_w (deg)**
A	Aug 11 '94	15:33	11.5	6.8	358.0	4.9	270(E)
B	Aug 11 '94	23:37	3.6	4.9	320.9	4.6	270(E)
C	Aug 12 '94	23:36	24.6	8.2	322.2	4.9	270(E)
D	Aug 13 '94	1:00	23.0	8.1	334.1	4.1	270(E)
E	Aug 13 '94	16:00	17.0	6.7	49.5	4.2	270(E)
F	Aug 13 '94	16:00	17.0	6.7	43.3	3.7	270(E)
G	Aug 13 '94	17:10	6.8	8.7	34.7	7.1	270(E)
			Conifer			**Deciduous**	
	Main fire spreading direction θ_E deg)	Main fire spreading speed Ve (m/h)	Side fire spreading speed Vs/h)	Opposite fire spreading speed Vbh)	Main fire spreading speed Ve (m/h)	Side fire spreading speed Vs/h)	Opposite fire spreading speed Vbh)
A	98	-258	-39	-9	-322	-49	-11
B	98	-173	-45	-15	-216	-56	-19
C	95	-329	-34	-6	-411	-43	-7
D	95	-323	-34	-6	-403	-43	-7
E	95	-250	-39	-9	-313	-49	-12
F	95	-251	-39	-9	-314	-49	-12
G	99	-341	-31	-5	-426	-39	-6
	Excluding the forest						
	Main fire spreading speed Ve (m/h)	Side fire spreading speed Vs/h)	Opposite fire spreading speed Vbh)			A G: Fire outbreak and fire spark points	
A	-297	-45	-10				
B	-199	-51	-18				
C	-379	-39	-7				
D	-372	-40	-7				
E	-288	-45	-11				
F	-289	-45	-11				
G	-393	-36	-5				

(2) Sectional maps of fire spread forecast district were made for fire outbreak points 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 A is shown in Figure 9.

(3) A map was made that combines a sectional map of fire spread forecast district and a fire risk district sectional map. The analysis is based on the topography of each wind direction at the time of fire outbreak and spark from point A to point G. Figure 10 shows the map on point A. It was assumed that the fire at the fire outbreak point and fire spark points will spread to areas of more fire risk than the area of the point. For example, in point A the area that has a higher fire risk than the area of point A and the area that borders on the area of point A exist on the north, south and west-southwest of points A (Figure 10). Thus, the fire should spread

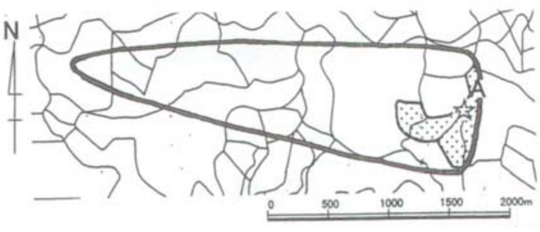


Figure 9: Sectional map of fire spread forecast district (Point A).

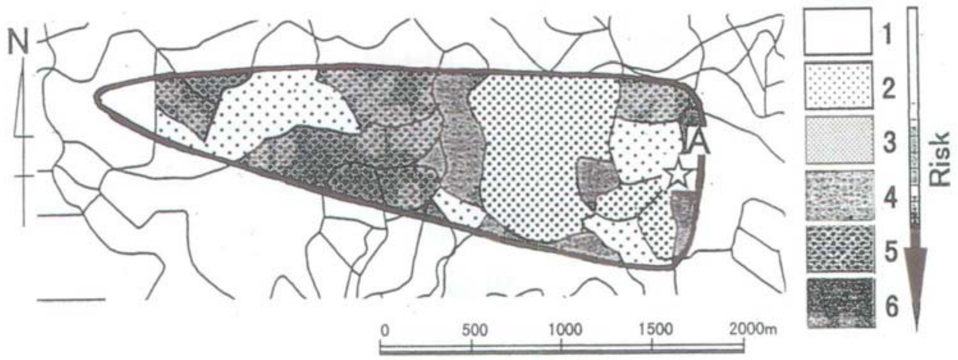


Figure 10: Combined map of sectional map of fire spread forecast district and sectional map of fire risk district (Point A, wind direction : east).

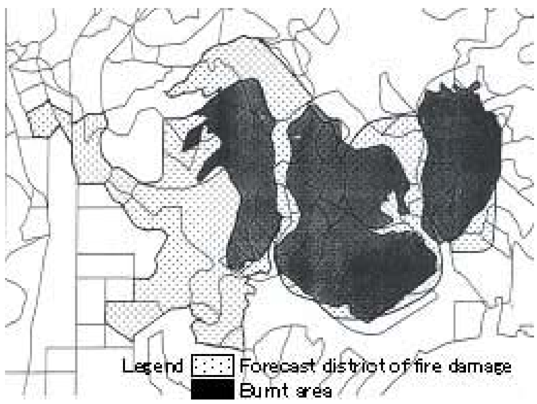


Figure 11: Sectional map of fire damage forecast district (point A).

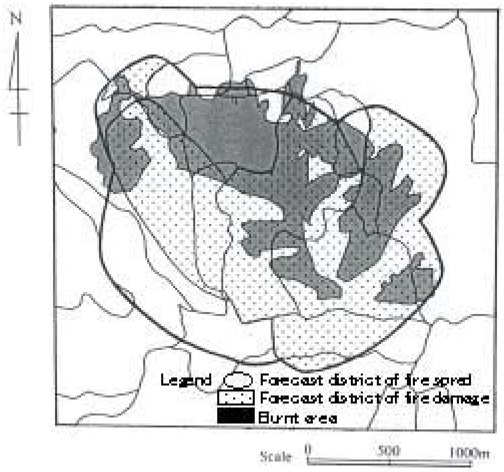


Figure 12: Sectional map of fire damage forecast district (whole area), Takehara.

to these areas from point A. Figure 11 shows the sectional map of fire damage forecast district at point A. Figure12 shows the sectional map of fire damage forecast district that combined points A and G into one. Furthermore, there is figure of burnt area in Figure 12. Figure 13 shows the final map in Manba.

CONCLUSIONS

The results of this paper are as follows:

1. Despite some difficulties, the validity of the forecast method of forest fires in this paper was confirmed. Notably, this method can be use for all wind directions.

2. The topographical features have great impact on the spread of forest fires. It was confirmed that the most important information is the topographic geometries representing how steep or moderate the topography is and in which directions the topographies are slanted. This topographic information, together with the wind direction and velocity turned out to allow the predictioj if zones affected by forest fires.

3. The predictions for Takehara improved when an analytical result of Takehara and Manba were compared. It is thought that the biggest reason for this effect is that the wind direction and the value of the velocity of wind in Takehara were more accurately determined than at Manba. These results show the importance of accurately setting the wind direction and the wind velocity when this technique is applied.

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