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Research Article

Tree mortality and dieback in Daland Forest Park, Iran: An assessment of Human and Environmental Factors

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Abstract
Forests are important ecosystems that contain a wide range of living organisms. Recently, many forest trees, particularly in forest parks, have been experiencing dieback due to various factors, causing concerns among the public, researchers, and relevan authorities. Due to the importance of this issue, this study investigated the effect of environmental and human factors on the dieback and death of trees in Daland Forest Park, located in the Golestan Province, northeastern Iran. We used an RTK-DGPS to record the positions of dieback-affected trees and their percentages of dieback in circular plots of 1000 m^2. In addition, all dead trees were visually identified using a UAV orthomosaic from 2021, and their locations were recorded. The effects of recreational areas, forest types, distance from water wells, and forest roads on tree dieback were analyzed. In addition, the relative impact of variables on dead trees was calculated. Based on tree dieback analysis using completely randomized factorial, tree dieback occurrence in the forest type is significantly affected, at a 99% confidence level. Additionally, the distance from water wells, recreation zones, and forest roads had a mutual effect on the amount of tree dieback. The analysis of dead trees showed that their occurrence was relatively higher in recreation-centered zones, certain forest types, and at distances of 0-100 meters from forest roads and 200-400 meters from water wells. Based on the findings, it is recommended to halt water extraction from the park's wells and implement management treatments around forest roads and recreation zones to reduce pressure factors. It is also necessary to investigate the causes of tree mortality and dieback in other parts of the Hyrcanian forest.

Keywords: Dead tree; Forest degradation; Forest health; Relative effect.

1. Introduction
Forests are vital ecosystems that support a diverse range of organisms, from microscopic life forms to large mammals (Brockerhoff et al., 2017; Naseri & Rostamian, 2020). They play a significant role in hydrological and biochemical cycles, regulate climate conditions (Behbahani et al., 2009), and contribute substantially to atmospheric carbon storage (Dixon et al., 1994; Hurteau, 2021). Although forests have traditionally been used for wood production (Rezvani & MeerTaghian Roodsari, 2019), they are also considered for various other purposes, including recreation in in forest parks for both domestic and inteernational tourists (Konu, 2015; Kuvan, 2005). Nowadays, people increasingly seek relaxation in natural environments due to the challenges of urbanization and industrialization (Dudek, 2016; Kanat & Breuste, 2019). Therefore, it is essential to conserve and develop forest parks and other recreational areas to protect natural resources, attract tourists, generate income, and provide leisure opportunities (Bagherian et al., 2022).

Maintaining the health of forest parks and their ecological conditions is one of the primary responsibilities of forest managers and

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other authorities to ensure the preservation of these services. Unfortunately, excessive use and human pressure on forest parks have led to increasing tree dieback and mortality, resulting in ecosystem decline. Tree dieback affects forest regions and can significantly impact ecosystem functionality (Jump et al., 2017; Scherrer et al., 2023). The first sign of dieback is the wilting of the tree, which is due to significant water stress leading to a drop in the water level in the tissues and vessels. It usually begins with the loss of moisture and the yellowing and drying out of the edges of leaves and organs before spreading to branches and trunks (Amir Ahmadi et al., 2015). After late autumn, when the leaves fall, thin branches begin to dry and fall. This process gradually spreads to the main branches and trunk, ultimately leading to tree mortality.

Due to the widespread increase in tree dieback in certain forest ecosystems and land uses, foresters, scientists and researchers are concerned about its causes and are working to find practical solutions. Despite recent research, some factors influencing tree dieback and mortality remain unknown. Various environmental and human activities, including agriculture, aquaculture, industrial and construction activities, tree branch harvesting for livestock, tannin extraction, and ecotourism, can directly or indirectly contribute to tree dieback and mortality (Ezzati et al., 2023; Hossain et al., 2013; Polidoro et al., 2010). As a result, it is essential to identify the factors that contribute to tree dieback and mortality. Identifying the unknown causes of tree dieback will help mitigate its effects and protect forest health and longevity.

Researchers across various forests (Ahmadi & Rostami, 2021; Amir Ahmadi et al., 2015; Barazmand et al., 2012; Bradford et al., 2022; Esmaili et al., 2016; Guarín & Taylor, 2005; Karami et al., 2017; Naseri & Shataee Jouibary, 2017) have studied factors contributing to tree decline and mortality. In Iran’s Hyrcanian forests, Barazmand et al. (2012) conducted a case study in the Shastkolah Forest to examine the effects of environmental factors on tree dieback using PCA analysis. They found a significant correlation between tree dieback and distance from roads and rivers, solar radiation, and slope. In addition, Esmaili et al. (2016) investigated the relational analysis between Buxus tree mortality and topographical and environmental factors in the Khibous forests, in Mazandaran Province. In Iran’s Zagros forests, several studies (Ahmadi & Rostami, 2021; Karami et al., 2017; Naseri & Shataee Jouibary, 2017) have identified key factors contributing to oak decline. For example, Naseri & Shataee Jouibary (2017) examined the impact of forest roads on the reduction of tree canopy density caused by oak decline in the Dasht Barm region, Fars province, Iran. They found a significant decline in canopy density around forest roads due to oak tree mortality.

Furthermore, Bradford et al. (2022) examined the effects of drought and competition on tree mortality in western U.S. regions. They found that competition at tree bases led to higher mortality in dense stands. Additionally, areas with high temperatures and low humidity during seven-year droughts were more prone to tree dieback than those experiencing three-year droughts. McDowell et al. (2019) reported that access to hydraulic refugia improved tree resistance to hot droughts. Ranasinghe et al. (2007) studied the relationship between soil chemistry and tree dieback in Sri Lanka's mountain forests. They found that soil compaction from heavy traffic near forest roads was significantly linked to tree dieback.

Forest Parks are a type of forest land use that is affected by damaging environmental and human factors. The overloading of travelers and visitors increases their vulnerability (Deng et al., 2003). As a result of these damages, trees begin to experience dieback, which may lead to mortality. Identifying the key factors contributing to tree weakness and dieback can help address this problem. Thus, few studies have examined the effects of various factors on tree dieback and mortality in forest parks. In this regard, an evaluation of the effects of individual characteristics, forest stand, habitat, and environment on the survival time of oak trees was conducted in the Ghorogh Forest Park located in the Hyrcanian forest region by Karami et al. (2017) using survival analysis. Their findings indicated that only the distance from roads and the distribution range significantly affected the survival rate of oak trees. In Yosemite National Park, California, Guarín & Taylor (2005) studied the effect of drought and topography on tree dieback and concluded that the correlation between drought and tree mortality was significant only for 2-5 years, and the density of dead trees on northern slopes was high. Negahdar Saber et al. (2003) reported that limited root space and prolonged dry seasons caused the death of coniferous trees at Cheshmeh-Sara Abu Al-Mahdi Park. Similarly, Tavakoli Neko et al. (2008) attributed the dieback of *Cupressus arizonica* in Qom Forest Park to soil and water salinity.

Given the stated context, investigating the factors contributing to tree dieback and mortality is crucial for sustainable forest management. Unfortunately, observations show a significant increase in the dieback and mortality of trees in the Golestan Province, particularly in the Daland Forest Park. This presents a major challenge for forest management, making it essential to identify the direct and indirect factors contributing to this issue for effective risk mitigation. While previous studies have primarily focused on environmental factors such as climatic and competition, limited research has explored the impact of human-related factors, including recreation zones, proximity to water wells (used for drinking water and agricultural irrigation), forest roads, and tree species, on tree dieback and mortality in forest parks. To address this research gap, this study examines the impact of human-related factors on tree dieback and mortality in Daland Forest Park, Iran. Identifying the specific factors influencing tree dieback and mortality in this region can inform sustainable forest management practices, reducing the damages caused by tree dieback and mortality.

2. Materials and methods

2.1. Study area

This research was conducted in Daland Forest Park, located in the Golestan Province, Northeast Iran, between 55˚ 4´ 20″ and 55˚ 6´ 7″ east longitude, and 37˚ 2´ 25″ and 37˚ 4´ 15″ north latitude. The park covers approximately 579 hectares, however, this study focused on 330 hectares due to financial constraints. The park's elevation ranges from 60 to 120 meters above sea level (Figure 1). The average annual rainfall in the area is 660 mm, and the average annual temperature is 16.5 degrees Celsius. The park's vegetation includes 11 tree species, three shrub species, and 18 herbaceous plant species (Hajizadeh et al., 2012; Naseri et al., 2023). The dominant species in the region include *Zelkova carpinifolia*, *Parrotia persica*, *Quercus castaneifolia*, and *Carpinus betulus*.

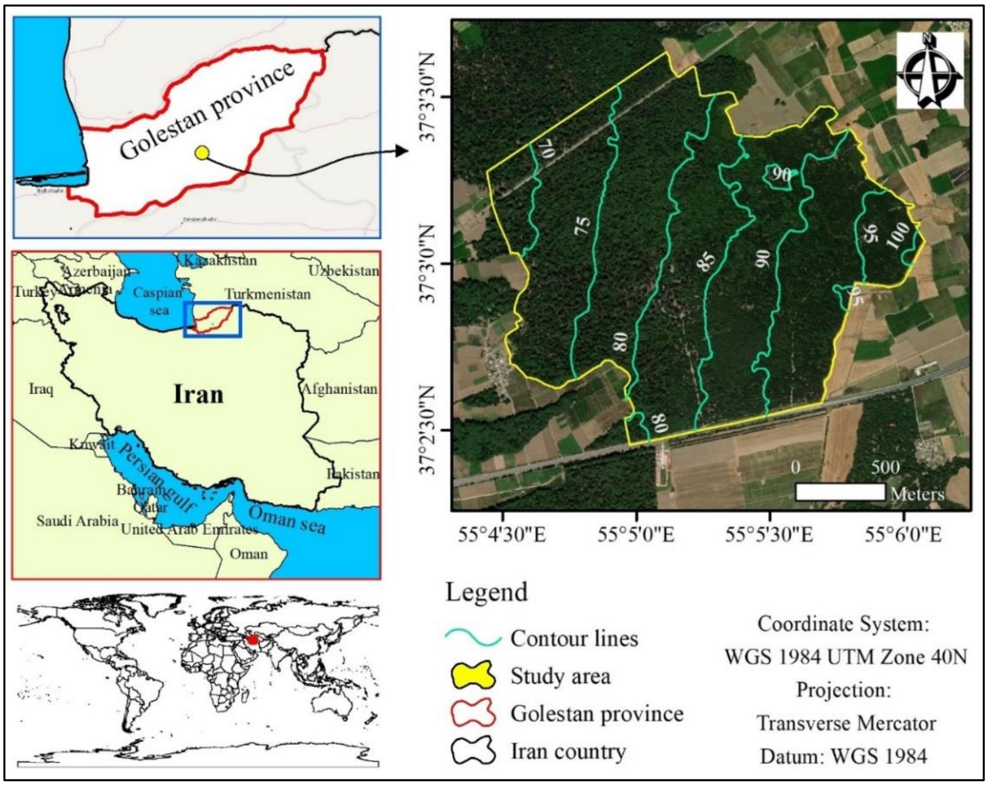

Figure 1. The location of the study area in the Golestan Province, Northeastern Iran

2.2. Data collection

First, 230 trees exhibiting varying degrees of dieback were selected throughout the study area. An RTK differential GPS device was used to determine the precise locations of tree diebacks. Fifty trees were randomly selected as the centers of circular plots, each with an area of 1000 m^2, based on a suitable distribution (Figure 2-a). Additionally, the tree locations within the plot were recorded to assess the dieback percentage of the trees. To determine the dieback percentages, the crown of each tree was divided into four sections, and the dieback percentage was calculated for each section. Finally, dieback percentages were calculated cumulatively (Cracknell et al., 2023).

The visual interpretation method, employed in previous studies (Cumming et al., 2001; Ghasemi Rozveh et al., 2017; Fallah & Haidari, 2018, Marchin et al., 2022), was also used in this study to select dead trees. The dead trees were detected and mapped using visual interpretation on a UAV orthomosaic image from 2021, captured by a Phantom 4 Pro drone (Table 1). The coordinates of each dead tree were recorded in the ArcGIS software (Figure 2-b).

2.3. Environmental and human-based factors

To prepare and map these factors, available resources in the area, as along with existing maps and the UAV orthomosaic image from 2021, were used. The recreational zones were categorized into three types: focused (centralized), extensive, and non-recreation (Figure 2-c). The map of forest tree types (Figure 2-d) was produced using the stratification method, based on plot-based tree statistics and the UAV orthomosaic image from 2021. The forest roads and water wells locations and shape files were created using UAV orthomosaic and GPS devices. In the identification of water wells' distance intervals (Figure 2-e), we considered three distance ranges: 0-200, 200-400, and over 400 meters. For forest roads (Figure 2-f), three distance ranges: 0-100 meters, 100-200 meters, and over 200 meters were considered (Figure 2-f). All required maps were created using ArcGIS 10.7.

Table 1. Specifications of UAV flight parameters and UAV image processing

Parameters	
Drone	Phantom 4 pro
Camera	FC6310S, 8.8 mm
Altitude (m)	100 m
Overlaps (%)	80 × 80
Resolution of Orthomosaic (cm)	2.6
Quality	High
Total Error (cm)	1.23

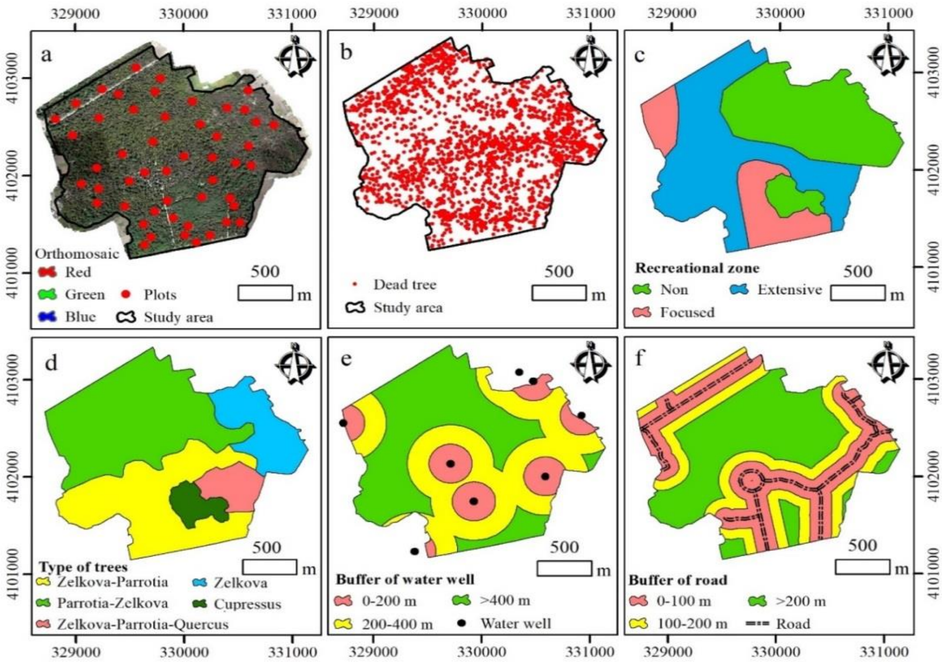

Figure 2. Maps of the location of plots (a), the dead trees (b), recreation zones (c), forest types (d), distance from water wells (e), and distance from forest roads (f)

2.4. Statistical analysis of the effects of independent variables on the occurrence of dieback

A completely randomized factorial design was used to analyze the relationship between the independent variables and their mutual effects on the percentage of tree dieback (the dependent variable). The independent variables included forest tree types (*Zelkova-Parrotia*, *Parrotia-Zelkova*, *Zelkova-Parrotia-Quercus*, *Zelkova*, *Cupressus*), types of recreation zones (focused, extensive, and non-recreation), distance from forest roads (0-100 meters, 100-200 meters, and over 200 meters), and distance from water wells (0-200, 200-400, and over 400 meters). Duncan's multiplerange test was used to calculate the percentage differences in the averages of variables using SAS 9.4 software.

2.5. Investigating the relative effects of independent variables on the occurrence of tree mortality

The UAV orthomosaic image was used to register the spatial locations of all dead trees within the study area, the areas of the independent variables were also taken into account. The relative effect of each class of independent variables on dead tree occurrence was calculated using Equation 1. According to this method, the class with the greatest amount of the relative effect was considered to have the most influence on the phenomenon (Alimohammadi et al., 2010). To determine the contribution of each variable to the dead trees occurrence, we independently extracted the number of dead trees at each class of variables. Finally, the areas of each class of variables and the total area of the study area were used to calculate the contribution of each class to the dead trees. Figure 3 presents a flowchartsummarizing the stages of conducting the research.

$$Relative\, effect = \left(\frac{Number\, of\, dead\, trees\, per\, class}{The\, total\, number\, of\, dead\, trees} \right) / \left(\frac{Area\, of\, each\, class}{The\, total\, area\, of\, study\, area} \right) \quad (1)$$

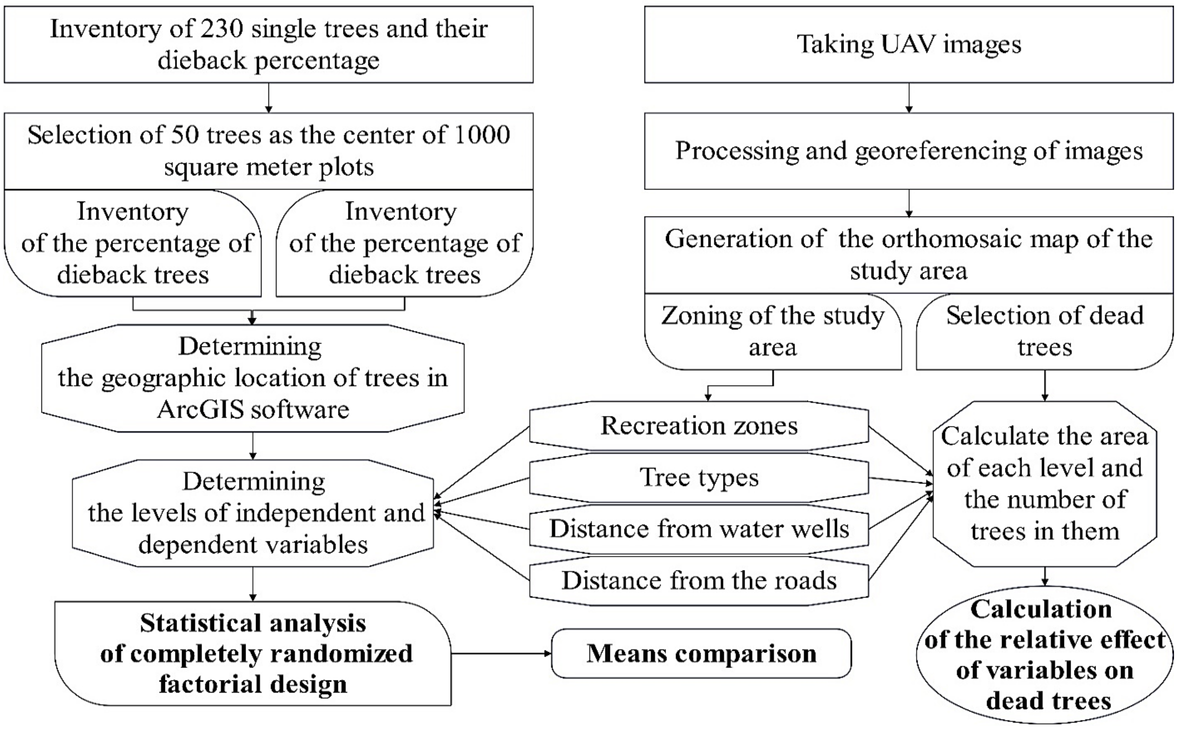

Figure 3. Flowchart of research

3. Results

3.1. Investigating the effect of independent variables on dieback trees

This study statistically analyzed the occurrence of 919 dieback trees to determine the relative effects of various variables. Based on the statistical analysis of the completely randomized factorial statistical design, the results showed that the effect of tree types on tree dieback occurrences was significant at a confidence level of 99%. In contrast, recreational zones, distances from water wells, and distances from forest roads did not significantly affect tree dieback. In investigating the mutual effects of variables on dieback occurrence, it was found that the mutual effects of a combination of recreation zones, and distance from water wells, and also a combination of distance from water wells and forest types on tree dieback occurrence was significant at a 95% confidence level. The mutual effect of distance from water wells and forest roads, as well as the water well distance and forest types on tree dieback was significant at the 99% confidence level (See Table 2). Other variables and their combinations did not show significant effects.

3.2. Comparing the significant analysis of the mean of variables using Duncan's multi-range test

3.2.1. The effect of the forest type

The results of Duncan's test revealed no significant difference in the percentage of dieback trees between *Zelkova-Parrotia*, *Parrotia-Zelkova*, and *Zelkova-Parrotia-Quercus* forest types. However, a significant difference was observed in the percentage of dieback trees between *Zelkova* and *Cupressus* forest types (Figure 4). Specifically, the highest percentage of dieback trees was found in the *Zelkova-Parrotia-Quercus* type (19.34%), while the lowest percentage was observed in the *Cupressus* type (4.24%).

Table 2. Significant relationship analysis of independent variables and their combination on dieback occurrence

Variables	DF	Mean Square	Pr >F
Recreational zones	2	1076.04$^{n.s}$	0.1863
Forest types	4	7197.84**	< 0.0001
Distance from water wells	2	1286.31$^{n.s}$	0.1342
Distance from forest roads	2	1793.35$^{n.s}$	0.0610
Recreational zones × Forest types	3	526.54$^{n.s}$	0.4808
Recreational zones × distance from water wells	3	2542.23*	0.0079
Recreational zones × distance from forest roads	2	1019.51$^{n.s}$	0.2034
Forest types × Distance from water wells	4	1608.80*	0.0401
Forest types × Distance from forest roads	3	617.94$^{n.s}$	0.4077
Distance from water wells × distance from forest roads	2	4514.64**	0.009

***significant at 99% confidence level,* * *significant at 95% confidence level*

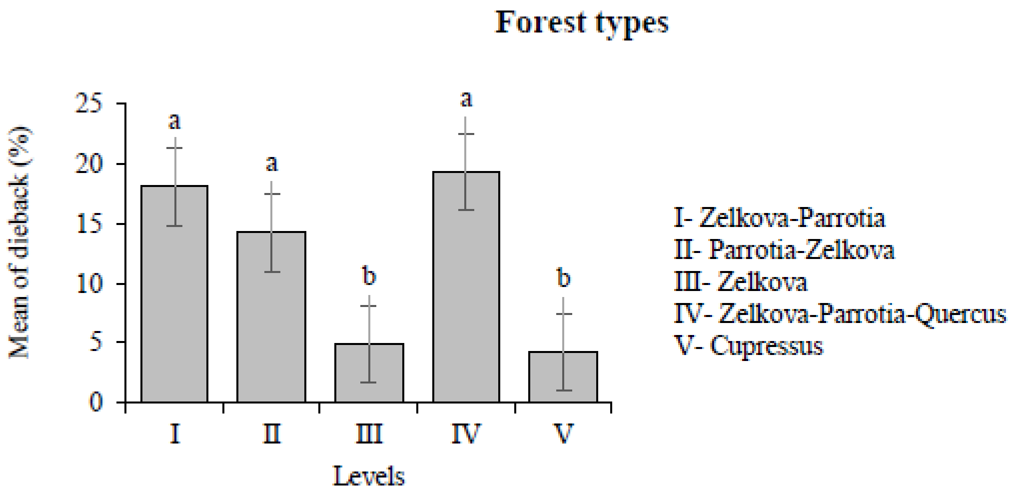

Figure 4. Comparison of averages related to levels of forest types

3.2.2. Interaction effect of forest type and distance from water wells

The comparison of percentage averages of dieback trees related to the interaction effects of forest type and distance from water wells revealed that certain combinations of forest types and distances did not show significant differences. These combinations included areas of *Parrotia-Zelkova* at >400m and *Zelkova-Parrotia-Quercus* at 200-400m, *Zelkova-Parrotia* at >400m and *Parrotia-Zelkova* at 200m-400m, and areas of *Zelkova* at 0-200m, *Zelkova* at 200-400m, and *Cupressus* at 200m-400m (Figure 5). However, the remaining areas showed statistically significant differences. The highest percentage of diebacks (36.25%)

was observed in the *Parrotia-Zelkova* type at the 0-200m distance from water wells, while the lowest percentage (4.24%) was recorded in the *Cupressus* forest type at the 200-400m distance from water wells.

3.2.3. Interaction influence of recreation zones and distance from water wells

The comparison of percentage averages of tree dieback rates with the mutual effects of recreation zones and water wells showed that certain combinations of recreation zones and distances were not significantly different. These combinations included the non-recreation zone at >400m, the focused recreation zone at 0-200m, extensive recreation zone at 0-200m, and extensive recreation zone at >400m. However, the remaining areas showed statistically significant differences (Figure 6). The highest percentage of diebacks was observed in the non-recreation zone and 0-200m distance from water wells, with a value of 26.36 %, while the lowest percentage (6.67%) was observed in the focused recreation zone at the of >400m distance.

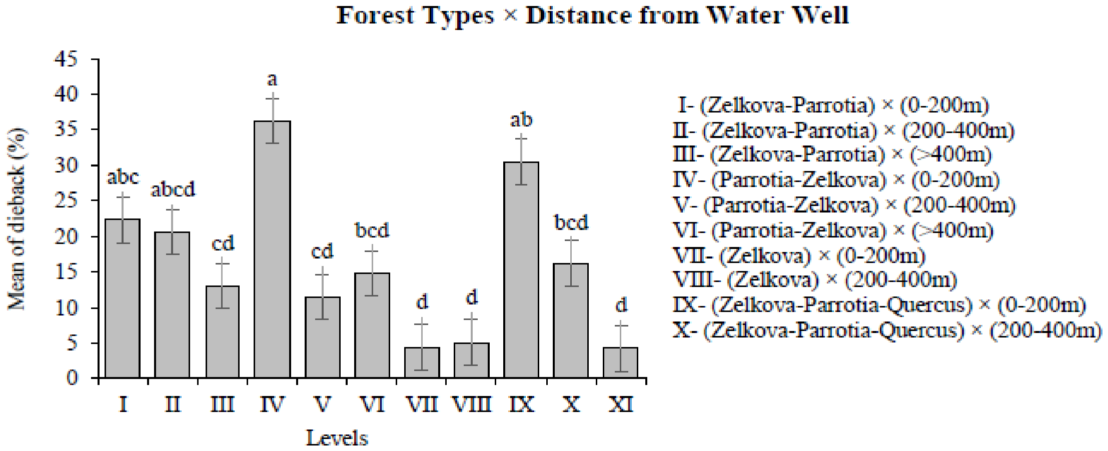

Figure 5. Comparison of the interaction effect of areas of forest types and distance from water well on the dieback occurrence percentage

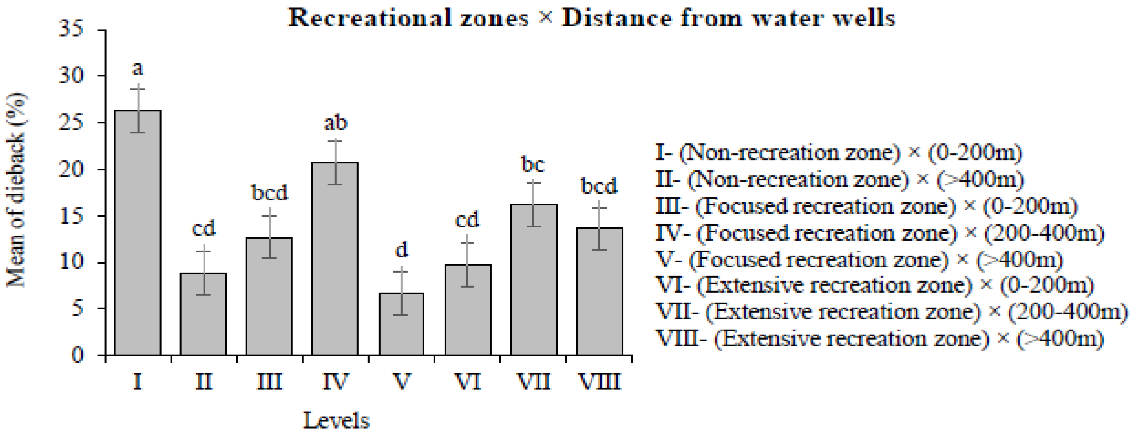

Figure 6. Comparison of the interaction effect of areas of recreational zones and distance from water well on the dieback occurrence percentage

3.2.4. Interaction effect of distance from water wells and distance from forest roads

The analysis results shown in Figure 7 indicate a significant difference in the percentage of tree dieback when combining the variables of distance from water wells and forest roads. Specifically, a significant difference was observed at the 0-200m distance from water wells and the 100-200m distance from forest roads, while no significant relationship was found between the other distance levels. The highest percentage of diebacks was observed at the areas of 0-200m distance from water wells of 100-200m distance from forest roads (35.5%), while the lowest percentage was observed at the 200-400m x 100-200m, with a value of 8.64%.

3.3. Investigating the relative effect of independent variables on the dead tree occurrence

The 2,212 dead trees were identified through visual interpretation of UAV orthomosaic images. The analysis of the relative effect of each class of independent variables on dead tree occurrence showed that the centralized recreational zone had the highest effect on the dead tree occurrence within the recreational zones. In addition, the pure *Zelkova* tree type, 200 to 400 meters from water wells and distances of 0 to 100 meters from forest roads, had the greatest influence on dead tree occurrence in the study area (Table 3).

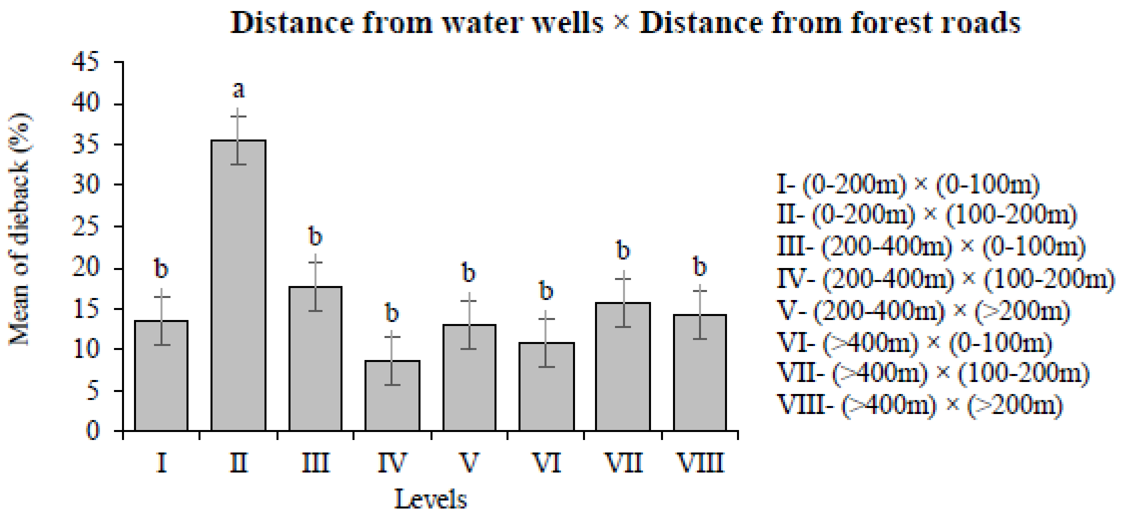

Figure 7. Comparison of the interaction effect of areas of distance from water wells and distance from forest roads on the dieback occurrence percentage

Table 3. The results of relative effects of independent variables and their classes on tree mortality

Parameters	Class	Number of dead trees	Class area (ha)	Relative effect
Recreational zones	Centralized recreation zone	396	88.7314	1.060
	Extensive recreation zone	955	142.957	0.996
	Non-recreation zone	861	131.306	0.978
Forest types	*Zelkova*	410	46.264	1.322
	Zelkova-Parrotia	811	104.533	1.157
	Parrotia-Zelkova	802	142.261	0.840
	Cupressus	82	15.5039	0.788
	Zelkova-Parrotia-Quercus	107	21.4319	0.744
Distance from water wells	200-400 m	1048	134.336	1.163
	0-200 m	327	54.4837	0.895
	>400 m	837	141.175	0.884
Distance from forest roads	0-100 m	855	109.899	1.160
	100-200 m	550	82.6135	0.993
	>200 m	807	137.482	0.875

4. Discussion

This research examined the effects of recreation zones, tree types, distance from water wells, and distance from forest roads on tree dieback in Daland Forest Park, Golestan Province, Iran. The study also investigated the relative effects of these variables on dead trees. The results showed that the *Zelkova* tree type had the highest susceptibility to dieback. It may result from the reaction and conditions of pure stands to environmental and non-environmental stressors. Pure stands generally exhibit lower resistance than mixed stands, and they are highly susceptible to stress, such as pests and diseases, drought, storms, snow, human intervention, and so forth (Alijani et al., 2013; EslamBonyad & Tavankar, 2014). According to reports and research conducted by forest experts in the studied area, the *Biscogniauxia mediterranea* fungi have been causing dieback and mortality of *Zelkova carpinifolia* species in recent years (Mir Abolfathi, 2013).

The results of investigating other variables separately indicate that they did not significantly affect tree dieback. However, when examining their combined effects, the combination of distance from water wells with tree types, recreation zones, and distance from forest roads showed a significant dieback occurrence rate. Therefore, the status of the underground water level available for plant roots plays a crucial role in tree stability and health. This is due to the simultaneous reduction in underground water on profile levels (Ganeshamurthya et al., 2020) and the damage caused to trees and their surrounding environment due to recreation, which can eventually result in dieback and death of the trees. However, in analyzing the interactional influence of recreational zones and the distance from water wells in this study, the combination of 0-200 meter distance levels with non-recreational zones had the greatest impact on dieback tree percentage. Our field observations showed that areas without recreation are heavily affected by livestock and wood smugglers, which has caused severe damage to trees. Therefore, illegal cutting by local communities creates wounds in trees, providing entry points for pathogens and eventually cause the trees to die (Wingfield, 1983; Mohan et al., 2022).

The relative effects of recreation zones, distance from forest roads, and distance from water wells on tree dieback were examined in Daland Forest Park. The results indicated that centralized recreation zones and distances between 0 and 100 meters from forest roads due to the excessive presence of visitors parking and resting had the greatest effect on dead trees and that the number of dead trees decreased with increasing distance from forest roads. This is because the accumulation of tourists and visitors in recreation zones and the proximity to forest roads can increase soil compaction, reducing the soil porosity and water absorption capacity. This soil compaction will reduce water infiltration (Chukwuka et al., 2018; Shaheb et al., 2021), decreasing soil moisture and increasing susceptibility to stress and mortality. In addition, the damage to trees caused by breaking branches and trunks, trampling herbaceous plants, and creating fires for food cooking under the tree canopy cover in recreation zones can weaken the trees' resistance to stress and ultimately cause their death. The study also found that the dieback occurred mostly at distances from 0 to 200 meters from water wells, while the relative effects of distance from water wells on dead trees indicated that the largest contribution to dead trees was related to distances of 200 to 400 meters. It is possible that the presence of drilled deep and semi-deep water wells inside Daland Forest Park to supplydrinking water for Daland City and the extensive drilling of agricultural water wells around the study area for rice farms has led to decline in underground water level. This has been previously reported in the research of Theis (1935); Ranjbar Naeini et al. (2017) & Mojid et al. (2019), and the effect of underground water and bedrock on tree resistance to stress has also been proven in the research of McDowell et al. (2019). Therefore, soil moisture is important for tree survival, especially during high temperatures and drought. Bradford et al. (2022) provided evidence for the influence of soil moisture on tree mortality under such conditions. In general, when soil moisture is high, trees can easily absorb water through their roots to compensate for water loss through transpiration. However, when soil moisture decreases, trees have greater difficulty replenishing their water reserves, resulting in accelerated dieback. This phenomenon is particularly pronounced during extended droughts.

Therefore, it is crucial to safeguard trees from physical harm and minimize human activities in concentrated recreational zones, areas near forest roads and to regulate water withdrawal from wells. Through systematic and efficient management, the impact of these stressorscan be reduced, thereby decreasing tree mortality rates.

5. Conclusion

This study investigated the effect of recreational zones, tree types, distance from water wells, and distance from forest roads on tree dieback and death. The results showed that only the tree types significantly affected tree dieback, with the highest percentage of dieback related to the type of Zelkova. This may be explained by the fact that pure stands are more sensitive to environmental factors and stresses than mixed stands, which may explain this finding. While distance from water wells did not have a significant individual effect on tree dieback, its effects were significant in combination with other variables. In general, the significant impact of the interaction between distance from water wells, tree types, recreation zones, and distance from forest roads on tree dieback highlights the complex interplay of factors affecting forest health. As deep-rooted plants, trees can serve as indicators of groundwater levels. When groundwater is depleted, trees may experience stress due to reduced water availability, leading to physiological stress and increased vulnerability to to pathogens and insect infestations. In centralized recreation areas, soil compaction occurs due to soil compactioncaused by the high foot traffic of park visitors, leading to decreased soil moisture. Therefore, a well-planned and balanced approach to tourism and recreation is required to maintain the health of forest trees. Treatments such as improving the supplies of water resources in tourist areas, strictly regulating tourist numbers, and creating restrictions on the use of some areas can help preserve the health of trees. The study suggests two main management measures: first, managing water well usage in collaboration with local communities to protect park trees, and second, efforts should be made to reduce soil compaction around forest roads to promote grass growth, increase soil permeability, and reduce water evaporation in these areas. The results of this research can greatly help forest managers minimize the effects of influential variables by implementing management treatments promptly to preserve and sustain these valuable resources. Further research is necessary to better understand the underlying causes of these patterns better and to develop more targeted management strategies for the protection and management of forests.

6. Acknowledgment

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مرگ‌ومیر و سرخشکیدگی درختان در پارک جنگلی دلند ایران: ارزیابی عوامل انسانی و محیطی

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چکیده

جنگل‌ها اکوسیستم‌های مهمی هستند که طیف وسیعی از موجودات زنده را شامل می‌شوند. اخیرا، بسیاری از درختان جنگلی، بـه‌ویژه در پارک‌های جنگلی، به دلیل عوامل مختلفی نظیر ظرفیت بیش‌ازحد گردشگران و دلایل ناشناخته در حـال خشـک شـدن هسـتند و باعـث ایجاد نگرانی‌های فراوانی در میان مردم، محققان و متصدیان مربوطه شده است. با توجه به اهمیت این موضوع، این پژوهش به بررسی تأثیر عوامل محیطی و انسانی بر خشکیدگی و مرگ درختان پارک جنگلی دلند واقع در استان گلستان واقع در شمال شرق ایران پرداخته است. از دستگاه DGPS-RTK برای ثبت موقعیت‌های درختان سرخشکیده و مقـدار خشـکیدگی آن‌هـا در قطعـات دایـره‌ای ۱۰۰۰ مترمربـع استفاده شد. همچنین، تمام درختان مرده با استفاده از ارتوموزاییک حاصل از تصاویر پهپاد مربوط به سال ۱۴۰۰ به‌صورت بصری شناسایی شدند؛ و موقعیت همه درختان ثبت گردید. سپس، تأثیر پارامتر زون‌هـای تفرجـی، تیپ‌هـای درختـی، فاصـله از چاه‌هـای آب و فاصـله از جاده‌های جنگلی بر سرخشکیدگی درختان مورد تجزیه‌وتحلیل قرار گرفت. علاوه بر ایـن، تـأثیر نسـبی متغیرهـای ذکرشـده بـر درختـان خشکیده محاسبه گردید. بر اساس تجزیه‌وتحلیل طرح آزمایشی کاملاً تصادفی در قالب فاکتوریل، تیپ‌های درختی بـه‌طور معنـی‌داری در سطح اطمینان ۹۹ درصد بر سرخشکیدگی درختان تأثیر دارد. علاوه بر این، اثرات متقابل فاصله از چاه‌های آب با مناطق تفرجی و فاصـله از جاده‌های جنگلی و همچنین تیپ‌های درختی تأثیر معنی‌داری را بر سرخشکیدگی درختان نشان دادند. همچنین، نتایج بررسـی اثـرات نسبی متغیرهای ذکرشده بر درختان خشکیده نشان داد که درختان خشکیده در مناطق تفرجی متمرکـز، تیپ‌هـای جنگلـی خـالص و در فواصل ۰ تا ۱۰۰ متری از جاده‌های جنگلی و فاصله ۲۰۰ تا ۴۰۰ متری از چاه‌های آب از فراوانی بیشـتری برخـوردار هسـتند. بـر اسـاس یافته‌های این پژوهش، توصیه می‌شود بایستی برداشت غیرضروری آب از چاه‌ها متوقـف گـردد و اقـدامات مـدیریتی و اجرایـی در اطـراف جاده‌های جنگلی و مناطق تفرجی برای کاهش فشار بر مناطق تحت تأثیر این عوامل کاهش یابد. همچنـین بررسـی علـل مـرگ و میـر و خشکیدگی درختان در سایر جنگل‌های هیرکانی ضروری می‌باشد.

واژه های کلیدی: اثر نسبی، تخریب جنگل، درختان خشکیده، سلامت جنگل.

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