**Abstract**

From early times, humanity has expressed a profound need to predict the future. In ancient Greece, oracles held a place of high respect, and influence. In modern times, the quest for accurate forecasting, has shifted to the realms, of research and science∙ empowered by advanced computational tools, provided by Artificial Intelligence, particularly Machine Learning. One of the fields, where Machine Learning, has established a fertile ground is in the domain, of forest fire management.

Forest fires, pose a major threat to both human, and animal life, with significant economic and social impacts. A reliable prediction system is crucial for mitigating these effects, especially during summer months, dry seasons, and in high-risk areas, such as the Mediterranean.

This study, explores feature construction, and selection methods, applied to forest fire data, collected over 10 years in Greece, incorporating prevailing weather conditions at ignition, and during suppression. By applying techniques like Principal Component Analysis (PCA), Minimum Redundancy Maximum Relevance (MRMR) feature selection, and Grammatical Evolution for feature construction, this research aims to identify key factors influencing fire duration.

These techniques, have become invaluable allies, in addressing complex predictive challenges, and advancing, our understanding of future events.

Our approach, leverages advanced computational methods, to analyze complex datasets, providing a deeper understanding of the primary drivers, of wildfire behavior, and enabling more effective mitigation strategies.

**Introduction**

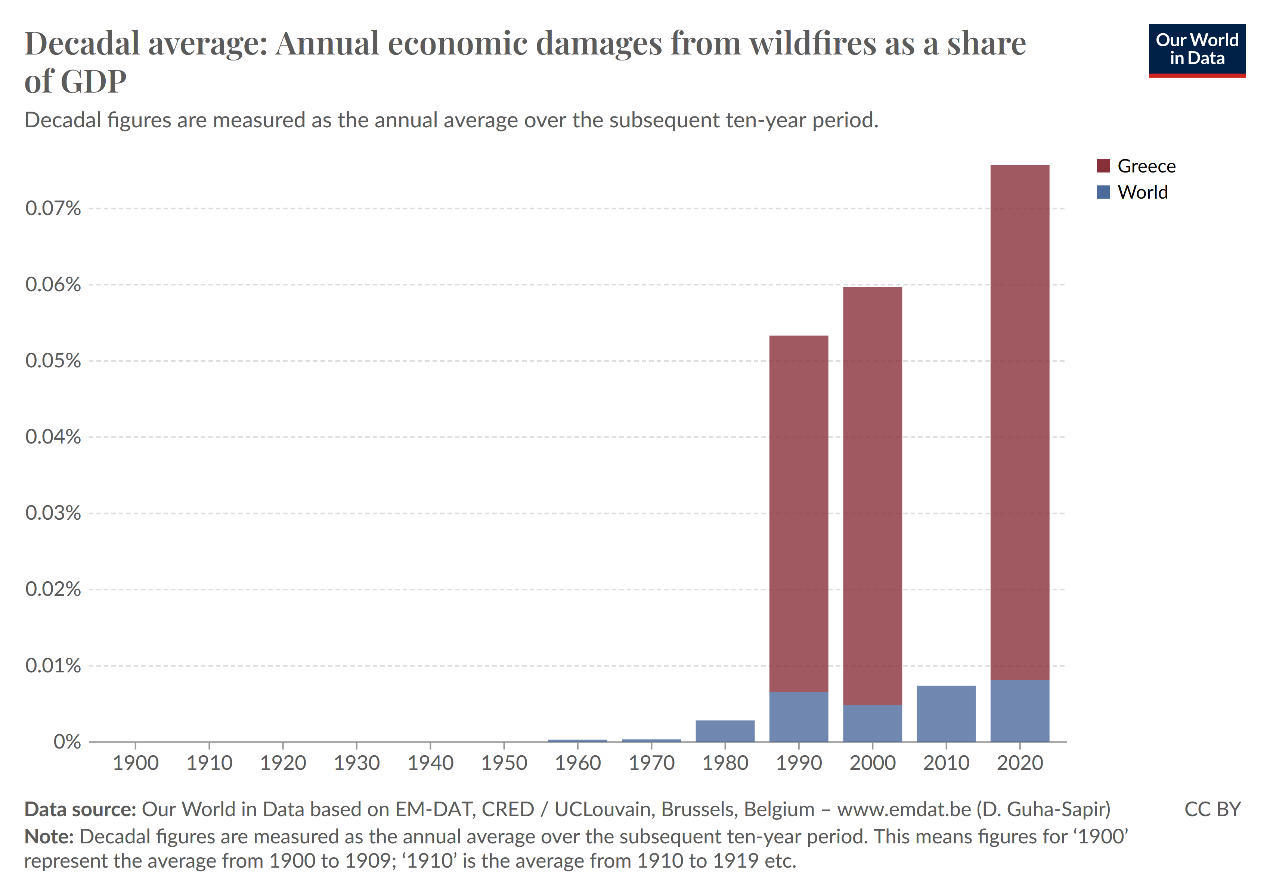
Fire, has always had a dual nature, in human history. On one hand, it has had the power to destroy civilizations, while on the other, it has significantly contributed to the evolution, of human society. From its destructive potential in warfare, and natural disasters, to its transformative role in technological, and cultural advancement, fire has shaped both, the rise, and fall of human civilizations. The ability to harness fire for cooking, metallurgy, and warmth played a crucial role in the development, of early human societies [[1](#_References._1" \o "Gowlett, J.A.J. The discovery of fire by humans: a long and convoluted process. Philosophical Transaction B, Biological Sciences, volume 371, Issue 1696. June 5, 2016. Available from:  https://royalsocietypublishing.org/doi/epdf/10.1098/rstb.2015.0164 (acc)] ∙ while. its unchecked force, has also led to widespread devastation. This duality, underscores fire’s paradoxical role, in human progress: a force capable of both creation and destruction.

This notion, is also evident in ancient Greek mythology, particularly in the tale of Prometheus, who defied the gods by stealing fire, and gifting it to humanity. This act symbolizes the transfer of divine knowledge and power to humans, enabling progress and civilization. The myth, underscores fire's dual role, as a tool for human advancement, and as a source of conflict, illustrating the tension between progress and its ethical implications, as well as the costs of rebellion and innovation [[2](#_References._1" \o "Heinonen, Keri. The Fire of Prometheus: More Than Just a Gift to Humanity. Greek Mythology. November 19, 2024. Available from: https://greek.mythologyworldwide.com/the-fire-of-prometheus-more-than-just-a-gift-to-humanity/ (accessed on November 29, 2024). )].

On this matter, fire, has played a multifaceted role in human history, both through myths and through its tangible impacts.

Nevertheless, in the modern era, wildfires are ranked among the most significant natural hazards [[3](#_References._1" \o "Sarah McCaffrey. Thinking of wildfire as a natural hazard. Society and Natural Resources, volume 17 (6) pp. 509–516. 2004 Available from: https://www.researchgate.net/publication/240346379_Thinking_of_Wildfire_as_a_Natural_Hazard (accessed on December 3, 2)], with immense effects on Earth's ecosystems, and human societies. Beyond that, according, the Chair, of ISO/TC 92, fire safety, Mr. P. Van Hees: ‘*With losses caused by fire estimated at 1% of the global GDP each year, fire safety must be viewed in the broader perspective of risk management and disaster mitigation’* [[4](#_References._1)].

In [Figure 1](#_Figures" \o " Ritchie, H., Rosado, P., Roser, M.  Decadal average: Annual economic damages from wildfires as a share of GDP. 2020. Natural Disasters. Our World in Data. Available from: https://ourworldindata.org/natural-disasters (accessed on November 29, 2024).  ), it is illustrated, through a graphical representation, the economic burden, from forest fires, on the annual GDP.



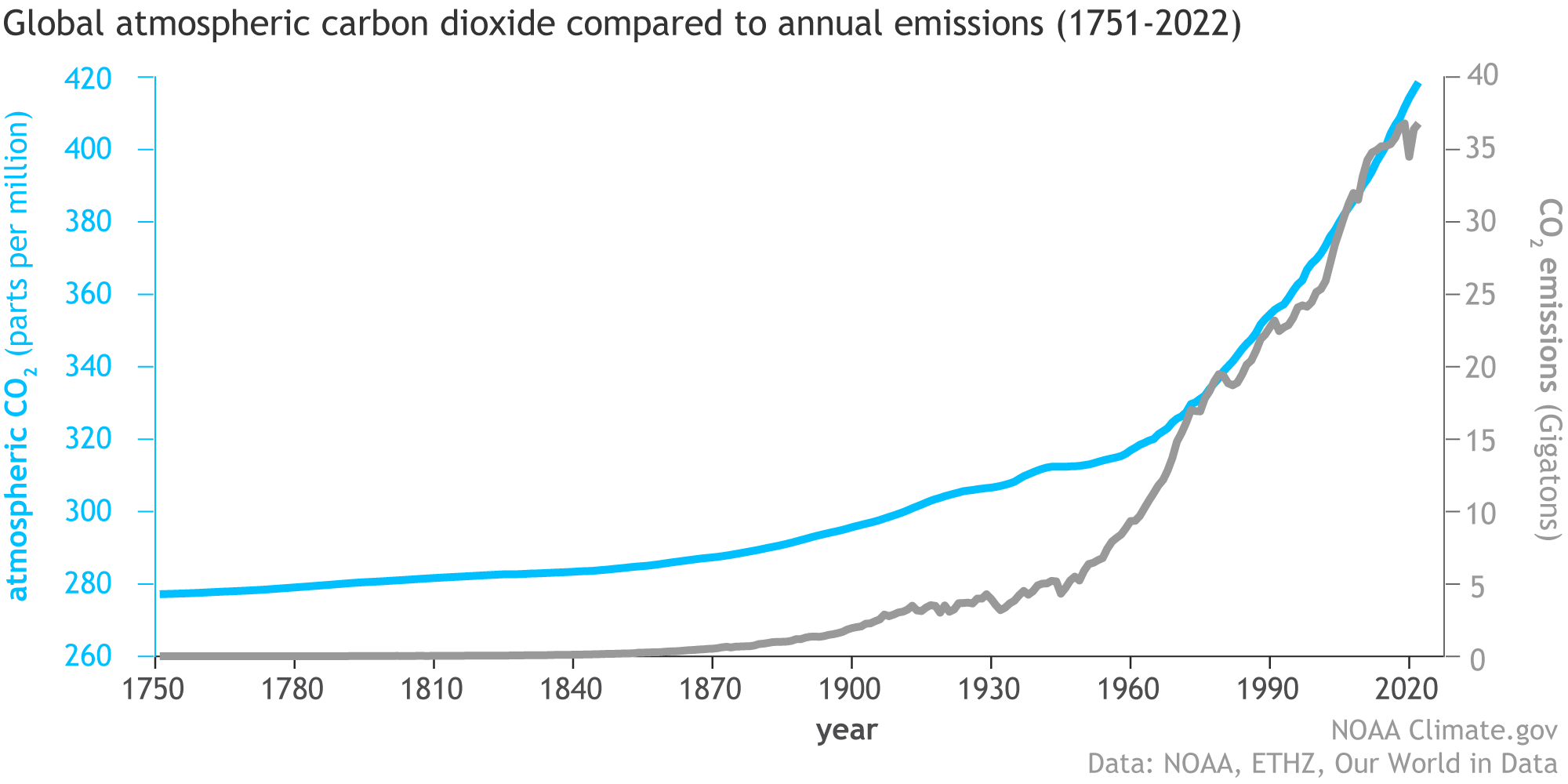
**Figure 1***.* The economic impact of forest fires in Greece, and around the world.

Namely:

* The cost of fire is estimated at about 1% to 2% of the annual GDP
* About 1% of fires are responsible for more than 50% of the costs
* The number of people dying in fire is estimated at 2.2 deaths per 100,000 inhabitants (based on 35 countries) [[4](#_References._1" \o "Patrick, Van Hees. The burning challenge of fire safety. ISO, International Organization for Standardization. Available from: https://www.iso.org/news/2014/11/Ref1906.html (accessed on December 3, 2024).)].

In other words, wildfires and climate change, intensify each other. Climate change, exacerbates wildfires by increasing drought, high temperatures, low humidity, lightning, and strong winds, leading to more severe, and prolonged fire seasons. Conversely, wildfires contribute to worsening climate change [[5](#_References._1)].

Thus, wildfires (along with the extraction and burning of fossil fuels, and volcanic eruptions) exacerbate Climate Change, by further releasing carbon dioxide, into the atmosphere [[6](#_References._1" \o "NASA. Carbon Dioxide, Vital Signs. October 2024. Available from: https://climate.nasa.gov/vital-signs/carbon-dioxide/?intent=121 (accessed on November 29, 2024). )]. Also, the Mediterranean region is recognized as a key "hot-spot" for the impacts of climate change [[7](#_References._1" \o "Giorgi, F. Climate Change Hot–Spots. Geophysical Research Letters. 2006. volume 33 (8). Available from: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2006GL025734 (accessed on December 5, 2024).)] At the same time, the critical need to address climate changes, effects on wildfire patterns, is highlighted, as essential for protecting both the environment, and public health in Greece [[8](#_References._1" \o "Chalaris, M., Illiopoulos, N., Aliferis, I. Effect of Climate Evolution on the Dynamics of the wildfires in Greece. Special Issue Effects of Climate Change on Fire Danger. 2024/ Volume 7 (5). Available from: https://www.mdpi.com/2571-6255/7/5/162#B2-fire-0)].

In [Figure 2](#_Figures" \o "Lindsey, Rebecca. Climate Change: Atmospheric Carbon Dioxide. Climate.gov. Available from: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide (accessed on November 29, 2024). ), we observe the continuous increase in carbon dioxide levels, beginning in 1751.

**Figure 2.** The environmental impact of carbon dioxide.

Concerning this, the United Nations of Environment Programme, are calling the governments: “*to radically shift their investments in wildfires to focus on prevention and preparedness*” [[5](#_References._1" \o "UNEP. United Nations Environment Programme. Number of wildfires to rise by 50 per cent by 2100 and governments are not prepared, experts warn. 23 February 2022. Available from: https://www.unep.org/news-and-stories/press-release/number-wildfires-rise-50-ce)].

Therefore, despite the challenging circumstances posed by Climate Change, driven by continuous human expansion, and technological progress, we aim to transform this disadvantage into an advantage, by focusing our efforts on advancing technology itself. On this, Artificial intelligence, particularly Machine learning, emerges as a valuable ally in addressing this global issue, offering innovative solutions and supporting sustainable development [[27](#_References._1" \o "Satish, M., Prakash., Babu, S.M., Kumar, P.P., Devi, S., Reddy, K.P. Artificial Intelligence (AI) and the Prediction of Climate Change Impacts. 2023. IEEE 5th International Conference on Cybernetics, Cognition and Machine Learning Applications (ICCCMLA). A) ,[9](#_References._1)].

Machine learning, refers to a collection of techniques, and algorithms, that enable systems to identify patterns, and make decisions based on data, improving their performance over time, without explicitly being programmed for specific tasks [[10](#_References._1)].

This was the vision, of Alan Turing, when, in 1936, he wrote his PhD ‘*On Computable Numbers, with an application to the Entscheidungproblem*’ [[11](#_References._1" \o "Watson, Ian. (2012). How Alan Turing Invented the Computer Age. Scientific American. Published: 26/04/2012.Available from: https://blogs.scientificamerican.com/guest-blog/how-alan-turing-invented-the-computer-age/  (accessed on November 30, 2024).)].

Namely, Machine learning, is a pivotal branch of artificial intelligence, presents endless opportunities for businesses, and society alike. Beyond its numerous advantages, it plays a critical role in driving groundbreaking advancements, in Climate Change adaptation, and mitigation. By accelerating, the development of solutions, to some of the most pressing challenges facing the planet∙ machine learning, is reshaping the way we address global environmental issues [[10](#_References._1" \o "ISO. Machine Learning (ML): All there is to know. International Organization for Standardization. Available from: https://www.iso.org/artificial-intelligence/machine-learning (accessed on November 30, 2024).)].

Although, modeling complex environmental variables, often presents challenges, due to the significant computational resources required, and the diversity or complexity of data formats [[12](#_References._1" \o "Jain, P., Coogan, S.C., Subramanian, S.G., Crowley, M., Taylor, S., Flannigan, M.D. A review of machine learning applications in wildfire science and management. Environmental. Reviews. 2020, volume 28, (4) pp.478–505. Available from: https://cdnsciencepub)].

Machine learning algorithms, however, can bypass these challenges, by deriving mappings, and relationships directly from the data, eliminating the need for predefined expert rules. This capability, is particularly beneficial when dealing with scenarios, involving a large number of parameters, with intricate physical properties, such as in forest fires. Consequently, adopting a machine learning approach to fire management, can help overcome many of the limitations, associated with traditional physics-based simulation models [[12](#_References._1)].

Regarding this, in the global literature, significant interest has been developed, in the role of machine learning, in the field of fire management [[13](#_References._1)]. Notably, depending on the area of focus, researchers employ corresponding algorithms, to address specific challenges.

In the following (Figure 3), we observe the machine learning algorithms, utilized according to the domain problem. Specifically, there are three main types, of machine learning, as we can see in [Figure 3.](#_Figures" \o "Tsoulos, I.G., Kopitsa, C., Charilogis, V., Stavrakoudis, A. Predicting the Duration of Forest Fires Using Machine Learning Methods. 2024. MDPI. Future Internet, volume 16 (11). Available from: https://www.mdpi.com/3016636 (accessed on December 1, 2024).)



**Figure 3.** Machine Learning Types.

In this respect, the science of forest fire management: is a distinct field encompassing six key problem domains. [[14](#_References._1" \o "Tsoulos, I.G., Kopitsa, C., Charilogis, V., Stavrakoudis, A. Predicting the Duration of Forest Fires Using Machine Learning Methods. 2024. MDPI. Future Internet, volume 16 (11). Available from: https://www.mdpi.com/3016636 (accessed on December 1, 2024).)].

These, domains include: fire detection, fuel characterization and mapping **/** climate change and fire weather **/** fire susceptibility, occurrence and risk **/** fire behavior prediction, fire effects **/** and fire management [[12](#_References._1)].

Nevertheless, the domain explored in this research is unprecedented, as previous studies, have primarily focused on different aspects. On this matter, we will reference in very few studies, that have approached the topic of estimating the duration, of a fire.

* Xiao, developed a wildfire duration prediction model, based on historical fire data, and geospatial information. The algorithms, employed included: RF (Random Forest), KNN, and XGBoost regression models, as well as image-based approaches such as CNN and Encoder. The model, achieved an accuracy exceeding 80%, for fires lasting longer than 10 days. Beyond this, however, the model did not achieve a satisfactory R² score [[13](#_References._1" \o " Xiao, Hansong. Estimating Wildfire Duration Using Regression Methods. 2023. Available online: https://arxiv.org/pdf/2308.08936 (accessed on December 2, 2024).)].
* Andela, validated the fire data from the Global Fire Atlas, using independent datasets, from the United States. The study utilized satellite data, and highlighted, that the duration of fires is significantly influenced, among others by the fire season [[15](#_References._1" \o "Andela, N., Morton, D.C., Giglio, L., Paugam, R., Chen, Y., Hantson, S., van der Werf, G.R., Randerson, T. The Global Fire Atlas of individual fire size, duration, speed, and direction. Earth System Science Data Discuss. September 2018. Available from: htt)]
* Ujjwal, settled a surrogate model, to capture the dynamic spread, of a wildfire over time. The surrogate model, designed to simulate the relationship between the burned area and key meteorological parameters (such as relative humidity, temperature, and wind speed), provides valuable insights, into fire behavior across different [[16](#_References._1" \o "Ujjwal, KC., Aryal, J., Hilton, J., Garg, S. A Surrogate Model fro rapidly Assessing the Size of a Wildfire over Time. Special Issue Wildfire Hazard and Risk Assessment. Fire volume 4 (2), 2020. Available from: https://www.mdpi.com/2571-6255/4/2/20 (access)]. Although, the research did not explicitly focus on predicting the duration of a fire, its findings could be utilized to estimate fire duration indirectly.
* Wang, also conducted research that, while capable of yielding results for predicting, wildfire duration∙ primarily, focused on forecasting the scale of a forest fire. The study utilized neural network algorithms, including Backpropagation Neural Network (BPNN), Recurrent Neural Network (RNN), and Long Short-Term Memory (LSTM). Among these classification methods, LSTM demonstrated the highest accuracy, achieving 90.9% [[17](#_References._1" \o "Wang, H., Liang, H., Zhang, M. A Neural Network Model for Wildfire Scale Prediction Using Meteorological Factors. IEEE, volume 7. 2019. Available from: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8924693 (accessed on December 4, 2024). )]
* Tsoulos, focused on predicting fire duration, in Greece, using machine learning techniques. Specifically, it compared the performance of various algorithms, including: Bayes Net, Naive Bayes, Logistic Regression, Multilayer Perceptron (MLP), J48, and Random Forest. Among these, Random Forest demonstrated the highest accuracy, achieving 87–92% in predicting forest fire duration [[14](#_References._1)].
* Xi, settled a framework, for jointly, modeling fire duration, and size using a bivariate finite mixture model. Four subpopulations (normal or extreme in duration and size) were analyzed, incorporating, variables such as: location, month, and environmental factors. The analysis, revealed a strong correlation between: duration, and size, and identified key predictors, influencing these subpopulations [[18](#_References._1" \o "Xi, D.D.Z., Dean, C.B., Taylor, S.W. Modeling the duration and size of wildfires using joint mixture models. Environmetrics, Special Issue Paper. 2021. volume 32, (6). Available from: https://onlinelibrary.wiley.com/doi/epdf/10.1002/env.2685 (accessed on D)].

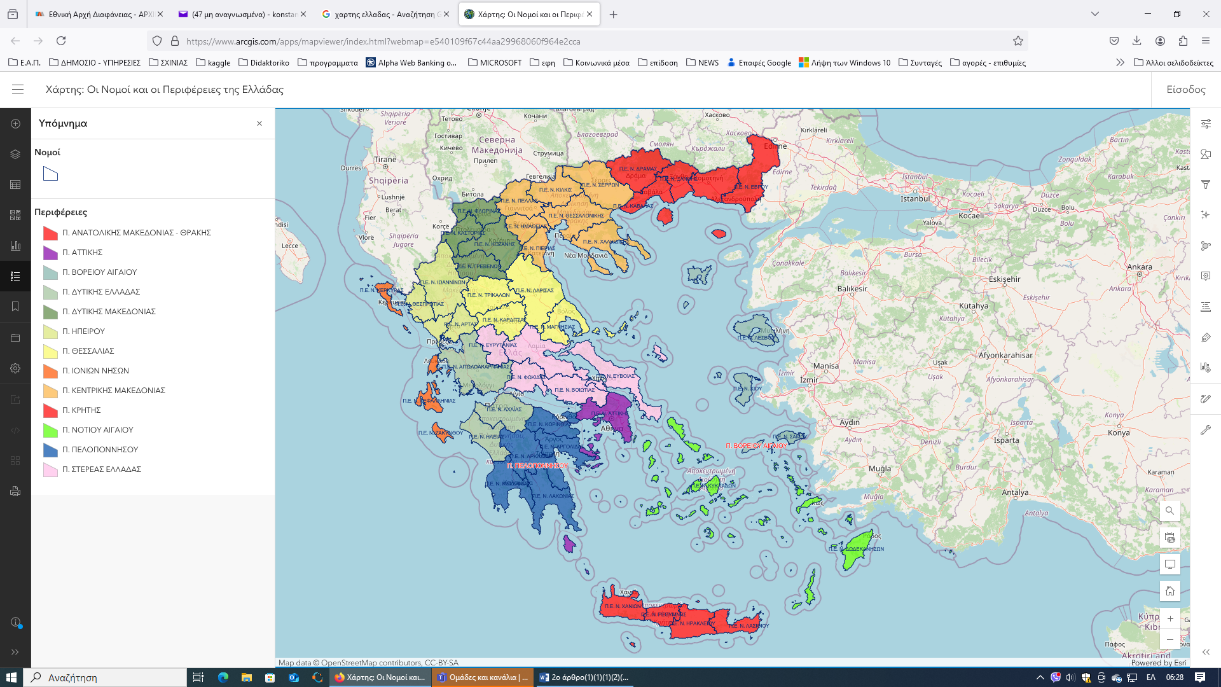
Predicting, the duration of a fire is crucial, as it allows for estimating the potential damage, to the affected area and determining the necessary human resources, for its suppression [[14](#_References._1" \o "Tsoulos, I.G., Kopitsa, C., Charilogis, V., Stavrakoudis, A. Predicting the Duration of Forest Fires Using Machine Learning Methods. 2024. MDPI. Future Internet, volume 16 (11). Available from: https://www.mdpi.com/3016636 (accessed on December 1, 2024))]. Besides that, forest fires and climate change are commonly exacerbating [[5](#_References._1)].

The Western fire chief’s association, from the U.S. emphasizes that climate change is drastically impacting the fire season. As a result, fire seasons now last six to eight months, compared to the four months, they previously spanned [[19](#_References._1)]. Face the Facts USA reports that, in the U.S., the average duration of wildfires increased from 8 days, before 1986, to 37 days by 2013 [[19](#_References._1" \o "WFCA. Western Fire Chiefs Association. How Long Do Wildfires Last? October 2022. Available from: https://wfca.com/wildfire-articles/how-long-do-wildfires-last/ (accessed on December 4, 2024). )].

Consequently, the noteworthy contribution, of our study lies in its focus on predicting the duration of a forest fire∙ and more specifically, in identifying the feature characteristic, that significantly influences its duration.

**Study Area**

**Figure 4. Map of Greece**

 The country, of interest, in our research is Greece, located in the Mediterranean region of Europe. According to the European census conducted by the Hellenic Statistical Authority in 2021, Greece has a permanent population of 10,482,487. The total area of the country is 131,957 square kilometers.

The Mediterranean climate, is characterized by mild winters, and hot, dry summers. Precipitation, is relatively infrequent, occurring primarily during the wet seasons, of autumn, and winter. However, extreme weather events, such as sudden and intense rainfall or thunderstorms, are not uncommon [[20](#_References._1" \o "Evelpidou, N., Tzouxanioti, M., Spyrou, E., Petropoulos, A., Karkani, A., Saitis, G., Margaritis, M. GIS – Based Assessment of Fire Effects on Flash Flood Hazard: The case of the Summer 2021 Forest Fires in Greece. Special Issue Advances in Applied Wildfir)].

It is evident that Greece, like other Mediterranean countries, faces a challenging combination of climatic conditions, that increasingly contribute to more severe, and frequent, forest fires. These fires have significant repercussions for the natural environment, cultural heritage sites located in or near forested areas, agriculture, livestock, and rural life as a whole [[21](#_References._1" \o " Lekkas, E., Parcharidis, I., Arianoutsou, M., Lozios, S., Mavroulis, S., Spyrou, N.-I., Antoniou, V., Nastos, P., Mavrouli, M., Speis, P., et al. The July–August 2021 Wildfires in Greece. Newsletter of Environmental Disaster Crises Management Strategies 2)].

Wildfires, in the Mediterranean region, have become increasingly severe, and hazardous, with scientists identifying the emergence of a "sixth-generation megafire" directly linked to global changes [[14](#_References._1)]. This new type of wildfire first occurred in Portugal and Spain in 2017, resulting in over 120 fatalities, and later in Greece in 2018, where it claimed 104 lives. According to the 2019 WWF report, these fires are characterized by their extreme intensity, uncontrollability, and high lethality available from <http://awsassets.panda.org/downloads/wwf__the_mediterranean_burns_2019_eng_final.pdf>

In Greece, over 5,000 wildfires occur annually, according to data obtained from the Hellenic Fire Service.

**Materials and Methods**

This section presents the datasets that are used in the experiments, as well as the machine learning techniques that are applied to these datasets.

**The Used Datasets.**

In this paper, publicly available data provided by the Hellenic Fire Service, were utilized, at the link: <https://www.fireservice.gr/el_GR/synola-dedomenon> (accessed on December 6, 2024).

The dataset, covering the years 2014–2021, underwent preprocessing before being used in machine learning models. It aligns with the objectives of the European transparency legislation 2013/37/EU, ensuring it is free from bias related to type or location and encompasses all fire incidents across Greece. The data provided by the Hellenic Fire Service is readily accessible, regularly updated, reliable, inclusive of all involved parties, and facilitates comprehensive analysis.

The initial 57.989 datasets, comprised both numerical, and alphanumeric data∙ including details about the location, of the forest fire, and information regarding the fire station involved, in the suppression efforts.

Beyond these data, our research was enhanced by incorporating meteorological information, for each fire incident. Specifically, we included weather conditions, at the time the fire began, and at the time it was extinguished. As a result, we incorporated an additional 115,978 data points encompassing various climatological factors, such as: wind speed, humidity, temperature, sunrise and sunset times, among others. The meteorological data, are available from: <https://opencagedata.com/about> (accessed on December 6, 2024).

The initial step, in Hellenic Fire data preprocessing, involved digitizing columns, containing alphanumeric data, particularly those with numerical content. This process entailed, converting categorical values into discrete integers, to ensure compatibility with machine learning algorithms, which require numerical inputs. Subsequently, a critical step was addressing missing values. Records with missing entries in key features, such as climatic variables or other relevant data, were excluded from the dataset. These omissions typically occurred due to unavailability, at the time of recording, and could potentially result in biased or unreliable outcomes.

To define the output variable, the duration of each forest fire was converted from hours or other time units into minutes, ensuring greater precision in classification. A logarithmic transformation of fire duration in minutes was then applied to manage the wide range of values effectively, preventing excessive influence from extreme durations. Based on this transformation, three distinct categories were established, serving as target values for experimental analysis. This approach enabled the classification of forest fires according to their duration. For the Greek forest fire data used in this study, the following classification scheme was adopted:

1. Up to 360 minutes (6 hours) is considered to be a fire, of short duration.
2. From 361 – 7200 minutes (6 hours – 5 days) is a fire of medium duration.
3. From 7201 - …. for the duration it persists (5 days - and more) is considered a long duration.

**Feature Construction**

To improve the predictive accuracy of Machine Learning (ML) models in forest fire analysis, there is increasing emphasis on leveraging **Feature Construction techniques**. These methods involve creating new, meaningful variables by combining or transforming existing data attributes [[22](#_References._1" \o "22) Tsoulos, I., Tzallas, A. A Feature Construction Method That Combines Particle Swarm Optimization and Grammatical Evolution. Special Issue Pattern Recognition and Artificial Intelligence in Biomedical Signal Processing. Applied Science Volume 13 (14). 2)]. For example, integrating material resources deployed during a forest fire event into a single metric constitutes feature construction, enabling models, to better capture the complexity, of fire incidents, and resource allocation. Another example, for Feature Construction, during a forest fire, is combining weather attributes, in order to form, a fire risk index. Such, approaches enhance data representation, facilitating more robust, and interpretable predictive models, in disaster management.

Τhis paper provides a concise overview of Feature Construction methods, applied to predicting forest fires, and improving early detection, systems. It also offers a comprehensive review of current models used in this field, highlighting their strengths and limitations.

In the domain of fire management, early warning systems for fire outbreaks serve as the cornerstone for timely containment and mitigation efforts. Over recent years, extensive research has been conducted to enhance fire detection methodologies through advanced computational techniques.

For instance, Harkat, utilized **feature construction** to train a model on multidimensional data. By eliminating irrelevant or redundant features and selecting the most relevant ones for classification, their approach achieved a remarkable accuracy of **96.21%.** However, their study also revealed limitations in the performance of deep learning (DL) models under constrained conditions [[23](#_References._1" \o "23) Harkat, H., Nascimento, J. M.P., Bernardino, A., Ahmed, H.F.T. Fires Images Classification based on a handcraft approach. Expert Systems with Applications, volume 212, February 2023, 118594. Available online: https://www.sciencedirect.com/science/artic)].

Another significant contribution is the work by Zhang, which demonstrated that every feature is integral to the overall performance of their algorithm. The combined use of features resulted in a highly impressive accuracy rate of **99.02%** for forest fire recognition. Nevertheless, the study identified a critical weakness: the removal of a single feature (mean) led to a substantial increase in false positives, underscoring its importance in minimizing errors [[24](#_References._1" \o "24) Zhang, C., Wu, D., Ji, L., Ran, R., Wu, H., Xu, Y. Forest Fire Recognition Based on Feature Extraction from Multi – View Images. Traitement du Signal, volume 38, No 3, pp. 775 – 783. June, 2021. Available online: https://www.researchgate.net/publicatio)]

Similarly, Yang, explored the construction of novel, dynamic features to improve accuracy and reduce false alarms in fire detection systems. By combining smoke and flame characteristics, their approach focused on enhancing early warning capabilities. However, the study had notable limitations, as it failed to disclose the source of their data or the specific results obtained, thereby impacting its reproducibility and transparency [[25](#_References._1" \o "25) Yang, Y., Sun, F., Lin, C., Liu, Z., Cho, L. Forest Fire Compound Feature Monitoring Technology Based on Infrared and Visible Binocular Vision. Journal of Physics: Conference Series, 1792 (2021) 012022. Available online: https://iopscience.iop.org/arti)].

At this point, we will mention a novel method, that was introduced by Tsoulos, for Featured Constructions. In order to improve the effectiveness of Artificial Intelligence, tools, such as Radial basis function (RBF), Multi-layer perceptron (MLP), K-nearest neighbor (KNN), and Neural Networks. The proposed method, is an experimental comparison, carried out against the accuracy obtained, on the original features, as well on features created by the PCA method, [[26].](#_References._1" \o "26) Tsoulos, I.G., Gavrilis, D., Dermatos, E. Selecting and constructing fetures using grammatical evolution. Pattern Recognition Letters, volume 29 (9), pp. 1358 – 1365. July 2008. Available from: https://www.sciencedirect.com/science/article/abs/pii/S016)

**Principal Component Analysis (PCA)**

The **Principal Component Analysis** (PCA) technique, introduced by mathematician Karl Pearson in 1901, and developed by Harold Hotelling (1933). This technique, operates on the principle when data from a higher-dimensional space is transformed into a lower-dimensional space, the resulting lower-dimensional representation should retain the maximum variance, of the original data.

Notably, it is worth mentioning that the use of PCA, on larger datasets, became practical only after the advent of electronic computers, which made it computationally feasible, to handle datasets, beyond trivial sizes [(28).](#_References._1" \o "Cadima, J., Jolliffe, I.T. Principal component analysis: a review and recent developments. National Library of Medicine. 2016. Available online: https://pmc.ncbi.nlm.nih.gov/articles/PMC4792409/  (accessed on 16 November 2024). )

Continuing, with the applications of PCA, it is a widely utilized technique in exploratory data analysis, and machine learning∙ particularly, in building predictive models. It is an unsupervised learning method, designed to analyze, the relationships among a set of variables. Often referred to as a form of general factor analysis, it involves regression to determine a line of best fit. The primary objective, of PCA, is to reduce the dimensionality of a dataset, while retaining the most significant patterns, and relationships, among the variables, all without requiring prior knowledge, of the target variables [(29).](#_References._1" \o "29) i2tutorials. What are the Pros and Cons of the PCA? October 1st, 2019. Available online: https://www.i2tutorials.com/what-are-the-pros-and-cons-of-the-pca/ (accessed on 16 November 2024)

Next, we will briefly reference studies, that have utilized PCA, covering different areas, such as: statistical physics, genetic improvement, face recognition, economic & environmental sciences, medical prediction, e.t.c.

Explicitly, the research conducted, by Park (2024), highlights the reasons behind the success of the PCA technique, for lattice systems. The study's primary limitation lies in the dependency of the proposed formula's accuracy on the dataset size. Specifically, the results achieve full precision, only under the condition of an infinite dataset. This constraint restricts the practical applicability, of the method, when working with finite or limited data, a common scenario, in real-world analyses, [[30].](#_References._1" \o "Park, Su-Chan. Physical Meaning of Principal Component Analysis for Lattice Systems with Translation Invariance. October 31, 2024. Available online: https://www.researchgate.net/publication/385386437_Physical_Meaning_of_Principal_Component_Analysis_for_Lat)

The following research, by Sarma, (2024), performed with PCA, in order to evaluate, morphometric traits, under a multivariate approach. The findings suggest, that PCA could significantly enhance the genetic improvement, [[31].](#_References._1" \o "Sarma, O., Rather, M.A., Shahnaz, S., Barwal, R.S. 2024. Principal Component Analysis of Morphometric Traits in Kashmir Merino Sheep. Journal of Advances in Biology & Biotechnology, volume 27 (9), pp. 362-69. Available from: https://www.researchgate.net/pu) Noteworthy, is the fact, that the 64.29%, of the total variance explained, can be considered relatively low. This suggests, that a significant amount of unexplained information remains, which is not captured, by the four principal components.

The next study, by Parante, the PCA was used for monitoring the cultivation, of cannabis, in Albania. Specifically, with PCA they remove redundant spectral information from multiband datasets, [[32].](#_References._1" \o "Gambardella, C., Parente, R., Ciambrone, A., Casbarra, M. A Principal Components Analysis – Based Method for the Detection of Cannabis Plants Using Representation data by Remote Sensing. Knowledge Extractions from data Using Machine Learning, volume 6 (10))

The article, by Slavkovic & Jevtic, presents the implementation of a face recognition system based on the Principal Component Analysis (PCA) algorithm [[33](#_References._1" \o "Slavkovic, M., Jevtic, D. Face Recognition Using Eigenface Approach. SERBIAN JOURNAL OF ELECTRICAL ENGINEERING, Volume 9, No. 1, February 2012, pp. 121-130. Available from )].

The PCA technique was utilized, by Hargreaves, for stock selection, specifically to identify, a limited number of stock variables, that could effectively aid, in determining winning stocks, [[34].](#_References._1" \o "13) Hargreaves, C.A., Mani, C.K. The Selection of Winning Stocks Using Principal Component Analysis. American Journal of Marketing Research, volume 1, (3), 2015, pp. 183 – 188. Available from: https://www.researchgate.net/publication/281042621_The_Selectio)

The following documents present a modified model of Principal Component Analysis (PCA).

The paper, by Xu (2024), presents an interesting example of a modified application of Principal Component Analysis (PCA)∙ utilizing, both linear and non-linear methods, through Kernel PCA (KPCA), in combination, with the Adaptive Boosting (AdaBoost) algorithm, [[35].](#_References._1" \o "Xu, Z., Guo, F., Ma, H., Liu, X., Gao, L. On Optimizing Hyperspectral Inversion of Soil Copper Content by Kernel Principal Component Analysis. Remote Sensing, volume 16, (16). 09 August 2024. Available from: https://www.mdpi.com/2072-4292/16/16/2914  (acce)

The study, by Zhang (2022), a neural network model, combining PCA and Levenberg-Marquardt Backpropagation (LMBP) was developed, to efficiently, and accurately analyze, and predict the interaction between IAQ and its influencing factors. In particular, it was examined indoor air quality (IAQ), and its relationship, with building features, and environmental conditions, [[36].](#_References._1" \o "Zhang, H., Srinivasa, R., Yang, X., Ahrentzen, S., Coker, E.S., Alwisy, A, Factors influencing indoor ai pollution in buildings using PCA – LMBP neural network: A case study of a university campus. Building and environment, volume 225. November 2022. Avail)

In the next research, by Akinnuwesi, it was employed a hybrid approach, combining Principal Component Analysis (PCA), and Support Vector Machine (SVM). They create, the Breast Cancer Risk Assessment and Early Diagnosis (BC-RAED) model, designed to accurately detect BCa, in its early stages. PCA, was initially applied to extract features, during the first preprocessing stage, followed by further feature reduction, in the second stage. The multi-preprocessed data, were analyzed for breast cancer risk, and diagnosis using SVM. The BC-RAED model, achieved, an accuracy of 97.62%, a sensitivity of 95.24%, and a specificity of 100% in assessing, and diagnosing breast cancer risk, [[37].](#_References._1" \o "37) Akinnuwesi, B., Macaulay, B.O., Aribisala, B. Breast cancer risk assessment and early diagnosis using Principal Component analysis and support vector machine techniques. Informatics in Medicine Unlocked, Volume 21, 2020. Available from: https://www.sci)

Subsequently, we will briefly mention certain studies, that have been conducted, in the field: of Forest Fires.

Guan's, research focuses on forest fire prediction using PCA-preprocessed data. The preprocessing step removed irrelevant information, simplifying analysis. Linear regression and random forest methods were then applied, revealing temperature, relative humidity, wind, and rain as the most influential factors in forest fire occurrence, [[38].](#_References._1" \o "38) Guan, R. Predicting Forest Fire with Linear Regression and Random Forest. Highlights in Science, Engineering and Technology, Volume 44 (2023). Available from: https://www.researchgate.net/publication/370220747_Predicting_Forest_Fire_with_Linear_Regress)

A novel model was developed, by Nikolov, using meteorological forecast data as input. Principal Component Analysis (PCA), with orthogonal rotation, was applied to reduce 195 meteorological variables, from the NARR dataset, to a smaller set of significant fire-ignition predictors, later used in logistic regression, to calculate wildfire ignition probabilities, [[39]](#_References._1" \o "39) Nikolov, N., Bothwell, P., Snook, J. USFS-CSU Joint Venture Agreement Phase 2 (2019-2021): Developing a Gridded Model for Probabilistic Forecasting of Wildland-Fire Ignitions Across the Lower 48 States. Available from: https://www.fs.usda.gov/rm/pubs_j) .

Like the aforementioned study, this one also belongs to Nikolov. This research, focuses on predicting wildfire ignitions, caused by lightning strikes, which account for the largest area burned annually, in the extratropical Northern Hemisphere. Principal Component Analysis (PCA), played a key role, in reducing 611 potential predictors, to 13 principal components, which were used in logistic regression to identify the primary factors influencing lightning occurrence, [[40].](#_References._1" \o "40) Nikolov, N., Bothwell, P., Snook, J. Probalistic forecasting of lightning strikes over the Continental USA and Alaska: Model development and verification. Scientific Journal, Fire (7). Available from: https://research.fs.usda.gov/treesearch/68447 )

**Minimum Redundancy Maximum Relevance (MRMR)**

The min-redundancy max-relevance algorithm, introduced by Chris Ding and Hanchuan Peng, in their 2005 paper titled: “Minimum Redundancy Feature Selection from Microarray Gene Expression Data.” The (MRMR) aims to optimize feature selection, by minimizing redundancy, and maximizing relevance by Ramirez – Gallego [[41](#_References._1)].

In sum, MRMR enhances relevance-only methods, such as using an f-test between the target, and the features. When two features are similar, MRMR prioritizes only the one, with the highest relevance.

From the literature review conducted, no studies, were identified, that specifically utilized the m RMR algorithm, in the domain, of forest fire research. Therefore, we will proceed, to reference other relevant studies, from other fields.

The study, by Zhao, extends traditional m RMR methods, by introducing, a **non-linear feature redundancy measure,** anda **model-based feature relevance measure**∙which are tested, on synthetic, and real-world datasets. Based on its empirical success, m RMR is integrated, into Uber's marketing machine learning platform, to automate, the creation and deployment, of scalable targeting, and personalization models, [[42].](#_References._1" \o "42) Zhao, Z., Wang, M., Anand, R. Maximum Relevance and Minimum Redundancy Feature Selection Methods for a Marketing Machine Learning Platform. 2019. Available from: https://ar5iv.labs.arxiv.org/html/1908.05376 (accessed 21 November 2024).)

In the next paper, by Yang, the m RMR (Minimum Redundancy Maximum Relevance) algorithm is utilized in conjunction with a Random Forest (RF) model to perform **feature selection** in the context of air quality prediction. MRMR, is employed, to determine which variables have the most significant impact, on the air quality index (AQI), while minimizing redundancy among them, [[43].](#_References._1" \o "43) Yang, T., Wu, H., Li, H., Zhou, Z. Air quality prediction model on mRMR – FR feature selection and ISSA-LSTM. Scientific Reports, volume 13 (1), August 2023. Available from: https://www.researchgate.net/publication/372959977_Air_quality_prediction_mode)

The article, by Elbeltagi, is an innovative approach, for estimating maize chlorophyll, by integrating hyperspectral indices with cutting-edge, six advanced machine learning techniques. The MRMR algorithm was incorporated into the process to enhance feature selection by pinpointing the most significant spectral bands, minimizing data redundancy, and boosting model efficiency, [[44].](#_References._1" \o "44) Elbeltagi, A., Nagy, A., Szabo, A., Nxumalo, G.S., Bodi, E.B., Tamas, J. Hyperspectral indices data fusion-based machine learning enhanced by MRMR algorithm for estimating maize chlorophyll content. Frontiers in Plant Science, Section Technical Advance)

In the energy sector, Liu conducted the following research, offering an improved method, for predicting transient stability, in power systems. The m RMR algorithm, is applied for feature selection, with minimal redundancy and maximum relevance, providing an enhanced approach, for forecasting transient stability, in power systems.

This approach addresses, the limitations of previous methods, such as low accuracy, difficult applicability, and high computational cost, while incorporating the "winner take all" (WTA) technique, for ensemble learning, and enhanced precision, [[45].](#_References._1" \o "45) Liu, J., Sun, H., Li, Y., Fang, W., Niu, S. An Improved Power System Transient Stability Prediction Model Based on mRMR Feature Selection and WTA Ensemble Learning. Applications of Machine Learning for Renewable Energy based Modern Power Systems. Appli)

Eristi, also refers to the energy sector. Specifically, this paper presents, a new PD detection system, that combines spectral analysis, spectrogram analysis, deep learning algorithms, minimum redundancy-maximum relevance (m RMR), and ensemble machine learning (EML). The most impactful features, are identified, by performing m RMR feature selection analysis, on the extracted deep features, [[46].](#_References._1" \o "46) Eristi Belkis. A New Approach Based on Deep Features of Convolutional Neural Networks for Partial Discharge Detection in Power Systems. IEEE, volume 12. Available from: https://ieeexplore.ieee.org/document/10643969/authors#authors (accessed 26 November)

Zhang, employed an Acoustic Emission (AE) technique to monitor, inaccessible areas of large storage tank floors, utilizing AE sensors positioned externally to the tank. The implemented algorithm, effectively distinguishes corrosion signals from interference signals, particularly drop-back signals induced by condensation. Experimental studies were conducted both in laboratory settings and in field environments, focusing on Q235 steel. Seven characteristic AE features, derived from signal hits, and frequency, were extracted, and subsequently selected for pattern recognition, using the Minimum Redundancy Maximum Relevance (m RMR) method, [[47]](#_References._1" \o "47) Zhang, Y., Li, Y., Zhu, H., Yan, R., Liu, Y., Sun, L., Zeng, Z. Recognition Algorithm of Acoustic Emission Signals Based on Conditional Random Field Model in Storage Tank Floor Inspection Using Inner Detector. Shock and Vibration, Volume 2015, Issue 1.) .

Razmi, proposes a methodology to examine the effects of climate change, on sea level variations, in coastal areas, using an artificial neural network model. Feature selection techniques, including Minimum Redundancy Maximum Relevance (MRMR) and Mutual Information (MI), are employed to identify the most suitable predictors for the neural network input, [[48].](#_References._1" \o "Razmi, A., Karamouz, M., Zahmatkesh, Z., Nazif, S. An Evaluation of Climate Change on Extreme Sea Level Variability: Coastal Area of New York City. Water Resources Management, volume 28 (11). September 2014. Available from: https://www.researchgate.net/pub)

The study, by Gui, introduced an innovative predictive screening approach, integrating mutual information (MI), and Random Forest (RF) methodologies, through the minimum-redundancy-maximum-relevance-recursive feature elimination-random forest (mRMR-RFE-RF) framework. This method, combines the strengths of both filter, and wrapper techniques, offering a comprehensive strategy for feature selection, [[49].](#_References._1" \o "Gui, G., Tang, T., Chen, T. A Novel mRMR – RFE – RF Method for Enhancing Medium – and Long – Term Hydrological Forecasting: A Case Study of the Danjiangkou Basin. IEEE Journal of Selected Topics in Applied Earth Observations And Remote Sensing. Volume 17. )

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