ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

TURKEY FOREST FIRE DECISION SUPPORT SYSTEM (TFFDSS)

M.Sc. THESIS

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Department of Geomatics Engineering

Geomatics Engineering Programme

FEBRUARY 2022

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

TÜRKİYE ORMAN YANGINI KARAR DESTEK SİSTEMİ (TFFDSS)

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Abdullah SUKKAR, a M.Sc. student of ITU Graduate School student ID 501201604, successfully defended the thesis/dissertation entitled "Turkey Forest Fire Decision Support System (TFFDSS)", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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For those who have faith in me,
I will never let you down,

FOREWORD

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Abdullah SUKKAR
Geomatics Engineer

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ABBREVIATIONS

AFD : Active Fire Detection
AFM : Accessory Fuel Moisture
AI : Artificial Intelligence
ANN : Artificial Neural Network
AQE : Air Quality and Emissions
BUI : Buildup Index
CFFDRS : Canadian Forest Fire Danger Rating System
DC : Drought Code
DMC : Duff Moisture Code
DSS : Decision Support System
DWD : Deutscher Wetterdienst
EBYS : Corporate Service Inventory System
EFFIS : European Forest Fire Information System
EOS : Earth Observing System
FAO : Food and Agriculture Organization
FBP : Fire Behavior Prediction
FDF : Fire Danger Forecast
FFA : Fire Fighting Advisor
FFMC : Fine Fuel Moisture Code
FGI : Fire Geo-Information
FIRMS : Fire Information for Resource Management System
FIS : Fire Information System
FOFDESS : Forest Fire Decision Support System
FOP : Fire Occurrence Prediction
FS : Fuzzy Switching
FWI : Fire Weather Index
GHG : Greenhouse Gas
GIS : Geographic Information Systems
GWIS : Global Wildfire Information System

HFD **:** Historical Fire Database

IoT **:** Internet of Things

ISI **:** Initial Spread Index

KML **:** Keyhole Markup Language

MENA **:** Middle East and North Africa

MEUS **:** Forest Fire Meteorological Early Warning System

MGM **:** Turkish State Meteorological Service

MODIS **:** Moderate Resolution Imaging Spectroradiometer

MTT **:** Minimum Travel Time

NABNEF **:** Naive Bayes Aided Neural-Fuzzy Algorithm

NASA **:** National Aeronautics and Space Administration

NBC **:** Naive Bayes Classifier

NBR **:** Normalized Burn Ratio

NDVI **:** Normalized Difference Vegetation Index

NFDRS **:** National Fire Danger Rating System

NIFC **:** National Interagency Fire Center

NIR **:** Near-Infrared

OGM **:** General Directorate of Forestry

ORBIS **:** Forest Information System

PFA **:** Post Fire Analyzing

RAVAR **:** Rapid Assessment Values at Risk

RM **:** Recovery Monitoring

SNPP **:** Suomi National Polar-orbiting Partnership

SWIR **:** Shortwave-Infrared

TFFDSS **:** Turkey Forest Fire Decision Support System

TOYTOS : Turkish National Forest Fire Danger Rating Decision Support System

VIIRS **:** Visible Infrared Imaging Radiometer Suite

WF **:** Weather Forecast

WFDSS **:** Wildland Fire Decision Support System of USA

SYMBOLS

CO_2	**:** Carbon Dioxide
CH_4	**:** Methane
NOx	**:** Nitrogen Dioxide
SO_2	**:** Sulphur Dioxide
°	**:** Degree
t	**:** ton
C	**:** Celsius
CO	**:** Carbon Monoxide
ha	**:** Hectare
min	**:** Minutes
BA	**:** Total Burnt Area
BD	**:** Total Burnt Biomass Density
BF	**:** Burning Efficiency
EF	**:** Emission Factor of Dry Matter

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Turkey Forest Fire Decision Support System

(TFFDSS)

SUMMARY

The global forest area covers about 31 percent of all land area. Natural disasters such as wildfires are continuous hazards that threaten forests all around the world. Wildfires cause massive environmental and economic devastation and they are considered a major risk in several parts of the world. Between 1990 and 2020 the world has lost 178 million hectares of its forest, and because of the current climate change there are expectations for forest fires to increase in frequency, extent, and severity. The same situation is in Turkey, where the forests cover about 29 percent of the total area of Turkey. The average of the burned area is 10 thousand hectares per year while the average of wildfire incidents is more than 2500 incidents annually.

Wildfires have become an increasingly serious concern on a global scale, causing environmental and economic damages. Climate change is the primary cause of wildfires, it leads to an increase in the number, severity, and burned area. Climate change has resulted in a warming climate and drier forests which have led to "megafires" – wildfires that are larger than the existing firefighting capabilities. However, climate change is not the only reason for forest fires, human activities — either accidentally or deliberately are responsible for most of the wildfires. In Turkey, Human activity was the primary cause of most of the fires in 2020.

Besides the effects of wildfires on the ecosystems and biodiversity, and causing humans and animals deaths, wildfire fighting also causes enormous economic losses, both in terms of resources destroyed and the costs of suppression. In Turkey, wildfire fighting activities in 2017 cost about 21.2% of the total budget of The General Directorate of Forestry.

Wildfire is a very complicated environmental crisis, responding effectively and minimizing the danger of a wildfire requires as much as possible information before making decisions. The complexity of the wildfires can make a negative impact on the decision-making process, while the decision-makers are under the pressure of conditions that are limited in time, dynamic, uncertain, and contradictory.

Effective wildfire-fighting requires cooperation between different institutions and agencies because wildfire is a very complex and highly risky phenomenon, controlling large fires exceed the ability of a single institute or agency. This cooperation needs integration between advanced technologies with scientific knowledge and combining different heterogeneous spatial and non-spatial data.

The technology advances in various fields such as Geographic Information Systems, remote sensing, Artificial Intelligence, Internet of Things, sensor networks, data analytics, and many others have led to support the decision-making through converting

the huge heterogeneous information related to a wildfire into key data for scientists and authorities allowing them better choices.

A decision support system (DSS) is an interactive computer-based information system developed to assist decision-makers. It integrates the theory of decision-making with interactive computer systems. Recently, GIS-based decision support systems have been used to increase the efficiency of fire control processes such as planning, managing, and decision making. The use of DSS by wildfire managers has grown quickly in recent years, the ability of the DSSs to pick tactics to control wildfires that are both functionally and economically efficient has resulted in improving the capacity to prevent and suppress wildfires while also safeguarding human lives and properties.

Some countries have their own wildfire DSS like the USA, Canada, Greece, and others. In addition, the European Commission has developed the European Forest Fire Information System (EFFIS) for the whole of Europe. Later, a joint initiative between international institutions has led to developing the Global Wildfire Information System (GWIS). In Turkey, several tools and systems have been developed recently, they have varied between early warning systems and decision support systems or even only fire monitoring and detection tools and systems, all of which aim to assist in preventing, managing, and suppressing wildfires.

In this research, a conceptual design of a GIS-based decision support system for forest fire prevention and fighting in Turkey was designed and prepared due to the national requirements and capabilities. This system was designed to assist fire managers to make better decisions during a wildfire by providing detailed information and analysis related to the fires and their surroundings.

The conceptual design of Turkey Forest Fire Decision Support System (TFFDSS) consists of several modules like Historical Fire Database Module, Weather Forecast Module, Fire Geo-Information Database Module, Fire Danger Forecast Module, Active Fire Detection Module, Fire Behavior Prediction Module, Fire Fighting Advisor Module, Post Fire Analyzing Module, Air Quality and Emissions Module, and Recovery Monitoring Module.

Historical Fire Database Module consists of a collection of spatial and non-spatial of the previous wildfires data from various sources. Weather Forecast Module provides real-time fire weather forecasting. Fire Geo-Information Database Module is a variety of geospatial layers that contain auxiliary information to help the decision-makers to improve their choices and decisions during wildfire events. Fire Danger Forecast Module is based on the Canadian Fire Weather Index provides a numerical value of the relative potential of wildfires. Active Fire Detection Module is based on the active fire detection products of the MODIS and VIIRS satellites that are provided by NASA. Fire Behavior Prediction Module is based on the FlamMap simulator and Minimum Travel Time (MTT) fire growth algorithm. Fire Fighting Advisor Module is a set of instructions that a machine learning model generates based on training on previous data. Post Fire Analyzing Module performs damage assessments by mapping the total burned area and classifying it according to the burn severity rate. Air Quality and Emissions Module calculates the emissions after controlling a wildfire. Recovery Monitoring Module controls the development of the recovery process based on satellite imagery.

For the inputs, the TFFDSS gathers data of different types from local and international institutions. These data contain spatial data types such as satellite images and weather observations, and non-spatial data types such as fuel types and fuel moisture codes. In

addition to a large database of the previous incidents. TFFDSS provides a variety of outputs that differs due to the fire stage (from early warning to post-fire analyzes passing through fire detection, controlling, and suppression).

The importance of TFFDSS is being an integrated system compatible with the essential four phases of disaster management (Prevention and Mitigation, Preparedness, Response, and Recovery). It has wide functions and tools that make it effective for each step of forest fire fighting like prediction, prevention, facing, controlling, suppression, and recovery.

TFFDSS aims to improve the quality of decisions related to preventing and controlling forest fires which result in environmental and economic effects, besides saving human and animals souls. It is not designed to replace the forest fire decision-makers but it is designed to help in enhancing the decision-making process in terms of time, effort, cost, and effectiveness.

TÜRKİYE ORMAN YANGINI KARAR DESTEK SİSTEMİ (TFFDSS)

Özet

Dünya üzerindeki toplam orman alanı, tüm yüzeyin yaklaşık yüzde 31'ini kaplamaktadır. Ancak, orman yangınları gibi doğal afetler, tüm dünyada ormanların varlığını tehdit eden en önemli tehlikedir. Orman yangınları çevresel ve ekonomik tahribata neden olmaktadır. Bu nedenle de dünyanın birçok yerinde önemli bir risk olarak değerlendirilir. 1990 ve 2020 yılları arasında dünya genelinde ormanların 178 milyon hektarı kaybolmuştur. Ayrıca, mevcut iklim değişikliği nedeniyle orman yangınlarının sıklık, boyut ve şiddetinde artış beklentisi vardır. Aynı durum, ormanların Türkiye'nin toplam yüzölçümünün yaklaşık yüzde 29'unu kapladığı Türkiye için de geçerlidir. Yakılan alanların yıllık ortalaması 10 bin hektar iken, orman yangını sayısının yıllık ortalaması 2500'ün üzerindedir.

Orman yangınları, küresel ölçekte giderek daha ciddi bir tehdit haline gelmiş ve ciddi boyutlarda çevresel ve ekonomik zararlara neden olmuştur. İklim değişikliği orman yangınlarının birincil nedenidir ve sayı, şiddet ve yanmış alanda artışa neden olmuştur. İklim değişikliği, iklimin ısınmasına ve ormanların daha kuru olmasına neden olmuştur ve bu da "mega yangınlara", yani mevcut yangın söndürme kapasitelerinden daha büyük olan orman yangınlarına yol açmıştır. Bununla birlikte, orman yangınlarının tek nedeni iklim değişikliği değildir. İnsanlar, gerçekleştirdiği faaliyetler nedeniyle orman yangınlarının çoğundan kazara veya kasıtlı olarak sorumludurlar. Türkiye'de 2020 yılındaki yangınların çoğunun birincil nedeni insan faaliyetleri olarak belirlenmiştir.

Orman yangınları, ekosistemler ve biyoçeşitlilik üzerindeki etkilerinin yanında insan ve hayvan ölümlerine neden olmaktadır. Bu durum ise orman yangınlarıyla mücadele, hem yok edilen kaynaklar hem de mücadele maliyetleri açısından çok büyük ekonomik kayıplara neden olmaktadır. Türkiye'de 2017 yılında orman yangını ile mücadele faaliyetleri Orman Genel Müdürlüğü'nün toplam bütçesinin yaklaşık %21,2'sine mal olmuştur.

Orman yangını çok karmaşık bir çevresel krizdir, etkin bir şekilde müdahale etmek ve orman yangını tehlikesini en aza indirmek, karar vermeden önce mümkün olduğunca fazla bilgi gerektirir. Orman yangınlarının karmaşıklığı karar verme sürecini olumsuz etkileyebilirken, karar vericiler zaman açısından sınırlı, dinamik, belirsiz ve çelişkili koşulların baskısı altındadır.

Etkili orman yangını mücadelesi, farklı kurum ve kuruluşlar arasında işbirliğini gerektirir, çünkü orman yangını çok karmaşık ve oldukça riskli bir olgudur ve büyük yangınları kontrol etmek tek bir kurum veya kuruluşun kabiliyetini aşar. Bu işbirliği,

ileri teknolojiler ile bilimsel bilgi arasında entegrasyona ve farklı heterojen mekansal ve mekansal olmayan verilerin birleştirilmesine ihtiyaç duyar.

Coğrafi Bilgi Sistemleri, uzaktan algılama, yapay zeka, nesnelerin interneti, sensör ağları, veri analitiği ve diğerleri gibi çeşitli alanlardaki teknolojik ilerlemeler, bir orman yangını ile ilgili devasa heterojen bilgileri dönüştürerek karar vermeyi desteklemeye başlamıştır. Bunlar, bilim insanları ve yetkililer için onlara daha iyi seçimler sağlayan temel verilerdir.

Karar destek sistemi (KDS), karar vericilere yardımcı olmak için geliştirilmiş etkileşimli bilgisayar tabanlı bir bilgi sistemidir. Karar verme teorisini etkileşimli bilgisayar sistemleriyle bütünleştirmektedir. Son zamanlarda planlama, yönetme ve karar verme gibi yangın kontrol süreçlerinin etkinliğini artırmak için CBS tabanlı karar destek sistemleri kullanılmaya başlanmıştır. KDS'nin orman yangını yöneticileri tarafından kullanımı son yıllarda hızla artmıştır. KDS'lerin orman yangınlarını kontrol etmek için hem işlevsel hem de ekonomik olarak verimli taktikler seçme yeteneği, yangınları önleme ve mücadele kapasitesini geliştirirken aynı zamanda insan yaşamlarını ve mülklerini de korumuştur.

ABD, Kanada ve Yunanistan gibi bazı ülkeler kendi orman yangını KDS'lerini geliştirmişlerdir. Ayrıca Avrupa Komisyonu, Avrupa'nın tamamı için Avrupa Orman Yangını Bilgi Sistemini (EFFIS) geliştirmiştir. Daha sonra, uluslararası kuruluşlar arasında ortak bir girişim, Küresel Orman Yangını Bilgi Sistemi (GWIS) geliştirilmesine yol açmıştır. Türkiye'de, son zamanlarda çeşitli araç ve sistemler geliştirilmiştir, erken uyarı sistemleri ve karar destek sistemleri veya hatta yalnızca yangın izleme ve algılama araçları ve sistemleri arasında değişiklik göstermiştir ve bunların tümü orman yangınlarını önlemeye, yönetmeye ve mücadeleye yardımcı olmayı amaçlamışlardır.

Bu çalışmada, Türkiye'de orman yangını önleme ve mücadele için CBS tabanlı bir karar destek sisteminin kavramsal tasarımı, ulusal gereksinimler ve yetenekler göz önünde bulundurularak tasarlanmış ve hazırlanmıştır. Bu sistem, yangınlar ve çevreleriyle ilgili ayrıntılı bilgi ve analiz sağlayarak yöneticilerin bir orman yangını sırasında daha iyi kararlar almalarına yardımcı olmak için tasarlanmıştır.

Bu tasarımda, Tarihsel Yangın Veritabanı Modülü, Hava Tahmin Modülü, Yangın Coğrafi Bilgi Veritabanı Modülü, Yangın Tehlikesi Tahmin Modülü, Aktif Yangın Algılama Modülü, Davranış Tahmin Modülü, Yangınla Mücadele Fikir Alış-Verişi Modülü, Yangın Sonrası Analiz Modülü, Hava Kalitesi ve Emisyon Modülü ve Geri Kazanım İzleme Modülü gibi birbirleriyle ilişkili birçok farklı modülden oluşmaktadır.

Tarihsel Yangın Veritabanı Modülü, çeşitli kaynaklardan gelen önceki orman yangınları verilerinin mekansal ve mekansal olmayan veri koleksiyonundan oluşmaktadır. Hava Tahmini Modülü, gerçek zamanlı yangın hava durumu tahmini sağlamaktadır. Yangın Coğrafi Bilgi Veritabanı Modülü, yardımcı bilgi yardımı içeren çeşitli mekansal katmanları kapsamaktadır. Yangın Tehlikesi Tahmin Modülü, Kanada Yangın Hava Durumu Endeksine dayalı olarak hazırlanmış ve orman yangınlarının göreceli potansiyelinin sayısal bir değerini sağlamaktadır. Aktif Yangın

Algılama Modülü, aktif yangın algılama ürünlerine dayalı olarak NASA tarafından sağlanan MODIS ve VIIRS uydularından sağlanan verilere bağlı olarak hazırlanmıştır., Yangın Davranışı Tahmin Modülü, FlamMap simülatörüne ve Minimum Seyahat Süresi (MTT) yangın büyüme algoritmasına dayalı olarak hazırlanmıştır, Yangınla Mücadele Fikir Alış-Veriş Modülü, bir makine öğreniminin modelinin önceki yangınların verilerine eğitime dayalı olarak ürettiği bir talimat seti olarak hazırlanmıştır. Yangın Sonrası Analiz Modülü, toplam yanmış alanı haritalayarak hasar değerlendirmelerini gerçekleştirmek ve yanma şiddeti oranına göre sınıflandırmaktadır. Hava Kalitesi ve Emisyon Modülü, bir orman yangınını kontrol ettikten sonra emisyonları hesaplamaktadır, Geri kazanım ve İzleme Modülü, uydu görüntülerine dayalı olarak geri kazanım sürecini kontrol eder.

Girdiler için sistem, yerel ve uluslararası kurumlardan farklı türde veriler toplar. Bu veriler, uydu görüntüleri ve hava durumu gözlemleri gibi mekansal veri türlerini, yanıcı madde türleri ve yanıcı madde nem kodları gibi mekansal olmayan (öznitelik) veri türlerini içermektedir. Türkiye'de orman yangını önleme ve mücadele için CBS tabanlı bir karar destek sisteminin kavramsal tasarımı ile yangın aşamasına göre farklılık gösteren çeşitli çıktılar sağlaması amaçlanmaktadır (erken uyarıdan yangın algılama, kontrol ve söndürme yoluyla geçen yangın sonrası analizlere kadar).

Bu sistemin önemi, afet yönetiminin temel dört aşaması (Önleme ve Zarar Azaltma, Hazırlık, Müdahale ve İyileştirme) ile uyumlu entegre bir sistem olmasıdır. Sistem, tahmin, önleme, iyileşme, kontrol, mücadele ve kurtarma gibi orman yangını mücadelesinin her adımında etkili olmasını sağlayan geniş işlevlere ve araçlara sahip olarak tasarlanmıştır.

Türkiye'de orman yangını önleme ve mücadelesi için CBS tabanlı bir karar destek sisteminin kavramsal tasarımı, canlıların korunmasının yanı sıra çevresel ve ekonomik etkileri olan orman yangınlarının önlenmesi ve kontrolüne ilişkin alınan veya alınacak olan kararların kalitesini iyileştirmeyi amaçlamaktadır. Orman yangını karar vericilere, karar verme sürecini zaman, emek, maliyet ve etkinlik açısından geliştirmeye yardımcı olmak için tasarlanmıştır.

1. INTRODUCTION

1.1. Global Forest Fire: an Overview

One-third of the Earth's surface is covered by forests and trees (Moayedi et al., 2020). Forests are one of the most important renewable natural resources because they help keep the environment clean and produce oxygen, which helps keep the ecosystem balanced (Pourtaghi et al., 2015). Illegal harvesting, increasing demand for land, climate-changing, forest fires, and many other factors are threatened forests (Akay et al., 2011; Ertugrul, 2005). According to the FAO, since 1990, the Earth has lost 178 million hectares (ha) of its forest area (Url-10). Over the last decade (2010 – 2020) the global rate of net forest loss was 4.7 million ha per year (Url -10) (Figure 1.1). Deforestation as it is defined by the FAO: the process of converting forest areas into different land uses, regardless of the cause. The FAO said that about 10 million ha of forests were cut down in the period from 2015 to 2020 (Url-10).

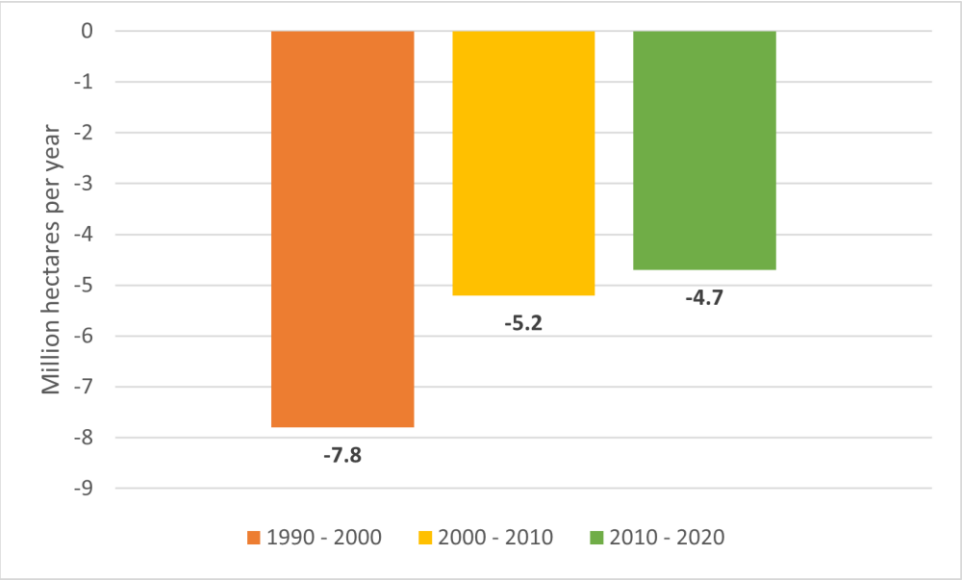

Figure 1.1 : Global annual forest area net change, by decade, between 1990 and 2020. (Adapted from Url-10)

Among the various environmental and anthropic factors that threaten the forests, fires are regarded as the most dangerous and destructive due to their rapid spread (Wu et al., 2018). Millions of hectares of forests, woodlands, and other vegetation are destroyed yearly by wildfires (Url-9). In addition to human and animal deaths, wildfires cause enormous economic losses (Url-9). Annual statistics between 2003 and 2012 indicate that the wildfires have affected approximately 67 million ha around the world (Wu et al., 2020). In this period (2003 – 2012) the wildfires affected great areas of the total forest area in some countries such as 38% in Portugal, 6% in Greece, 5.6% in Italy, 4.2% in Spain, 1.2% in France, and 0.4% in Turkey (Eker and Abdurrahmanoğlu, 2018). While the National Interagency Fire Center (NIFC) in the US recorded only in 2020 about 60 thousand wildfire incidents, that affected more than 4 million ha (Figure 1.2). In Russia, an average of 9.3 million ha of forests have burned each year, whereas in Canada, unfortunately through the last four decades, wildfires affected about 2 million ha per year (Flannigan et al., 2009).

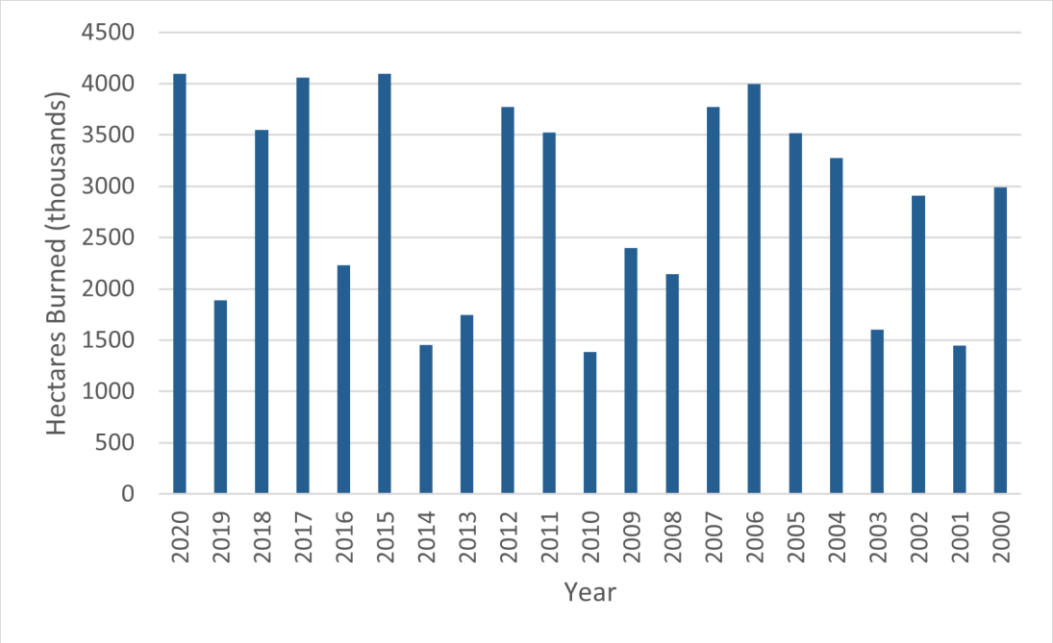

Figure 1.2 : Annual burden area in the US, 2000 – 2020. (Adapted from Url-1)

1.2. Causes of The Forest Fires

Climate change is the primary cause of wildfires, it is driving a global trend toward increased wildfire activities (Vásquez et al., 2021). As a result of the warming climate, forests become drier and more vulnerable to fire (Url-15). Since climate change

extends the fire season with hot and dry days in a year it has a risk-increasing impact on fire (Url-15). However, climate change is not the only reason for forest fires. According to the World Wide Fund for Nature (Url-15), in the Mediterranean region, wildfires are mostly caused by humans — either accidentally or deliberately (Url-15). The official statistics by WWF indicate that wildfires caused by natural phenomena are uncommon (Table 1.1).

Table 1.1 : Causes of forest fires in Portugal (2014), Spain (2013), and Italy (2014) (Url-15).

Country	Unknown Cause	Known Cause	of which			
			Arson	Carelessness	Re-ignition	Natural
Portugal	38%	62%	31%	57%	10%	1%
Spain	12%	88%	59%	31%	3%	7%
Italy	24%	76%	85%	14%	-	1%

Despite its minor role in the overall picture, the lightning strikes may result in massive forest cover losses, carelessness is also one of the significant causes of fires. Besides that, some other factors such as using fire in farming, burning coal seams, and sparks flying from railway or power lines could also be the possible reasons for forest fires (Url-15).

1.3. Impacts of The Forest Fires

Each year, savannah and forest fires emit between 1.7 and 4.1 billion tons (t) of carbon dioxide (CO_2) into the atmosphere. Furthermore, approximately 39 million t of methane (CH_4) (each 1 t of CH_4 is equal to 21 t of CO_2), 20.7 million t of nitrogen oxides (NOx), and 3.5 million t of Sulphur dioxide (SO_2) are also emitted. Wildfires are responsible for 15% of worldwide greenhouse gas GHG emissions, the majority of which are produced by fire suppression in tropical rainforests and subsequent land conversion. Wildfires account for 32% of worldwide carbon monoxide (CO) emissions, 10% of CH_4 emissions, and 86% of soot emissions (Lavorel et al., 2007; Url-15).

According to their location and size, wildfires can be categorized into three main classes. The underground fire in which no flames are visible but only smoke can be seen. The surface fire where flames and smoke can be seen, the crown wildfire which is happened if the surface fire becomes out of control. The crown wildfire causes tremendous flames and the ability to destroy enormous areas of forest (Chowdary et al., 2018).

1.4. GIS-Based Decision Support Systems

Wildfire is a very complicated environmental crisis (Vasilakos et al., 2009), responding effectively and minimizing the danger of a wildfire requires as much as possible information before making decisions (Vásquez et al., 2021). The complexity of the wildfires can make a negative impact on the decision-making process. The technology advances in various fields such as Geographic Information Systems (GIS), Remote Sensing, Artificial Intelligence (AI), Internet of Things (IoT), Sensor Networks, Data Analytics, and many others (Vásquez et al., 2021) have led to support the decision-making through converting the huge heterogeneous information related to a wildfire into key data for scientists and authorities allowing them better choices.

Kucuk and Bilgili (2006) indicated that by using (GIS) technology, gathering and analyzing data and information is simpler, more cost-effective, and faster than classical approaches. Not only for firefighting efforts but also for pre-fire preventive measures and post-fire operations as well. In recent years, GIS-based decision support systems have been used to increase the efficiency of fire control processes such as planning, managing, and decision making (Akay et al., 2011).

A decision support system (DSS) is an interactive computer-based information system developed to assist decision-makers (Liu et al., 2010). DSS integrates the theory of decision-making with interactive computer systems (Vásquez et al., 2021). In a very complex and highly risky phenomenon such as wildfire, the decision-makers are under the pressure of conditions that are limited in time, dynamic, uncertain, and contradictory (Zimmerman, 2012). These conditions make the wildfires DSSs precious techniques for managing and preventing forest fires (Sakellariou et al., 2017) and improving the quality of decisions (Lourenço et al., 2021)

According to Sakellariou et al., (2017), wildfires DSSs should include the following functions:

- Retrieval, analysis, update, edit and predict models of different geospatial data,
- Risk indexes and thematic maps (historical data, moisture content) of original vegetation cover,
- Forest fuel types,
- The fire spread and behavior models,
- Use of interactive programs to prepare, plan, coordinate, and deploy fire department forces (human force, number, and type of fire machinery - land or airborne forces, or a combination of them).

The use of DSS by wildfire managers has grown quickly in recent years, owing to the ability of the DSSs to pick tactics to control wildfires that are both functionally and economically efficient. In turn, this has improved the capacity to prevent and suppress wildfires while also safeguarding human lives and properties (Vásquez et al., 2021).

1.5. Scope of This Research

In this research, a conceptual design of a GIS-Based DSS for forest fire early warning, preventing, controlling, suppressing, and forest recovery monitoring in Turkey was designed. This DSS is proposed by considering the national requirements and capabilities. The introduced DSS is designed with multi modules compiled into one unified system. The designed DSS consists of different modules including:

- Historical Fire Database Module,
- Weather Forecast Module,
- Fire Geo-Information Database Module,
- Fire Danger Forecast Module,
- Active Fire Detection Module,
- Fire Behavior Prediction Module,
- Fire Fighting Advisor Module,

- Post Fire Analyzing Module,
- Air Quality and Emissions Module,
- Recovery Monitoring Module.

The designed system has a large database for the previous wildfire enabling it to make queries and analyses to detect the high fire potential forests. In addition, it supports the visualization and analysis of weather forecast observations. The system gathers great available geospatial databases from different local government institutions to use them in better fire fighting. It is also based on NASA's open recourses products of MODIS and VIIRS missions to monitor forests and detect active fires.

Furthermore, the designed system provides two damage assessment modules one for post-fire analysis and the other for air quality and emissions calculations. In addition to the above, the system has a firefighting advisor module that has a significant role both in planning and preparation for potential fires and in suppressing the fires. Moreover, the system has a recovery monitoring module to control the development of the recovery process after a wildfire.

the DSS aims to assist the decision-makers effectively to prevent and suppress forest fires and improve the fire policy for better management of forests and fires.

This research was guided by the following research questions:

- Requirement of the design of TFFDSS?
- What kind of benefits does TFFDSS contribute to the decision-makers?
- Due to the nature of DSSs being significantly complex, how users will deal with the complexity of the TFFDSS?
- Is training valuable for the usage of TFFDSS?
- Is a level of experience needed to execute TFFDSS for decision making?
- How do fire administrators perceive the importance of TFFDSS?

This study consists of 5 chapters. The first chapter is the Introduction which is deals with the general information about forest fire and related issues. In the second section, the most important DSSs at different scales are reviewed. While in the third section

the importance and necessity of forest fire DSSs are discussed. The fourth and fifth sections are the methodology and the conceptual design respectively, wherein the methodology section the mathematical and structural base of each function in TFFDSS is explained, and how the system works in was discussed in the conceptual design in detail. The sixth and last section is the conclusion and recommendations.

2. LITERATURE REVIEW

In this section, wildfire decision support systems, which were previously implemented and efficiently used in different countries, were examined. For this purpose, those wildfire decision support systems were considered at global, continental, and national scales based on their coverage area. Additionally, best practices in Turkey were also evaluated within the context of this chapter.

2.1. Global Scale Forest Fire Decision Support Systems

2.1.1. Global wildfire information system (GWIS)

The GWIS seeks to provide a continuous and seamless platform of standardized data on wildfires that can be utilized at both national to global scales. At the global scale, where wildfires-related data is dispersed and not harmonized, be a unique source of information for worldwide efforts and regulations, while also facilitating the investigation and research of the global wildfires (Url-11).

Regional and national partners at a high degree of collaboration are required for the validation of the various components of GWIS (Url-11). GWIS serves as a bridge for countries that have not developed a forest fire information system yet, allowing them to participate in international cooperation. While it is an independent source for complementary and harmonized information in countries that have already developed their forest fire information systems (Url-11).

GWIS has several services (Figure 2.1) that provide harmonized fire information (Url-11) including:

- Fire danger estimation based on different fire danger indices with the Canadian FWI as a default,
- Active fire detection based on MODIS, VIIRS, and Sentinel-3 satellites,

- Burned area mapping based on MODIS (MCD64A1) product with monthly updating,
- Emissions assessment provided by the Copernicus Atmospheric Monitoring service,
- Background and ancillary data where are available only for researchers and non-profit organizations.

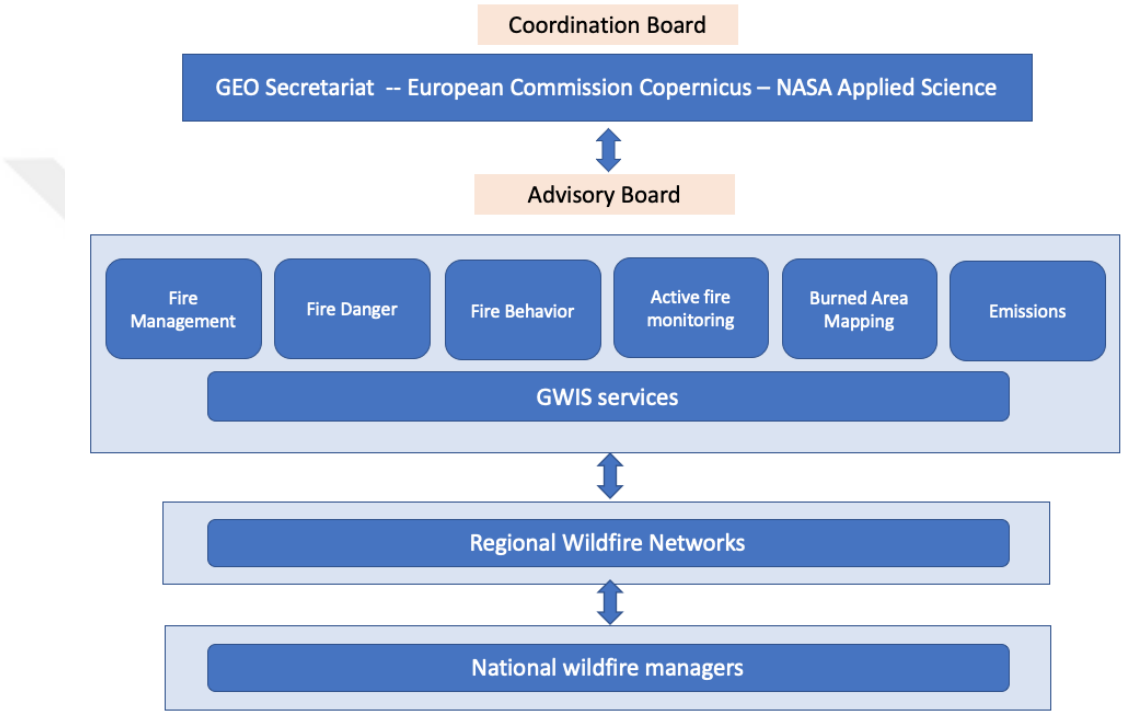

Figure 2.1 : The Structure of GWIS. (Url-11)

2.2. Continental Scale Forest Fire Decision Support Systems

2.2.1. European forest fire information system (EFFIS)

EFFIS was developed by the European Commission Joint Research Centre and DG Environment in 2000. EFFIS aims to provide near real-time data on forest fires and their impacts on the surrounding environment, as well as to encourage international cooperation in forest fire prevention and suppression. A total of forty European, Middle Eastern, and North African countries are now involved with the EFFIS network.

EFFIS is a comprehensive system that encompasses the whole cycle of forest fire management, from prevention and readiness through post-fire damage assessment (Kalabokidis et al., 2016). EFFIS services include fire danger estimation based on the Canadian FWI (Van Wagner, 1987) where Meteo France and Deutscher Wetterdienst (DWD) provide the weather forecast observations, active fire detection via MODIS satellites, rapid damage assessment, and post-fire modules that analyze land cover damage, post-fire soil erosion, smoke plume emissions, and dispersion, and finally, vegetation recovery in large burned areas (Kalabokidis et al., 2016).

2.3. National Scale Forest Fire Decision Support Systems

2.3.1. Canadian forest fire danger rating system (CFFDRS)

CFFDRS as shown in Figure 2.2, is a complete set of tools for evaluating environmental elements that affect the ignition, spread, and behavior of a wildfire (Stocks et al., 1989). The CFFDRS has been developing since 1968, it is composed of four interconnected modules including:

- The Canadian Fire Weather Index (FWI) System (Van Wagner, 1987; Van Wagner and Pickett, 1985). Since 1970, the FWI System has been used across Canada to estimate relative fire potential based only on meteorological observations (Stocks et al., 1989).
- The Canadian Fire Behavior Prediction (FBP) System (Wotton et al., 2009; Hirsch 1996; Van Wagner et al., 1992). Since 1990, The final production of the FBP System has been used to predict the rate of spread, fuel consumption, and frontal fire intensity (Stocks et al., 1989).
- The Accessory Fuel Moisture (AFM) System (Wotton, 2009a; Lawson et al., 1997). It is used to generate three primary daily moisture codes necessary for the FWI System, these three codes are generated through estimation of the moisture content in different fuel types at different times of the day (Wang et al., 2017).
- The Canadian Fire Occurrence Prediction (FOP) System. It consists of both lightning strikes and human-caused fire components (Stocks et al., 1989).

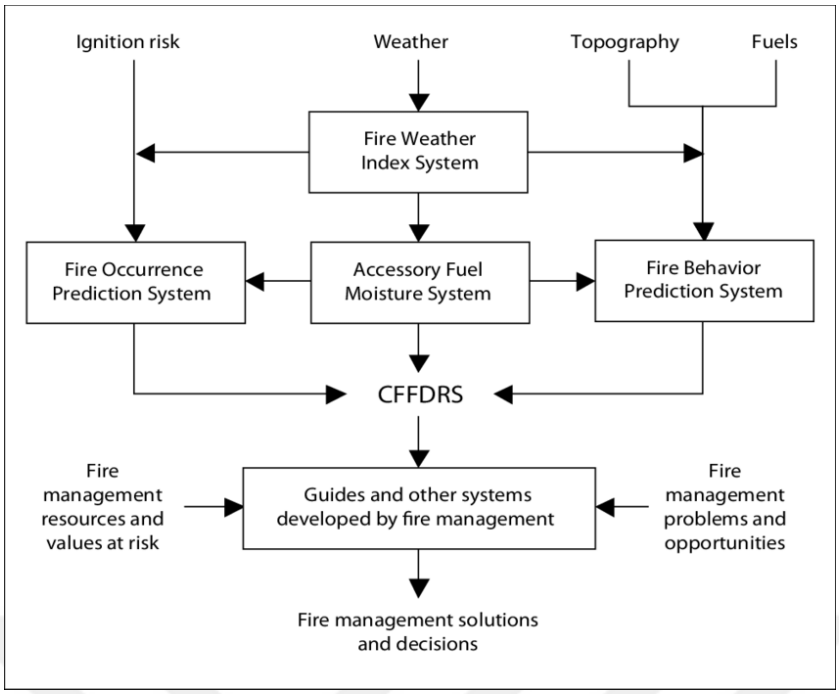

Figure 2.2 : Canadian Forest Fire Danger Rating System (CFFDRS). (Stocks et al., 1989)

2.3.2. Wildland fire decision support system of USA (WFDSS)

WFDSS is a multiagency web-based tool that was designed to assist fire administrators and managers in risk-informed decision-making for wildfires in the United States (Noonan-Wright et al., 2011). WFDSS has access to various local functions and services including (national weather data and forecasts, fire behavior prediction, economic assessment, smoke management assessment, and landscape databases) these accesses allow WFDSS to effectively enhance the decision-making process (Noonan-Wright et al., 2011). Figure 2.3 shows the conceptual design of WFDSS.

WFDSS estimates the fire danger through applying the National Fire Danger Rating System (NFDRS) (Burgan, 1988) whereas weather analysis is performed using data from RAWS (Zachariassen et al., 2003). Minimum Travel Time (MTT) (Finney, 2002) is the algorithm used for the estimation of the potential fire spread (Kalabokidis et al., 2016). WFDSS is distinguished by applying the Rapid Assessment Values at Risk (RAVAR) model (Calkin et al., 2011) and the Stratified Cost Index (Gebert et al., 2007) for providing damage assessments for the burned areas (Kalabokidis et al., 2016).

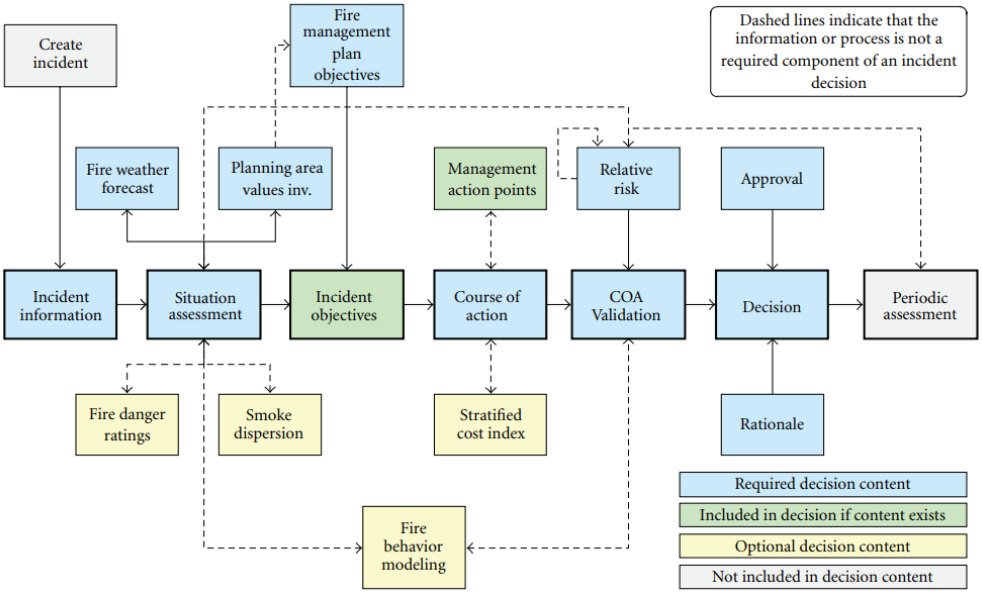

Figure 2.3 : In the conceptual design of WFDSS, the bolded horizontal flow represents the key stages required to make a decision in WFDSS. (Noonan-Wright et al., 2011)

2.3.3. AEGIS

AEGIS is a web-GIS-based decision support system platform, that aims to manage and prevent wildfire in Greece. AEGIS is designed as an integrated and user-friendly tool (Figure 2.4), it provides critical data and information make it essential for early fire warning, fire planning, fire control, and coordination of firefighting forces (Kalabokidis et al., 2016).

AEGIS support wildfires simulation based on Minimum Travel Time (MTT) (Finney, 2002), very high spatial resolution satellite images, and a few inputs like fire duration, ignition point, and weather forecast (Kalabokidis et al., 2016). For wildfire ignition risk assessment, AEGIS has utilized Artificial Neural Networks (ANNs), the ANNs besides the predicted burned area maps are used to predict the fire hazard map (Kalabokidis et al., 2016).

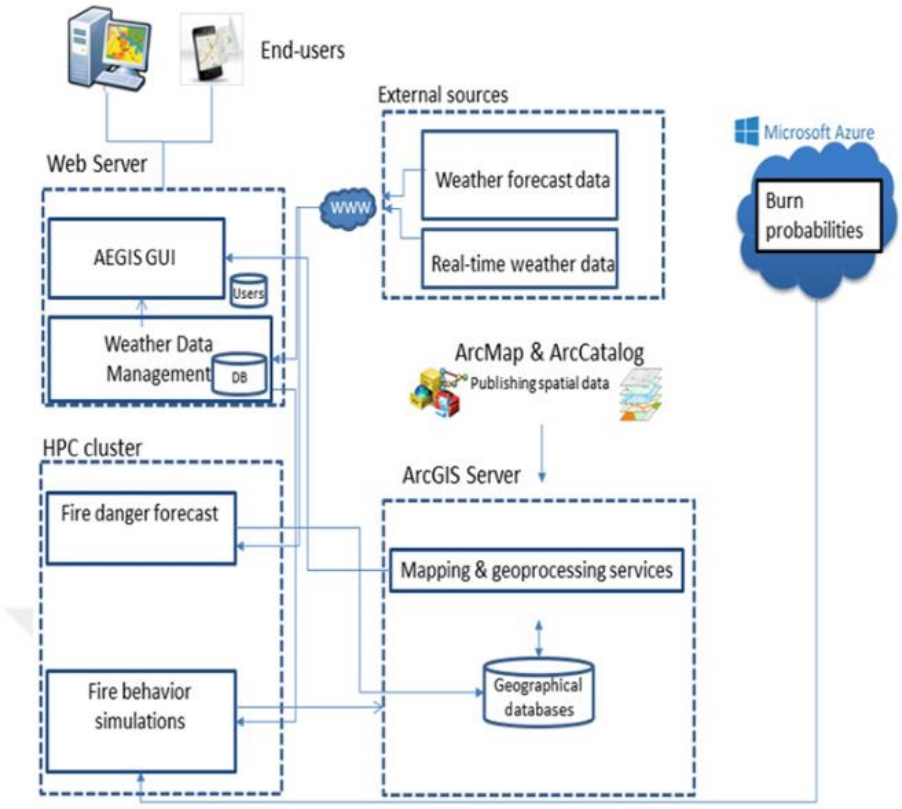

Figure 2.4 : Architectural components of AEGIS. (Kalabokidis et al., 2016)

2.4. Forest Fire Decision Support Systems In Turkey

Several tools and systems have been developed recently in Turkey, they have varied between early warning systems and decision support systems or even only monitoring and detection tools and systems, all of which aim to assist in preventing, managing, and suppressing wildfires.

2.4.1. Forest fire meteorological early warning system (MEUS)

Weather conditions play a significant role in the occurrence, severity, and duration of forest fires. Forest fires whether natural or man-made caused cannot happen without suitable meteorological conditions (Url-2). Precisely measured weather observations are required at each stage of fire control, the effects of these conditions may vary according to topography, forest area, and fuel type (Url-2).

When temperature rises above 40°C and the relative humidity falls below 20%, the probability of forest fires is very high, at this situation wind can play important role in fire spread. Besides weather conditions, analyzing the topography and fuel types is necessary for successful and effective firefighting (Url-2).

Temperature, relative humidity, precipitation, wind direction and speed, and the stability of weather are critical for any early warning system. MEUS has been developed by the general directorate of meteorology as a forest fire meteorological early warning system through five stages (Figure 2.5):

- Weather forecast analyzing,
- Forest map-based data processing,
- Topography analyzing and blow-dry effect,
- Danger results classification,
- Generating danger maps.

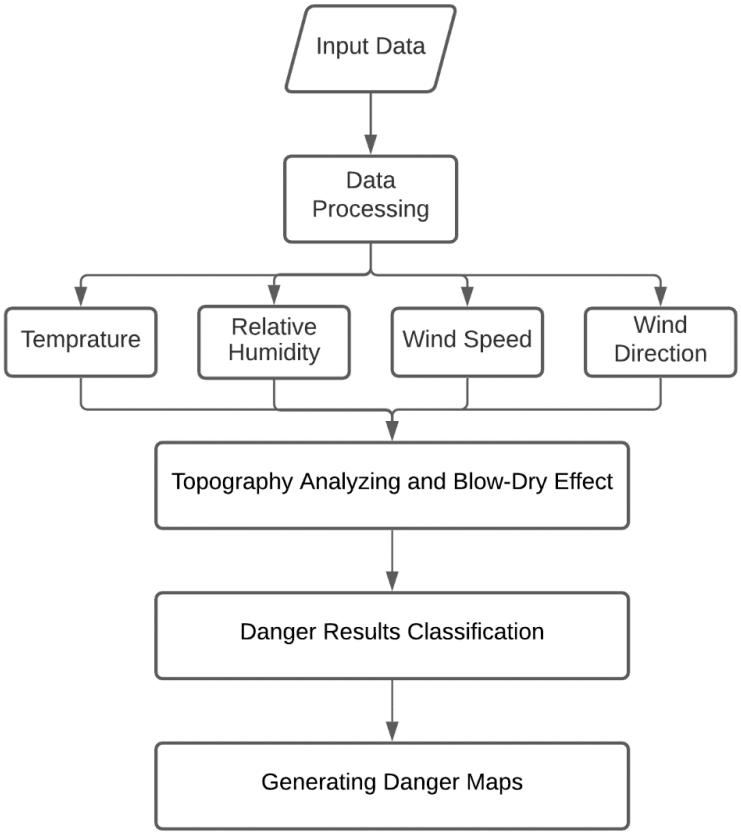

Figure 2.5 : The flowchart of MEUS.

2.4.2. Foogle: fire monitoring tool for EUMETSAT's active fire product over Turkey using google earth

It is a satellite-based forest fire visualization system in Turkey, developed by the Turkish State Meteorological Service, which assists in firefighting efforts. Foogle is based on the near-real-time FIR product of EUMETCast (a system for distributing environmental data operated by EUMETSAT) probable and possible fires are generated in the type of ASCII and Google Earth file (KML) formats (Sönmez et al., 2011). Where ASCII files contain the coordinates and KML files provide areal representation (Figure 2.6). EUMETCast generates the FIR products are generated every 15 min.

In the case of probable fires, the firefighters are to be alert. While in possible fires, firefighting actions have to be performed (Sönmez et al., 2011).

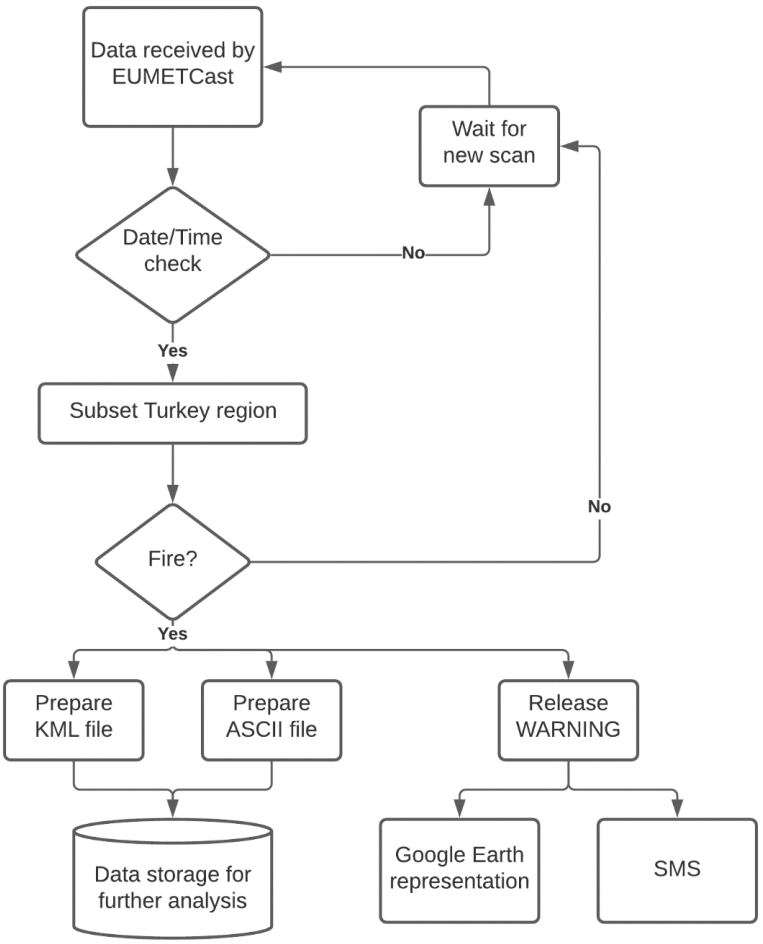

Figure 2.6 : Foogle workflow (Adapted from Sönmez et al., 2011).

2.4.3. Forest fire decision support system (FOFDESS)

FOFDESS is a multi-agent forest fire decision support system based on meteorological conditions and environmental measurements. FOFDESS estimates the fire danger, rate of fire spread and can detect a started fire (Elmas and Sonmez, 2011).

FOFDESS performs Artificial Neural Network (ANN), Naive Bayes Classifier (NBC), Fuzzy Switching (FS), and image processing for data fusion. A data fusion framework was used to connect these algorithms (Figure 2.7). In addition, a unique hybrid method named NABNEF (Naive Bayes Aided Neural-Fuzzy Algorithm) was enhanced for fire danger estimation (Elmas and Sonmez, 2011).

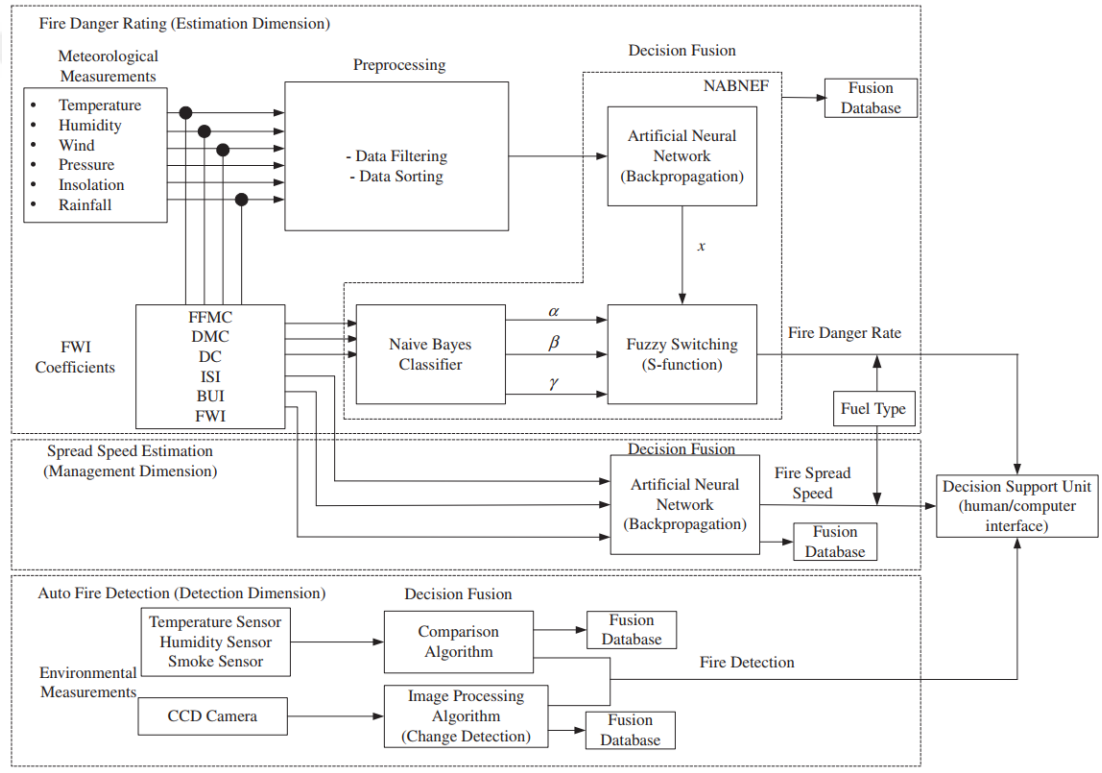

Figure 2.7 : FOFDESS data fusion framework (Elmas and Sonmez, 2011).

2.4.4. Forest information system (ORBIS)

ORBIS was a project developed by the General Directorate of Forestry (OGM) in 2011. The goal of ORBIS is to create an informatics infrastructure for the effective protection, planning, and management of Turkey's environment and forest ecosystem. In addition, to enabling OGM to fulfill its duties effectively and efficiently. ORBIS also will enhance the transformation of services and information between citizens, the

public sector, private sector. ORBIS will improve the economy based on forest products and forest ecotourism services in terms of quality and quantity (Url-12).

ORBIS consists of three modules, each module contains several modules, each module has several functions:

- Forest Inventory Management Information System,
- Corporate Service Inventory System and Electronic Document Management System (EBYS),
- Corporate Resource Planning System.

Forest Fires Management Module is developed within the Corporate Resource Planning System, this module consists of the following functions:

- Fire Management and Damage Assessments,
- Arvento Integration,
- High Fire Potential Area Monitoring,
- Meteorology Integration.

2.4.5. Turkish national forest fire danger rating decision support system (TOYTOS)

TOYTOS was designed as prototype software at Karadeniz Technical University in 2019. It consists of four main modules, where each module may execute alone or run within the whole system (Figure 2.8). The modules are Fire Information System (FIS), Fire Occurrence Prediction System (FOP), Fire Weather Index System (FWI), and Fire Behavior Prediction System (FBP) (Coskuner, 2019).

The FIS module was created to make it as simple as possible for fire chiefs to input, store, update, and manage data. The FOP module was designed in response to fire risk parameters that contribute to fire ignition. The FWI module estimates the fuel's ignition potential and generates information related to fire spread rate and fire intensity. The FBP module predicts fire behavior under different weather conditions, different fuel types, and topographic variations.

TOYTOS software aims to provide fire administrators with the necessary tools for prevention, suppression, and post-fire analysis.

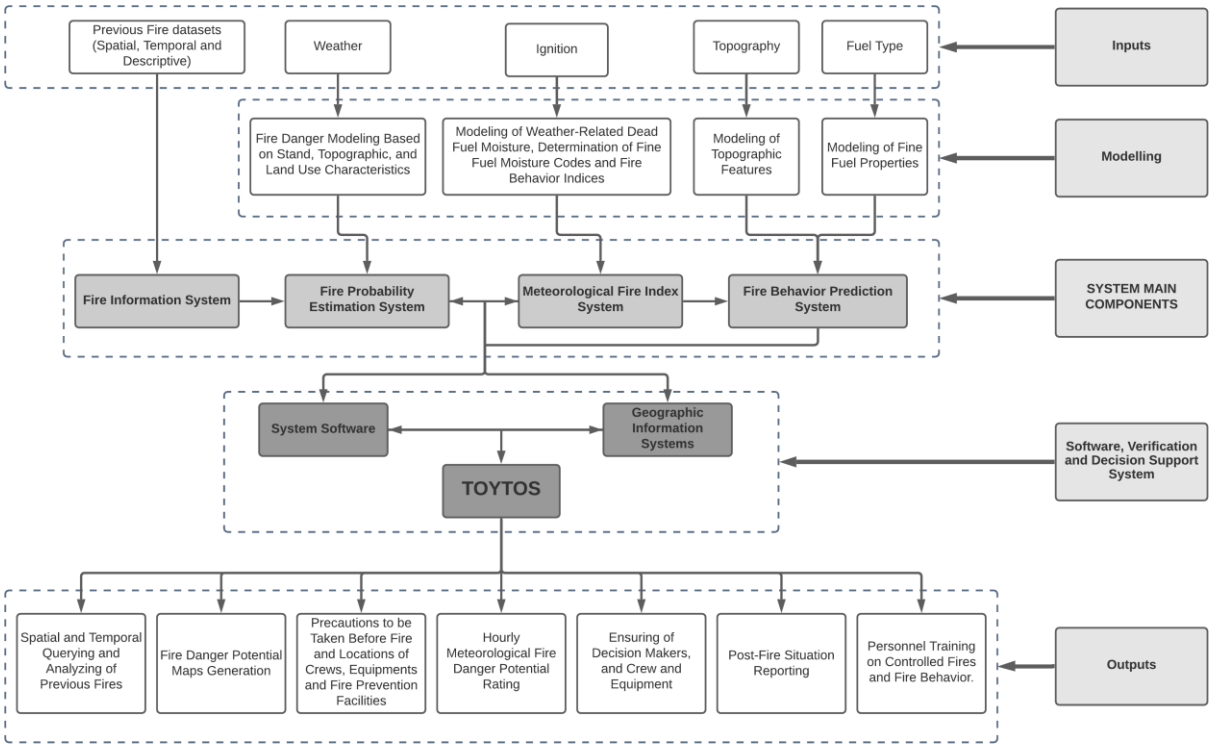

Figure 2.8 : The workflow diagram of the Turkish National Forest Fire Danger Rating Decision Support System (TOYTOS).

2.4.6. A GIS-based decision support system for determining the shortest and safest route to forest fires

An additional study was introduced a GIS-based DSS developed by utilizing the Network Analyst extension within ArcGIS 9.2, and it was implemented in the Kahramanmaras Forestry Regional Directorate in Turkey. It is a GIS-based decision support system, designed by Akay et al., (2011) in such a way that allows fire administrators to select the fastest and the safest access routes from firefighting headquarters to fire regions. The system performs topographic and forest management maps, as well as fire sensitivity data analysis to produce a spatial database, containing a road network, land use classes, and fire sensitivity levels.

Based on road length and average speed of a fire truck, the presented system estimates the average travel time of fire trucks and adds it to the road network GIS-based database. The system incorporates four Network Analyst techniques including new

closest facility, new route, new service area, and new origin-destination cost matrix, to examine routing possibilities (Akay et al., 2011).

3. IDENTIFICATION OF REQUIREMENTS FOR TFFDSS

Worldwide response to fires must be proactive and committed at all levels, including local, subnational, national, and regional. Preventing fires before they start is significantly superior in all respects to just controlling them after they start. It's not enough to have good ideas and dedication; they should be put into efficient action.

3.1. Wildfire As a Global Challenge

Wildfires have become an increasingly serious concern on a global scale, causing environmental and economic damages. From the Amazon to the Arctic in 2020, there was a 13% increase in the fire alerts compared to the same period of 2019 which was already a record year of fires (Url-4). The main causes behind this increase are the persistently hotter and drier weather, as well as other human activities like land conversion for agriculture and inadequate forest management (Url-16).

Forest fires have a devastating effect on all biomes, and they are considered responsible for almost 25% of all fire-related emissions due to their increased carbon-storing potential, even though cover only 10% of total burnt land (Url-8). According to statistics between 2000 and 2015, 85% of the worldwide surface area burnt each year is in tropical savannahs (Url-14).

Climate change leads to an increase in the number, severity, and area burned by wildfires (Lidskog et al., 2019). Since the early 1990s, "megafires" – wildfires that are larger than the existing firefighting capabilities have been more common in Europe with an expectation to further increase in their frequency as a result of climate change (Tedim et al., 2016). According to (Url-5), 39 countries in Europe and MENA had large fires of more than 30 hectares during 2020, with a total burned area of 1075145 hectares being mapped, which is almost 35% larger than the previous year.

If nothing is done to fight climate change, the world's forest loss might go back up. Global forest loss has been decreasing consistently since 1900 when records began.

However, if we don't adjust our land use and management policies, scientists expect that the yearly burned area will rise to levels not seen since the 1950s (Url-16).

3.2. Wildfire As a National Challenge in Turkey

The forests cover an area of about 12 million hectares in Turkey, starting from the Western Black Sea coastline and extends to the Marmara, Aegean, and Mediterranean Regions. Approximately 60% of the total forest area in Turkey is highly sensitive to forest fires (Url-13).

According to (Akay et al., 2012) around 2,000 forest fires incidents, every year from 1990 and 2006 destroyed an average of 10,000 hectares of forest area per year. The last statistics from the general directorate of forestry (Url-3) between 2015 and 2020 approved that the average burned area is still about 10,000 hectares each year (Figure 3.1). However, the number of wildfire incidents is increased up to an average of 2667 incidents per year (Figure 3.2).

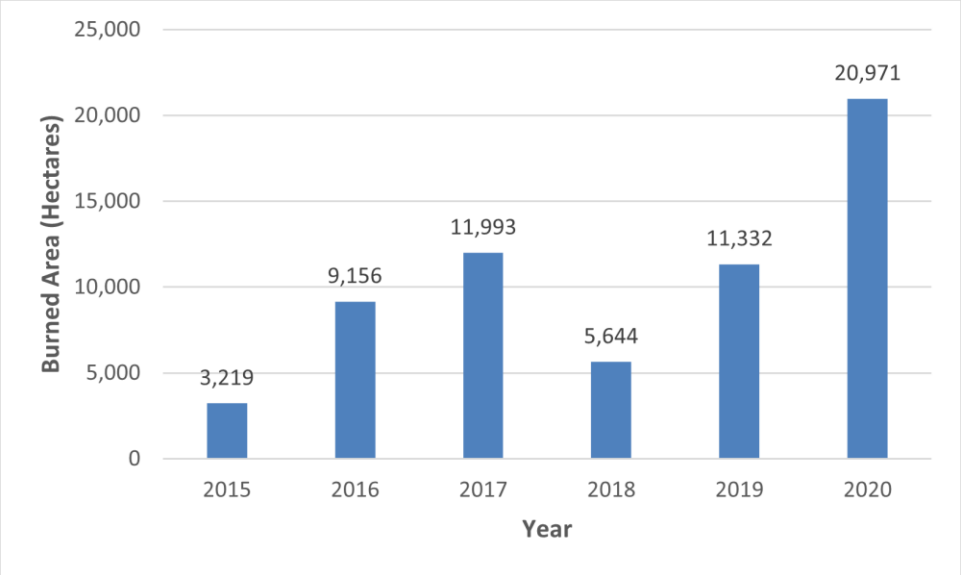

Figure 3.1 : Burning forest areas, 2015 – 2020 (Adapted from Url-3).

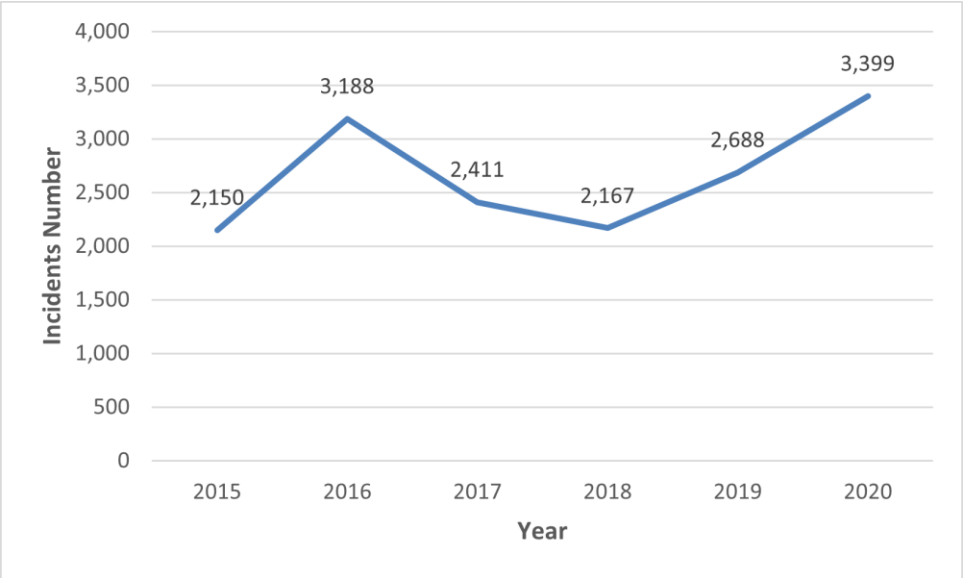

Figure 3.2 : The number of fires, 2015 – 2020 (Adapted from Url-3).

Fire season in Turkey occurs between March and December, where June, July, August, and September are the most severe. In August 2020, the highest numbers of fire incidents have been recorded (Url-5) while in September of the same year the largest burned area has happened (Table 3.1).

Table 3.1 : The monthly distribution of forest fires in Turkey, in 2020 (Url-5).

Month	Number of Fires	Burnt Area (Ha)
Jan	37	22.85
Feb	33	10.09
Mar	157	165.52
Apr	187	183.7
May	179	281.11
Jun	242	182.09
Jul	474	1725.92
Aug	797	6748.56
Sep	608	9029.7
Oct	410	2446.89
Nov	157	83.74
Dec	118	87.34
Total	3399	20967.51

According to (Url-5) in Turkey, 78% of wildfires occur at elevations of 400 meters or above. The main properties of these areas are:

- High Population Density,
- High Migration Rate,
- Valuable Lands,
- Cadastral Issues,
- Tourism Hotspots.

Human activity was the primary cause of most of the fires in Turkey, Figure 3.3 represents the causes of forest fires in 2020 (Url-3).

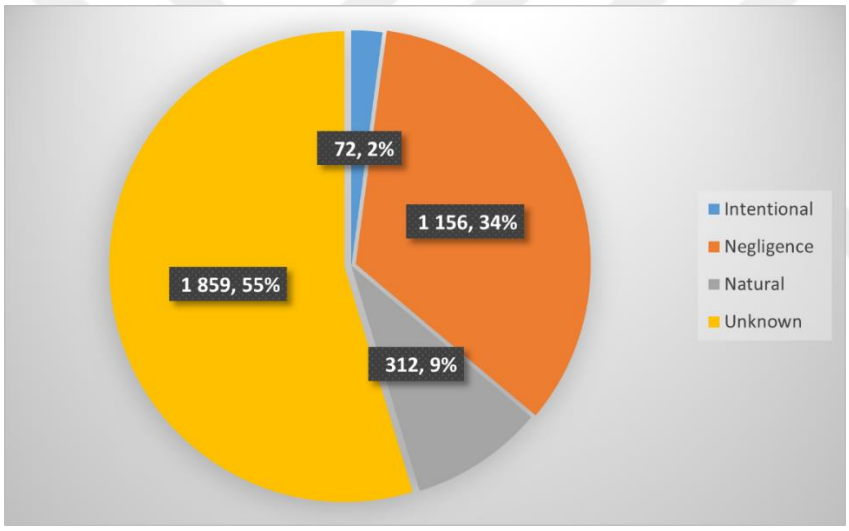

Figure 3.3 : The wildfire causes in Turkey, in 2020 (Adapted from Url-3).

3.3. Can The Designed System Be a Solution For The Forest Fire Issue of Turkey?

The General Directorate of Forestry (OGM) is responsible for fire management in Turkey. OGM has several regional directorates which carry out their duties through operating state forest enterprises (Url-5). Along with the great impacts of wildfire on the environment and ecosystem, they also cause a big economic loss. Wildfire fighting takes a significant place in the budget of OGM (Eker and Abdurrahmanoğlu, 2018). In 2017, wildfire fighting activities cost about 21.2% of the total budget of OGM (Url-13).

When evaluating the previous situations, it is clear that there is a need to decision support systems that can contribute to the analysis of both the ecological and economic effects of forest fires. However, despite emphasizing the necessity and importance of using decision support systems, the worldwide forest fire decision support systems are still not applied effectively (Coskuner, 2019).

For that, The introduced conceptual design is developed to take its role in preventing, managing, controlling, and suppressing forest fires based on globally applied algorithms and techniques. It is coming with a strong conceptual structure that enables converting the heterogeneous inputs into organized information.

The developed DSS in this research is designed in a way that enhances the available systems. It is an integrated DSS that has a variety of functions to assist the decision-makers at each stage of a wildfire.

4. METHODOLOGY

The TFFDSS is proposed to be a web-based information system, designed to be an integrated wildfire control system. TFFDSS is based on heterogeneous sources of data. It is designed to assist decision-makers in predicting, facing, controlling, and suppressing wildfires. It aims to improve the quality of decisions by providing more choices to analyze the fires and the environmental, weather, and spatial conditions surrounding them in a comprehensive and effectively interpretable manner.

The purpose of TFFDSS is not to substitute the role of decision-makers but rather to help them make faster and more efficient decisions. The designed system consists of several modules including:

- Historical Fire Database Module,
- Weather Forecast Module,
- Fire Geo-Information Database Module,
- Fire DangerForecast Module,
- Active Fire Detection Module,
- Fire Behavior Prediction Module,
- Fire Fighting Advisor Module,
- Post Fire Analyzing Module,
- Air Quality and Emissions Module,
- Recovery Monitoring Module.

4.1. Historical Fire Database (HFD) Module

The Historical Fire Database (HFD) Module is very important to understand and predict the wildfires and their behaviors by analyzing their preceding incidents. HFD

consists of a collection of spatial and non-spatial of the previous wildfires data from various sources.

The goals of the HFD module are to:

- Determine the forests with high fire potential,
- Determine the main reasons for previous wildfires in some regions (e.g., Mediterranean Sea, Black Sea),
- Determine the most frequent weather conditions that happened before the fire,
- Allow users to make queries and analyses about specific parts of the data.

The HFD module contains data such as:

- Fire ID,
- Stardate,
- End date,
- Fire cause,
- Fire-type,
- Fire location,
- Weather observations before the fire,
- Fire start points,
- The total burned area,
- Burn severity rate.

This module enables users to search, store, query, and analyze the data. In addition, the results of the HFD module can be presented as reports, graphs, or maps. Figure 4.1, represents the flowchart of the HFD.

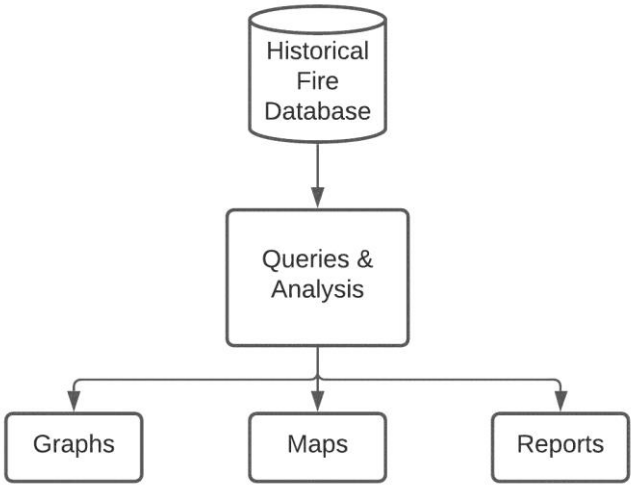

Figure 4.1 : The Historical Fire Database (HFD) Module Design.

4.2. Fire Danger Forecast (FDF) Module

This module is based on the Canadian Fire Weather Index (FWI). The FWI was originally created in Canada (Van Wagener, 1987) but has been used in many countries around the world such as (United States, Mexico, south-east Asia, New Zealand, Portugal) also the FWI system was verified appropriate for European conditions (Viegas et al., 1999). Recently, the FWI is used in the European Forest Fire Information System (EFFIS) and it is selected by several European countries as the best approach to wildfire risk assessment (San-Miguel-Ayanz et al., 2018)

The main inputs of the FWI system (temperature, wind speed, relative humidity, and precipitation) are measured from weather observations (Lawson and Armitage, 2008). The FWI system consists of six standard components, three of them are fuel moisture codes while the others are fire behavior indexes. All together are aggregated into a single numerical value of the relative potential of wildfires as shown in Figure 4.2.

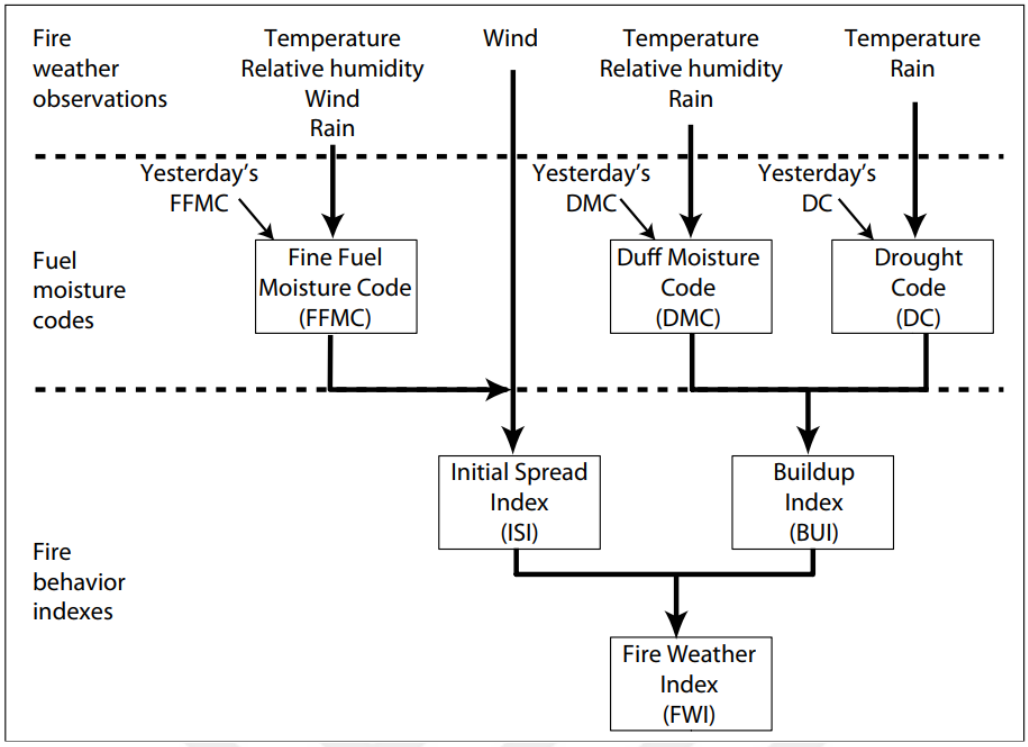

Figure 4.2 : The Canadian Fire Weather Index System (Lawson and Armitage, 2008).

The three fuel moisture components within the FWI system correspond to daily variations in the moisture content of three distinct classes of forest fuel of different drying rates. Each moisture component is calculated in two stages (witting by rain and drying), they have structured in such a way that higher values indicate lower moisture content and therefore higher flammability (Van Wagner, 1987).

The other three components (the fire behavior indexes) within the FWI system represent the rate of spread, amount of available fuel, and fire intensity. The values of the three fire behavior indexes are related to the fire weather severity where they increase as fire weather severity gets worse (Url-6).

The six components of the FWI system are described below.

4.2.1. Fine fuel moisture code (FFMC)

The FFMC code refers to the relative ease of ignition and flammability of fine fuel. It is a numerical value that indicates the moisture content of litter and other cured fine fuels (Lawson and Armitage, 2008).

4.2.2. Duff moisture code (DMC)

The DMC is a numerical value that represents the moisture content of loosely compacted organic (duff) matter, it indicates the fuel consumption in the moderate duff layers and medium-size fuels (Lawson and Armitage, 2008).

4.2.3. Drought code (DC)

The DC value represents the average moisture content of deep, compact, organic matter layers. The DC could be useful for representing the effects of seasonal drought on fuels and the amount of burning in thicker fuels that have a longer drying rate (Lawson and Armitage, 2008).

4.2.4. Initial spread index (ISI)

ISI is a numerical valuation of the expected rate of fire spread. The ISI combines the impacts of wind and FFMC on the fire rate of spread without affecting the different amounts of fuel (Url-6).

4.2.5. Buildup index (BUI)

The BUI value refers to the entire amount of fuel existing for combustion that combines DMC and DC (Url-6).

4.2.6. Fire weather index (FWI)

The FWI numeric value combines ISI and BUI to represent the fire intensity. The FWI is designed to be a general index of forest fire danger (Url-6). For each component of the FWI system, there is one essential value that is calculated daily during the peak combustion period in the mid-afternoon, this value represents the fire danger conditions expecting a normal daytime weather pattern (Van Wagner, 1987). However, the calculation of the different fuel moisture codes for rainy days was standardized by considering the effect of rain, and the corresponding degree of drying (Lawson and Armitage, 2008).

The components (three indexes and three codes) of the FWI System are diurnal fire potential predictors (Alexander and Degroot, 1988). The FWI does not point to the hourly changes and does not take into account changes in fuel type from season to

season or from location to location because each component of the system has only one value to be determined. However, the FWI system provides reference scales for comparing the fire danger with other days and places. In addition, the FWI system allows the reconstruction of past fire danger conditions when sufficient historical weather observations are available. (Lavoie et al., 2007; Girardin et al., 2006; Parisien et al., 2004; Amiro et al., 2004; Harrington et al., 1983; Kiil et al., 1977; Stocks, 1974; Turner, 1973).

4.2.7. Calculation instructions

Four weather essentials are required to calculate the six parts of the FWI system. These essentials are temperature, relative humidity, rain, and wind speed. Figure 4.3, represents the workflow of the Canadian FWI system.

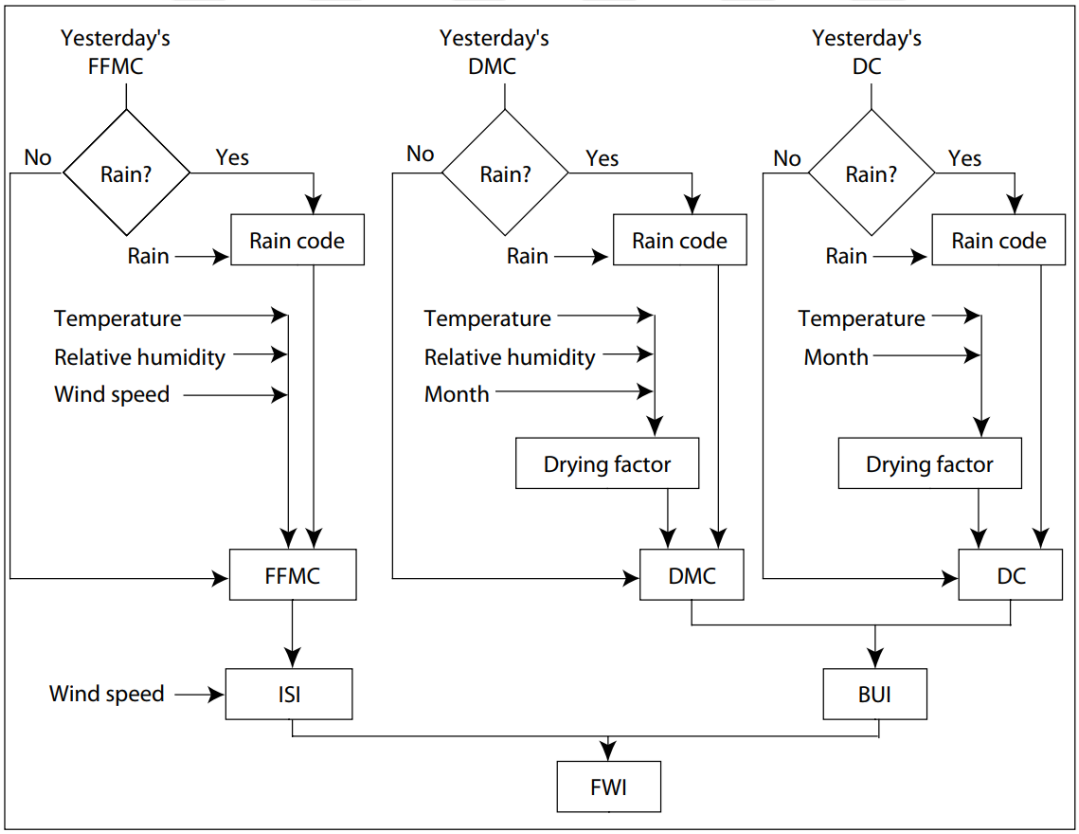

Figure 4.3 : The workflow diagram of the Canadian WFI system and the calculation of its six standard components (Lawson and Armitage, 2008).

4.3. Weather Forecast (WF) Module

Meteorological data (also referred to as fire weather) plays a critical role at each stage of wildfire progress, it affects the potential, behavior, and suppression of the wildfire.

Weather Forecast (WF) Module can provide real-time fire weather forecasting through its direct access to the Directorate General for Meteorological Service portal. It supplies the users with an hourly forecast of the necessary weather data. Also, the WF Module allows users to visualize weather maps for up to 5 days.

The weather observations of (Temperature, Relative Humidity, Wind Speed, Wind Direction, and Precipitation) are also the base of the Fire Danger Forecast Module. These observations affect the way which fires can be begun, the rate of spread, and the difficulty of fighting already started fires (Lawson and Armitage, 2008).

4.3.1. Temperature

The calculations of the three fuel moisture codes of the FWI system require measuring the noon (dry-bulb) temperature (in degrees Celsius).

4.3.2. Relative humidity

The atmospheric ability to hold moisture is based largely on atmospheric temperature. The increase in temperature, increase the atmosphere's ability to retain more moisture. The Relative Humidity is expressed as a percentage, it is the ratio between the moisture in the atmosphere at a defined temperature, and the whole moisture amount that the atmosphere can hold at that temperature (Lawson and Armitage, 2008).

Relative humidity and temperature follow a predictable pattern on a typical day when no substantial moisture is added or taken from the atmosphere (Figure 4.4).

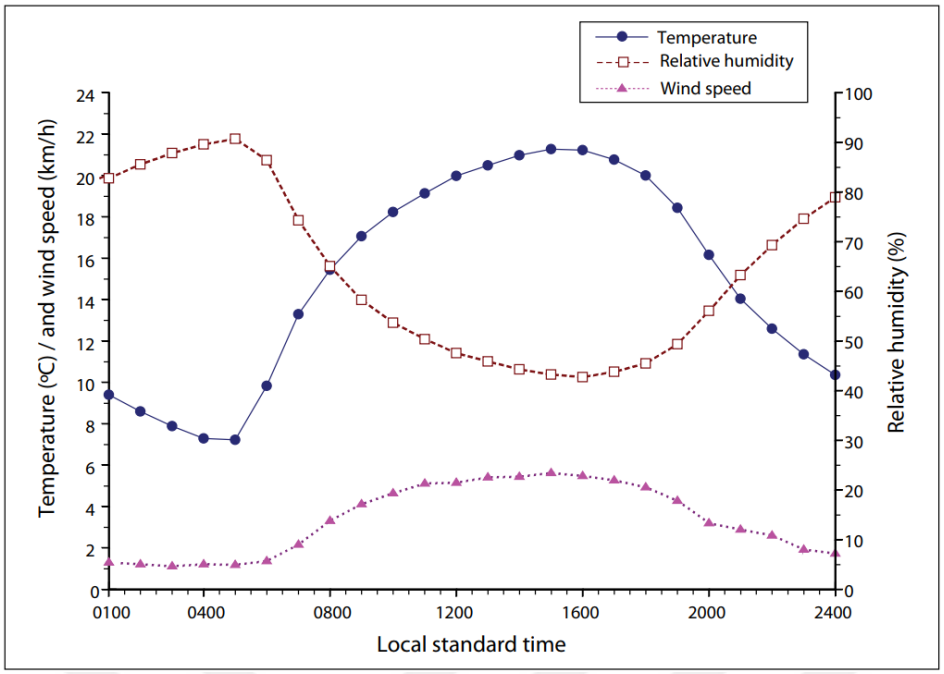

Figure 4.4 : A typical continental station's daily patterns of temperature, relative humidity, and wind speed throughout July, Leighton Lake, B.C. (Lawson and Armitage, 2008).

4.3.3. Rain

The amount of rain that has accumulated in 24 hours is measured from noon to noon and recorded to the nearest fifth millimeter (0.2) (Url-6). If the moisture content of forest fuel contact with liquid water, it is possible to increase it up to 300% or more. While for the dead woody fuels in a saturated atmosphere, the maximum fiber saturation value can be about 30% (Schroeder and Buck, 1970). Rain is the only way to reduce the values of FFMC, DMC, and DC to lower than those values which have been recorded in the preceding day (Van Wagner, 1987).

In order to consider the effects of the rain on the moisture content of the fuel, the total amount of rainfall in 24 hours must exceed a certain threshold. Table 4.1 represents the specific values of the threshold for each one of the three fuel moisture codes (Lawson and Armitage, 2008). Decreasing the value of each moisture code depends on the amount of rain and the value of the code before raining (Lawson and Armitage, 2008).

Table 4.1: Threshold rain values for fuel moisture codes

Fuel moisture code	24-h rain (mm)
Fine Fuel Moisture Code	> 0.5
Duff Moisture Code	> 1.5
Drought Code	> 2.8

In the case of snow (or hail), which may remain on the ground during the measurements, the three moisture codes continue to be calculated by equivalent the amount of the fallen snow with water (where 1 cm of snow equals 1 mm of rain) (Url-6). However, under these conditions, the values of ISI and FWI will be zero until the snow or hail melts (Lawson and Armitage, 2008).

4.3.4. Wind speed

The wind speed is measured (in kilometers per hour) and averaged over at least 10 minutes (Url-6). The FWI system is affected by wind speed in two ways (weak and stronger); there is a relatively weak impact on daily FFMC changes, with wind speed mostly influencing the rate of recovery following rain. The combined impact of wind and fine surface fuel moisture content on a fire's rate of spread is reflected in the ISI in a considerably greater way (Lawson and Armitage, 2008).

Lawson and Armitage (2008) indicate that the ISI duplicates its value for every 14 km/h growth in wind speed, while the FFMC remains constant (Table 4.2). At the same time and in moderate to severe conditions, when the wind speed is constant, five to seven FFMC units should be added to duplicate the ISI (Table 4.2).

Table 4.2 : Wind's effect on the Initial Spread Index (ISI).

	ISI at various wind speeds			
FFMC	5 km/h	19 km/h	33 km/h	47 km/h
77	1	2	5	9
80	2	3	6	12
83	2	4	9	17
86	3	6	13	26
89	5	10	20	40

92	7	15	30	61
95	11	23	46	93
98	17	34	68	138

4.3.5. Wind direction

As wind speed, the wind direction should be measured over at least 10 minutes. It is measured clockwise from geographic north (in degrees) with an accuracy of 5°. The wind direction can be defined as the direction when the wind is blowing (Lawson and Armitage, 2008).

The wind direction is one of the standard weather observations, it is used by the Fire weather forecasters to combine local wind patterns with wider winds and topography. Wind direction is essential for the prediction of fire behavior (Lawson and Armitage, 2008).

4.4.Fire Geo-Information (FGI) Database Module

A variety of geospatial layers that contain auxiliary information help the decision-makers to improve their choices and decisions during wildfire events. The Fire Geo-Information Module provides easy access to users and allows them to select, display, and turn on / off some features. Also, the Fire Geo-Information module provides some functions to calculate distance and area, detect location, and search for specific features. In addition to the “closet route” query to find the shortest distance between features.

The Fire Geo-Information data include:

- A digital base map for the forest in Turkey,
- Road network,
- Natural reserves,
- Monuments,
- Pumping stations,
- Water tanks,

- Fire hydrants,
- Helipads,
- Gas/petrol stations,
- Gas/petrol lines,
- Petrol site for the vehicle of the firefighters,
- Fire watch outlooks,
- Landfills,
- Weather stations,
- Evacuation sites,
- Electric high voltage lines,
- Electric substations,
- Hospitals,
- Schools,
- Homes,
- Firefighter sites.

4.5. Active Fire Detection (AFD) Module

The Active Fire Detection (AFD) module is based on the active fire detection products that are provided by NASA FIRMS (Fire Information for Resource Management System). Since the 1980s, it has been available to get data from space related to the active fires on the earth's surface (Ichoku et al., 2012; Setzer and Pereira, 1991; Matson and Holben, 1987). The detection algorithms look for the differences between the temperatures of a potential fire and the surrounding ground cover; if the temperature difference exceeds a certain threshold, it will confirm the fire potential as an active fire or a "hot spot" (Giglio et al., 2003).

The AFD module is proposed to use the products (MOD14 and MYD14) of the Moderate Resolution Imaging Spectroradiometer (MODIS), and (VNP14 and VNP14IMG) of the Visible Infrared Imaging Radiometer Suite (VIIRS).

4.5.1. MODIS

The MODIS satellite was designed with specific spectral bands to detect fires (Justice et al., 2002). MODIS is aboard the Terra and Aqua satellites of the NASA Earth Observing System (EOS). For more than 20 years, MODIS has been scanning the Earth's surface every day for fires, it has provided considerable advances in the field of global fire detection with 1 km spatial resolution (Justice et al., 2011a). Moreover, MODIS has represented improvements in the geolocation and orbit stability when compared with its predecessors (Justice et al., 2011a). During the last 2 decades, a great number of citations, researches, and data applications were evidenced by the fire products of MODIS (Csiszar et al., 2014).

MODIS discriminates regions that are much hotter than its surrounding classify them as active fires. This classification is based on the temperature differences between the actively burning areas and their neighbors (Giglio et al., 2003).

4.5.2. VIIRS

VIIRS is the new generation of the medium resolution imager (Url-7), it is onboarding the NASA/NOAA Suomi National Polar-orbiting Partnership (SNPP), which was launched on 28 October 2011.

In the field of global fire detection, VIIRS uses the same algorithms as MODIS (Csiszar et al., 2014). The active fire products of VIIRS are complementary to those of MODIS. However, the VIIRS products provide better spatial resolution, where the resolution of VIIRS is 375 m. The increased resolution of VIIRS allows it to detect much smaller fires and discriminate the boundaries of the active large fires (EFFIS). Although MODIS and VIIRS are similar in orbit, they differ in many things (e.g., spatial resolution), Table 4.3 represents the specifications of the MODIS and VIIRS products.

Table 4.3 : The main specifications of the products of the MODIS and VIIRS.

	MODIS Fire Product	VIIRS Fire Product
Platform	NASA EOS Terra and Aqua satellites	NASA/NOAA SNPP
Lunch Date	2002	2011

Primary Detection Band	4 μm, 11 μm channels	4 μm, 11 μm channels
Spatial Resolution	1 km at Nadir	375 m at Nadir
Global Coverage	twice per day	twice per day
Potential Pixel Selection	$T_4 > 305$ and $\Delta T > 10$	$T_4 > 305$ and $\Delta T > 10$
Platform	NASA EOS Terra and Aqua satellites	NASA/NOAA SNPP
Lunch Date	2002	2011

4.6. Post Fire Analyzing (PFA) Module

The goal of the Post Fire Analyzing (PFA) module is to map the total burned area and classify it according to the burn severity rate. The PFA module requires pre-fire and post-fire satellite images (e.g., Landsat-8 and Sentinel-2) to the area of interest. The evaluation of landscape conditions post-wildfire is based on spectral indexes because of the increase in the reflectance of the near-infrared (NIR) and shortwave-infrared (SWIR) regions of the electromagnetic spectrum, due to the regression in the green cover of vegetation and the increase in both soil and charred materials (Roy et al., 2006; Navarro et al., 2017). These spectral indexes often use the differenced ratios between the visible and infrared bands to highlight the burned areas in the pre-fire and post-fire satellite images (Lewis et al., 2021). One of the most common spectral indexes for post-wildfire severity mapping is the Normalized Burn Ratio (NBR) (Keeley, 2009). NBR (equation 4.1) can be calculated from the NIR and SWIR bands and the burn severity rate is usually measured from the difference between the pre-fire NBR to the post-fire NBR (Lewis et al., 2021).

In addition to the NBR, the Normalized Difference Vegetation Index (NDVI) has also been operationally used for burn severity mapping, The NDVI (equation 4.2) calculates the normalized ratio of the NIR and red spectral bands. It is a widely accepted method for assessing vegetation health and the vegetation presence or absence (Lewis et al., 2021). Both the NBR and NDVI measures enable the discrimination of healthy green plant cover from bare soil, as well as the change caused by fire.

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \tag{4.1}$$

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (4.2)$$

4.7.Air Quality and Emissions (AQE) Module

Wildfires emit huge volumes of particulate matter and toxic gases into the atmosphere, such as carbon monoxide, nitrogen oxides, and non-methane organic compounds. Air quality and human health are negatively affected by large and frequent wildfires (Bowman and Johnston, 2005).

The AQE module aims to calculate the emissions after controlling a wildfire. A common method for calculating wildfire-related CO2 emissions was to use equation 4.3. (Shiraishi, 2021; Shi, 2015; Paton-Walsh, 2014; Michel, 2005).

$$Emissions = \sum_{i=1}^{n} BA \times BD \times BE \times EF \quad (4.3)$$

Where BA represents the total burnt area (m^2), BD represents the total burnt biomass density (kg m^{-2}), BE represents the burning efficiency (0 to 1), and EF represents the emission factor of dry matter (g kg^{-1}), which can be defined as the number of trace gases released per unit of fuel combusted, and i represents the types of land cover.

4.8. Fire Behavior Prediction (FBP) Module

The FlamMap simulator and Minimum Travel Time (MTT) fire growth algorithm (Ager and Finney, 2009; Finney, 2006) have been used in the majority of wildland fire behavior modeling studies in Europe (Mitsopoulos et al., 2017; Alcasena et al., 2015; Salis et al., 2015; Mitsopoulos et al., 2014). FlamMap's inputs are divided into four primary categories (Finney, 2006):

- Topographic data,
- Forest characteristics,
- Weather forecast data,
- Fuel moisture data.

FlamMap is one of the most commonly used and highly acknowledged fire behavior modeling, fuel management, and mapping programs at the landscape scale (Finney,

2006). It is capable of performing fire behavior calculations individually for each site using a single set of environmental circumstances (Finney, 2006). The spread rate, flame length, fireline intensity, and much more of the potential fire behavior characteristics can be calculated by FlamMap (Finney, 2006).

FlamMap results provide valuable information for fire control management and are appreciated for landscape comparisons to determine risky fuel, topographic, and weather combinations in evaluating fire hazard and prioritizing field crews during operational phases (Yavuz, 2018; Ager and Finney, 2009; Stratton, 2006; Stratton, 2004), and they can be used directly by other firefighting and management software and tools without converting to another data format (Ager et al., 2011).

4.8.1. FlamMap input overview

Different geospatial inputs are required for FlamMap software in order to estimate fire behavior characteristics. Some of these inputs are necessary and the others are optional. The eight required raster inputs include topographic features, fuel canopy characteristics, and fuel model table. These input data must be (Finney, 2006):

- Co-registered to the same reference point and units,
- At the same resolution and extent,
- Have the same projection and datum.

Table 4.4 : FlamMap inputs data.

Category	Data
Topography	Elevation
	Slope
	Aspect
Canopy Characteristics	Canopy height
	Canopy cover
	Canopy base height
	Canopy bulk density
Fuel Model	Fuel model
	Temperature

Weather	Wind Speed
	Wind Direction
	Relative humidity
	Rain
Fuel Moisture Content	Live fuel moisture
	Dead fuel moisture

Some characteristics of fire behavior (such as a crown fire) need additional data to be calculated, which might be critical to the fire behavior analysis process. Table 4.4, represents the required and optional data of the FlamMap inputs.

4.8.2. Basic fire behavior

The most basic use of FlamMap is for assessing fire behavior over a whole landscape under a consistent set of environmental circumstances. For surface and crown fire simulations, basic fire behavior results are produced in a raster format (Table 4.5). It is possible to display spread vectors that illustrate the rate of spread and maximum spread direction of the fire (Finney, 2006).

Table 4.5 : FlamMap outputs.

Fire Behavior Value	Output Type	Units
Fireline Intensity	Raster	kW m^{-1} or BTU ft^{-1} sec^{-1}
Flame Length	Raster	meters or feet
Rate of Spread	Raster	M min^{-1} or ft min^{-1} or ch hr^{-1}
Heat per unit Area	Raster	kW m^{-2} or BTU ft^{-2} sec^{-1}
Horizontal Movement Rate	Raster	M min^{-1} or ft min^{-1} or ch hr^{-1}
Midflame Windspeed	Raster	mph or kph
Spread Vectors	Vector	m min^{-1}
Crown Fire Activity	Raster	Index, 0 1 2 or 3
Solar Radiation	Raster	W m^{-2}
1-hr Dead Fuel Moisture	Raster	Fraction (0.0-1.0)
10-hr Dead Fuel Moisture	Raster	Fraction (0.0-1.0)

4.8.3. Minimum travel time (MTT)

FlamMap employs the MTT technique (Finney, 2002) to compute fire growth between cell corners at random resolution. Fire growth is calculated using the same assumptions as fundamental fire behavior — all environmental factors are assumed to remain constant throughout time. (Finney, 2006). Thus, the MTT computations can produce fire growth in the lack of time-varying winds or moisture content, allowing just the impacts of fuel spatial patterns and terrain to be studied. The MTT computations produce a distinct set of results from the standard FlamMap products (Table 4.6). These outputs are influenced by fire movement direction, disclosing heading, flanking, and backing spread. Also, they are limited to the region inside the spreading fire (Finney, 2006). Therefore, they will vary from the values obtained for the outputs indicated in Table 4.5.

Table 4.6 : The MTT outputs.

Fire Behavior Value	Output Type	Units
Rate of Spread	Raster	m min^{-1} or ft min^{-1} or ch hr^{-1}
Influence Grid	Raster	Index (logarithm of nodes burned after this node)
Arrival Time Grid	Raster	minutes
Fireline Intensity Grid	Raster	kW m^{-1} or BTU ft^{-1} sec^{-1}
Flow Paths	Vector	
Major Paths	Vector	
Arrival Time Contour	Vector	Interval 1/10th range
Burn Probabilities	Raster	0.0 - 1.0

4.9. Fire Fighting Advisor (FFA) Module

The Fire Advisor (FFA) module plays a significant role at each stage of the fire controlling and suppression. When no active fires are occurring, the FFA serves as an early warning system that depends on the WF and HFD modules to predict the possible fires. Where the FFA module is supposed to be trained on the weather-related data of the HFD module to continuously make predictions of possible fires based on the

weather observations of the WF module. When detecting a fire, the FFA firstly will provide information about the detected forest such as fuel type, previous firs, closest Gas/petrol lines, and so on. Moreover, the FFA will warn if any change in the speed or direction of the wind happens.

4.10. Recovery Monitoring (RM) Module

Recovering forest ecosystems requires more than just reducing dangerous fuels. Forest recovery is important to restore structure and function, in addition to preserving and enhancing essential habitat, riparian regions, watersheds, and a variety of other characteristics. Ecological restoration can be defined as the assistance of the recovery procedure of the degraded, damaged, or destroyed system (Robert et al, 2005).

The condition of a forest after a wildfire is directly affected by the fuel type and the fire severity. The burn severity is used by fire ecologists to describe how fires affect hydrologic function and soil health. Mostly, dense vegetation is more affected by long fires, these fires can affect the soils in terms of the ability to absorb and process water (Url-17). The decision-makers guide the post-fire recovery process based on the evaluating reports of the forest condition. This process contains some steps like (assessing resource damage, minimizing erosion, removing hazard trees, and replanting trees where needed).

The role of the Recovery Monitoring Module is to control the development of the recovery process based on satellite imagery to measure vegetation greenness. The module performs time-series NDVI analysis to extract seasonal and inter-annual changes. The equation 4.4, is used to detect the vegetation cover anomalies of the burned forest by calculating the difference between the current NDVI and the average NDVI of a few previous seasonal. The results of this module can provide insight into the post-fire vegetation recovery response.

$$\Delta \boldsymbol{NDVI} = \boldsymbol{NDVI}current - \boldsymbol{NDVI}average \quad (4.4)$$

5. TFFDSS CONCEPTUAL DESIGN

TFFDSS is proposed to be a web-based decision support system for early warning, preventing, controlling, suppressing wildfires, and forest recovery monitoring in Turkey. It is based on processing different spatial and non-spatial data that come from different national and international sources. Figure 5.1 represents the TFFDSS organizational architecture, it shows how data gathered from different institutions pass through the system modules to the decision-makers to evaluate their decisions.

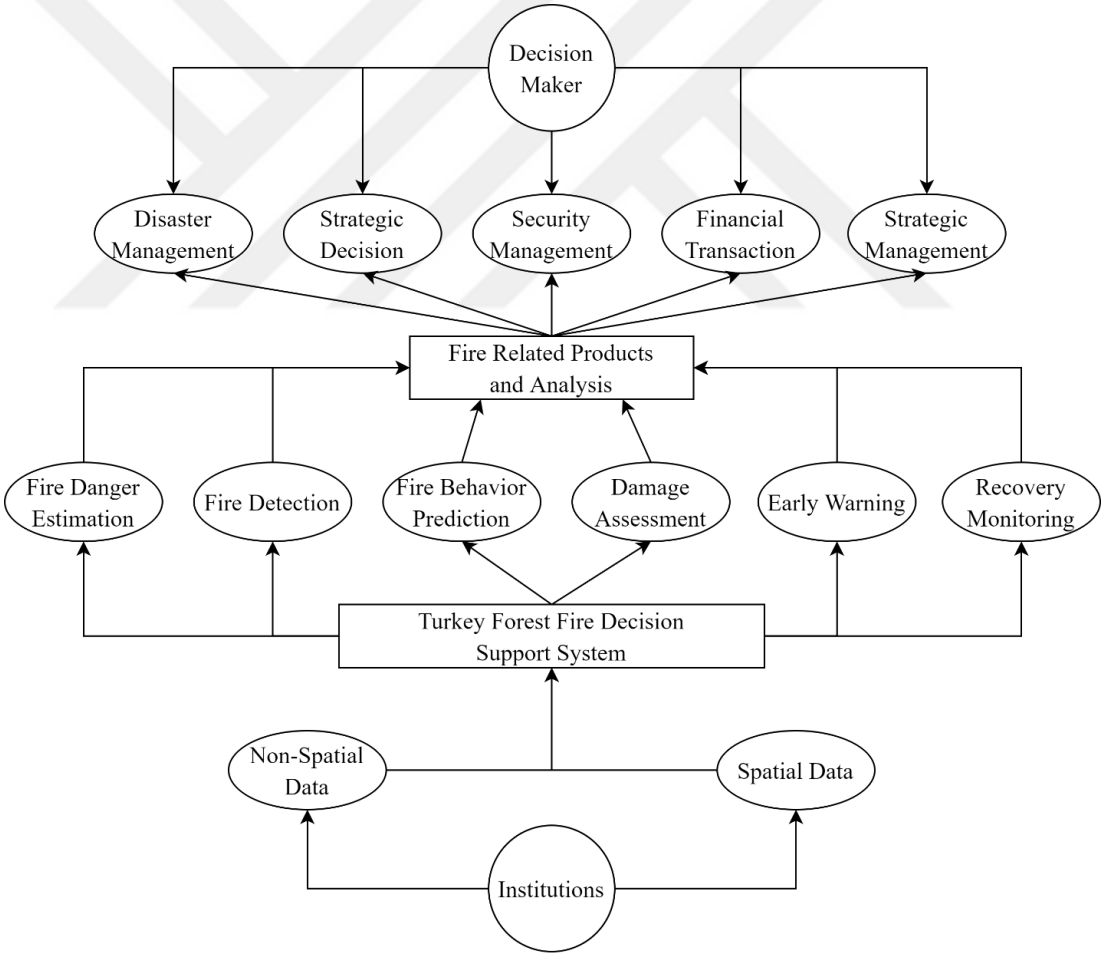

Figure 5.1 : TFFDSS organizational architecture.

TFFDSS as a web-based DSS facilitates spatial and non-spatial data process, retrieval, display, and analysis, and executes the modules through several servers (Figure 5.2)

including GIS Server, DSS Server, Database Server, Instruction Server, and the Application Server. These components are briefly described below.

- GIS Server: provides access to the geographic maps, models, and tools. It also manages and organizes large geodatabases and enables comprehensive GIS functions and techniques like query and modeling.
- DSS Server: enables access to the different modules of the system. These modules support the decision-makers with the necessary information and analysis.
- Database Server: provides access to the large spatial and non-spatial databases, which come from different national and international sources.
- Instruction Server: contains a set of rules that define how the Fire Fighting Advisor Module works. In addition, the weights of the machine learning model which is trained on the Historical Fire Database.
- Application Server: it is a front end that is used to connect between the user instructions and the other servers like GIS Server and DSS Server.

In order to execute a module or the whole system, users need a web browser that can be used to data visualize, map interface, data select and so.

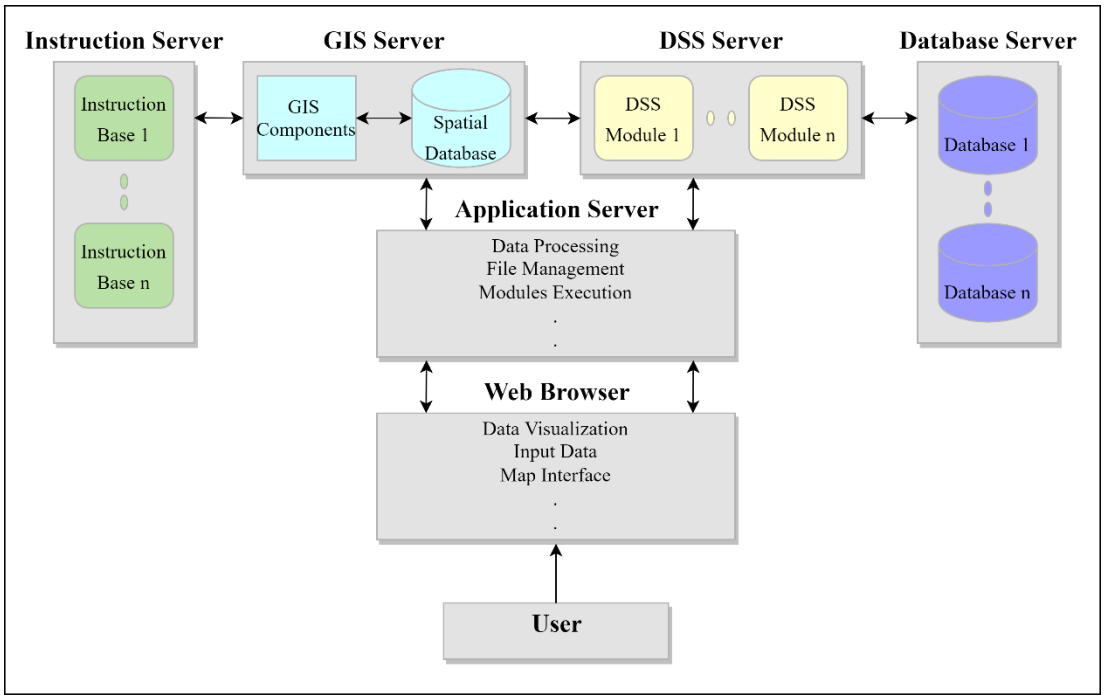

Figure 5.2 : TFFDSS schematic representation.

TFFDSS implements worldwide used technologies and algorithms to get benefit from the advances in the field of forest fire management. TFFDSS benefits from different essential services provided by several national institutions like the general directorate of forestry, the Turkish state meteorological service, the general directorate of land registry and cadastre, and many others. In addition, TFFDSS gets benefits from international services like the active fire detection products of NASA FIRMS, and it utilizes broadly used techniques and algorithms such FlamMap and MTT algorithm for fire behavior predictions and simulation. Figure 5.3, represents the components and conceptual design of the TFFDSS.

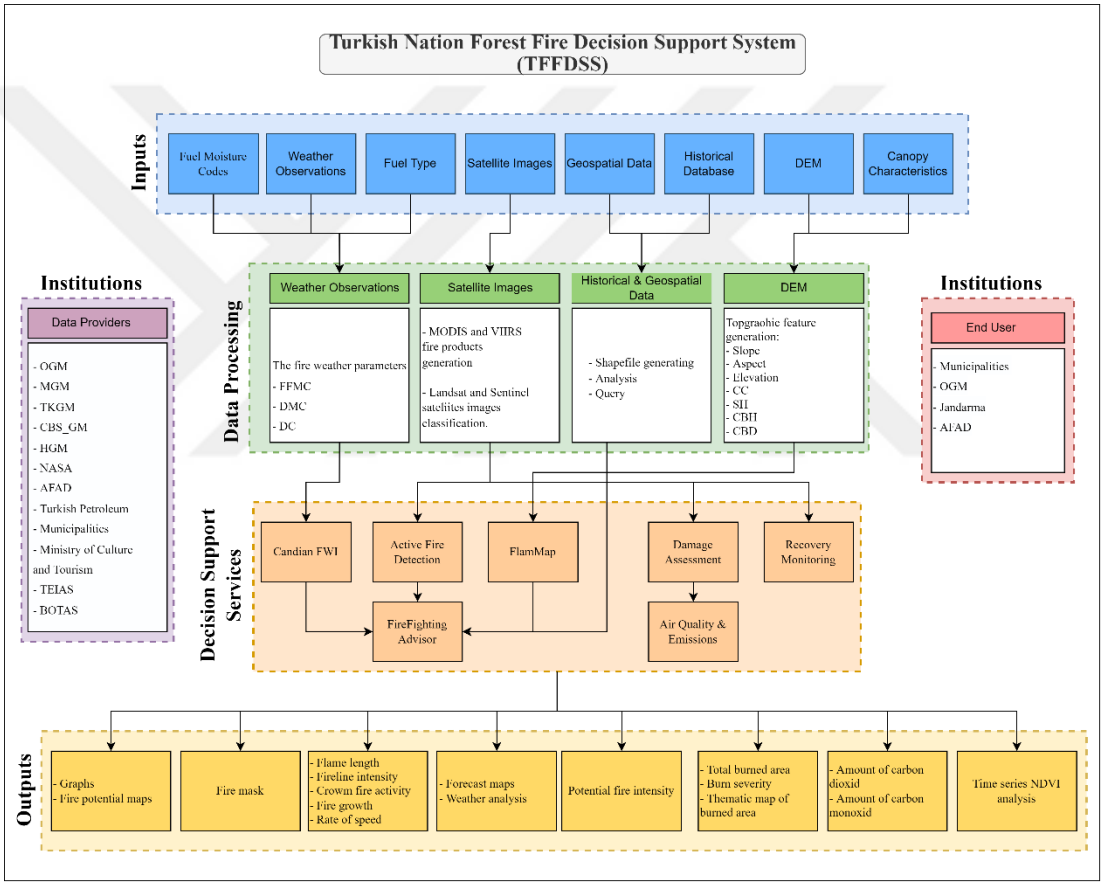

Figure 5.3 : The conceptual design of the Turkey forest fire decision support system (TFFDSS).

TFFDSS produces fire ignition probability maps based on the HFD, then depending on these maps, TFFDSS makes predictions for the high fire ignition probability forest based on the WF observations. When a similar weather observation happens the TFFDSS will send an alarm through the FA module. In addition, the TFFDSS supports the visualization and analysis of the observations of the WF module depending on the

access to the Turkish state meteorological service. Fire danger estimation maps are generated based on the Canadian FWI, then the higher danger forests will be monitored by the AFD module. At the same time, the firefighting crews near those forests will be alarmed by the FA module. Figure 5.4 represents a simple simulation model of TFFDSS. Once a fire is detected, the TFFDSS will calculate the fire behavior index, and the firefighting crews will start fighting depending on the outputs of the FBP module that they will be provided by the main information of the fire behavior such as fireline intensity, flame length, and rate of spread. Also, the crews will be informed if the wind changes its speed or direction suddenly. In addition, the FGI module will provide a map containing the geospatial information close to the fire. When the fire is suppressed, the PFA provides a thematic map for the damage that happened to the forest. Then, the amount of CO_2 emitted by the fires will calculate by the AQE.

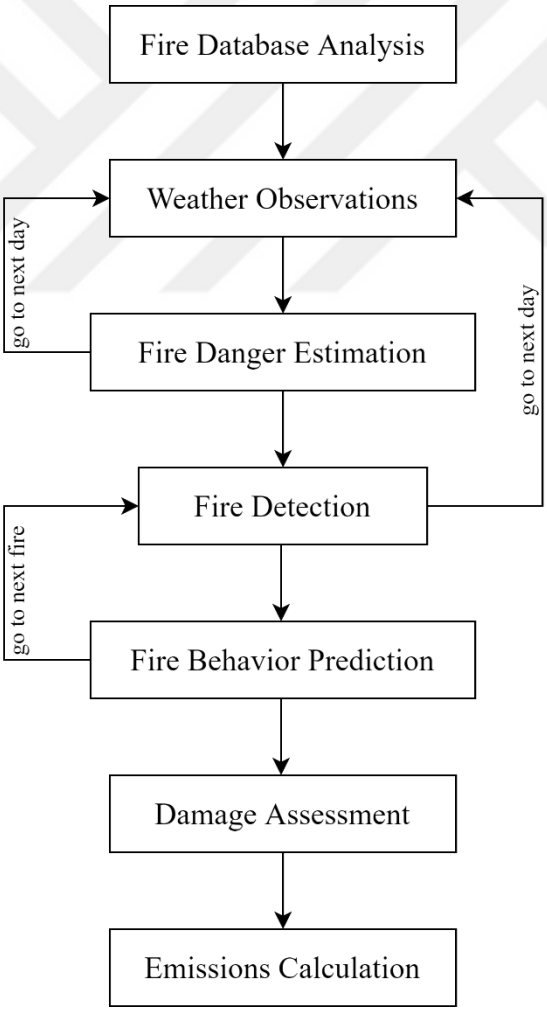

Figure 5.4 : TFFDSS simulation model.

The design of TFFDSS is compatible with the essential four phases of the disaster management cycle (Figure 5.5). Fighting a disaster such as a wildfire requires cooperation between different institutions because controlling large fires exceeds the ability of a single institute or agency.

TFFDSS was designed to gather the efforts of the different institutions to manage wildfire disasters in a way that ensures reducing vulnerabilities, enhancing readiness, improving capabilities, and making better responses and decisions.

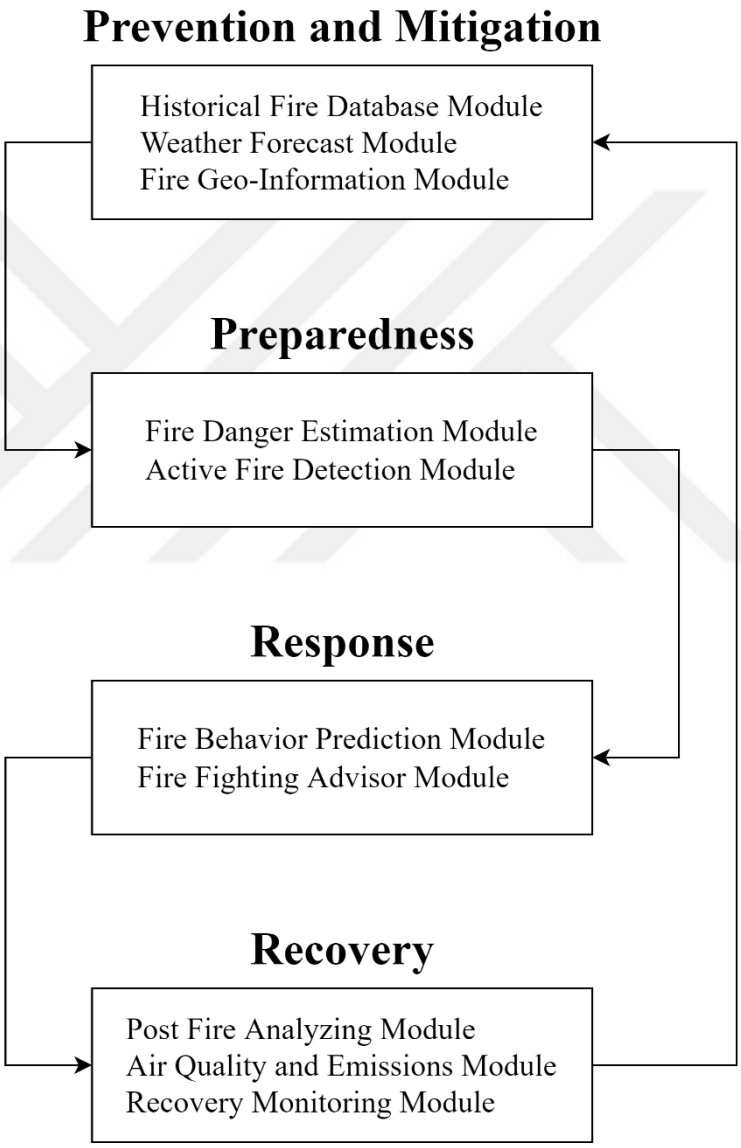

Figure 5.5 : TFFDSS as a disaster management system.

6. CONCLUSION

In this research, a GIS-based decision support system was designed to be a potential solution for the forest fires challenge in Turkey. It is designed in a way that transfers the data, experience, and knowledge between the different institutions involved in forest fire prevention and control. TFFDSS aims to unify the efforts of all entities and address them to manage forest fires by taking advantage of the advanced technologies and well-connected and designed modules.

TFFDSS architecture makes it able to deal with forest fire at each progress which results in reducing the high economic cost of forest fire fighting and the environmental effects, improving the quality of the urgent decisions related to fire, and improving the performance of fire administrators in terms of time because all needed are available in one system.

TFFDSS is proposed to collect large heterogeneous data from a variety of local and international entities which maybe lead to undesired complexity. However, TFFDSS consists of multi modules each one is responsible for specific functions. Some of these modules depend on internal data for input and others depend on external data. This flexibility prevents complexity and enables even junior engineers with basic training to execute the system.

The importance of TFFDSS is being an integrated system. It has wide functions and tools that make it effective for each step of forest fire fighting like prediction, prevention, facing, controlling, and suppression. Also, it is compatible with the essential phases of the disaster management cycle which results in better responses and decisions.

TFFDSS is not designed to replace the forest fire decision-makers but it is designed to help in improving the decision-making process in terms of time, effort, cost, and effectiveness. Its main goal is to get benefits from all available firefighting related data and transform it into one system with many tools and services.

REFERENCES

Ager, A. A., Finney, M. A. (2009). Application of wildfire simulation models for risk analysis. Paper presented at the *EGU General Assembly Conference Abstracts.*

Ager, A. A., Vaillant, N., & Finney, M. A. (2011). Application of fire behavior models and geographic information systems for wildfire risk assessment and fuel management planning. *Journal of Combustion*, *572452*.

Akay, A. E., Wing, M. G., Sivrikaya, F., & Sakar, D. (2012). A GIS-based decision support system for determining the shortest and safest route to forest fires: a case study in Mediterranean Region of Turkey. *Environmental monitoring and assessment*, *184*(3), 1391-1407.https://doi.org/10.1007/s10661-011-2049-z

Alcasena, F. J., Salis, M., Ager, A. A., Arca, B., Molina, D., & Spano, D. (2015). Assessing landscape scale wildfire exposure for highly valued resources in a Mediterranean area. *Environmental management*, *55*(5), 1200-1216.

Alexander, M. E., & De Groot, W. J. (1988). Fire behavior in jack pine stands: as related to the Canadian Forest Fire Weather Index (FWI) System. *Can. For. Serv., North For. Cent., Edmonton, AB. Poster (with text).*

Amiro, B. D., Logan, K. A., Wotton, B. M., Flannigan, M. D., Todd, J. B., Stocks, B. J., & Martell, D. L. (2004). Fire weather index system components for large fires in the Canadian boreal forest. *International Journal of Wildland Fire*, *13*(4), 391-400.

Andrews, Patricia L.; Butler, Bret W., (2006) Fuels Management-How to Measure Success: Conference Proceedings. *28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station.* p. 213-220 (Vol. 41).

Burgan, R. E. (1988). revisions to the 1978 national fire-danger rating system (Vol. 273). *US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.*

Calkin, D. E., Thompson, M. P., Finney, M. A., & Hyde, K. D. (2011). A real-time risk assessment tool supporting wildland fire decisionmaking. *Journal of Forestry*, *109*(5), 274-280.

Cao, C., et al. (2013a), Visible Infrared Imaging Radiometer Suite (VIIRS) Sensor Data Record (SDR) User's Guide. *Version 1.2, 10 September 2013, NOAA Technical Report NESDIS 142, Available at* https://cs.star.nesdis.noaa.gov/NCC/UsersGuideVIIRS.

Chowdary, V., Gupta, M. K., & Singh, R. (2018). A review on forest fire detection techniques: a decadal perspective. *Networks*, *4*, 12.

Coskuner K. A., Türkiye Orman Yangin Tehlike Oranlari Karar Destek Sistemi (TOYTOS), 2019, Doktora Tezi, *Karadeniz Teknik Üniversitesi.*

Csiszar, I., Schroeder, W., Giglio, L., Ellicott, E., Vadrevu, K. P., Justice, C. O., & Wind, B. (2014). Active fires from the Suomi NPP Visible Infrared Imaging Radiometer Suite: Product status and first evaluation results. *Journal of Geophysical Research: Atmospheres*, *119*(2), 803-816.

Eker, Ö. & Abdurrahmanoğlu, D. M. (2018) An Analysis on the Expenses of Combating Forest Fires: Case of Kahramanmaraş Regional Directorate of Forestry. *Turkish Journal of Forest Science,* 2(1), 34-48.

Elmas, C., Snmez, Y. (2011) A data fusion framework with novel hybrid algorithm for multi-agent Decision Support System for Forest Fire Expert Syst. *Appl., 38* (8) pp. 9225-9236

Ertugrul, M. (2005). The situations of forest fires in the world and in Turkey. *ZKU Bartin Faculty of Forestry Journal*, *7*(7), 43-50.

Fengbo, W., Xitong, L., & Huike, Z. (2018, October). Design and Development of Forest Fire Monitoring Terminal. In *2018 International Conference on Sensor Networks and Signal Processing (SNSP)* (pp. 40-44). IEEE.

Finney, M. A. (2002). Fire growth using minimum travel time methods. *Canadian Journal of Forest Research*, *32*(8), 1420-1424.

Finney, M. A. (2006). An overview of FlamMap fire modeling capabilities. *Paper presented at the Fuels management—how to measure success: conference proceedings, 28-30 March 2006;* Portland, OR.

Flannigan, M., Stocks, B., Turetsky, M., & Wotton, M. (2009). Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global change biology*, *15*(3), 549-560.

Gebert, K. M., Calkin, D. E., & Yoder, J. (2007). Estimating suppression expenditures for individual large wildland fires. *Western Journal of Applied Forestry*, *22*(3), 188-196.

Giglio, L., Descloitres, J., Justice, C. O., & Kaufman, Y. J. (2003). An enhanced contextual fire detection algorithm for MODIS. *Remote sensing of environment*, *87*(2-3), 273-282.

Girardin, M. P., Bergeron, Y., Tardif, J. C., Gauthier, S., Flannigan, M. D., & Mudelsee, M. (2006). A 229-year dendroclimatic-inferred record of forest fire activity for the Boreal Shield of Canada. *International Journal of Wildland Fire*, *15*(3), 375-388.

Harrington, J. B., Flannigan, M. D., & Van Wagner, C. E. (1983). A study of the relation of components of the Fire Weather Index to monthly provincial area burned by wildfire in Canada 1953-*80 Environ. Can., Can. For. Serv., Petawawa Natl. For. Inst., Chalk River, ON. Inf. Rep. PI-X-25.* 65 p.

Hirsch, K. G. (1996). *Canadian forest fire behavior prediction (FBP) system: user's guide* (Vol. 7).

Ichoku, C., Kahn, R., & Chin, M. (2012). Satellite contributions to the quantitative characterization of biomass burning for climate modeling. *Atmospheric*

Research, 111, 1-28.

Justice, C. O., Giglio, L., Korontzi, S., Owens, J., Morisette, J. T., Roy, D., ... & Kaufman, Y. (2002). The MODIS fire products. *Remote sensing of Environment, 83*(1-2), 244-262.

Justice, C. O., Giglio, L., Roy, D., Boschetti, L., Csiszar, I., Davies, D., ... & Morisette, J. (2011a). MODIS-derived global fire products. In *Land remote sensing and global environmental change* (pp. 661-679). Springer, New York, NY.

Kalabokidis, K., Ager, A., Finney, M., Athanasis, N., Palaiologou, P., & Vasilakos, C. (2016). AEGIS: a wildfire prevention and management information system. *Natural Hazards and Earth System Sciences, 16*(3), 643-661.

Keeley, J. E. (2009). Fire intensity, fire severity and burn severity: a brief review and suggested usage. *International journal of wildland fire, 18*(1), 116-126.

Kiil, A. D. (1977). Calibration and performance of the Canadian fire weather index in Alberta. . *Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, AB. Inf. Rep. NOR-X-173.* 45 p.

Küçük, Ö., & Bilgili, E. (2006). The conveyance of fire behavior characteristics into practice by using Geographical Information Sysyems (GIS): A case study in Kastamonu. *Kastamonu University Journal of Forestry Faculty (Turkey)*.

Lavoie, N., Alexander, M. E., & Macdonald, S. E. (2007). Fire weather and fire danger climatology of the Fort Providence area, Northwest Territories. *Can. For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-412.*

Lavorel, S., Flannigan, M. D., Lambin, E. F., & Scholes, M. C. (2007). Vulnerability of land systems to fire: Interactions among humans, climate, the atmosphere, and ecosystems. Mitigation and Adaptation Strategies for Global Change, 12(1), 33-53.https://doi.org/10.1007/s11027-006-9046-5

Lawson, B. D., & Armitage, O. B. (2008). Weather guide for the Canadian forest fire danger rating system. *Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.* 84 p.

Lawson, B. D., Dalrymple, G. N., & Hawkes, B. C. (1997). *Predicting forest floor moisture contents from duff moisture code values* (Vol. 6).

Lewis, S. A., Robichaud, P. R., Hudak, A. T., Strand, E. K., Eitel, J. U., & Brown, R. E. (2021). Evaluating the Persistence of Post-Wildfire Ash: A Multi-Platform Spatiotemporal Analysis. *Fire, 4*(4), 68.

Lidskog, R., Johansson, J., & Sjödin, D. (2019). Wildfires, responsibility and trust: public understanding of Sweden's largest wildfire. *Scandinavian Journal of Forest Research, 34*(4), 319-328.

Liu, S., Duffy, A. H., Whitfield, R. I., & Boyle, I. M. (2010). Integration of decision support systems to improve decision support performance. *Knowledge and Information Systems, 22*(3), 261-286.https://doi.org/10.1007/s10115-009-0192-4

Lourenço, M., Oliveira, L. B., Oliveira, J. P., Mora, A., Oliveira, H., & Santos, R. (2021). An Integrated Decision Support System for Improving Wildfire Suppression Management. *ISPRS International Journal of Geo-Information, 10*(8), 497. https://doi.org/10.3390/ijgi10080497

Matson, M., & Holben, B. (1987). Satellite detection of tropical burning in Brazil. *International Journal of Remote Sensing*, *8*(3), 509-516.

Michel, C., Liousse, C., Grégoire, J. M., Tansey, K., Carmichael, G. R., & Woo, J. H. (2005). Biomass burning emission inventory from burnt area data given by the SPOT-VEGETATION system in the frame of TRACE-P and ACE-Asia campaigns. *Journal of Geophysical Research: Atmospheres*, *110*(D9).

Mitsopoulos, I., Mallinis, G., Karali, A., Giannakopoulos, C., & Arianoutsou, M. (2014, March). Mapping fire behaviour in a Mediterranean landscape under different future climate change scenarios. In *International Conference ADAPTtoCLIMATE, Nicosia, Cyprus* (pp. 27-28).

Mitsopoulos, I., Mallinis, G., Zibtsev, S., Yavuz, M., Saglam, B., Kucuk, O., ... & Zaimes, G. (2017). An integrated approach for mapping fire suppression difficulty in three different ecosystems of Eastern Europe. *Journal of Spatial Science*, *62*(1), 139-155.

Moayedi, H., Mehrabi, M., Bui, D. T., Pradhan, B., & Foong, L. K. (2020). Fuzzy-metaheuristic ensembles for spatial assessment of forest fire susceptibility. *Journal of environmental management*, *260*, 109867.

Navarro, G., Caballero, I., Silva, G., Parra, P. C., Vázquez, Á., & Caldeira, R. (2017). Evaluation of forest fire on Madeira Island using Sentinel-2A MSI imagery. *International Journal of Applied Earth Observation and Geoinformation*, *58*, 97-106.

Noonan-Wright, E. K., Opperman, T. S., Finney, M. A., Zimmerman, G. T., Seli, R. C., Elenz, L. M., ... & Fiedler, J. R. (2011). Developing the US wildland fire decision support system. *Journal of Combustion*, *2011*. https://doi.org/10.1155/2011/168473

Parisien, M. A., Hirsch, K. G., Lavoie, S. G., Todd, J. B., & Kafka, V. G. (2004). *Saskatchewan fire regime analysis* (Vol. 394). Edmonton, Alberta, Canada: Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre.

Paton-Walsh, C., Smith, T. E. L., Young, E. L., Griffith, D. W., & Guérette, É. A. (2014). New emission factors for Australian vegetation fires measured using open-path Fourier transform infrared spectroscopy–Part 1: Methods and Australian temperate forest fires. *Atmospheric Chemistry and Physics*, *14*(20), 11313-11333.

Pourtaghi, Z. S., Pourghasemi, H. R., & Rossi, M. (2015). Forest fire susceptibility mapping in the Minudasht forests, Golestan province, Iran. *Environmental Earth Sciences*, *73*(4), 1515-1533.

Robert J. Naiman, Henri Décamps, Michael E. McClain, Gene E. Likens, (2005) 10 - Restoration, *Riparia*, P. 291-325.

Roy, D. P., Boschetti, L., & Trigg, S. N. (2006). Remote sensing of fire severity: assessing the performance of the normalized burn ratio. *IEEE Geoscience and Remote Sensing Letters*, *3*(1), 112-116.

Sakellariou, S., Tampekis, S., Samara, F., Sfougaris, A., & Christopoulou, O. (2017). Review of state-of-the-art decision support systems (DSSs) for prevention and suppression of forest fires. *Journal of Forestry Research*, *28*(6), 1107-1117.https://doi.org/10.1007/s11676-017-0452-1

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Libertà, G., Branco, A., De Rigo, D., ... & Leray, T. (2018). Forest Fires in Europe, Middle East and North Africa 2017. *Publications Officer of the European Union. doi*, *10*, 663443. https://doi.org/10.2760/663443.

Schroeder, M. J. (1970). Fire weather: a guide for application of meteorological information to forest fire control operations *(No. 360). US Department of Agriculture, Forest Service.*

Setzer, A. W., & Pereira, M. C. (1991). Amazonas biomass burnings in 1987 and an estimate of their tropospheric emissions. *Ambio (Journal of the Human Environment, Research and Management);(Sweden)*, *20*(1).

Shi, Y., Matsunaga, T., Saito, M., Yamaguchi, Y., & Chen, X. (2015). Comparison of global inventories of CO2 emissions from biomass burning during 2002–2011 derived from multiple satellite products. *Environmental pollution*, *206*, 479-487.

Shiraishi, T., & Hirata, R. (2021). Estimation of carbon dioxide emissions from the megafires of Australia in 2019–2020. *Scientific reports*, *11*(1), 1-10.

Sonmez, I., Erdi, E., Tekeli, A. E., Demir, F., & Arslan, M. (2011). Foogle: Fire monitoring tool for EUMETSAT's active fire product over Turkey using Google Earth. *Geomat. Nat. Hazards Risk*, *2*, 1-13.

Stocks, B. J. (1974). Wildfires and the fire weather index system in Ontario. *Environ. Can., Can. For. Serv., great Lakes For. Res. Cent., Sault Ste. Marie, ON. Inf. Rep. O-X-232.* 27 p.

Stocks, B. J., Lynham, T. J., Lawson, B. D., Alexander, M. E., Wagner, C. V., McAlpine, R. S., & Dube, D. E. (1989). Canadian forest fire danger rating system: an overview. *The Forestry Chronicle*, *65*(4), 258-265.https://doi.org/10.5558/tfc65450-6

Stratton, R. D. (2004). Assessing the effectiveness of landscape fuel treatments on fire growth and behavior. *Journal of Forestry*, *102*(7), 32-40.

Stratton, R. D. (2006). Guidance on spatial wildland fire analysis: models, tools, and techniques. *United States Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-183.*

Tedim, F., Leone, V., & 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*, *18*, 138-153.

Turner, J.A. (1973). A Fire Load Index for British Columbia. *Environ. Can., Can. For. Serv., Pac. For. Res. Cent., Victoria, BC. Inf. Rep. BC-X-80.* 14 p.

Van Wagner, C. E., & Forest, P. (1987). Development and structure of the canadian forest fireweather index system. In *Can. For. Serv., Forestry Tech. Rep*.

Van Wagner, C. E., & Pickett, T. L. (1985). *Equations and FORTRAN program for the Canadian forest fire weather index system* (Vol. 33).

Van Wagner, C. E., Stocks, B. J., Lawson, B. D., Alexander, M. E., Lynham, T. J., & McAlpine, R. S. (1992). Development and structure of the canadian forest fire behavior prediction system. *Forestry Canada Fire Danger Group Information Report ST-X-3.(Ottawa, ON)*.

Vasilakos, C., Kalabokidis, K., Hatzopoulos, J., & Matsinos, I. (2009). Identifying wildland fire ignition factors through sensitivity analysis of a neural network. Natural hazards, 50(1), 125-143.

Vásquez, F., Cravero, A., Castro, M., & Acevedo, P. (2021). Decision Support System Development of Wildland Fire: A Systematic Mapping. *Forests*, *12*(7), 943. https://doi.org/10.3390/f12070943

Wang, X., Wotton, B. M., Cantin, A. S., Parisien, M. A., Anderson, K., Moore, B., & Flannigan, M. D. (2017). cffdrs: an R package for the Canadian forest fire danger rating system. *Ecological Processes*, *6*(1), 1-11.https://doi.org/10.1186/s13717-017-0070-z

Wotton, B. M., Alexander, M. E., & Taylor, S. W. (2009). *Updates and revisions to the 1992 Canadian forest fire behavior prediction system*. Great Lakes Forestry Centre.

Wotton, M. (2009, October). A grass moisture model for the Canadian Forest Fire Danger Rating System. In *Eighth Symposium on Fire and Forest Meteorology* (pp. 13-15).

Wu, F., Lv, X., Zhang, H. (2018) Design and development of forest fire monitoring terminal. *In Proceedings of the International Conference on Sensor Networks and Signal Processing (SNSP)*, Xi'an, China, 28–31 October 2018; pp. 40–44.

Wu, Z., He, H. S., Keane, R. E., Zhu, Z., Wang, Y., & Shan, Y. (2020). Current and future patterns of forest fire occurrence in China. International journal of wildland fire, 29(2), 104-119.

Yavuz, M., Sağlam, B., Küçük, Ö., & Tüfekçioğlu, A. (2018). Assessing forest fire behavior simulation using FlamMap software and remote sensing techniques in Western Black Sea Region, Turkey. *Kastamonu University Journal of Forestry Faculty*, *18*(2), 171-188.

Zachariassen, J. (2003). A review of the Forest Service remote automated weather station (RAWS) network. *General Technical Report RMRS-GTR-119, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO,* 153 pp.

Zimmerman, T. (2012). Wildland fire management decision making. *Journal of Agricultural Science and Technology. B*, *2*(2B), 169.

Url-1

<https://www.nifc.gov/fire-information/statistics/wildfires>, date retrieved: 11.12.2021

Url-2

<https://www.mgm.gov.tr/arastirma/dogal-afetler.aspx?s=ormanyangin**>,** date retrieved: 15.12.2021

Url-3

<https://www.ogm.gov.tr/tr/e-kutuphane-sitesi/Istatistikler/Ormanc%C4%B1l%C4%B1k%20%C4%B0statistikleri/Ormanc%

C4%B1l%C4%B1k%20%C4%B0statistikleri%202020.rar >, date retrieved: 23.12.2021

Url-4

https://www.worldwildlife.org/press-releases/2020-forest-fires-globally-could-be-worse-than-2019-wwf-warns , date retrieved: 25.12.2021

Url-5

<https://effis-gwis-cms.s3-eu-west-1.amazonaws.com/effis/reports-and-publications/effis-related-publications/Advance_EFFIS_Report+on+Forest+Fires+in+Europe_2020_210401xv_finalv2.pdf>, date retrieved: 27.12.2021

Url-6

< https://d1ied5g1xfgpx8.cloudfront.net/pdfs/31168.pdf >, date retrieved: 27.12.2021

Url-7

<https://ncc.nesdis.noaa.gov/documents/documentation/viirs-users-guide-tech-report-142a-v1.3.pdf>, date retrieved: 27.12.2021

Url-8

<https://doi.org/10.4060/ca8642en> , date retrieved: 27.12.2021

Url-9

<https://www.fao.org/3/a0969e/a0969e00.htm>, date retrieved: 27.12.2021

Url-10

<https://doi.org/10.4060/ca8753en> date retrieved: 03.01.2022

Url-11

<https://www.earthobservations.org/documents/gwp20_22/geo_global_wildfire_information_system_ip.pdf>, date retrieved: 03.01.2022

Url-12

<https://web.ogm.gov.tr/ekutuphane/SurdurulebilirOrmanYonetimi/2018%20%C3%87ALI%C5%9ETAY/%C3%87ALI%C5%9ETAY%20TEMMUZ%202018/SUNUMLAR/TEMAT%C4%B0K%20SUNUMLAR/ORB%C4%B0S%20Metin%20G%C3%9CLTEK%C4%B0N.pdf >, date retrieved: 03.01.2022

Url-13

<https://www.ogm.gov.tr/tr/e-kutuphane-

sitesi/FaaliyetRaporu/Orman%20Genel%20M%C3%BCd%C3%BCrl%C3%BC%C4%9F%C3%BC%202017%20Y%C4%B1l%C4%B1%20Faaliyet%20Raporu.pdf>, date retrieved: 03.01.2022

Url-14

<https://stateoftheworldsplants.org/2017/report/SOTWP_2017.pdf >, date retrieved: 03.01.2022

Url-15

<https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF-Study-Forests-Ablaze.pdf>**,** date retrieved: 03.01.2022

Url-16

<https://wwfeu.awsassets.panda.org/downloads/wwf_fires_forests_and_the_future_report.pdf >, date retrieved: 03.01.2022

Url-17

<https://csfs.colostate.edu/forest-management/restoration-rehabilitation/>**,** Colorado State University, date retrieved: 03.02.2022

APPENDICIES

APPENDIX A: A fire history map

APPENDIX B: Fire history statistics in turkey

APPENDIX C: Fire danger estimation of EFFIS

APPENDIX D: Weather forecast

APPENDIX E: MODIS vs VIIRS

APPENDIX F: Post-fire analysis

Appendix A

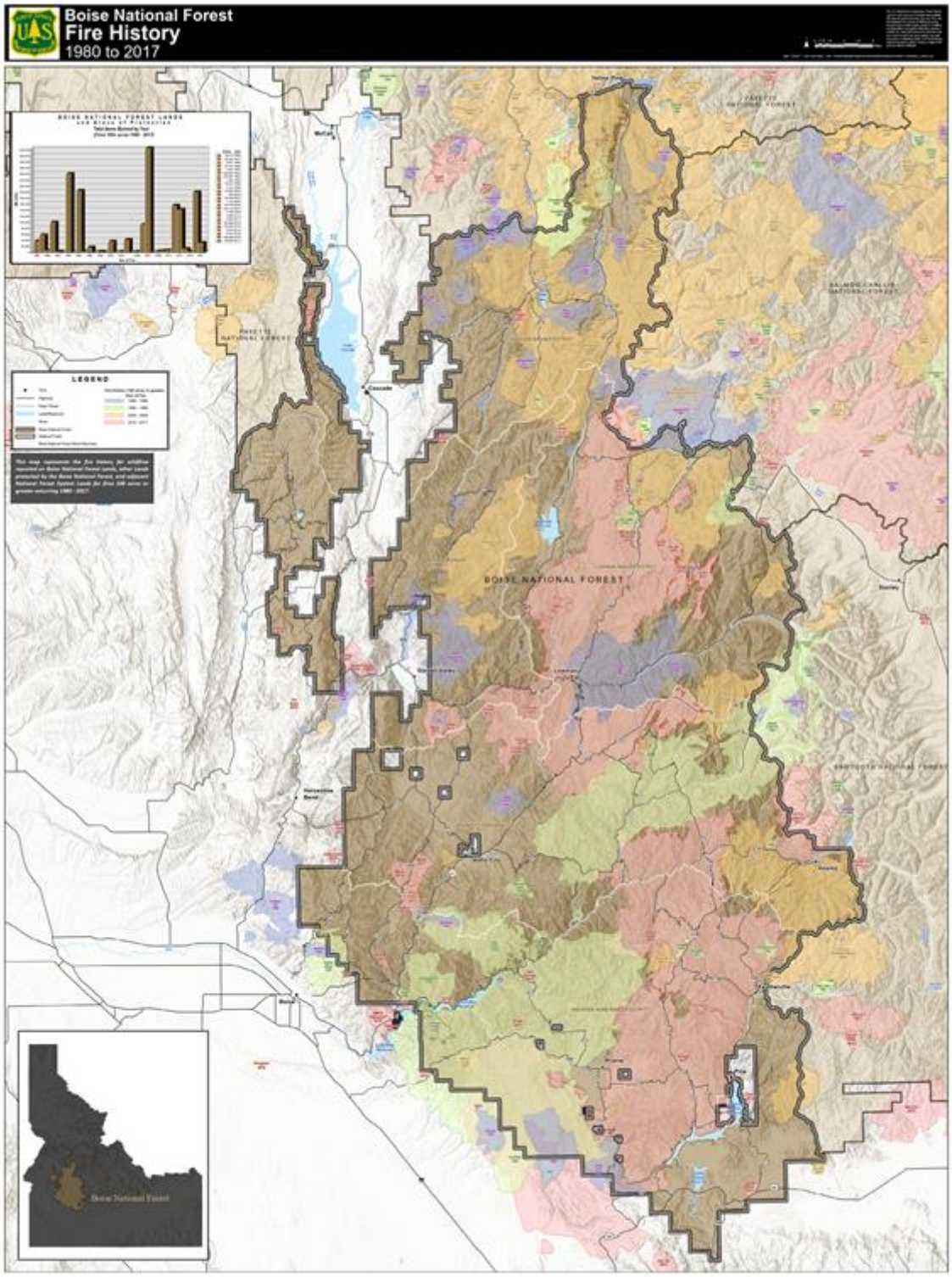

Figure A.1 : The fire history of the Boise national forest between 1980 and 2017 (https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd580115.pdf)

Appendix B

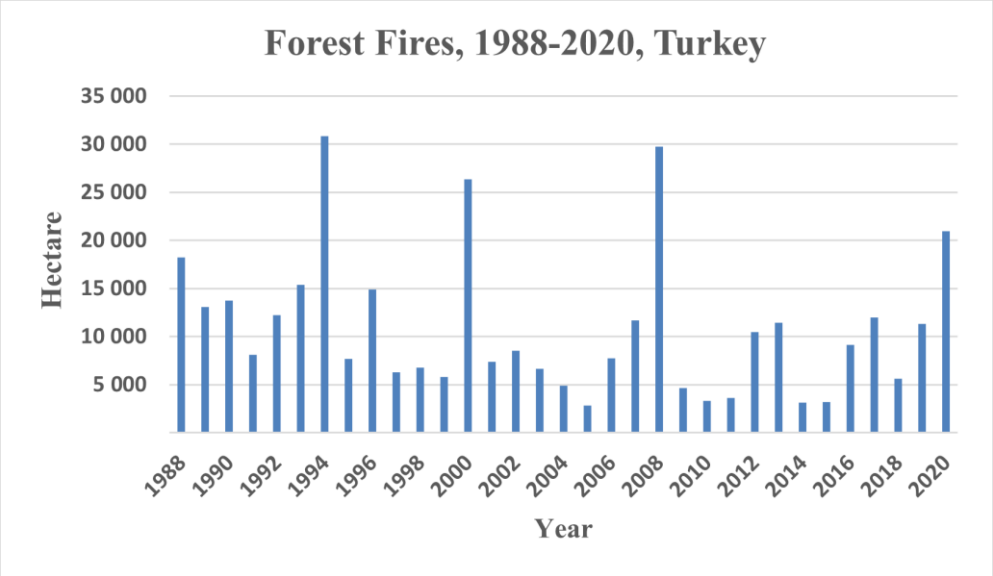

Figure B.1 : Total Burned Area in Turkey Between 1988 and 2020.

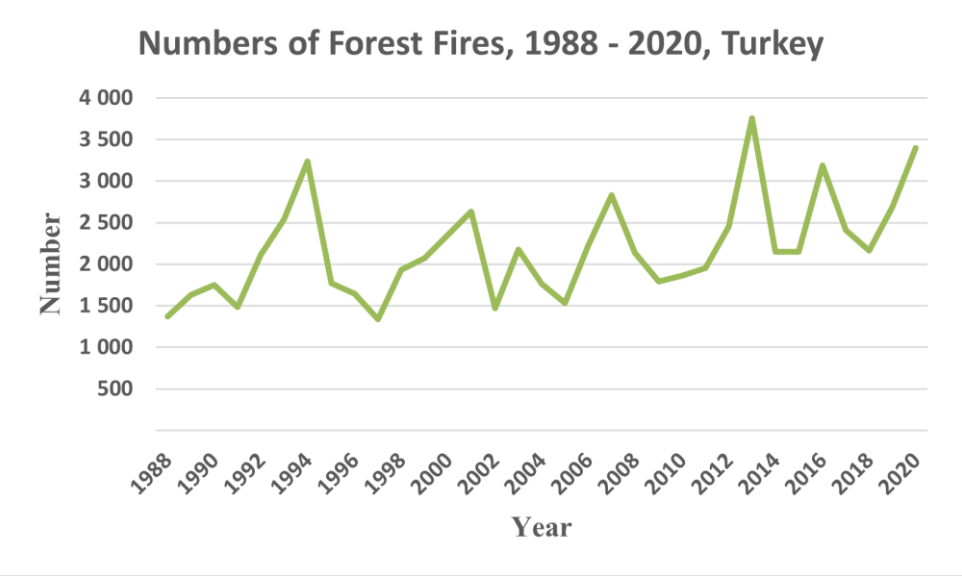

Figure B.2 : Forest fires incidents in Turkey Between 1988 and 2020.

Appendix C

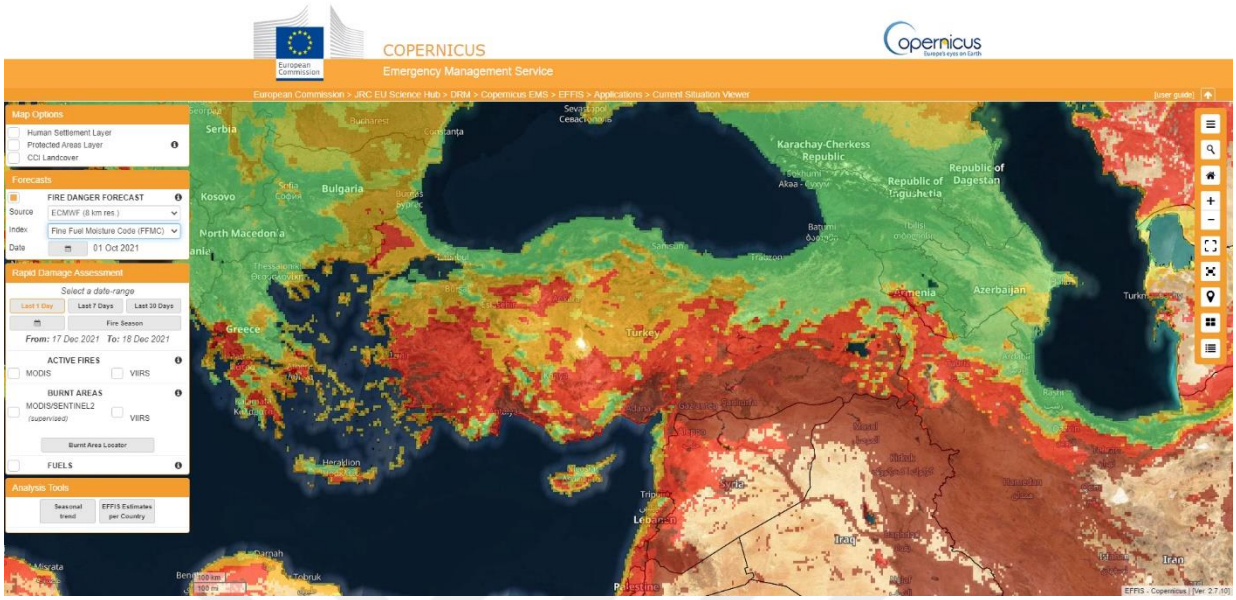

Figure C.1 : Fine Fuel Moisture Code (FFMC) on 1 Oct 2021.

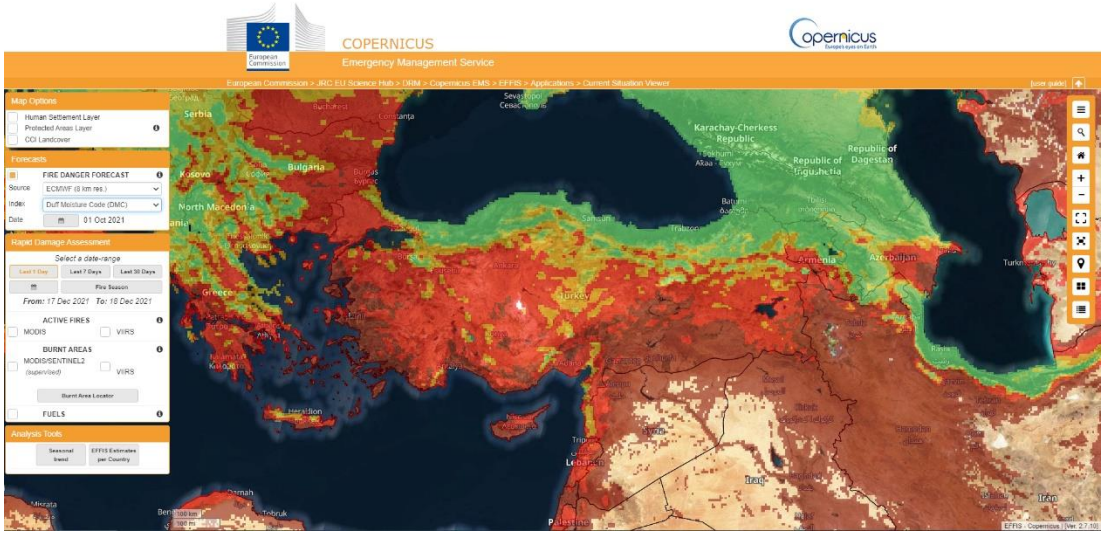

Figure C.2 : Duff Moisture Code (DMC) on 1 Oct 2021.

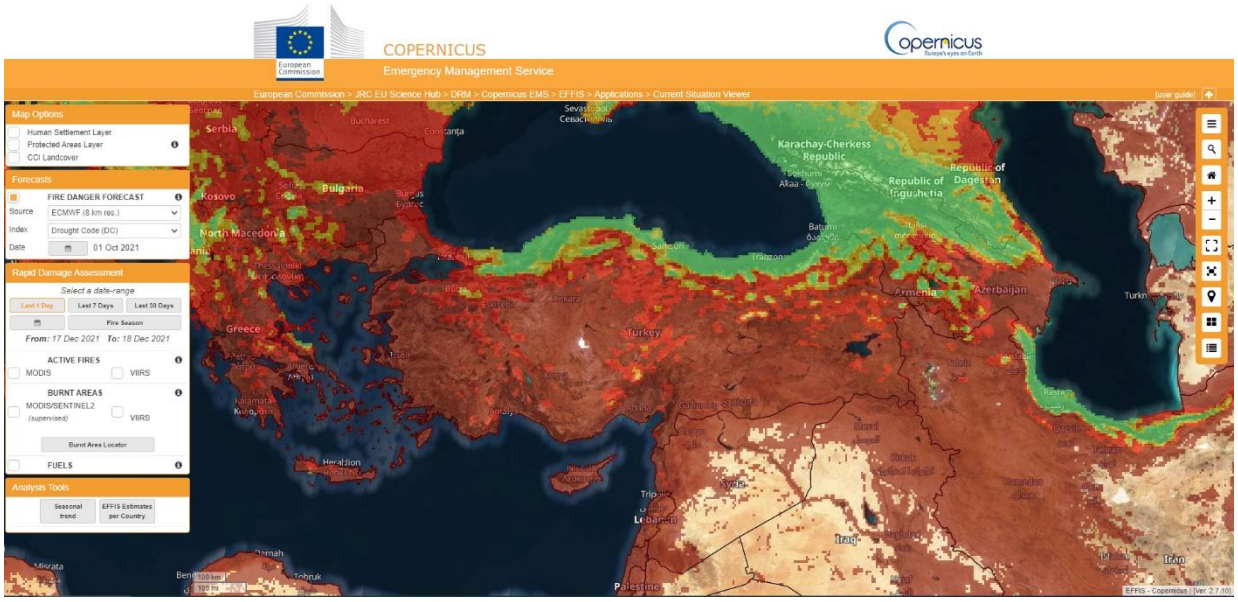

Figure C.3 : Drought Code (DC) on 1 Oct 2021.

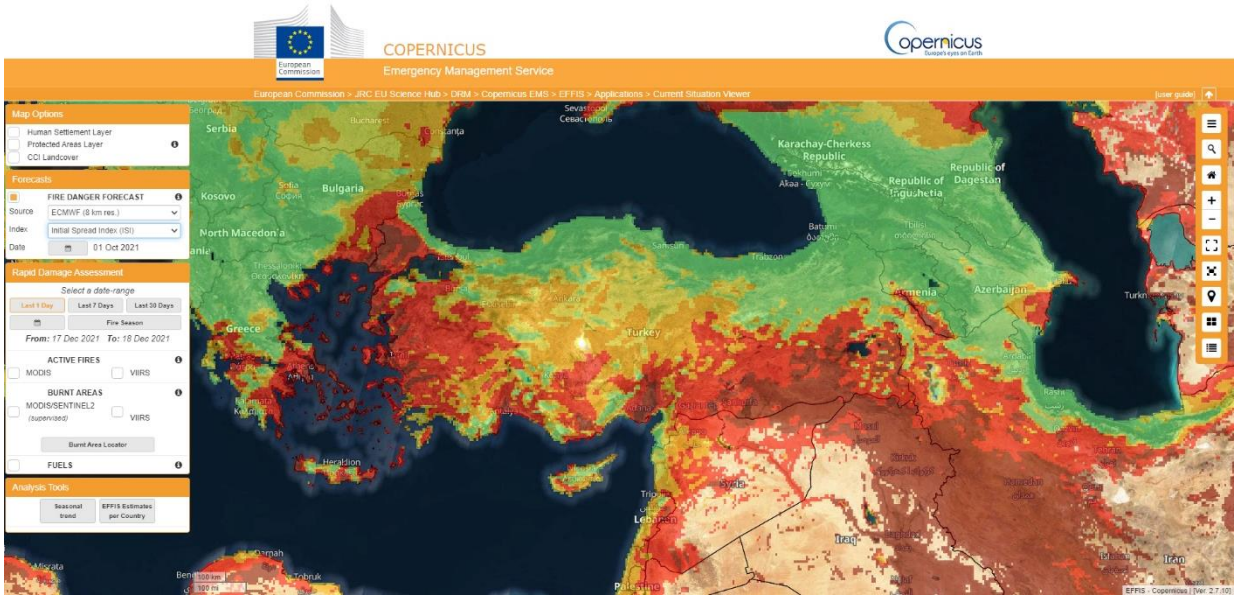

Figure C.4 : Initial Spread Index (ISI) on 1 Oct 2021.

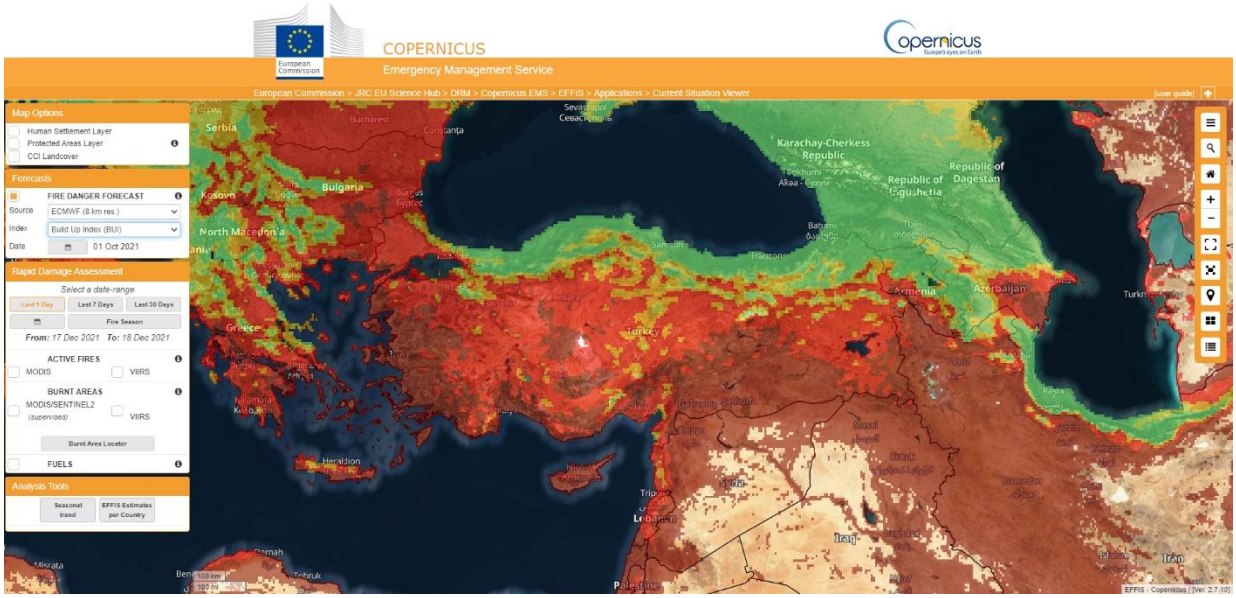

Figure C.5 : Buildup Index (BUI) on 1 Oct 2021.

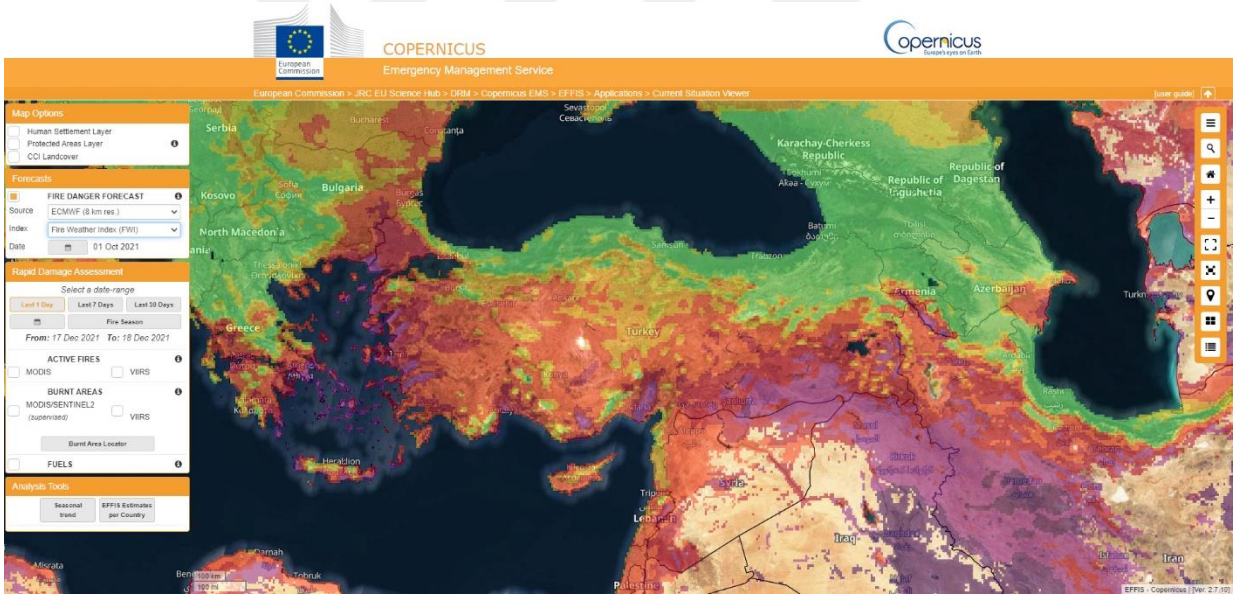

Figure C.6 : Fire Weather Index (FWI) on 1 Oct 2021.

Appendix D

Figure D.1 : a weather forecast map from the Turkish State Meteorological Service (MGM) on 12 Jan 2022.

5 GÜNLÜK TAHMİN

TARİH	TAHMİN EDİLEN							GEÇMİŞTE GERÇEKLEŞEN			
	Hadise	Sıcaklık (°C)		Nem (%)		Rüzgar (km/sa)		Uç Sıcaklık (°C)		Ortalama Sıcaklık (°C)	
		En Düşük	En Yüksek	En Düşük	En Yüksek	Yön	Hız	En Düşük	En Yüksek	En Düşük	En Yüksek
12 Ocak Çarşamba		3	4	77	96		43	-1,4	15,7	4	9,4
13 Ocak Perşembe		0	2	62	71		35	-4	16,4	3,6	8,9
14 Ocak Cuma		-1	4	53	82		15	-5,7	17,4	3,3	8,4
15 Ocak Cumartesi		1	7	69	83		12	-6,3	17	3,3	8,4
16 Ocak Pazar		2	7	55	89		18	-3,3	18,3	3,4	8,6

Figure D.2 : Five days weather forecast predictions from the Turkish State Meteorological Service (MGM) between 12 and 16 Jan 2022.

Appendix E

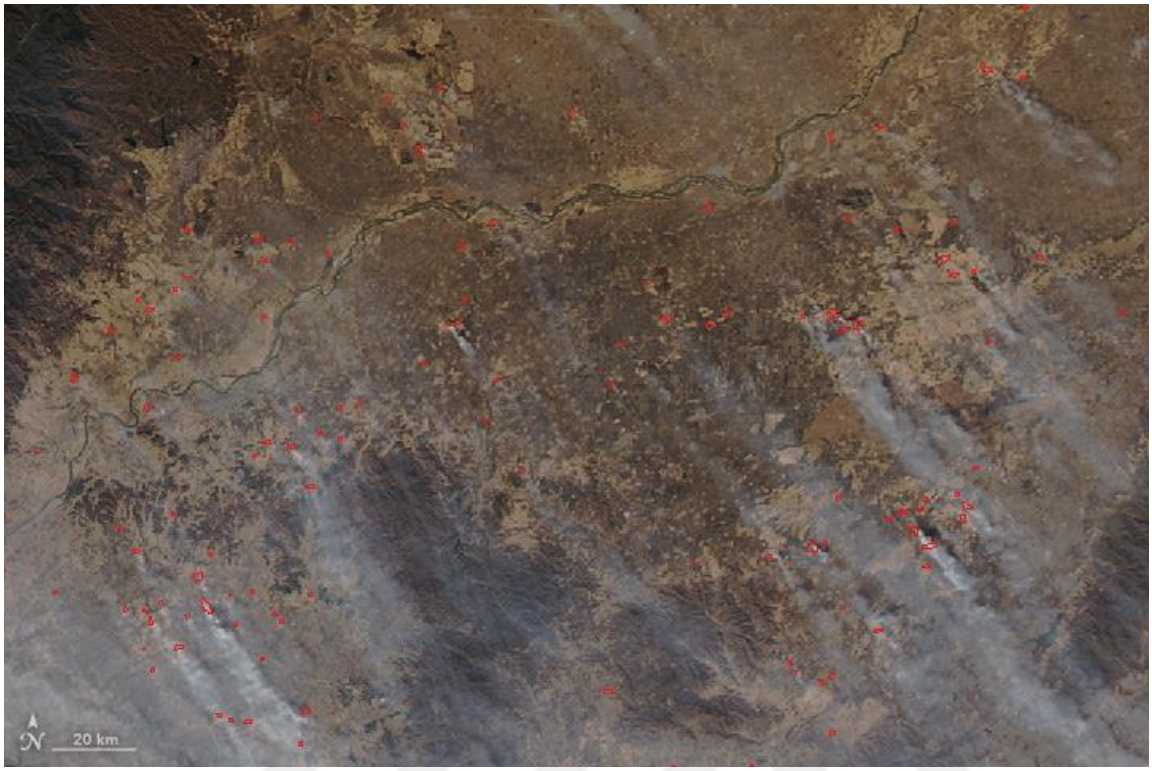

Figure E.1 : Probable fires detected in a predefined area by Aqua MODIS.

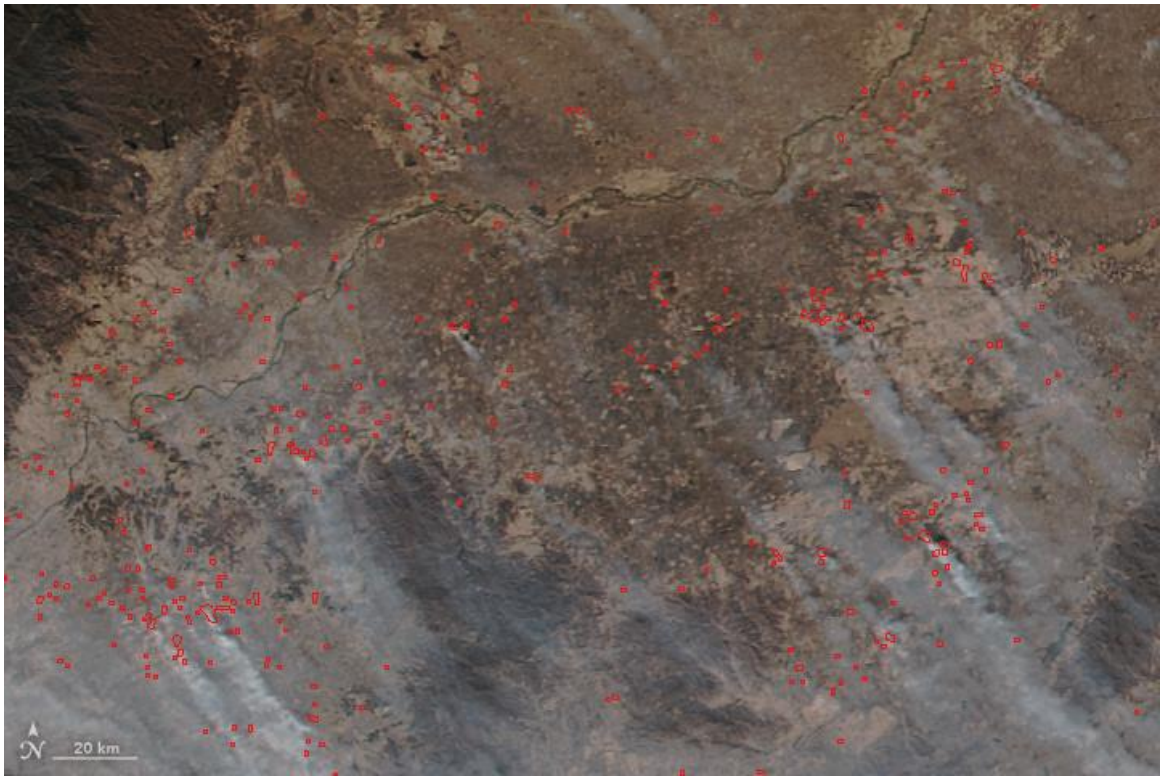

Figure E.2 : Probable fires detected by VIIRS in the same defined area as in Figure E.1

Figure E.3 : Probable fires as detected by MODIS on 01 Oct 2021 through the FIRMS portal.

Figure E.4 : Probable fires as detected by VIIRS on 01 Oct 2021 through the FIRMS portal.

Appendix F

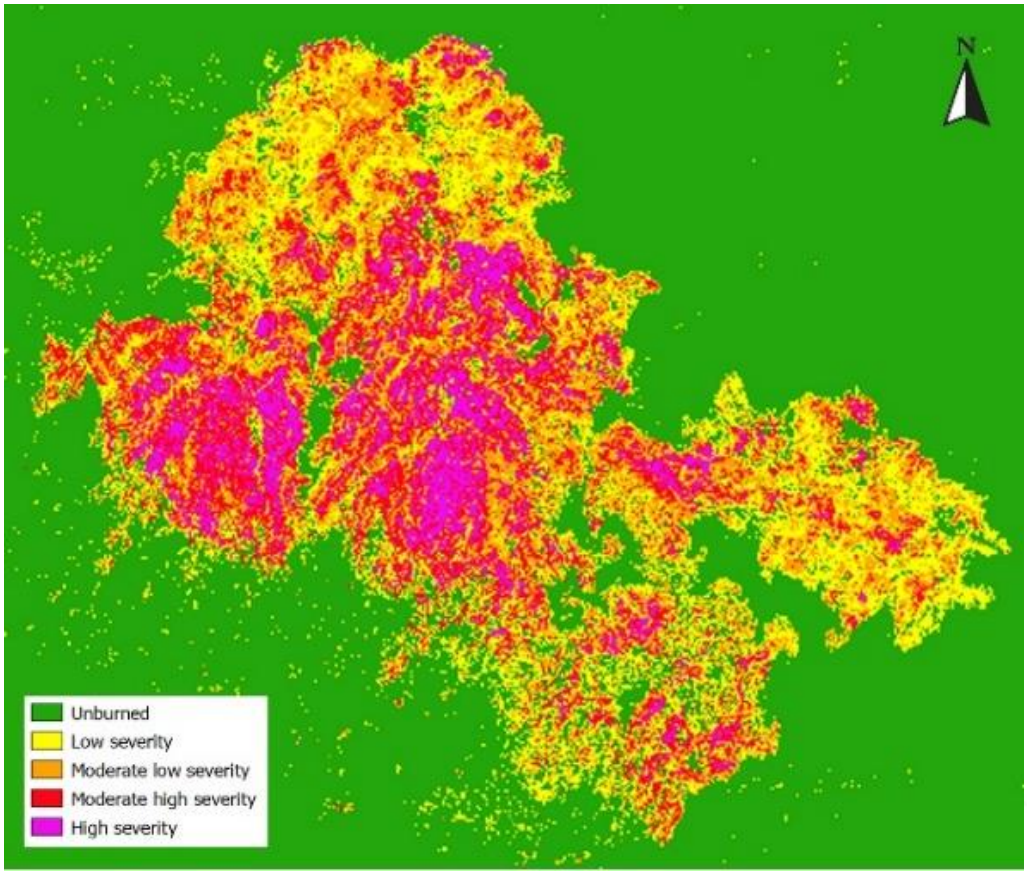

Figure F.1 : Post-fire analysis of Manavgat 2021 wildfire by using NBR.

CURRICULUM VITAE

ABDULLAH SUKKAR

GEOMATICS ENGINEER

A Ph.D. candidate at ITU, Interested in remote sensing, GIS, and deep learning. extremely motivated to constantly develop my skills and grow professionally. I am patient, considerate and structured. I love complex problem solving and enjoy multidisciplinary projects. I believe in the ability of science and technology to make our world better place.

PROFESSIONAL SKILLS

Language Skills:
Arabic, English and Turkish
Programming Skills:
Python, Matlab and PostgreSQL
Software Skills:
Pix4D, ArcGIS, Erdas Imagine, QGIS, Terrasolid, Global Mapper, PCI Gematica and MS Office

WORK EXPERIENCE

Geomatics Engineer

Alya Proje | 2019 - present

- 3D Modeling Projects
- Photogrammetric Projects
- Cadastre Projects
- Digital Base-Map Production

PUPLICATION

ISAG-21 Conference - Presented

The impacts of weather conditions and topography on manavgat wildfire behavior

MedGU-21 Conference - Presented

Tree detection from very high spatial resolution RGB satellite imagery using deep learning

Arabian Journal of Geosciences - Submitted

Extraction of water bodies from very high-resolution remote sensing images using spectral indices based deep learning models
Submission ID: AJGS-D-21-06178

EDUCATION

Istanbul Technical University
Ph.D. | 2022 - Present
Ph.D. in Geomatics Engineering

Istanbul Technical University

Master of Science | 2020 - 2022
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Hacettepe University

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