ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

Research Progress in the Study of Smoke Spread and Composition of Forest Fires

Qingqing Wang, Zhongliang Gao*, Chenyang Wang He, Yufei Cao, Wentian Yu

Department of Civil Engineering, University of Southwest Forestry University, Kunming, Yunnan, China

Abstract

The smoking spread in forest fires is an extremely complex and variable process, influenced by a variety of environmental factors, and characterized by suddenness and variability, which can intensify the uncertainty of forest fire development, cause casualties, reduce the chance of The smoking spread in forest fires is an extremely complex and variable process, influenced by a variety of environmental factors, and characterized by suddenness and variability, which can intensify the uncertainty of forest fire development, cause casualties, reduce the chance of Based on the research progress of forest fire smoke spread at home and abroad, the research properties of forest fire smoke spread were Based on the research progress of forest fire smoke spread at home and abroad, the research properties of forest fire smoke spread were discussed, and wind speed, terrain, temperature, etc. were selected as the evaluation indicators The impact of each evaluation index is synthesized, and combined with the current scientific and technological equipment for forest fire smoke spread, the impact of each evaluation index on forest fire smoke spread was analyzed. The impact of each evaluation index is synthesized, and combined with the current scientific and technological equipment for fire smoke monitoring, the response strategies such as strengthening smoke monitoring and The influence of each index on forest fire smoke spread was analyzed.

Keywords

Smoke spread; Environmental factors; Evaluation indicators; Smoke monitoring; Personnel escape.

1. INTRODUCTION

In the past decade, China's annual average number of forest fires are higher than 2000, the total surface of forest fires more than 485,000 hectares. Forest fires are characterized by extreme suddenness, destructiveness and more difficult disposal and rescue, which seriously restrict the sustainable development of modern forestry, and timely and effective extinguishing of forest fires can reduce casualties and property losses. The burning of combustible materials in forest fires can release a large amount of harmful gases, smoke concentration, and large particulate matter, which seriously affects the air quality in the area around the fire and indirectly affects the health of the surrounding people, and also seriously threatens the lives of trapped people and firefighters, so it has been a concern to fight fires quickly and effectively and avoid casualties in recent years.

At present, domestic and foreign research on fire smoke spread and smoke release characteristics mainly focuses on engineering applications, such as tunnels, subways, elevator shafts, mines and other fields have accumulated certain research results, but less research on

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

the smoke spread of forest fires. In recent years, with the rapid development of computer technology, simulation technology of fire smoke spread has been improved, and the application of Fluent, FDS, HYSPLIT and other computer simulation software can effectively solve many difficulties in simulation technology in the past. Lu Wei et al.[1]studied the chaotic behavior generated by heat in fire based on the change of Prandtl value of the Lorentz equation, and the results pointed out that the chaotic behavior occurred within a certain range of Prandtl value. Xin Z et al.[2]used FDS simulation software to construct a simplified model of grassland fire in an actual pasture, simulated the three-dimensional numerical spread of grassland fire under different factors, and obtained the change of fire Damoah R et al.[3]used the Lagrangian particle diffusion model FLEXPART to determine the origin and transport of the plume, comparing simulations based on ECMWF and GFS meteorological data, but the final conclusions did not lead to a model more consistent with observations. Luther G et al.[4]used a simple unified hypothesis simulation to study the atmospheric effects of smoke ejection scenarios Smith A K et al.[5]planned to develop a four-dimensional intelligences-based modeling framework and implemented a four-dimensional case study approach for smoke propagation from forest fires, and the simulations yielded realistic spatial patterns of smoke propagation dynamics. Hacking S et al.[6]observed Australian wildfire around 2020 and found that they produced a persistent smoke eddy with a 35km rise and a single stratospheric combustion product from the fire that had a significant effect on many climate-driven stratospheric variables. Godiva A et al.[7]studied forest fire and smoke spread from forest fires in the Siberian region, using remote sensing satellites combined with urban environmental monitoring network data to effectively assess the overall level of pollution caused by forest fires.

2. FACTORS AFFECTING THE SPREAD OF SMOKE FROM FOREST FIRES

2.1. Wind speed

The rate of smoking spread of forest fire is affected by the role of wind is very obvious. Hot air from combustible combustion rises to form a column of smoke, and when it meets cold air, it is easy to form a column of hot and cold air convection smoke, which changes the wind direction and causes changes in the fire, and if the mountainous environment and complex topographic conditions, it is easy to cause accidents. The "3-30" forest fire in Liangshan Prefecture, Sichuan Province, was dominated by flammable vegetation with high oil content and low ignition point, such as Yunnan pine and alpine pine, which was affected by various turbulent flows and cross-mountain air currents after the fire[8] . Permalloy V[9]proposes a new mathematical setup and numerical solution method to solve The study shows that in the absence of wind, radioactive smoke particles are re-deposited on the subsurface after a period of time; as the wind speed increases, the transfer distance of particles in the ground layer is proportional to the wind speed. Alexander et al.[10]uses a Reynolds-averaged Navier-Stokes hydrodynamic model to study the effect of wind and buoyancy The model can be used for semi-qualitative assessment of smoke plume evolution. Wang Xishi et al.[11]studied the fire spread characteristics of two samples of wood surfaces under different wind conditions by simulating wind speed using a combustion wind tunnel combined with a measurement system, and showed that wind conditions have a significant effect on combustion, and the fire spread rate of wood surfaces under downwind conditions increases continuously in a certain wind speed range.

2.2. Topography

Topography can affect solar radiation, reflecting solar radiation to the ground back to the atmosphere, which in turn reflects it back to the ground to form inverse radiation. Large terrain can have a significant macroscopic effect on temperature distribution and change within a large environmental area, and even for small local terrain. It can have a significant effect on

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

temperature change within a short distance. Jingbiao Yang et al.[12]calculated the heat exchange relationship between forest surface and smoke from two perspectives of heat flow density and total heat exchange, respectively, and analyzed the effects of slope and wind speed on smoke movement based on this mathematical relationship, and came to a series of conclusions such as the slope of the mountain slope decreases and the range covered by smoke increases. Wei Jianheng et al.[13] used FDS software to establish a microscopic mountain craggy forest model to study the combustion spread and smoke release characteristics, and analyzed the effects of different slope conditions on the combustion spread pattern of craggy wood, showing that the smoke flow rate was negatively correlated with slope. Zhu Jiajin et al.[14] carried out by the combustion of different slope conditions in the laboratory, and concluded that there was a positive correlation between slope and thermal radiation.

2.3. Turbulence

Depending on the presence or absence of radial pulsation, the flow can be divided into laminar and turbulent flow. Turbulence is characterized by randomness, transient mobility. Etc. It is one of the important influencing factors of smoke spread in forest fire. Ran Haichao[15]pointed out that the suspended smoke particle mesh, agglomeration effect and turbulent effect of smoke in smoking are important influencing factors for fire detection. Normally, smoke turbulence is a stochastic process with small scale and rapid changes, while the smoke turbulence effect on fire is essentially a thermal turbulence effect of smoking[16]. Shu-Ming Du et al.[17]pointed out that environmental turbulence has an important influence on the lifting of smoke, and in addition this influence is not only limited to the mass exchange between smoke and environment, but also can promote the process of momentum and heat exchange between smoke and environment. In forest fire, the huge temperature difference between the internal temperature of the smoke and the surrounding environment makes the effect of thermal turbulence on the spread of smoke more significant. Meng Lan et al.[18]pointed out that buoyancy is a decisive factor in controlling flame motion in an environment where there is a higher temperature difference bringing about a larger density difference, but so far, studies on the effect of buoyancy on turbulent flow states are still relatively few.

2.4. Temperature

In addition to wind and turbulence, which are the main influencing factors on smoke spread in forest fire, temperature is also an important factor. Since the temperature inside the smoke is higher than the temperature outside the smoke, this temperature difference produces a buoyancy force that makes the height of the smoke change, and the effect of thermal factors can also be used as a spreading indicator. Yi Cao[19] simulated the atmospheric haze flow field based on Fluent software, and pointed out that the buoyancy force difference generated by the temperature difference between the flue gas and the atmosphere is the main factor affecting the flue gas floating stage, and the temperature increase will make the atmospheric haze flow field lifting height at different location points show an accelerated decreasing trend.

Smoke temperatures from forest fire can reach hundreds of degrees, causing physical harm to trap people and firefighters. Humans are constant temperature animals, and there is an important correlation between the body's maintenance of thermal equilibrium and the ambient temperature. When the ambient temperature exceeds the body's tolerance temperature, the body's heat production increases and the radiative and convective heat exchange decrease[20]. In addition, studies have shown that the biological activity of proteins is usually maintained at about 60°C, above which denaturation begins, so high temperature environments can lead to reducing biological activity or denaturation of proteins. The radiation temperature of forest fire

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

smoke can reach hundreds of degrees Celsius, and in this elevated temperature environment, human cells will be directly dehydrated and carbonized.

3. FOREST FIRE SMOKE COMPOSITION

3.1. Carbon monoxide

The initial stage of forest fires is often a slow burn with no visible flame, i.e., the phenomenon of negative combustion. Due to the negative combustion stage a large amount of carbonaceous forest combustibles do not have sufficient contact with oxygen, which leads to an increased release of carbon monoxide. As the main toxic gas in the fire smoke, carbon monoxide can cause cardiovascular damage as well as anoxic poisoning, etc. High concentrations of carbon monoxide can even cause gaseous lesions in humans. The extent of the risk of carbon monoxide to humans depends on the concentration and duration, as shown in Table 1. Studies have shown that the hydrocarbons produced by carbon monoxide contain a variety of compounds that can cause chronic toxicity in humans, some of which can have a direct irritating effect on the sensory system (eyes and nose), thereby reducing its normal function.[21] . Paris J D et al.[22] have used the FLEXPART-Lagrangian model to study the origin of air masses and the contribution of biomass combustion to CO enhancement, the study concluded, among others, that the average CO emission factor is 65.5 ± 10.8 g CO per kg of combusted dry matter.

Table 1. Effects of different volume fractions of CO

CO volume fraction (%)	Effects on the human body
0.01	Little effect for a few hours
0.05	Little effect within 1h
0.1	Dizziness, vomiting and other symptoms within 1h
0.5	Death by asphyxiation within 20 to 30 min
1.0	Death by poisoning within 1 to 2 min.

3.2. Carbon dioxide

Forest fires produce a large amount of smoke, the main components of which are carbon dioxide and water vapor, in general 350 to 1000 ppm concentration of carbon dioxide, the human body can maintain normal breathing, and no physical discomfort, etc., see Table 2. Wang Guangyu[23] simulated outdoor environment in the laboratory, combustion experiments were conducted on the collected samples to determine the undecomposed layer and semi-decomposed layer of the main vegetation on the surface of major forests, and calculate their emission factors and releases during combustion, the experimental results showed that gas emissions during combustion were dominated by CO_2 . Rio C et al.[24] calculated the vertical distribution of gases emitted from the plume given live in characteristics and environmental conditions, CO_2 and temperature of heat flux release, showing that CO_2 can be injected well above the height of the boundary layer, resulting in a daily excess of CO_2 in the troposphere.

Table 2. Effects of different concentrations of CO_2 on humans

CO_2 Concentration content (ppm)	Effects on the human body
350-450	Same as normal outdoor environment
450-1000	The human body feels comfortable and breathes smoothly
1000-2000	Feels like the air is cloudy and drowsy
2000-5000	Headache, drowsiness, rapid heartbeat, etc.
Greater than 5000	May lead to severe oxygen deprivation and even death

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

3.3. Sulfur dioxide

Sulfur dioxide is a toxic gas with high solubility, and after entering the human body, it can quickly dissolve in the moist mucous membranes of the human body, producing a strong irritating effect. The harm of sulfur dioxide on the human body includes skin, eyes, respiratory tract, etc.[25]. Studies have shown that when the concentration of sulfur dioxide is 10-15 bpm. The cilia movement of the respiratory tract and the secretion function of the mucous membrane is inhibited[26]. Peng, Xujian et al.[27] estimated sulfur dioxide emissions in the Daxingan Mountains using the emission factor method and found that the largest proportion of sulfur dioxide was released from biomass burning, and the highest sulfur dioxide emission factor was found in camphor pine and the lowest in white birch among all trees. It can be found that the sulfur dioxide released from forest fires has a significant impact on air pollution, and the sulfur dioxide content released from different tree species has variability, so that tree species can be selected to control the amount of toxic gases released from forest fire smoke.

3.4. Respirable particulate matter

Fire smoke typically contains large amounts of suspended carbonaceous particles with diameters of a few microns to tens of microns. Forest fires produce large amounts of respirable particulate matter, including PM2.5, PM10, etc., which are globally important sources of particulate matter pollution. Pengfei Y et al.[28]used a segmented aerosol climate quantification model, combining fire site and remote measurements, to quantify the smoke mass distribution, the proportion of BC in smoke, etc. The simulations found that the observed stratospheric smoke lifetime was about 150 days, indicating that the photochemical lifetime of smoke particulate organic matter is quite long. Li L et al.[29]used the meteorological model MM5 to analyze the weather pattern during a fire, indicating the presence of a long-term stationary high-pressure system in the area, which kept the concentration high during the slow long-range transport and caused more severe air pollution. Ning J et al.[30]examined the relationship between PM 2.5concentrations in relation to environmental and fuel characterization experiments and concluded that although PM2.5 concentrations increased with increasing wind speed, decreasing fuel moisture content, and increasing fuel loading, there was a fuel loading threshold above which concentrations decelerated rapidly.

Human health can also serve as affected by certain concentrations of respirable particulate matter. High concentrations of PM2.5 not only affect human respiratory health in the short term, but also pose a long-term threat to human cardiopulmonary function, with acute exposure to fire smoke triggering systemic inflammatory responses and long-term exposure to urban fine particulate matter increasing cardiovascular morbidity and mortality. Henderson S B et al.[31]found that a 10μg/m3 increases in PM10 were associated with a 5% increase in the odds of respiratory hospitalization. A 10μg/m3 increases in PM10 were associated with a 6% increase in the odds of an asthma-specific medical visit. Honduran I C et al[32]studied the relationship between PM10 and daily emergency admissions for cardiopulmonary disease for each fire season from 1996 to 2005, showing that a 10μg/m increase in estimated ambient PM10 on that day3 was associated with a 4.81% increase in total respiratory admissions.

4. COPING STRATEGIES FOR THE SPREAD OF FOREST FIRE SMOKE

4.1. Flue gas monitoring

With the development of science and technology, the application of sundry high technologies has led to the improvement of the accuracy of forest fire smoke monitoring. At present, equipment commonly used for forest fire smoke monitoring include satellites, unmanned aerial vehicles, manned aircraft, cameras and multi-sensor fusion technology[33].

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

River A C et al.[34]used six different algorithms such as data representation methods to process land cover maps of Sentinel-2 data covered by smoke to avoid the influence of forest fire smoke during the mapping of fire trails, and found an accuracy of up to 91.61% when compared with the field situation. Heinz et al.[35]established a dedicated tower camera system and proposed an intelligent video smoke detection algorithm and optimal field camera placement strategy, which can effectively achieve field smoke monitoring. Liu Shudong et al.[36]proposed a machine vision-based forest fire monitoring method that can remove the interference of clouds and smoke in monitoring and use diffusivity analysis to make effective judgments on fire. Chickeree S et al.[37]proposed a Sentinel-2 image de-smoking technique based on normalized vegetation index classification, which can obtain more accurate monitoring under the condition of uniformly distributed thick smoke. The results are quite diverse. The current fire monitoring methods are very diverse and can achieve accurate multi-angle and multi-directional monitoring in forest fire, based on the fact that effective fire smoke monitoring is an important prerequisite and guarantee for personnel escape and fire fighting.

4.2. Personnel escape

The spread of smoke from forest fires can lead to increased psychological fear of trapped people; thick smoke can lead to loss of judgment and disorientation in the fire; the rising temperature of smoke can burn human skin or even cause death; the large amount of harmful gases and respirable particles carried in smoke can lead to suffocation or poisoning.

In general, minimum visibility for smoke escape from forest fire is about 5m, and when smoke visibility is less than 3m, the possibility of personnel to escape drops dramatically. Under the effect of thermal turbulence and topography, smoke usually spreads from the ground to high altitude, spreading from low to high terrain. Therefore, when people are trapped in a fire, they should first remain calm and analyze the general direction of smoke spread, do not act blindly, and avoid escaping towards the top of the hill; make full use of the terrain, choose open areas with flat and open terrain and sparse forest cover; the density of smoke is greater than the density of surrounding air, and sedimentation is easily formed in low-lying areas, so avoid stepping into low-lying areas to cause trapping. Wen Shixi et al.[38]selected different resistance factors according to the judgment method of animal migration resistance factor, and combined with the distribution of fire in forest fires and other factors to construct a forest fire escape path network decision model, using mathematical modeling to provide some scientific guidance for personnel to escape.

4.3. Fire fighting and rescue

Based on the above smoke monitoring analysis, when rescue is implemented by personnel outside the fire scene, technological equipment such as drones and cameras can be used to provide a safer and scientific escape route. Zhang H G et al.[39]used a firefighting particle swarm algorithm to simulate the dynamic rescue process between forest fire spread and forest fire rescue, and tested the performance of the particle swarm firefighting algorithm in searching for dynamic optimal solutions and other aspects. Zhang H G et al.[40]also introduced a benchmark dataset to rescue integration consisting of rescue simulator and rescue algorithm to support dynamic simulation of forest fire rescue. Simulation studies based on recent unmanned monitoring systems and large firefighting aircraft in the field of forest fire rescue are very rare and have strong reference value. Peng, Xujian et al.[41]after an in-depth analysis of the shortcomings of the current forest fire rescue system in China, they proposed the idea of constructing an "air-sky-sky integrated" forest fire emergency response system based on three aspects: fire field element collection, fire field communication technology, and command and rescue technology. Using the current mature fire monitoring system, through satellite remote sensing, aerial remote sensing, ground remote sensing and other means to achieve integrated rescue.

5. CONCLUSION

Forest fires are characterized by high suddenness, destructiveness, and more difficult to deal with and rescue, while the complex and variable smoke spread will intensify the uncertainty of forest fire development, cause casualties, reduce the chance of escape, and increase the degree of difficulty in forest fire fighting. The typical influencing factors such as wind speed, turbulence, terrain and temperature are selected to influence the smoke spread of forest fires. The increase of temperature can make the smoke spread more intense; the increase of wind speed can speed up the smoke spread rate; the difference of terrain can cause the change of heat radiation, etc., which all show that the smoke spread of forest fires is the result of the combined effect of many influencing factors. In addition, the smoke composition of forest fires is also one of the key research directions, and the complexity and harmfulness of smoke composition have certain effects on fire fighting, personnel escape and human health and safety, for example, the increase of respirable particulate matter concentration can obviously cause damage to the surrounding environment.

Based on the above analysis of the factors influencing the spread of forest fire smoke, the response strategies are proposed from three aspects of smoke monitoring, personnel escape, and fire fighting and rescue, respectively. At present, the use of satellites, drones, cameras and other detection equipment to form an all-round, multi-angle and multi-level integrated forest fire smoke monitoring can provide important support and guarantee for personnel escape and firefighting rescue, etc. In terms of personnel escape, the psychological quality of trapped personnel and emergency knowledge reserve is a very important indicator, making full use of the fire environment conditions to implement self-help can significantly improve the chances of survival. Firefighting and rescue rely more on the professional ability of firefighters and the use of advanced technology and equipment, and should ensure their own safety as the primary prerequisite for the rescue of trapped persons while extinguishing forest fires. In the future, the optimization of monitoring equipment and the analysis of smoke spread mechanism are still the key directions of forest fire smoke spread research. In addition, there is more room for improvement in the popularization of forest fire safety knowledge and other aspects.

ACKNOWLEDGMENTS

This work is supported by National Nature Science Foundation of National Natural Science Foundation of China (31860214), Joint Agricultural Project of Yunnan Province (202101BD070001-094), Science and Technology Innovation Project for University Students of Yunnan Education Department (202010677078), National Key Research and Development Program (2017YFD0600106).

REFERENCES

[1] Lu Wei,Ma Xiaoxi,Zhang Ling,et al. Chaotic Behavior of Smoke Plume in Fires[J]. Combustion Science and Technology,(2002)No.3,p.220-223.

[2] Xin Z, Wang S , F Yun, et al. Numerical Analysis on Spreading Laws of Grassland Fire Based on Fire Dynamics Simulator (FDS)[J]. Transactions of the Chinese Society of Agricultural Engineering, 29(2013)No.11,p.156-163.

[3] Damoah R, Spichtinger N, Forster C, et al. Around the World in 17 Days-hemispheric-scale Transport of Forest Fire Smoke From Russia in May 2003 [J]. Atmospheric Chemistry and Physics, 4(2004)No.5,p.1311-1321.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

[4] Luderer G, Trentmann J, Winterrath T, et al. Modeling of Biomass Smoke Injection into the Lower Stratosphere by a Large Forest Fire (Part II): sensitivity studies[J]. Atmospheric Chemistry and Physics, 12(2006)No.12,p.5261-5277.

[5] Smith A K, Dragićević S. A four-dimensional agent-based model: a case study of forest-fire smoke propagation[J]. Transactions in GIS, 23(2019)No.3,p.417-434.

[6] Khaykin S, Legras B, Bucci S, et al. The 2019/20 Australian wildfires generated a persistent smoke-charged vortex rising up to 35 km altitude [J]. Communications Earth & Environment, 1(2020)No.1,p.1-12.

[7] Gosteva A A, Yakubailik O E, Shaparev N Y. Wildfires and the Spread of Smoke from Forest Fires in the Krasnoyarsk Territory in Summer 2019[C]//IOP Conference Series: Materials Science and Engineering. IOP Publishing,862(2020)No.6,p.062057.

[8] Wei Shujing, Luo Bijin, Li Xiaochuan, et al. Analysis of the Causes and Revelations of Casualties in the "3-30" Forest Fire in Liangshan Prefecture[J]. Forest fire prevention,(2020)No.2,p.10-13.

[9] Perminov V. Mathematical Modelling of the Spread of Contamination During Fires in Forests Exposed to Radioactive Contamination[C]//IOP Conference Series: Materials Science and Engineering. IOP Publishing, 81(2015)No.1,p.012-040.

[10] Lavrov A, Utkin A B, Vilar R, et al. Evaluation of Smoke Dispersion from Forest Fire Plumes Using Lidar Experiments and Modelling [J]. International Journal of Thermal Sciences, 45(2006), No.9,p.848-859.

[11] Wang Xishi, Liao Guangxuan, Fan Weicheng. Experimental Study of Fire Spread Characteristics of Wood Surface Under Downwind Conditions[J]. Journal of the University of Science and Technology of China,(1999)No.9,p.111-115.

[12] Yang Jingbiao, Ma Xiaoxi. Study of Smoke Flow and Heat Transfer Characteristics in Forest Fires[J]. Forestry Science and Technology,(2002)No.6,p.25-29.

[13] Wei Jianheng, Gao Zhongliang, Ma Zenan, et al. Study on the Burning Spread Pattern and Smoke Release Characteristics of Quercus Serrata[J]. Journal of Jiangxi Agricultural University, 43 (2021), No.6,p. 1371-1380.

[14] Zhu Jiajin, Zhou Ruliang, Gao Zhongliang, et al. Influence of Slope on the Spread of Forest Fire[J]. Agricultural Disaster Research, 2(2012),No.4,p.80-83.

[15] Ran H. C. Experimental study of fire smoke characteristics[J]. Journal of Sensing Technology, (2002)No.1,p.94-96.

[16] Liu LH, Ran HC, Sun LH. The Effect of Smoke Turbulence Effect on Fire Image Detection[J]. Fire Science,(2001)No.3,p.171-173.

[17] Du Shu-Ming, Li Zong-Kai. On the Role of Ambient Turbulence on Flue Gas Lift[J]. Journal of Meteorology, (1994)No.4,p.470-476.

[18] Meng Lan, Gao Ye. Interaction of Turbulence, Combustion and Buoyancy in Fire Flow Field[J]. Journal of Harbin Engineering University, (2002)No.2,p.111-117.

[19] Cao Yi. Fluent-based Study of Atmospheric Haze Flow Field [D]. Qingdao University of Science and Technology, (2018).

[20] Tang M.Y.. Effect of High Temperature Exposure on Human Heat Balance and Thermal Damage[J]. Energy Conservation,37(2018)No5,p.77-80.

[21] Yang Xinxing. Carbon Monoxide Hazards to Human [J]. Energy Engineering, (1999)No.1,p.46-46.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

[22] Paris J D, Stohl A, Nédélec P, et al. Wildfire Smoke in the Siberian Arctic in Summer: Source Characterization and Plume Evolution from Airborne Measurements[J]. Atmospheric Chemistry and Physics, 9(2009)No.23,p. 9315-9327.

[23] Wang Guangyu. Smoke Analysis of Ground Cover Burning in Major Forest Types in Heilongjiang Province[D]. Northeast Forestry University, (2009).

[24] Rio C, Hourdin F, Chédin A. Numerical Simulation of Tropospheric Injection of Biomass Burning Products by Pyro-thermal Plumes[J]. Atmospheric Chemistry and Physics Discussions, 9(2009) No.5,p. 18659-18704.

[25] Chen GQ, Yuan XY, Wu J. Analysis of Fire Smoke Toxicity[J]. Practical general medicine, 2 (2004) No.4,p. 353-354.

[26] Chen, Juan, Cui, Shuqing. The Harm of Sulfur Dioxide in Air to Human Body and Related Issues [J]. Inner Mongolia Water Resources,(2012)No.3,p.174-175.

[27] Peng XJ, Guo FT, Hu HQ, et al. Estimation of NO and SO2 Release From Forest Fires in Daxinganling[J].Forestry Science and Technology Development,29(2015)No.5,p.134-138.

[28] Yu P, Toon O B, Bardeen C G, et al. Black Carbon Lofts Wildfire Smoke High into the Stratosphere to Form a Persistent Plume [J]. Science, 365(2019)No.6453,p. 587-590.

[29] Li L, Cheng S, Yue D, et al. Forest Fire Smoke Long-distance Transport Track Analysis and Its Impacts on air quality[C]//2010 18th International Conference on Geoinformatics. IEEE, (2010),p.1-4.

[30] Ning J, Yang G, Liu X, et al. Effect of Fire spread, Flame Characteristic, Fire Intensity on Particulate Matter 2.5 Released from Surface Fuel Combustion of Pinus Koraiensis Plantation-a Laboratory Simulation Study[J]. Environment International, (2022),p.107-352.

[31] Henderson S B, Brauer M, Kennedy S, et al. Three Measures of Forest Fire Smoke Exposure and Their Association with Respiratory and Cardiovascular Physician Visits and Hospital Admissions[J]. Epidemiology, 20(2009)No.6,p. S82.

[32] Hanigan I C, Johnston F H, Morgan G G. Vegetation Fire Smoke, Indigenous Status and Cardio-respiratory Hospital Admissions in Darwin, Australia, 1996-2005: a time-series study[J]. Environmental Health, 7(2008)No.1,p. 1-12.

[33] Ma Ze-Nan, Gao Zhong-Liang, Wei Jian-Heng, et al. Research Progress of Forest Fire Smoke Monitoring Equipment[J]. Forestry Machinery and Woodworking Equipment, 50(2022)No.2,p.4-9.

[34] Grivei A C, Văduva C, Datcu M. Assessment of Burned Area Mapping Methods for Smoke Covered Sentinel-2 Data [C]//2020 13th International Conference on Communications (COMM). IEEE, (2020),p.189-192.

[35] Heyns A , Plessis W , Kosch M , et al. Optimisation of Tower Site Locations for Camera-based Wildfire Detection Systems [J]. International Journal of Wildland Fire, 28(2019)No.9,p.651-665.

[36] Liu Shudong,Yao Wenbo,Zhang Yan. Forest Fire Monitoring Based on Machine Vision Under foggy weather conditions[J]. Computer Engineering and Science,42(2020)No.7,p.1253-1261.

[37] Khetkeeree S, Petchthaweetham B, Liangrocapart S, et al. Sentinel-2 Image Dehazing Using Correlation Between Visible and Infrared Bands [C]// 2020 8th International Electrical Engineering Congress (iEECON). IEEE, (2020),p.1-4.

[38] Wen S. X., Zhang G., Wu X. Research on Forest Fire Escape Path Network Decision Making[J]. Journal of Central South University of Forestry Science and Technology,36(2016)No.9,p.62-65.

[39] Zhang H G, Liang Z H, Liu H J, et al. Ensemble Framework by Using Nature Inspired Algorithms for the Early-stage Forest Fire Rescue-A Case Study of Dynamic Optimization Problems[J]. Engineering Applications of Artificial Intelligence, 90(2020),p.103-517.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202305_9(5).0016

[40] Zhang H G, Liang Z H, Liu H J, et al. A Benchmark Dataset for Ensemble Framework by Using Nature Inspired Algorithms for the Early-stage Forest Fire Rescue[J]. Data in brief, 31(2020),p.105-686.

[41] Peng Xujian, Wu Zhiwei. Construction of forest fire emergency disposal technology system [J]. Green Technology,24(2022)No.6,p.133-135.