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Impacts of wildfire on soil characteristics in subtropical Chir Pine forests of Murree, Pakistan

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Abstract
Wildfires are a natural component of forest ecosystem. These fires are a major cause of significant perturbations in the forest habitat due to temperature extremes and drought conditions particularly in summer. Wildfires occur frequently during summer in the subtropical Chir pine forests of Murree, Pakistan. These fires influence soil characteristics as well as tree-species growth and survival. The present study was thus conducted to investigate soil characteristics of wildfire-affected and non-affected areas. Four sites were selected based on wildfire incidents in the study area. Soil samples were collected from the fire-affected and adjacent non-affected areas. The collected soil samples were analyzed for physical and chemical characteristics using appropriate methods. The study showed that bulk density, moisture content, electrical conductivity, and soil nitrogen and soil carbon content declined in the burnt soil. However, soil pH, and phosphorus and potassium contents were higher in the burnt soils than those in the non-burnt soils. Generally, low intensity forest fire (surface fire) is an important component of forest ecosystem and it enhances natural regeneration as well as soil fertility. It is suggested that government forest departments should take into account burn severity while developing hazard reduction and restoration strategies of wildfire affected areas.

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Introduction

Wildfire is an accidental fire that breaks out in natural vegetation, i.e., forest or grassland. It can happen anytime at anyplace and is frequently brought about by human action or a natural happening such as lightning, high temperature, dry weather conditions, etc. (WHO, 2017; Britannica, 2021). Globally, about 340 million hectares of vegetated surface are burnt each year and 3.5% of the global disaster is due to wildfire, costing 68 million US$ to the world; wildfires annually affect an estimated 150 to 250 million ha of tropical forests (FAO, 2010; SOTWP, 2017). In Pakistan, during the year 2022, a weeklong forest fire started and destroyed an estimated 30% of the UNESCO-designated pine-nut forest in the Koh-e-Suleman mountain range of Baluchistan province. A severe fire in the same year broke out in the Murree forests, burning a sizable portion of the Goda Paphrail and Sunbhal Biah forests; there had been more wildfire incidents than usual in the year 2022 in Pakistan due to extreme dry and hot weather (Nation, 2022: Dawn, 2022: Reliefweb, 2022).

Wildfires affect the forest ecosystems including soil and vegetation. These fires can have both short-term and long-term impacts. The disintegration of soil structure, pH transition, fluctuation in soil

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nutrients and electrical conductivity (EC) as well as diminished moisture content and capacity, are all instant effects on soil by wildfire (Agbeshie et al., 2022). Wildfire can cause prolonged impacts on chemical properties of soil, resulting variable nutrients' response over time based on the severity of the wildfire. Vegetation destruction, mineral leaching, soil erosion, and after fire vegetation intake contributes to soil nutrient depletion (Otero et al., 2015). Soils certainly require more time for recovery following wildfire disturbance, particularly in areas where fire severity is high (Marcos et al., 2009; Pereira et al., 2017; Romeo et al., 2020).

Soil is a vital component of ecosystem and can be greatly altered by fire's direct (heating) or indirect (ash) effects. In most of the fire instances, the effects are observed in little depth (centimeters) of the top soil. The impacts of fire on soil have been well known and it is dependent on soil type, ecology and species burned, topography of the affected region, weather conditions during and after the fire, and the intensity of the fire (Narhi et al., 2013; Badía et al., 2014).

Subtropical Chir pine forests are very prone to wildfires in summer due to the presence of needles and other plant parts on the forest floor and hot scorching weather conditions. The highest vulnerability of a wildfire depends upon hot climate and vegetation (Kangna et al., 2017). In Pakistan, Chir pine forests are located in Murree and surroundings, and every year frequent occurrence of wildfires in the summer season are reported to the local fire departments. Tehsil Murree in Rawalpindi division is considered widely as a recreational resort for local tourists, but it is neglected as a study subject for scientific research. Thus, there was a pressing need to study short-term impacts of wildfires of subtropical Chir pine forests of Murree.

This study was conducted with a primary objective to identify short-term impacts of wildfires on soil characteristics in the subtropical Chir pine forests. Further, the soil characteristics of wildfire-affected and non-affected areas were also compared to get a future insight for devising appropriate strategies to overcome the devastating issue of the area.

Materials and Methods

Study area

Murree hills cover an area of about 80,000 ha. The study area's latitude and longitude ranged between 33° 47′ 15′′ to 33° 54′ 47′′ N and 73° 16′ 54′′ to 73° 29′ 18′′ E. The elevation extended over 939 to 1873 m above sea level, results in three types of forests: moist temperate forests at the top, sub-tropical Chir pine forests in the middle, and sub-tropical broad-leaved forests at the bottom/foothills. In the study area, average annual precipitation is recorded as from 500 mm to 1200 mm, with temperature ranging from 5 °C in winter to 40 °C in summer. Shales, sandstones, limestone, and marls are among the sedimentary rocks found in the area. The soil is loamy, with varying percentages of sand, silt, and clay. *Pinus roxburghii* (Chir pine) is the dominant tree species in the region. *Quercus incana* (Rhin), *Pinus wallichiana* (Kail) and *Pyrus pashia* are the associated tree species. The geographic location of the study area is presented in Figure 1.

Data collection

The study was subjected to the incident of wildfire in the study area. An effective contact with stakeholders was maintained for acquiring quick information of the fire incident. The soil samples were collected from the fire-affected area and nearby nonfire-affected area according to the sampling procedure. Four sites were selected based on the fire incidents in the study area. Soil from the burnt and nearby unburnt area was collected for further investigation.

Sampling procedure

The composite sampling method was adopted to collect soil samples. The soil samples from each plot within the affected area were collected in polyethylene bags after the incident of wildfire took place. The samples were collected up to the depth of 30 cm (0-30 cm) from each plot using an auger and brought to the laboratory. All samples were stored at 4 °C to find dissolved organic carbon, and microbial biomass carbon content, while the remaining samples were dried for the determination of total carbon, soil pH, soil EC and bulk density.

Analysis of soil physico-chemical properties

The acidity or alkalinity of soil was determined by measuring pH. A conventional pH meter, standardized with a buffer solution of known pH was used (Romeo et al., 2020).

Soil organic carbon (SOC) is the most abundant component of soil organic matter (SOM), which is essential for soil productivity and a variety of ecosystem processes. Soil organic carbon was estimated with a CN element analyzer (Vario MICRO Cube, Elementar, Germany) (Walhert et al., 2010).

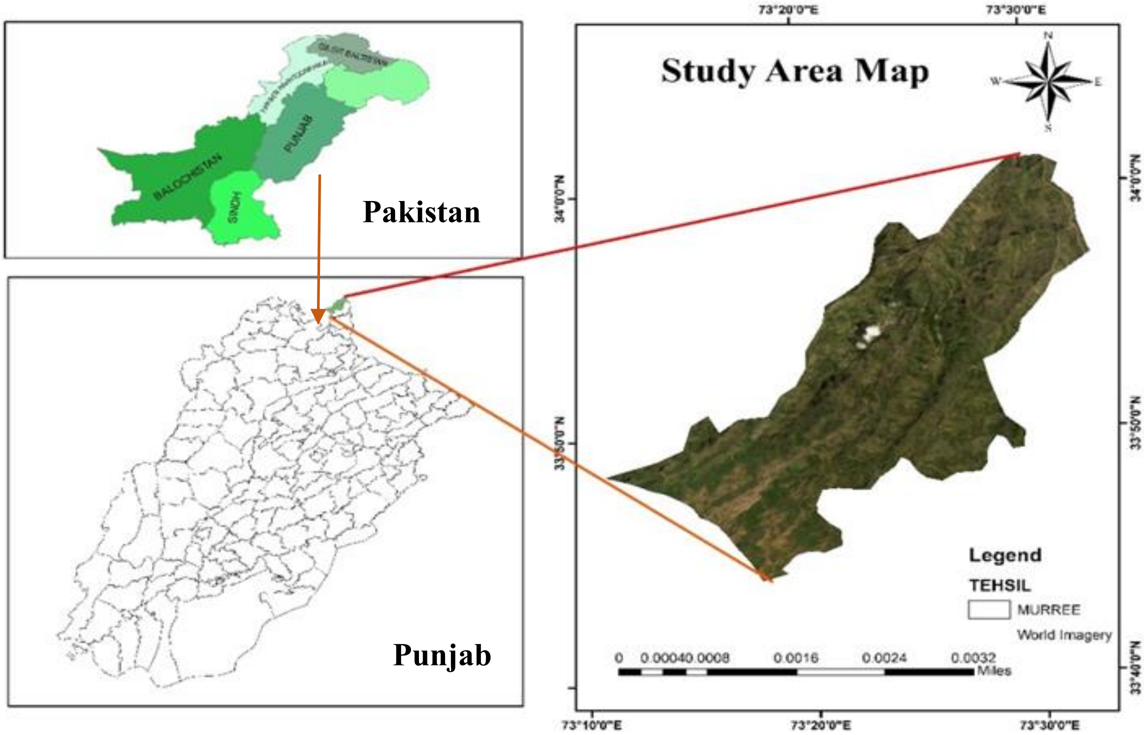

Figure 1. Map of the study area in Punjab, Pakistan

Soil electrical conductivity (EC) influences many physical and chemical properties of the soil. The soil EC in the laboratory was measured by an EC probe. The probe was immersed in a standard solution (1.41 dS m^{-1} at 25 °C). After 10 seconds of stabilization, the readings were recorded (Schilfgaarde, 1976).

Potassium (K) is the limiting source of microbial activity in the soil. The major cation in soil microbes including fungi and bacteria is potassium. The LAQUA potassium ion meter method was adopted to measure potassium in the soil samples (Khan et al., 2022).

Soil P was determined using the Olsen method. Twenty milliliters of 0.5 molar sodium bicarbonate along with one gram of air-dried soil was shaken for 30 min. Blue color in the filter paper appeared. This complex is reduced with ascorbic acid to form a blue complex which absorbs light at 880 nm. The absorbance is proportional to the concentration of orthophosphate in the sample (Latrou et al., 2014).

Soil nitrogen was determined using the Kjeldahl method (Saez-Plaza et al., 2013).

Soil compaction was measured by bulk density (BD). It was determined by separating the dry weight of the soil by its volume. The volume of soil particles and the volume of pores between the soil particles were included in this volume. Generally, BD is expressed in g cm^{-3} (Onwuka et al., 2018).

$$\text{BULK DENSITY (BD)} = \frac{\textit{Weight of dry soil}(g)}{\textit{Volume of dry soil}\ (cm^3)} \qquad \text{EQ. 1}$$

Statistical analysis

Relevant statistical analysis, i.e., Pearson's t-test was applied to compare and test significance between the characteristics of wildfire-affected and non-affected soils (burnt and unburnt) (Posten, 2007).

Results and Discussion

Comparison of soil physico-chemical properties

Bulk density (BD) of burnt and unburnt soils, at the depth of 0-30 cm was estimated by analyzing the field samples from four sites of the study area. Figure 1 shows soil bulk density in the study area. Mean BD value of burnt soil, for four different sites, was 1.18, while the mean BD value of unburnt soil, for four different sites, had been 1.42. The comparison of mean BD values of the burnt and unburnt soils showed that the BD of the burnt soil was significantly lower than that of the unburnt soil. Our results agree with those of Jhariya and Singh (2021) in which it was found that fire severity had a drastic effect on soil properties in a seasonally dry forest ecosystem of Central India.

Figure 2 shows results of soil pH in the study area. Mean pH of the four burnt sites was 7.65, while mean pH as 7.44 was observed for the unburnt soil. This indicates that the pH of the burnt soil was greater than that of the unburnt soil, which being alkaline in nature. A study conducted by Alcaniz et al. (2018) also reported that the pH of burnt soil was higher than that of unburnt soil.

Figure 3 shows comparison of EC values for the burnt and unburnt soils. The mean EC value of the burnt soil was 0.58 dS m^{-1}, whereas that of the unburnt soil as 0.78 dS m^{-1}. The comparison clearly indicated that the EC of the burnt soil was lower than that of the unburnt soil. Brye (2006) reported that the EC of burnt soil was low due to removal of extractable cations from the soil.

Figure 4 demonstrates the comparison of soil phosphorus for the burnt and unburnt soils in the study area. The mean soil phosphorus value of the burnt soil was 6.25 mg kg^{-1} while that of the unburnt soil as 2.02 mg kg^{-1}. The results of the soil analysis indicated that the burnt soils contained more phosphorus than that of the unburnt soil. A study conducted on long-term absence of wildfire by Lagerstrom et al. (2009) showed that if wildfire does not occur for a longer period of time the soil phosphorus binds in a more stable form; its availability reduces and when the wildfire occurs the soil phosphorus becomes available to plants due to heat.

Soil potassium in the study area is presented in Figure 5. The mean potassium value of the burnt soil was 107.37 mg kg^{-1}, whereas that of the unburnt soil 85.87 mg kg^{-1}. The results indicated that potassium in the burnt soils was higher than that in the unburnt soil. Kong et al. (2018) studied the long-term effects of wildfire on Chinese boreal forests, and they reported similar results to what we have recorded for the K content.

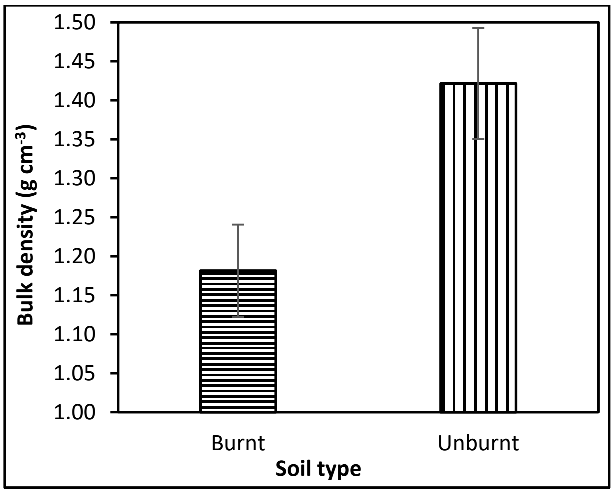

Figure 1. Mean soil bulk density in the study area. *Error bars represent percent error.

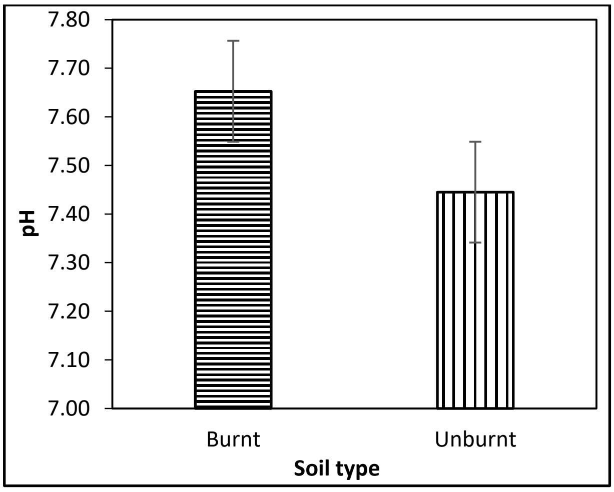

Figure 2. Mean soil pH in the study area. *Error bars represent percent error.

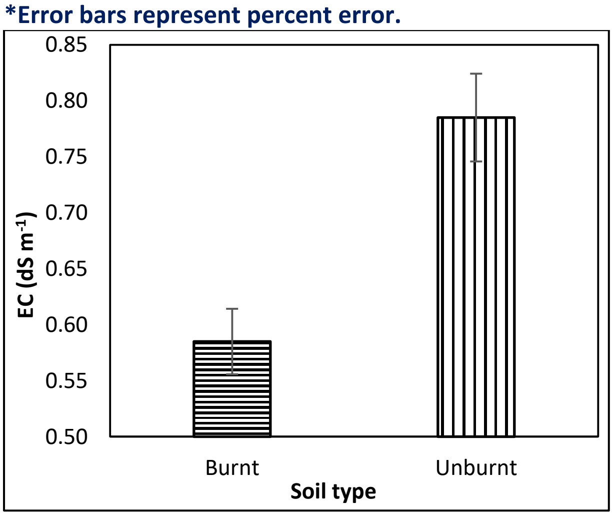

Figure 3. Mean soil EC in the study area. *Error bars represent percent error.

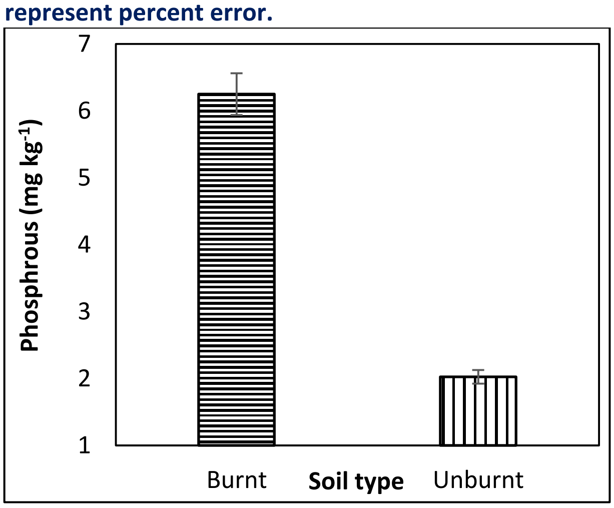

Figure 4. Mean soil phosphorus in the study area. *Error bars represent percent error.

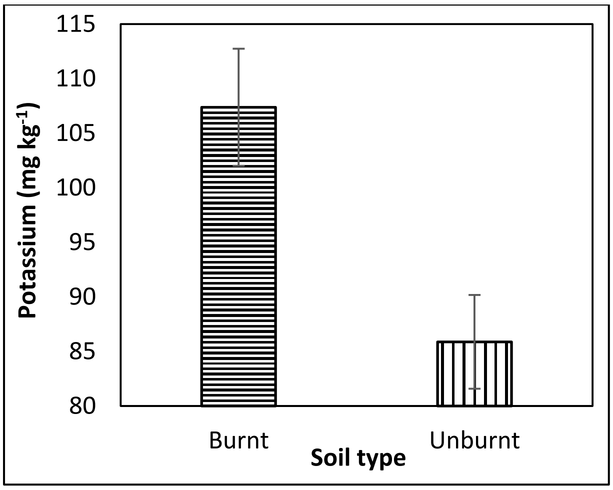

Figure 5. Mean soil potassium in the study area. *Error bars represent percent error.

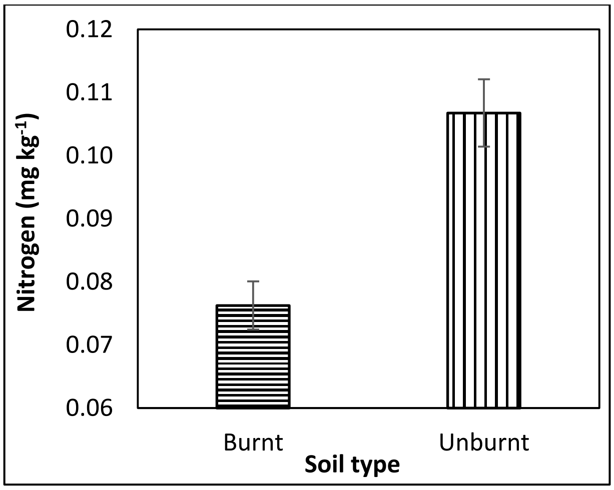

Figure 6. Mean soil N in the study area. *Error bars represent percent error.

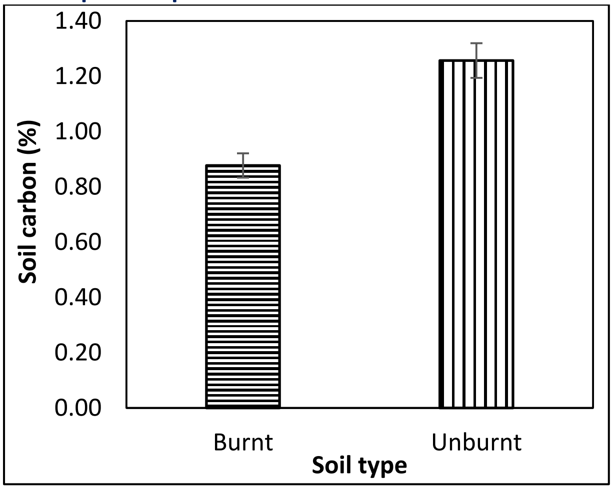

Figure 7. Mean soil carbon in the study area. *Error bars represent percent error.

Mean N value of the burnt soil was 0.07 mg kg^{-1}, while that of the unburnt soil 0.10 mg kg^{-1}. The comparison indicated low amount of N in the burnt soil than that in the unburnt soil. A study conducted by Verma and Jayakumar (2012) have analogously reported similar results while reviewing the impact of forest fire on physical, chemical and biological properties of soil.

Carbon content of the burnt and unburnt soils in the study area is presented in Figure 7. Mean carbon value of the burnt soil was 0.87%, whereas that of the unburnt soil 1.25%. The results indicated higher carbon content in the unburnt soil than that in the burnt soil. A study conducted by Kelly et al. (2021) is in agreement with our study showing that the availability of carbon reduces after wildfire, as the top soil layer is burnt and turned into ash.

Conclusion

The study concluded that bulk density, moisture content, EC, and soil N and soil C content were reduced in burnt soils, while pH, P and K were higher in burnt soils than those in unburnt soils. Further studies are required to observe recovery of total carbon and SOM at pre-fire levels.

Declaration of Author(s), Editor(s) and Publisher

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Supplementary material
No supplementary material is included with this manuscript.

Conflict of interest
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Declared none.

Contribution of authors
Supervised the research: MIA. Conceptualization and designing of the study: AH, MIA. Conduction of experiment and collection of data: AH, SH, BAK. Written first draft of the manuscript: AH. Helped to prepare figures and tables: SH, AH. Soil analysis: SH, BAK. Statistical analysis of data: MA, AH. Final draft read by all authors.

Ethical approval
This study does not involve human/animal subjects, and thus no ethical approval is needed.

Handling of bio-hazardous materials
The authors certify that all experimental materials were handled with care during collection and experimental procedures. After completion of experiment, all materials were properly discarded to minimize any types of bio-contamination(s).

Availability of primary data and materials
As per editorial policy, experimental materials, primary data, or software codes are not submitted to the publisher. These are available with the corresponding author and/or with other author(s) as declared by the corresponding author of this manuscript.

Authors' consent
All authors contributed in designing and writing the entire review article. All contributors have critically read this manuscript and agreed for publishing in IJAaEB.

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