Challenges and Lessons Learned from past major Environmental Disasters due to Technological or Wildland Urban Interface Fire Incidents

Sofia Karma,

MSc in Analysis and Management of Manmade and Natural Disasters Eastern Macedonia and Thrace Institute of Technology & Hellenic Fire Academy/School of Fire Officers, Kavala, Greece;

School of Chemical Engineering, National Technical University of Athens, Athens, Greece

Spyros Schismenos,

MSc in Analysis and Management of Manmade and Natural Disasters Eastern Macedonia and Thrace Institute of Technology & Hellenic Fire Academy/School of Fire Officers, Kavala, Greece;

UNESCO Chair on Conservation and Ecotourism of Riparian and Deltaic Ecosystems, Eastern Macedonia and Thrace Institute of Technology, Kavala, Greece

Dimitrios Emmanouloudis,

UNESCO Chair on Conservation and Ecotourism of Riparian and Deltaic Ecosystems, Eastern Macedonia and Thrace Institute of Technology, Kavala, Greece;

Department of Forestry and Natural Environment, Eastern Macedonia and Thrace Institute of Technology, Kavala, Greece

Michail Chalaris,

MSc in Analysis and Management of Manmade and Natural Disasters Eastern Macedonia and Thrace Institute of Technology & Hellenic Fire Academy/School of Fire Officers, Kavala, Greece;

Hellenic Fire Corps, Athens, Greece

Abstract

The increased number of intense heat waves and wildfires that has been recorded the recent years in a global basis has raised great concerns; it is apparent that the projected climatic changes may affect such phenomena to a largest extent in the future. Each year, wildfires result to high mortality rates and property losses, especially in the wildland urban interface (WUI), affecting millions of people and having devastating global consequences on the biodiversity and the ecosystems. It has to be considered that wildfire disasters may rapidly change their nature into technological disasters, e.g. in the mixed areas of forest and residential, heavy industrial, or recycle zones. In such cases, there is a global concern because toxic components are released, like dioxins, as well as, fine and ultra-fine particles with transboundary effects. Even though international relative policies and fire safety legislations have resulted to effective prevention mechanisms, both environmental and technological fire hazards continue to threaten the sustainability of the local populations and the biodiversity of the affected areas.

Focusing on the “Priority 1: Understanding disaster risk” and “Priority 4: Enhancing disaster preparedness” of the Sendai Framework for Disaster Risk Reduction, this work attempts to highlight the possible health and environmental impacts of WUI and technological fire incidents; to further support its findings, this study presents recent indicative cases from all around the world. The main goal is to gather a number of lessons learned and best practices as a basis for brainstorming, in order to improve disaster preparedness and resilience techniques; they can be utilized in the future by the relevant stakeholders and involved parties in order to optimize risk reduction strategies , but also for enhancing the self-awareness of the large majority.

Introduction

Extreme meteorological conditions and their possible interactions or interrelationships with natural hazards, such as earthquakes, wildfires, landslides, volcanoes' eruption etc., can pose significant risks on the populations in a global basis; such hazards potential can be based on a single-hazard assessment approach, or can be treated under a multi-hazard concept; e.g. dry thunderstorms can initiate wildfires, earthquakes can trigger volcanoes, torrential rainfalls can lead to flash floods, etc. (Kappes, et al, 2012; Oblack, 2018). It is a fact that natural hazards can be provoked or affected by anthropogenic processes, such as the excessive land-use, the exploitation of natural resources, as well as the urbanization and deforestation (Gill & Malamud, 2017; Fischer & Knutti, 2015). Those activities contribute to global warming, mostly because of the fossil fuel burning; since 1880, the average surface temperature worldwide has been increased about 0.8 °C (1.4 °F), relatively to the mid-20th-century baseline of 1951-1980 (What's in a name? Weather, global warming and climate change). According to the National Oceanic and Administration (NOAA) Global Climate Report for June 2018, it seems that was one of the warmest affecting not only the European Mediterranean countries, such as Greece, Portugal, Spain and Italy, but also countries of the Central or North Europe; e.g. Austria's June 2018 national temperature was 1.9°C (3.4°F) above average and was one of the ten warmest Junes on record (NOAA, 2018). Generally, higher temperatures have been correlated with extreme weather events, such as prolonged droughts, heatwaves and flash floods; the short-term precipitation period that is spatially intensive, usually causes flash-floods and hence it leads to dryer climates (Allan, 2011; Allan & Soden, 2008; Allan, et al, 2010). Under such circumstances, the fire incidents in dry climate zones can easily be converted to mega fires, e.g. the Greek fires of August 2007 (Gouveia, 2016; FFnet 5, 2007), destroying huge forest areas even in the Arctic Cycle, e.g. the Swedish wildfires in July 2018 (Anderson & Cowell, 2018).

Besides the natural hazards, threats may also be posed by intentional or unintentional serious manmade disasters, such as nuclear radiation release, as well as transport, industrial or technological accidents; namely explosions, fires, or chemical spills. In some cases, technological fire incidents can be the secondary effect of natural disasters, e.g. an earthquake, or even a forest fire that might have been expanded to an industrial area; for example, during the forest fires of Kineta, Greece, in July 2018, the oil refinery that was situated in some kilometers away at the region called Aghioi Theodoroi, was in high danger by the flames (ekathinerini-com, 2018).

These disasters are known as NATECH (Natural Hazard Triggering –Technological Disasters) (Krausmann, Cruz & Salzano, 2017), a so called dynamic, or domino effect that may pose tremendous risks to the countries and communities, e.g. the earthquake in Turkey on August 17th, 1999 resulted to hazardous materials' release by the industrial facilities in the region of Kocaeli (Cruz, 2003).

In any case of a fire event, whether it is natural or manmade oriented, it is crucial to be positioned and suppressed at its early stages. Otherwise, it may threaten the lives of the first responders, including also the volunteers, as well as the nearby communities and the local environmental sites. Considering the above, the present study is striving to gather information on possible environmental impacts in terms of air, water and soil quality, as well as health effects for the exposed populations and the first responders when large scale technological or wildland urban interface (WUI) fire incidents occur. Focusing on the "Priority 1: Understanding disaster risk" and "Priority 4: Enhancing disaster preparedness" of the Sendai Framework for Disaster Risk Reduction, this study intents to enhance the public awareness on fire safety issues; activate the readers on how to be prepared in case of a fire emergency; promote "evacuation planning thinking" for fostering communities' capacity against fire risks. Under this prospect, it presents selected major fire incidents around the world, emphasizing on response approaches, challenges and lessons learned, with the aim of improving future fire disaster preparedness and resilient techniques that could be used by the relevant experts and individuals.

Wildland Urban Interface Fires: A threat for the local communities and the environment

WUI Fires general overview

A fire in the wildland urban interface (WUI) can generally be triggered either by natural, e.g. lightning strike, or manmade, e.g. campfire, arson etc., causes. As it spreads, it can fuel all types of flammable sources, expand in size and impact and hence, under specific conditions, may turn into a mega fire (Ronchi, et al, 2017). Mega fires nearby residential areas (WUI fires) can generally pose significant risks on the exposed receptors, such as the population, the critical infrastructures and the environment; fire expansion usually leads to human casualties and property losses, e.g. Greece 2018, California 2017, Portugal 2017 (California wildfires by the numbers: 40 killed, 5,700 homes destroyed, 2017; Lekkas et al, 2018). Though, apart from the fire expansion impacts, the smoke produced also poses significant risks on the exposed receptors; it is a complex chemical mixture of a variety of substances, such as particles or gaseous pollutants, like carbon monoxide, carbon dioxide, or ammonia, dioxins, or other highly toxic compounds that can be produced based on the types of the materials burnt towards the fire-front expansion (Karma, 2018; Statheropoulos & Karma, 2007). The huge quantities of smoke particles produced in combination with the extreme thermal radiation emitted, usually causes suffocation and death for the people that are directly exposed, e.g. Greece 2018, Attica Fires of Village Mati (Herald sun, 2018).

However, smoke impacts can be a serious problem for all the areas affected by the generated smoke plume, depending on the meteorological conditions, such as the wind direction and velocity. For example, fine particles, like $PM_{2,5,}$ PM_1 and ultrafine particles ($PM_{0,1}$) can be transferred far away from the fire source, affecting areas in long distances (transboundary effects) (Goldammer, Statheropoulos & Andreae, 2008; Sapkota, et all, 2005). According to epidemiological studies, fine and ultrafine particles are known to have adverse health effects, especially for the vulnerable groups of population, such as the elderly, pregnant women, children, people with disabilities, or hidden disabilities, like asthma and cardiopulmonary diseases (Le, et all, 2014; Mott, et all, 2005; Chen, et all, 2016; Díaz-Robles, et al, 2014). The degree of human exposure to a fire smoke event is based on the frequency, duration and the routes of exposure (inhalation, skin absorption, ocular absorption, ingestion) to the possible contaminants. A combination of different routes of exposure is usual for the fire-fighters when coping with fire disasters; this fact results to short-term and long-term effects, evidenced by several epidemiological studies (Hejl, et al, 2013; Yang, et al, 2013; Greven, et al, 2011; Baxter, et al, 2010).

In respect to the environmental impacts of the large scale wildfires, it seems that the huge quantities of carbon dioxide (CO_2) and water vapour (H_2O) produced may have significant greenhouse effect (Kim & Sarkar, 2017). Equally, flora and fauna are heavily damaged with major impacts on the biodiversity (Boisramé, et al, 2017; Gomez, et al, 2015). Wildfire impacts on hydrology, soil properties and soil erosion by water are also of high importance (Shakesby, 2011); physicochemical properties and microbial characteristics of burnt soils due to wildfires are strongly disturbed (Rodríguez, et al, 2018). Moreover, there is a high possibility that some of the toxic compounds produced, such as heavy metals absorbed on the emitted particulates, e.g. ashes, can be deposited on soil and water (Perreira & Ubeda, 2010) with the respective negative consequences on the crops' quality and the food chain's safety in general. According to a recent study, severe wildfires may also endanger the water supply of human and natural communities (Robinne, et al, 2018).

Indicative WUI Fire Incidents around the world

In the following, recent WUI fires with catastrophic results in terms of deaths, property losses and forest area burnt that have been globally recorded, are presented. Table 1, summarizes the major information of each described fire incident.

Attica Fires in Village Mati - Greece, 2018

One of the worst wildfires in the Greek history after the mega fires occurred in Peloponnese in 2007 (FFNet 5, 2007) were the ones in Attica that initiated on July, 23th 2018, affecting areas like Penteli Mountain, Neos Voutzas, Rafina and mainly Village Mati, which is situated at the coastline. Over 100 people died, while others reported as missing. Hundreds of residents have been evacuated or rescued, mainly from the seaside of the Village Mati (Herald Sun, 2018); nevertheless, the access to the beach by the people was difficult due to the rough slopes of the coast in the eastern part of the village (Lekkas, et al, 2018).

The specific morphology, together with the extreme weather conditions contributed to the entrapment of a significant number of people, while they were trying to evacuate though the nearby coastal routes; they were caught and burnt by the huge flames that were expanding extremely fast downslope to the coast due to the strong winds; the thermal radiation produced during the pine trees combustion that mostly covered the area, was intensively high, since pine trees are considered extremely flammable (Simeoni, et al, 2012). Combined also with the combustion of residential houses and burning of the entrapped cars, there were minimum possibilities to survive due to the extremely high temperatures (NIST, 2018; Witkowski, Stec & Hull, 2016; Deans & Schiraldi, 2014; Lyon & Janssen, 2005); there were in total 305 completely burned cars, found by the first responders with melt aluminum wheel rims and windscreens; it is noted that the melting point of the aluminum is about 660°C, while glass completely melts/liquefies at approximately 1400°C to 1600°C, based on the composition of glass (Lekkas, et al, 2018).

It was indeed a major environmental disaster; the area affected based on satellite data provided by the Copernicus Emergency Management Service – Mapping platform was approximately 12.8 km^2 (Lekkas, et al, 2018). Figure 1, shows a satellite image recorded on the 23rd of July 2018 by Sentinel-2 and processed by Copernicus Emergency Management Service, indicating the fire expansion to Neos Voutzas, Mati and Rafina areas.

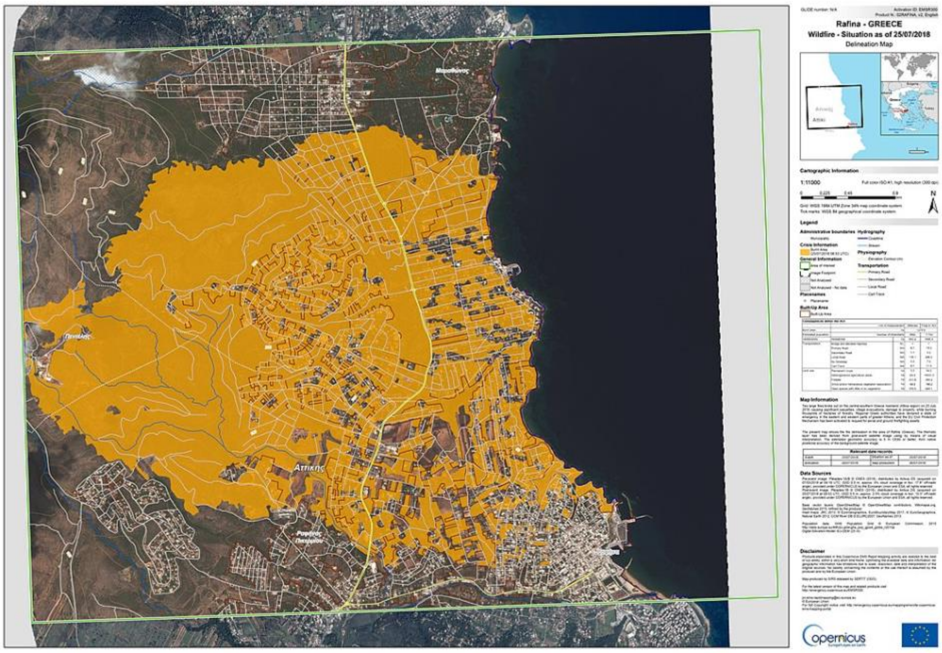

Figure 1. A satellite image recorded on the 23rd of July 2018 by Sentinel-2 and processed by Copernicus Emergency Management Service, indicating the fire expansion to Neos Voutzas, Mati and Rafina areas (COPERNICUS EMSR300, 2018)

According to detailed assessment of the disaster in Village Mati recorded by unmanned aerial vehicles (UAVs) of high spatial analysis (3,5 cm) on July 25th, 2018, (National Observatory of Athens), it seems that 70% of the total village areas are completely burnt, whereas, the rest 30% are partially or non-burnt areas (BEYOND, NOA, 2018).

There were also great impacts on the built and infrastructure environment, e.g. damage in the low and medium voltage distribution networks, as well as in the water network of the affected areas (Lekkas, et al, 2018). The complete list of the factors which led to this disaster, with all the above catastrophic consequences has been examined by a number of experts; a committee was set up by the government to prepare an extensive report (Greek City Times, August 6, 2018) .

British Columbia - Canada, 2017

In regard to wildland fires, the year 2017 was extremely disastrous for Canada. The province of British Columbia experienced its largest single fire in its history with 1.3% burnt area of its total territory. This was the largest fire incident that was ever recorded in a fire season. Another world breaking record was the total of evacuees that was the highest of all times (Ghoussoub, 2017). The fire season started on July 6th, 2017 when a 2-hectare (0.02 km^2) wildfire ignited. Approximately 160 fires were reported during that period (A timeline of B.C. wildfires, 2017). According to BC Wildfire Service[1], a total of 12160.53 km^2 that includes both forest and residential areas were burnt. The causes were natural (dry lightning), as well as manmade, accidental and intentional according to the authorities. Even though no fatalities were reported, almost 40000 people evacuated from their homes and more than 30000 cattle were threatened. Additionally, over 300 buildings were destroyed completely (Canada wildfires: almost 40,000 evacuated in British Columbia amid state of emergency, 2017; Karstens-Smith, 2017). Approximately 4000 firefighters were deployed. In total 233 helicopters and airplanes provided assistance (1 helicopter crashed on July 15th, 2017 in the Chilcotin region). Firefighters from Australia, New Zealand and Mexico contributed in the missions as well. The fire was completely suppressed on September 20th, 2017 (Karstens-Smith, 2017).

Carr, California – USA, 2018

The fire incident in northern California, or Carr Fire, as it is known widely, is currently among the worst 10 recorded fires in the state, and one of the largest in US history, burning an area of more than 1150 km^2. It ignited on July 23rd, 2018 when a fire was reported in Whiskeytown (Whiskeytown–Shasta–Trinity National Recreation Area). Until August 1st, 2018 the fire spread rapidly to other regions as well, including Redding City, Summit City,

[1] http://bcfireinfo.for.gov.bc.ca/hprScripts/WildfireNews/Statistics.asp

Keswick, Lewiston and French Gulch due to the weather conditions and inaccessibility of the firefighters in several rough terrains of the affected areas. According to the media, it is seems that the mechanical failure of a vehicle was the cause of this WUI fire. Until July 26th, 2018 the fire was responsible for the evacuation of at least 38000 people. There were certainly 6 fatalities and 11 casualties recorded; among those, 2 firefighters lost their lives and 3 more were injured. The fire destroyed over 1500 buildings, 1000 of which were residences. Additionally, it caused damages to 255 structures and threatened 1500 more. Besides the environmental, health and transportation impacts, the fire caused problems on the socio-economic and tourism activities. Specifically, it resulted to access restrictions to Gas Point Ghost Town and Whiskeytown–Shasta–Trinity National Recreation Area, the evacuation of French Gulch Town, etc. (Carr Fire Becomes 6th Most Destructive Fire in California State History, 2018; Vercammen, Vera & Chavez, 2018).

Arctic Circle, Scania – Sweden, 2018

According to the Swedish Civil Contingencies Agency, the fires that ignited in May 2018 were the worst in the country’s modern history. This was due to the warm and dry conditions, extensive heatwaves and reduced precipitation; unusual weather phenomena for a Scandinavian country. The fires, most of which were forest fires, burnt an area of total 250 km^2 (from the Arctic Circle to Scania County). There were no fatalities, as the fires occurred in areas with low population density; yet, due to the unprecedented conditions and smoke plumes, several people had to evacuate their residences or use other protective measurements (stay indoors with sealed windows and doors etc.). Besides the Swedish firefighters, numerous civilian volunteers and military units participated in the operations. In June 2018, Sweden requested help via European Union (EU) Civil Protection Mechanism, as well as from other countries. Denmark, Estonia, France, Finland, Germany, Italy, Lithuania, Norway, Portugal and Turkey responded and participated in the operations. The fires, 50 in total until July 23rd, 2018, were significantly reduced in late July when extensive rain assisted the operations of the firefighters. It should be noted that wildfires also occurred in the other Scandinavian countries but they were not as intense as those in Sweden (Tanner, 2018; What you need to know about Sweden's historic wildfire outbreak, 2018). Figure 2, shows the delineation map of the wildfire situation in Enskogen, Sweden recorded on the 7th of August, 2018 (COPERNICUS EMSR298, 2018).

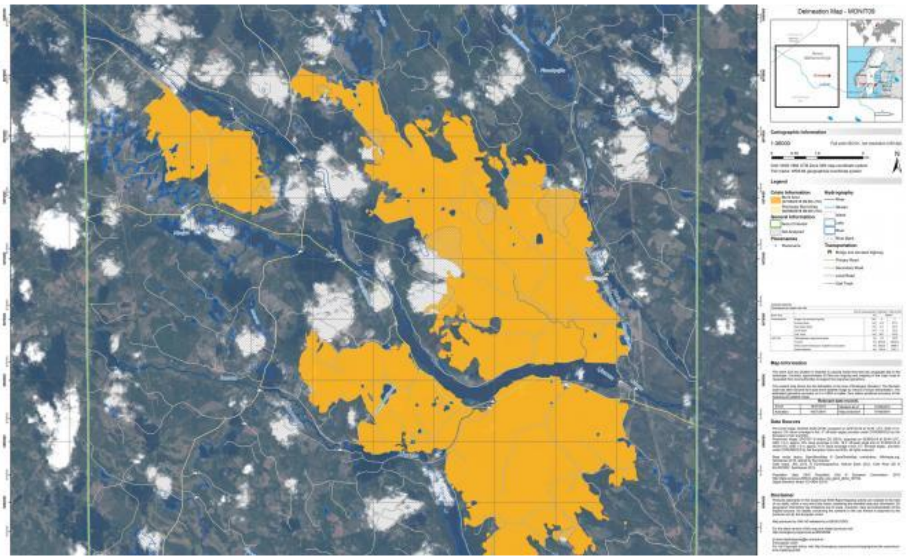

Figure 2. Delineation map of wildfire situation in Enskogen, Sweden recorded on the 7th of August, 2018 (COPERNICUS EMSR298, 2018)

Southern Siberia-Inner Mongolia - Russia/China, 2015

On April 12th, 2015, a number of fatal WUI fires that killed 33 people in total, injured over 900 and left 6000 people homeless, were ignited in the Republic of Khakassia - southern Siberia, Russia. The fires spread across several territories, including Zabaykalsky Krai (Chita) and continued until Inner Mongolia, China. According to the authorities, the cause of this incident was the intentional fires that were set by local citizens to clear the grass from their farms (agricultural land clear). However, the intense weather (strong warm winds) and dry weather conditions resulted to the rapid fire spread, with the later unpredictable consequences. Over 11000 km^2 of burnt land and numerous losses in livestock were recorded. More than 1400 buildings and other infrastructures were destroyed; 1300 of which were residencies of a total of 34 villages. The fires were suppressed completely on April 16th, 2018. Among the affected cities and townships, Shira that is located near the lake Shira had the greatest impact, with over 420 residences completely destroyed. It should be mentioned that besides the damages of the fire and its aftermath, e.g. financial losses of local business, deaths of the remaining livestock due to the lack of grass etc., looting incidents were also reported in several affected cities (Liesowska, 2015; Russia battles deadly new wildfires in eastern Siberia, 2015; Smolchenko, 2015).

Castanheira de Pera and Pedrógão Grande – Portugal, 2017

On June 17th, 2017 the largest human loss due to wildfires in Portugal was recorded, when a series of four fire sources initiated at the central areas of the country. The incident burnt an area of 449.69 km^2, caused the death of at least 66 people, as well as the injury of over 200 more, including 13 firefighters. The fires, 156 in total, spread rapidly due to the dry weather conditions and high temperatures. Most of the fatalities (47 confirmed deaths) that were evacuees occurred in the municipality of Pedrógão Grande. According to the witnesses, most of the victims died in or near their cars when the fire expanded towards the roadway they were driving in order to escape from the flames. In total, 1700 Portuguese firefighters were engaged to suppress the fire, whereas, more firefighters and equipment from Spain, France, Italy and Morocco were sent to contribute into the operations. The fire was suppressed completely on June 24th, 2017. Besides the forest areas, the fire affected also communities and public infrastructures (Minder, 2017; Portugal fire: Firefighters battle deadly blaze as temperatures soar, 2017; Portugal remembers 66 victims from deadly year for wildfires, 2018). Figure 3, shows a MODIS/NASA satellite image of the fires in Castanheira de Pera and Pedrógão Grande on June 18th, 2017, as well as the smoke plumes while they were expanded to Northern Portugal and Spain.

Figure 3. MODIS/NASA satellite image of the fires in Castanheira de Pera and Pedrógão Grande and associated smoke plumes expanded to Northern Portugal and Spain on June 18th, 2017.

Table 1. Notable fire incidents around the world – General information

Location	Date	Burnt area (in km^2)	Fatalities	Casualties
Southern Siberia, Russia – Inner Mongolia, China	April 12th ,2015	>11000	33	>900
British Columbia, Canada	July 6th ,2017	12160.53	0	Unknown
Carr (California), USA	July 23rd ,2018	514	6	11
Arctic Circle - Scania, Sweden	May 2018	250	0	Unknown
Castanheira de Pera and Pedrógão Grande, Portugal	June 17th, 2017	449.69	66	204
Attica Fires of Village Mati, Greece	July 23rd , 2018	12.8	> 100	>1000

Technological Fire Incidents - Health and Environmental impacts

Technological Hazards Overview

Generally, a technological hazard is defined as a hazard originating from technological or industrial conditions, including accidents, dangerous procedures, infrastructure failures or specific human activities that may cause loss of life, injury, illness or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage (WCDRR, 2015). Technological (non-natural) incidents include accidents at hazardous installations, e.g. accidental chemicals release or explosions and fires at chemical or nuclear power plants, as well as, accidents while hazardous substances are in transport, e.g. oils or chemicals transported by trains, tankers etc. The level of health and environmental impacts due to a technological fire depends on parameters, such as the time, the amount of burning fuels and the distance from the source; specifically for the distance, all the nearby areas can be categorized in zones, depending on how close or far they are from the fire source (vulnerable zones-VZs). The expansion range of the produced plume is mainly depended on the topography, local environmental conditions and the meteorological conditions, such as wind speed, air stability, etc. that occur during the fire event (Schismenos, Karma & Chalaris, 2018).

The fire zone describes the area and the surroundings at which the emission plumes are released while the fire disperses. In that zone, the physical and toxic hazards are more critical compared to the other zones; therefore, emphasis is mainly given at these zones on the emergency response actions, such as the health protection of the responders, the evacuation of the local population and generally the safety during the operations. In case of a chemical release, the VZs can be computed by using data on the chemical's toxicity, its quantity available for release, the type of spill, e.g. liquid or gaseous, the release duration, e.g. 15 minutes, the assumed meteorological conditions, such as wind speed and atmospheric stability and the characteristics of terrain, e.g. urban or rural, by using available hazard modelling programs, like ALOHA software (US Environmental Protection Agency)[2]; this is mainly for preparing emergency response plans in order to cope with large scale technological accidents; protection of communities, critical infrastructures and the environment from acute, short and long term impacts.

During technological fire incidents, harsh environments are actually produced; industrial fires can be intense emitters of heat, smoke and other combustion products. This is particularly true if the fuel is a petroleum based substance, due to its high heat of combustion and sooting potential (McGrattan, Baum & Hamins, 2000). It has to be noted that a number of fire incidents have also been recorded in recycling plants (landfills) nearby urban areas, which can be initiated by nearby forest fires or vice versa; such fires, may be considered as "technological fire incidents", since significant quantities of plastics, rubber, batteries, or other materials of high heat of combustion are burnt (Schismenos, Karma & Chalaris, 2018). Table 2, shows how the fire and heat damages the

[2] https://www.epa.gov/cameo/aloha-software

human skin and clothing in case of plastics combustion (Schismenos, Karma & Chalaris, 2018; NIST, 2017; Witkowski, Stec & Hull, 2016; Deans & Schiraldi, 2014; Lyon & Janssen, 2005).

Table 2. Observed effects on human body and commonly used clothing material when they are exposed to the high temperatures during fire events.

Temperature (°C)	Results of thermal exposure
44	Skin starts to feels pain
48	Occurrence of 1st degree burn injuries
55	Occurrence of 2nd degree burn injuries
72	Skin is being destroyed
250	Natural cotton starts to char
300	Modern protective fabrics start to char
407	Ignition temperature of polyethylene terephthalate (PET). The PET, also known as polyester is widely used in fiber/fabric industries.

The first responders are the ones who cope with harsh environments, encountering serious health risks in case of an industrial fire incident, e.g. Petroleum Plant fire; the black smoke produced contains carbon monoxide, sulphur dioxide, nitrogen oxides, unburned hydrocarbons, as well as soot, fine and ultrafine particles, with intense direct health impacts; carbon monoxide is poisonous, fine particles are enriched with heavy metals, e.g. lead, cadmium, mercury, dioxins and dioxin-like toxic compounds, causing skin and eye irritation, chest tightening or dyspnea, sore throat, headache and cough, or even death in case of intense exposures (Fabian, et al, 2014; Baxter, et al, 2010; Upshur, et al, 2001; Goldammer, et al, 2008; Statheropoulos & Karma, 2007). It is noted that the generated smoke and its components is usually dispersed in long distances, threatening the exposed communities directly, through smoke inhalation, or indirectly, through water and soil contamination, having also the respective environmental impacts. Table 3, summarizes the short- and long-term health impacts from acute or long-term exposure, respectively, to the smoke plume compounds; asphyxiant gases, e.g. carbon monoxide, carbon dioxide; particulates, categorized as allergen or carcinogen, based on the compounds absorbed on their surface, e.g. toxic heavy metals like mercury, plaster, etc. (Schismenos, Karma & Chalaris, 2018).

Table3. Short and long term environmental and health impacts due to smoke plume and fume compounds in fire events (Schismenos, Karma & Chalaris, 2018)

Possible impacts on different receptors	Asphyxiant gases		Irritant and/or allergen particulates		Carcinogen particulates	
	Short term exposure	Long term exposure	Short term exposure	Long term exposure	Short term exposure	Long term exposure
Humans	Possible impacts mainly within the smoke zone	No effect	Possible impacts mainly in fire and smoke plume zone	Possible impacts	Possible impacts	Potential impacts
Livestock/ wildlife	No effect	No effect	Possible impacts in smoke plume zone	Possible impacts	Possible impacts	Potential impacts
Deposition on land (crops, vegetation, food chain)	No effect	No effect	Possible impacts	Possible impacts	Possible impacts	Potential impacts
Deposition on water (human health)	No effect	No effect	Possible impacts	Possible impacts	Possible impacts	Potential impacts
Deposition on Water	No effect	No effect	Possible	Possible	Possible	Potential

(water resources, marine wildlife and fisheries)			impacts	impacts	impacts	impacts

Indicative Industrial Fire Incidents

Sunlight Systems - Greece, 2018

On May 1st, 2018, a fire ignited at the Sunlight Systems Olympia Group battery manufacturing plant, situated at Neo Olvio, Xanthi, Greece. The fire broke out at 13:00 p.m. Even though it was successfully under control during the same day, it managed to destroy essential units within the facilities, including the central building. Due to the flammable materials stored at that location, several concerning explosions occurred until it was fully suppressed. Furthermore, the extreme weather conditions, such as the strong and dry wind, made it difficult for the firefighters to put out the fire in shorter time. The produced smoke plumes were visible from distance, as they were expanding towards the nearby villages of Neo Olvio, Kremasti, Toxotes, Exochi, Agios Athanasios, Kallithea, Thalassia, Evmiros and Tympano (Xanthi and Topiros Municipalities, Eastern Macedonia and Thrace). For that reason, local populations were advised to evacuate their homes. The cause of the fire was unknown; however, it is believed that it was the short circuit from a battery charger. Overall, the plant followed all the necessary safety regulations. Therefore, the response procedures were effective and no casualty was reported. Additionally, there was no toxic gas leak in the area (Ana, 2018; Newsroom, 2018). Though, the toxicity of the products due to batteries combustion and the respective impacts on the water or soil has not been assessed yet at the affected area.

Tianjin Dongjiang Port Ruihai International Logistics - China, 2015

One of the worst technological disasters in the recent global history is the Tianjin explosions disaster that occurred at the facilities of Tianjin Dongjiang Port Ruihai International Logistics, which is a logistics company responsible for handling hazardous chemical compounds, on August 12th, 2015 in Tianjin, China. A series of explosions resulted to 173 deaths, 797 casualties and 8 missing people. According to the investigations, an overheated container of dry nitrocellulose was the cause of the first explosion. The second explosion that occurred 30 seconds later, had a much greater impact as it detonated approximately 800 tones of ammonium nitrate. Smaller explosions followed as the fire was spreading. It should be noted that the first two explosions were registered as a magnitude of 2.3 and 2.9 earthquake, respectively. Over 300 buildings, more than 12000 cars, almost 7600 intermodal containers and 17000 residential units were damaged. Several roads, a department store, metro facilities and other public or private infrastructures were affected by this incident. In regard to the environmental and health impacts there were numerous serious cases recorded, both short- and long-term. After this incident, the authorities decided to tighter industrial regulations in terms of safety measurements (Dearden, 2015; Huang & Zhang, 2015; Mortimer, 2016).

How to cope with Fire and Smoke Impacts in case of WUI or Industrial Fires: Lessons learned and Best practices

Generally, the efficient preparedness planning prior any technological or WUI fire incident could be a key factor for the success of the operations, as it increases the readiness capability of the first responders and may help the decision makers to act effectively and on time when a fire event occurs. Emergency Response and Evacuation Plans or Action Plans are mandatory as a precaution measure, focusing on the WUI areas; training exercises including all the involved parties, based on near-real fire disaster scenarios are encouraged for upgrading such emergency plans. In that prospect, fire resistant landscaping zones, upgraded fire safe constructions, sufficient fire suppression and safety inspections, as well as other relative preventive measures should be stimulated and applied on industrialized and WUI areas. Emphasis should be given on the critical infrastructures, e.g. the telecommunication and power facilities, major transportation routes and their accessibility during extreme fire events, critical public infrastructures, e.g. airports, hospitals, etc. Moreover, early warning and alert notification systems, e.g. phone applications, sirens, etc. is very critical for informing the mass population in order to escape from an emergency situation on time; the 112 European emergency line (European Commission, 2013) for mass sending of emergency SMS messages to the citizens in danger need to be extensively used by all countries. Moreover, emphasis should be given on the safety and security of the water resources during and after the fire events, as well as of the waste and other harmful materials' storage, the storage of fuels and supplies for emergency use, etc.

Instruments, such as the European Forest Fire Information System (EFFIS)[3] can support the relevant services in the EU countries in terms of monitoring the forest fire propagation; in 2015, EFFIS became one of the components of the Emergency Management Services in the EU Copernicus program. However, it seems that for effectively copying with wildfires there is a need to focus on the situational awareness (Tedim, Leone & Xanthopoulos, 2016); according to the same study, the Fire Smart Territory (FST) theory argues that understanding of the fire risk by the local communities, especially the ones that live nearby forests is the key item to be less wildfire prone and reduce their vulnerability. Especially for the sensitive groups, such as the elderly, the young populations and people with disabilities is vital to be better prepared in case of an emergency, since they are considered more vulnerable (Karma et al, 2018); Sendai Framework for Disasters Risk Reduction 2015-2030 foresees the inclusion of vulnerable groups, such as people with disabilities in the preparedness and response phases of the disaster management cycle in order to enhance their capacity upon disaster risks (Sendai 2015-2030)[5]. Recently, state-of-the art wildfire simulation dynamic models for evacuation have been tested in a wildfire-prone region in Victoria, Australia (Beloglazov, et al, 2016). Moreover, a novel framework for modelling wildfire urban evacuations and calculating the available safe escape time has been prepared by the US National Fire Protection Agency (Ronchi, et al, 2017). Personal fire evacuation plans may be proved vital for the communities in the vicinity of forest or industrial areas; Ready-Set-Go plans for copying with WUI fires have been established, providing with residential safety checklist and tips to improve family and property survival during a wildfire (Ready Set Go, 2018).

With the scope of minimizing the possible health impacts from fire and smoke exposure, a number of guidelines for the local populations have been established so far by the World Health Organization (WHO)

---

[3] http://effis.jrc.ec.europa.eu/

(Schwela, et al, 1999); under the aegis of the Council of Europe, the Global Fire Monitoring Center (GFMC) in cooperation with the European Center for Forest Fires (ECFF), prepared a booklet entitled "Defence of Villages, Fars and Other Rural Assets against Wilfires: Guidelines for Rural Populations, Local Communities and Municipality Leaders in the Balkan Region" (Goldammer, et al, 2013); Environmental and Health Organizations in several counties, such as the US had prepared a "Wildfire Smoke Guide for Public Health Officials" (NWCG, 2014; PNWBHA, 2012; Sandberg, et al, 2002; Ammann, et al, 2001; Hardy, et al, 2001). In that framework, a number of useful guidelines-actions for civil protection have been proposed, e.g. based on 1- and/or 3-hour average concentrations of fine particles (PM2.5 or PM10). Such tools can be extremely useful, as they can propose whether an evacuation is necessary, rather than taking decisions empirically and based on the visibility estimation in km (Ammann, et al, 2001); however, the visibility estimations own a critical role in the operations, since they can inform all the different types of ground means and secure a safe transportation (NWCG, 2014). In order to enhance the efficiency of those empirical techniques and particularly to identify the risk level in the disaster field, technological means for the on-line air quality monitoring could be turned into a valuable tool for major operations; in case of technological or WUI fire incidents, chemical sensors or biosensors and unmanned platforms (UAVs or UGVs) could be used as a remote early warning systems for the safety and security of the first responders that are engaged in the field, as well as for the decision making upon evacuation of the affected areas through detection of selective hazardous smoke components, known as Critical Key Indexes-CKIs (Karma, 2018; Karma, et al, 2015; Booze, et al, 2004).

Conclusions and discussion

Communities nearby forests or industrial areas are considered more vulnerable to relevant fires risks. Taking into consideration that the number of large scale wildfires will be possibly increased in the coming years due to the extreme weather conditions observed in a global basis, such as heat waves, prolonged droughts, strong winds interconnected with the climate change, collaborative wildfire planning and policies prepared by the relevant stakeholders, as well as the active participation of the population in the fire emergency preparedness and response is vital. It is a fact that the firefighters in cooperation with the relevant emergency response organizations of each country are the ones who will fight against the extraordinary harsh conditions resulted in case of fire incidents. Though, the existing aerial firefighting means, or those provided by other countries through the EU Civil Protection Mechanism for supporting fire-fighting operations may be unable to operate in many cases, e.g. due to the strong winds; or the ground means may be found inadequate to cope with wildfire flames, e.g. due to restricted accessibility to rough terrains.

It seems that for coping with extreme wildfire phenomena there is a need of a policy shift to prevention and preparedness, together with suppression. Effective evacuation planning is the major factor at least to minimize the impacts, if eliminating them is impossible. Fire safety measures should be taken, as well as concrete, targeted and realistic escape plans need to be established by the responsible authorities, specifically for the residential areas situated at mixed forest or industrial zones, so that the first responders to be suitably pre-trained and hence, be proactive and coordinated in a real emergency.

As a conclusion, building a culture of preparedness upon fire risks is crucial for enhancing resilience of high fire risk areas; emphasis should be given towards self-awareness and education towards “Living with the Fire”, focusing on the sensitive groups who are considered more vulnerable; this fire safety perception should not be limited only during the fire season but need to be continuing. Nevertheless, it has to be highlighted that WUI or Technological fire Incidents may threaten even people who are not residents of the high fire risk areas; visitors or tourists of those areas might also be in danger and hence, be aware and respectively prepared.

References

A timeline of B.C. wildfires. 2017. Available at: http://www.princegeorgecitizen.com/news/local-news/a-timeline-of-b-c-wildfires-1.21164609 (Accessed on 15 05 2019).

Allan, R.P. 2011. Climate change: Human influence on rainfall. *Nature*. Vol. 470, Issue 7334: 344.

Allan, R.P. and Soden, B.J. 2008. Atmospheric warming and the amplification of precipitation extremes. *Science*. Vol. 321, Issue 5895: 1481-1484.

Allan, R.P., Soden, B.J., John, V.O., Ingram, W. and Good, P. 2010. Current changes in tropical precipitation. *Environmental Research Letters*. Vol. *5*, Issue 2: 025205.

Ammann, H., Blaisdell, R., Lipsett, M., Stone, S.L., Therriault, S., Jenkins, J.W.P., and Lynch, K. 2001. *Wildfire smoke: a guide for public health officials*. Sacramento, California, USA. California Air Resources Board.

Ana. 2018. Major Fire Breaks out at Battery Factory in Xanthi, Greece. Available at: https://www.thenationalherald.com/199312/major-fire-breaks-out-at-battery-factory-in-xanthi-greece/ (Accessed on 14 05 2019).

Anderson, C., and Cowell, A. 2018. Heat Wave Scorches Sweden as Wildfires Rage in the Arctic Circle. Available at: https://www.nytimes.com/2018/07/19/world/europe/heat-wave-sweden-fires.html (Accessed on 14 05 2019).

Attica Wildfires. 2018. Available at: https://wikivisually.com/wiki/2018_Attica_wildfires#cite_note-5 (Accessed on 14 05 2019).

Baxter, C.S., Ross, C.S., Fabian, T., Borgerson, J.L., Shawon, J., Gandhi, P.D., Dalton, J.M. and Lockey, J.E. 2010. Ultrafine particle exposure during fire suppression—Is it an important contributory factor for coronary heart disease in firefighters?. *Journal of Occupational and Environmental Medicine*. Vol. 52, Issue 8: 791-796.

Beloglazov, A., Almashor, M., Abebe, E., Richter, J., and Steer, K.C.B. 2016. Simulation of wildfire evacuation with dynamic factors and model composition. *Simulation Modelling Practice and Theory.* Vol. 60: 144-159.

BEYOND, NOA, 2018, National Observatory of Athens, Detailed assessment of disaster in village Mati recorded on the 25th of July 2018 by UAVs with high spatial analysis, Available at: http://www.noa.gr/index.php?option=com_content&view=article&id=1336:uav&catid=86:news-eaa-greek&lang=el&Itemid=428 (Accessed on 14 05 2019)

Boisramé, G.F., Thompson, S.E., Kelly, M., Cavalli, J., Wilkin, K.M., and Stephens, S.L. 2017. Vegetation change during 40 years of repeated managed wildfires in the Sierra Nevada, California. *Forest Ecology and Management*. Vol. 402: 241-252.

Booze, T.F., Reinhardt, T.E., Quiring, S.J., and Ottmar, R.D. 2004. A screening-level assessment of the health risks of chronic smoke exposure for wildland firefighters. *Journal of Occupational and Environmental Hygiene*. Vol. 1, Issue 5: 296-305.

California wildfires by the numbers: 40 killed, 5,700 homes destroyed. Available at: http://www.ktvu.com/news/california-wildfires-by-the-numbers-17-confirmed-dead-170000-acres-burned (Accessed on 14 05 2019).

Canada wildfires: almost 40,000 evacuated in British Columbia amid state of emergency. 2017. Available at: https://www.theguardian.com/world/2017/jul/18/canada-wildfires-evacuated-british-columbia-state-of-emergency (Accessed on 14 05 2019).

Carr Fire Becomes 6th Most Destructive Fire in California State History. 2018. Available at: https://fox40.com/2018/07/31/carr-fire-in-california-becomes-6th-most-destructive-fire-in-state-history/ (Accessed on 14 05 2019).

Chen, R., Hu, B., Liu, Y., Xu, J., Yang, G., Xu, D., and Chen, C. 2016. Beyond PM2. 5: the role of ultrafine particles on adverse health effects of air pollution. *Biochimica et Biophysica Acta (BBA)-General Subjects*. Vol. 1860, Issue12: 2844-2855.

COPERNICUS EMSR300 2018, Emergency Management Service-Mapping, EMSR300:Forest Fires in Attika, Greece, Available at: http://emergency.copernicus.eu/mapping/list-of-components/EMSR300, (Accessed on 14 05 2019)

COPERNICUS EMSR298 2018, Emergency Management Service-Mapping, EMSR298: Enskogen: Delineation Map, Monitoring 9, Available at: http://emergency.copernicus.eu/mapping/ems-product-component/EMSR298_01ENSKOGEN_01DELINEATION_MONIT09/1 (Accessed on 14 05 2019)

Cruz, A.M. 2003. Cascading events and hazardous materials releases during the Kocaeli Earthquake in Turkey. *NEDIES Workshop Proceedings.* Ispra, Italy. 9-16.

Deans, T., and Schiraldi, D.A. 2014. Flammability of polyesters. *Polymer*. Vol. *55,* Issue 12: 2825-2830.

Dearden, L. 2015. Tianjin explosions: New footage from China shows both devastating blasts at terrifyingly close range. Available at: https://www.independent.co.uk/news/world/asia/tianjin-explosions-new-footage-shows-both-devastating-blasts-at-terrifyingly-close-range-10455135.html (Accessed on 14 05 2019).

Díaz-Robles, L.A., Fu, J.S., Vergara-Fernández, A., Etcharren, P., Schiappacasse, L.N., Reed, G.D., and Silva, M.P. 2014. Health risks caused by short term exposure to ultrafine particles generated by residential wood combustion: a case study of Temuco, Chile. *Environment International.* Vol. *66*: 174-181.

ekathimerini-com, 2018. Large fires across Attica, two people confirmed dead, Available at :http://www.ekathimerini.com/231007/article/ekathimerini/news/large-fires-rage-across-attica-two-people-confirmed-dead, (Accessed on 11 08 2018)

European Commission, 2013. Flash Eurobarometer 368, The European Emergency Number 112 Report, Available at: http://ec.europa.eu/commfrontoffice/publicopinion/flash/fl_368_en.pdf, (Accessed on 14 05 2019)

Goldammer, J.G., Mitsopoulos, I., Byambasuren, O., and Sheldon, P. 2013. Defence of villages, farms and other rural assets against wildfires: guidelines for rural populations, local communities and municipality leaders in the Balkan region. Published by the Global Fire Monitoring Center (GFMC) on behalf of the European and Mediterranean Major Hazards Agreement (EUR-OPA) Council of Europe. Available at: http://www.fire.uni-freiburg.de/Manag/Village-RuralAssets-Wildfire-Defense-Guidelines-2013-ENG-web.pdf (Accessed on 14 05 2019).

Goldammer, J.G., Statheropoulos, M., and Andreae, M.O. 2008. Impacts of vegetation fire emissions on the environment, human health, and security: a global perspective. *Developments in Environmental Science.* Vol. 8: 3-36.

Gomez, C., Mangeas, M., Curt, T., Ibanez, T., Munzinger, J., Dumas, P., Jérémy, A., Despinoy, M., and Hély, C. 2015. Wildfire risk for main vegetation units in a biodiversity hotspot: modeling approach in New Caledonia, South Pacific. *Ecology and Evolution.* Vol. *5*, Issue 2: 377-390.

Gouveia, C.M., Bistinas, I., Liberato, M.L., Bastos, A., Koutsias, N. and Trigo, R. 2016. The outstanding synergy between drought, heatwaves and fuel on the 2007 Southern Greece exceptional fire season. *Agricultural and Forest Meteorology*. Vol. 218: 135-145.

Greece wildfires: At least 74 dead as blaze 'struck like flamethrower'. Available at: https://www.bbc.com/news/world-europe-44941934 (Accessed on 14 05 2019).

Greven, F.E., Rooyackers, J.M., Kerstjens, H.A. and Heederik, D.J., 2011. Respiratory symptoms in firefighters. *American Journal of Industrial Medicine*. Vol. 54, Issue: 5: 350-355.

Hardy, C.C., Ottmar, R.D., Peterson, J.L., Core, J.E., and Seamon, P. 2001. *Smoke management guide for prescribed and wildland fire: 2001 edition*. PMS 420-2. NFES 1279. Boise, ID: National Wildfire Coordination Group. USA. US National Wildfire Coordination Group, Fire Use Working Team. 226.

Hejl, A.M., Adetona, O., Diaz-Sanchez, D., Carter, J.D., Commodore, A.A., Rathbun, S.L., and Naeher, L.P. 2013. Inflammatory effects of woodsmoke exposure among wildland firefighters working at prescribed burns at the Savannah River Site, SC. *Journal of Occupational and Environmental Hygiene*. Vol.10, Issue: 4: 173-180.

Herald Sun 2018, Greece fires: Death toll rises as search for missing continues, Available at: https://www.heraldsun.com.au/technology/death-toll-rises-from-greek-fires/news-story/ecb64b91cbd6454796ac7fe7edad7ec2 (Accessed on 14 05 2019)

Huang, P., and Zhang, J. 2015. Facts related to August 12, 2015 explosion accident in Tianjin, China. *Process Safety Progress*. Vol. 34, Issue 4: 313-314.

Fabian, T.Z., Borgerson, J.L., Gandhi, P.D., Baxter, C.S., Ross, C.S., Lockey, J.E., and Dalton, J.M. 2014. Characterization of firefighter smoke exposure. *Fire Technology*. Vol. 50, Issue 4: 993-1019.

FFNet Forest Fire Net Volume 5. Forest fires in Greece during summer 2007: The data file of a case study. European Center for Forest Fires, Council of Europe. Available at: https://www.civilprotection.gr/sites/default/gscp_uploads/ffnet_5.pdf (Assessed on 14 05 2019).

Fischer, E.M., and Knutti, R., 2015. Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. *Nature Climate Change*. Vol. *5*, Issue 6: 560.

Ghoussoub, M. 2017. B.C. surpasses worst wildfire season on record. Available at: http://www.cbc.ca/news/canada/british-columbia/b-c-surpasses-worst-wildfire-season-on-record-and-threat-is-far-from-over-1.4249435 (Accessed on 14 05 2019).

Gill, J.C., and Malamud, B.D. 2017. Anthropogenic processes, natural hazards, and interactions in a multi-hazard framework. *Earth-Science Reviews*. Vol. *166*: 246-269.

Greek City Times, August 6, 2018. Fire tragedy inevitable without a national plan, says world expert. Available at: https://greekcitytimes.com/2018/08/06/fire-tragedy-inevitable-without-a-national-plan-says-world-expert/(Accessed on 14 05 2019)

Kappes, M.S., Keiler, M., von Elverfeldt, K. and Glade, T. 2012. Challenges of analyzing multi-hazard risk: a review. *Natural Hazards.* Vol. 64, Issue 2: 1925-1958.

Karma, S. 2018. Tools for Analyzing Risks from Human Exposure to Chemical Environments: The case of exposure to Smoke Components during Forest or Other Field Fires. Chapter 9. In: *Novel Approaches in Risk, Crisis and Disaster Management*. Chalaris, M., Emmanouloudis, D., Wen, J.C., and Wu. Z.P. New York, USA. Nova Science Publishers.

Karma, S., Kakaliagou, O., Boukis, I., Pelli, E., Chalaris, M., Statheropoulos, M. 2018. Evacuation Planning of Critical Infrastructures in case of an Earthquake or a fire for People with Disabilities, Council of Europe, ISBN: 978-618-83079-0-2

Karma, S., Zorba, E., Pallis, G.C., Statheropoulos, G., Balta, I., Mikedi, K., Vamvakari, J., Pappa, A., Chalaris, M., Xanthopoulos, G., and Statheropoulos, M. 2015. Use of unmanned vehicles in search and rescue operations in forest fires: Advantages and limitations observed in a field trial. *International Journal of Disaster Risk Reduction*. Vol. 13: 307-312.

Karstens-Smith, G. 2017. B.C. wildfires have destroyed 300-plus buildings. 2017. Available at: https://vancouversun.com/news/local-news/b-c-wildfires-have-destroyed-300-plus-buildings (Accessed on 14 05 2019).

Kim, B., and Sarkar, S. 2017. Impact of wildfires on some greenhouse gases over continental USA: A study based on satellite data. *Remote Sensing of Environment*. Vol. 188: 118-126.

Krausmann, E., Cruz, A.M. and Salzano, E. 2016. *Natech risk assessment and management: reducing the risk of natural-hazard impact on hazardous installations*. Amsterdam, Netherlands. Elsevier.

Le, G.E., Breysse, P.N., McDermott, A., Eftim, S.E., Geyh, A., Berman, J.D., and Curriero, F.C. 2014. Canadian forest fires and the effects of long-range transboundary air pollution on hospitalizations among the elderly. *ISPRS International Journal of Geo-Information*. Vol. *3*, Issue 2: 713-731.

Lekkas, E., Carydis, P., Lagouvardos, K., Mavroulis, S., Diakakis, M., Andreadakis, Emm., Gogou, M.E., Spyrou, N.I., Athanassiou, M., Kapourani, E., Arianoutsou, M., Vassilakis, M., Kotsi, E., Speis, P.D., Delakouridis, J., Milios, D., Kotroni, V., Giannatros, T., Dafis, S., Kargiannidis, A., and Papagiannaki, K. 2018. The July Attica (Central Greece) Wildfires-Scientific Report (Version 1.0). *Newsletter of Environmental, Disaster, and Crisis Management Strategies*. Vol. 8.

Liesowska, A. 2015. Fire rages on as death toll from two blazes reaches 33. Available at: http://siberiantimes.com/ecology/casestudy/news/n0187-fire-rages-on-as-death-toll-from-two-blazes-reaches-33/ (Accessed on 14 05 2019).

List of Wildfires. Available at: https://wikivisually.com/wiki/List_of_wildfires (Accessed on 14 05 2019).

Lyon, R.E., and Janssens, M.L. 2005. *Polymer Flammability.* DOT/FAA/AR-05/14, Final Report. Washington, DC, USA. US Department of Transportation, Federal Aviation Administration.

McGrattan, K.B., Baum, H.R., and Hamins, A. 2000. Thermal radiation from large pool fires. USA. National Institute of Standards and Technology, US Department of Commerce.

Minder, R. 2017. Portugal Fires Kill More Than 60, Including Drivers Trapped in Cars. Available at: https://www.nytimes.com/2017/06/18/world/europe/portugal-pedrogao-grande-forest-fires.html (Accessed on 14 05 2019).

Mortimer, C. 2016. Tianjin explosion: Gigantic crater left by Chinese factory accident revealed. Available at: https://www.independent.co.uk/news/world/asia/tianjin-explosion-photos-china-chemical-factory-accident-crater-revealed-a7199591.html (Accessed on 14 05 2019).

Mott, J.A., Mannino, D.M., Alverson, C.J., Kiyu, A., Hashim, J., Lee, T., Falter, K., and Redd, S.C. 2005. Cardiorespiratory hospitalizations associated with smoke exposure during the 1997 Southeast Asian forest fires. *International Journal of Hygiene and Environmental Health*. Vol. 208 Issue: 1-2: 75-85.

Newsroom. 2018. Xanthi extends emergency pollution measures after Sunlight plant fire. Available at: http://thegreekobserver.com/greece/article/42326/xanthi-extends-emergency-pollution-measures-after-sunlight-plant-fire/ (Accessed on 14 05 2019).

NIST National Institute of Standards and Technology, US Department of Commerce. Fire Dynamics. Fire Research Division. Published online July 2018. Available from: https://www.nist.gov/%3Cfront%3E/fire-dynamics (Accessed on 14 05 2019).

NOAA National Centers for Environmental Information. State of the Climate: Global Climate Report for June 2018. Published online July 2018. Available at: https://www.ncdc.noaa.gov/sotc/global/201806 (Assessed on14 05 2019).

NWCG National Wildfire Coordinating Group Smoke Committee’s Training Subcommittee and the University of Idaho. Wildland Fire Personnel Smoke Exposure Guidebook, Version 3. Published in 2014. Available at:

https://www.nifc.gov/wfstar/modules/FireEnviro/smoke2014/smoke_exposure_guidebook.pdf (Accessed on14 05 2019).

Oblack, R. 2018. What Is a Dry Thunderstorm? Beware of Microbursts and Wildfires. Available at: https://www.thoughtco.com/what-is-a-dry-thunderstorm-3444302 (Accessed on 14 05 2019).

Pereira, P., and Úbeda, X. 2010. Spatial distribution of heavy metals released from ashes after a wildfire. *Journal of Environmental Engineering and Landscape Management*. Vol.18, Issue 1: 13-22.

PNWBHA Pacific North West Border Health Alliance. Guidelines for Health Staff in Northern Saskatchewan Communities Preparation for Forest Fires and the Assessment of Health Effects from Forest Fire Smoke. Forest Fire and Smoke Guidelines for Evacuations. Published in 2012. Available at: http://www.pnwbha.org/wp-content/uploads/2012/07/SMOKE-and-Fire-Guidelines-2012.pdf (Accessed on 14 05 2019).

Portugal fire: Firefighters battle deadly blaze as temperatures soar. 2017. Available at: https://www.bbc.com/news/world-europe-40336622 (Accessed on 14 05 2019).

Portugal remembers 66 victims from deadly year for wildfires. 2018. Available at: http://www.foxnews.com/world/2018/06/17/portugal-remembers-66-victims-from-deadly-year-for-wildfires.html (Accessed on 14 05 2019).

Ready Set Go, 2018. Your Personal Wildland Fire Action Guide, Available at: https://www.sandiego.gov/sites/default/files/legacy/fire/pdf/rsgsandiego.pdf, (Accessed on 14 05 2019).

Robinne, F.N., Bladon, K.D., Miller, C., Parisien, M.A., Mathieu, J., and Flannigan, M.D. 2018. A spatial evaluation of global wildfire-water risks to human and natural systems. *Science of the Total Environment*. Vol. 610: 1193-1206.

Rodríguez, J., González-Pérez, J.A., Turmero, A., Hernández, M., Ball, A.S., González-Vila, F.J., and Arias, M.E. 2018. Physico-chemical and microbial perturbations of Andalusian pine forest soils following a wildfire. *Science of the Total Environment*. Vol. 634: 650-660.

Ronchi, E., Gwynne, S., Rein, G. 2017, e-Sanctuary: Open Multi-Physics Framework for Modelling Wildfire Urban Evacuation, National Fire Protection Agency, Available at: https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Research-Foundation-reports/Other-research-topics/RFWUIEvacuationModelingFramework.pdf (Accessed on 14 05 2019).

Russia battles deadly new wildfires in eastern Siberia. 2015. Available at: https://www.bbc.com/news/world-europe-32301620 (Accessed on 14 05 2019).

Sandberg, D.V., Ottmar, R.D., Peterson, J.L., and Core, J. 2002. Wildland fire on ecosystems: effects of fire on air. In: *Gen. Tech. Rep. RMRS-GTR-42-vol*, *5*. Ogden, Utah, USA. US Department of Agriculture, Forest Service, Rocky Mountain Research Station .79.

Sapkota, A., Symons, J.M., Kleissl, J., Wang, L., Parlange, M.B., Ondov, J., Breysse, P.N., Diette, G.B., Eggleston, P.A., and Buckley, T.J. 2005. Impact of the 2002 Canadian forest fires on particulate matter air quality in Baltimore City. *Environmental Science & Technology*. Vol. 39, Issue 1: 24-32.

Schismenos, S., Karma, S., and Chalaris, M. 2018. Large-Scale Fire Incidents in Recycling Plants: Lessons Learned from two Indicative Case Studies and Future Needs. Chapter 5. In: *Novel Approaches in Risk, Crisis and Disaster Management*. Chalaris, M., Emmanouloudis, D., Wen, J.C., and Wu. Z.P. New York, USA. Nova Science Publishers.

Schwela, D.H., Goldammer, J.G., Morawska, L.H., and Simpson, O. 1999. Health Guidelines for Vegetation Fire Events. Guideline document. Published on behalf of UNEP, WHO, and WMO. *Institute of Environmental Epidemiology, Ministry of the Environment*. Singapore.

Shakesby, R.A. 2011. Post-wildfire soil erosion in the Mediterranean: review and future research directions. *Earth-Science Reviews*. Vol. 105, Issues 3-4: 71-100.

Simeoni, A., Thomas, J.C., Bartoli, P., Borowieck, P., Reszka, P., Colella, F., Santoni, P.A., and Torero, J.L. 2012. Flammability studies for wildland and wildland–urban interface fires applied to pine needles and solid polymers. *Fire Safety Journal*. Vol. 54: 203-217.

Smolchenko, A. 2015. Huge Siberia wildfires kill 26. Available at: http://www.gmanetwork.com/news/news/world/469210/huge-siberia-wildfires-kill-26/story/ (Accessed on 14 05 2019).

Statheropoulos, M., and Karma, S. 2007. Complexity and origin of the smoke components as measured near the flame-front of a real forest fire incident: A case study. *Journal of Analytical and Applied Pyrolysis.* Vol. 78: 430–437.

Tanner, J. 2018. EU nations help Sweden as wildfires rage above Arctic Circle. Available at: https://www.washingtonpost.com/amphtml/world/europe/eu-nations-help-sweden-as-wildfires-rage-above-arctic-circle/2018/07/20/2f921770-8c27-11e8-9d59-dccc2c0cabcf_story.html?noredirect=on (Accessed on 14 05 2019).

Tedim, F., Leone, V., and Xanthopoulos, G. 2016. A wildfire risk management concept based on a social-ecological approach in the European Union: Fire Smart Territory. *International Journal of Disaster Risk Reduction*. Vol. 18:138-153.

Upshur, R., James, M.L., Richardson, E., Brunton, G., Hunter, W., and Chambers, L. 2001. Short-term adverse health effects in a community exposed to a large polyvinylchloride plastics fire. *Archives of Environmental Health: An International Journal*. Vol. 56, Issue 3: 264-270.

Vercammen, P., A. Vera, and N. Chavez. 2018. Carr Fire in California is so hot it's creating its own weather system. Available at: https://edition.cnn.com/2018/07/30/us/carr-fire-california/index.html (Accessed on 08 08 2018).

WCDRR United Nations World Conference for Disaster Risk Reduction. Published March 2015. Sendai, Japan, Addressing Technological Hazards in the Post-2015 DRR Framework. Available at: https://www.wcdrr.org/uploads/34-UNEP-Technological-Accidents-Prepcom-2.pdf (Accessed on 14 05 2019).

What's in a name? Weather, global warming and climate change. Available at: https://climate.nasa.gov/resources/global-warming/ (Accessed on 14 05 2019).

What you need to know about Sweden's historic wildfire outbreak. 2018. Available at: https://www.thelocal.se/20180717/sweden-battles-most-serious-wildfire-situation-of-modern-times-heres-what-you-need-to-know (Accessed on 14 05 2019).

Witkowski, A., Stec, A.A., and Hull, T.R. 2016. Thermal decomposition of polymeric materials. In: *SFPE Handbook of Fire Protection Engineering*. Hurley, M.J., Gottuk, D.T., Hall Jr., J.R., Harada, K., Kuligowski, E.D., Puchovsky, M., Torero, J.L., Watts Jr., J.M., Wieczorek, C.J. New York, USA. Springer. 167-254.

Yang, J., Teehan, D., Farioli, A., Baur, D.M., Smith, D., and Kales, S.N. 2013. Sudden cardiac death among firefighters≤ 45 years of age in the United States. *The American Journal of Cardiology*. Vol. 112, Issue: 12: 1962-1967.