Insights and Realism of Stubble Burning in India: Health Economics Analyses

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The authors

On behalf of Professor Koustuv Dalal

ABSTRACT

In India, burning of crop residues is often carried out to remove residues from paddy cultivation. A sharp rise in rice production has exacerbated the problem of crop waste in Punjahis research takes a unique approach by exploring community perception, experience, and social and psychological factors associated with stubble burning. It also assesses the pattern of health-related quality of life (HRQoL) of the people in certain regions of the north Indian state of Punjab. Air, water and soil quality measurements are also a part of this study. The innovative aspect lies in the new understanding of the mapping of HRQoL with the air, water, and soil quality during stubble burning, which could create capacity building and community participation to prevent stubble burning.

For a comprehensive collection of data related to health and other socio-economic characteristics of households affected by stubble burning, we conducted an extensive primary survey. We selected four districts in Punjab in India, where stubble burning is a recurrent annual problem. The target populations who lived in these four districts were studied. The impact of environmental pollution due to stubble burning was measured in relation to air, water and soil quality. Both qualitative and quantitative data were collected and analyzed, ensuring a thorough and reliable study.

As a part of our survey methodology, we also conducted Focus Group Discussions (FGDs) and Key Informants Interviews (KIIs). On average, we have collected survey data from about 25 household units from each selected sample village, with a total of 100 household units covering four villages of a district. We also measure health related quality of life (HRQoL) by EQ-5D appropriate versions. As a part of our entire primary survey, we also measured the air, water and soil quality in all of our sample districts and the corresponding sample villages in all four districts before and after the stubble burning.

Our study yielded significant findings. For instance, we found that the overall health status in Punjab is HRQoL 76.05 (100 is maximum health), indicating a needfor health improvement initiatives. The health status of migrant labourers who work in Punjab agricultural farms was found to be higher at HRQoL 83.82, suggesting a potential link between stubble burning and health deterioration. The emission level, especially for the air (PM2.5, PM10, AQI, CO, CO2, HCHO, TVOC),

was found to increase significantly after stubble burning, highlighting the urgent need for measures to control air pollution.

Our study also indicates a high level of awareness regarding the negative consequences of stubble burning among participants, with the majority (55.3%) feeling moderately informed. This essentially means that the farmers are resorting to burning even after being aware of its harmful consequences.

This work aims to help us understand and evaluate the likely positive outcome for the participants through increased information, knowledge sharing, change of perceptions regarding stubble burning, and the probable steps to be taken to mitigate the adverse impacts of stubble burning. This study also explores how stubble burning affects the agricultural migrated labourers. The conducted research findings add valuable knowledge to the field and have potential implications for the other parts of India where the burning of crop residues is prevalent and is identified as a major cause of the disease burden.

Economic factors which are mostly considered to be relevant for finding ways to control the adverse impacts of stubble burning include the provision of subsidies to farmers to purchase appropriate machinery that can mix crop residue with soil and help farmers avoid crop burning. Moreover, the government can create appropriate markets for stubble as raw material for bio-industries or animal bedding that can provide economic incentives for farmers to avoid burning. Diversification of crops by farmers to less water-intensive options is also thought to help mitigate the adverse effects of stubble burning. However, before implementing any plan to change, it is necessary to understand its dynamics.

KEY FINDINGS

- Overall health status in Punjab is HRQoL76.05 (100 is maximum health).
- The migrant labourer who works in Punjab agricultural fields has a higher health status of HRQoL 83.82.
- The emission level, especially for the air, increases tremendously after stubble burning, causing very high health expenditure.
- Punjab's stubble burning may not be the major contributing factor for Delhi's air pollution, as the air speed in the core burning areas is very low, and the direction is generally towards the opposite side, that is, towards the Himalayas and/or Himachal Pradesh during the months of October and November.
- Almost 71% of families in Punjab experience catastrophic health expenditure where they spend more than 10% of their monthly expenditure on health.
- Various health related problems such as coughing, breathing issues, eye irritations, skin rashes, respiratory allergies, lung diseases, hurt diseases, indigestion, loss of appetite, irritations increase enormously during stubble burning.
- Students are also affected in their daily activities, including physical activities.
- Infertility has increased significantly in the core areas of stubble burning.
- Families and Communities do not emphasize stubble burning effects.
- Decision-makers and Punjab residents need a comprehensive understanding and wholesome approach to preventing stubble burning.

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INTRODUCTION

Governmental perspective

Burning of crop residues, i.e. 'stubble burning' appears to be a major problem in Asia and Africa, including India, causing health hazards, adverse socioeconomic impacts and global warming (Abdurrahamn et al. 2020). In India, burning of crop residues is often used as a tool for agricultural management, such as removing residues from paddy cultivation. These fires mainly occur during the post-monsoon season (roughly October–November) due to widespread stubble burning in preparation for planting the next round of crops (Chandra et al. 2018; Kulkarni et al. 2020). A sharp rise in rice production and yields in India has exacerbated the problem of crop waste in the northwestern states of Punjab and Haryana, generating more than 27 million tons of rice straw a year. These problems are highlighted in SDG 13.3.b *"Promote mechanisms for raising capacity for effective climate change-related planning and management in the least developed countries and small developing States, including focusing on women, youth and local and marginalized communities" (UN web, p. 26).* The federal government as well as provincial governments in India, similar to in other low- and middle-income countries show concern for an effective solution to this problem, providing policies and intervention and suggesting practices to curb the associated problems. Since 2015, India has experienced an alarming increase in the level of air pollution caused by stubble burning. A recent study by Mor et al. (2023) confirms that the situation has become worse during the last 15 years. Recent estimates reveal that approximately 46 million tons/year of cereal crop residue is generated in Punjab alone, out of which ~21 million tons is burnt in a year ~7− 8 million tons during winter (Bhuvaneshwari et al. 2019; Kumar et al. 2015). The disposal of a large amount of burning crop residues during wheat and rice harvesting periods in the north Indian state of Punjab is one of the major challenges to the government and

policymakers as well as environmental scientists, public health scientists and health economists.

Community perception

From behavioral perspectives, it is also worthy to mention that scientific and technological solutions might become challenging unless there are changes in attitudes/perceptions of the farmers (Mor et al. 2023).

The effectiveness of these policies is contingent upon the implementation of a strategic plan and readiness of the farmers to change their established perceptions to pro-health and pro-environment behaviours. Even though efforts have been made in this line, unfortunately, the effectiveness of these efforts has not been observed yet. People are made aware of the consequences of environmental degradation through various ways following stubble burning, however, changing human behavior requires more than informational and fear appeals. There is hardly any effort to scrutinize the firmly established belief of farmers. Among other factors, which are responsible for stubble burning, the lack of knowledge about the social, economic and psychological dynamics of stubble burning behavior, plays a pivotal role. Present study helps us understand more effective strategies to control stubble burning which has significant potential for positive health impacts as shown in the evaluation by Mor et al. (2023) and Aburrahamn et al. (2020).

Stakeholder collaboration

Active stakeholder involvement including imparting required education and empowering the farmers with socio-economic assistance along with technical solutions can also assist tremendously. Even though the issue of burning of crop residues touches many sectors, such as environment, agriculture, society, and

energy, the governmental efforts mainly centered around agriculture and energy. It is argued that the compartmentalized approach towards the prevention of stubble burning focusing only on these two sectors should be replaced by nexus thinking which promotes integration among other sectors, such as environment, economy, and society which goes beyond the disciplinary boundaries (Bhuvaneshwari et al. 2019). The economic loss, environmental and health hazards due to burning of crop residues form parts of annual disaster, hampering the achievement of the SGD 11[1], with focus on safe, resilient and sustainable cities and human settlement. Therefore, a holistic approach, combined with wisdom from diverse domains to curb this tendency to provide a more comprehensive solution to the problem, was used in this study.

Earlier studies have found the quality of air, water and soil differs considerably from place to place within a locality (Jain et al. 2014; Mor et al. 2023; Abdurrahamn et al., 2020). The effect on human health is different for people staying close to or far from the place of stubble burning. Additionally, the pollution level was higher during the daytime than at night. This apparently shows that pollution due to stubble burning is very much local and its impact on health should be measured locally. Although the National Air Quality Monitoring Program (NAMP) has had some effect on decreasing the environmental and health hazards of stubble burning, most of the work is monitored from urban areas. In fact, stubble burning takes place in rural areas where a representative from the NAMP seldom is present (Abdurrahamn et al., 2020).

[1]SGD 11.5 By 2030, significantly reduce the number of deaths and number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water related disasters, with a focus on protecting the poor and people in vulnerable situations.

Toxic particulates

Burning of crop residues emits a significant quantity of the emissions of greenhouse gases and air pollutants (such as, CO, NO, CH, CO, NH3, NOx, SO2), and hazardous smoke, leading to potential adverse consequences to human health along with other adverse consequences on soil and the productivity of crops (Jain et al. 2014; Mor et al. 2023; Abdurrahamn et al. 2020). Burning of paddy straw (Kumar et al. 2015) results in the emission of hazardous smoke which, in addition to the gases present in the air such as methane, nitrogen oxide, and ammonia, can result in severe atmospheric pollution. Burning of straw causes emission of trace gases and emits large number of particulates which cause adverse impacts on human health. However, the health effects, especially the quality of health in relation to stubble burning is under studied. It is estimated that India annually emits 144,719 Mg of total particulate matter from open field burning of paddy straw (Gadde et al. 2009). Existing epidemiological studies also support the possibility of adverse health impacts (WHO, 2019).

Health hazards

Many of the components of agricultural smoke cause health hazards. Air pollution results in health risk, aggravating asthma, eye irritation, chronic bronchitis and decreased lung function etc. (Novotny et al. 2015; Mor et al. 2023; Abdurrahamn et al. 2020; Das et al. 2024). The household survey by Kumar et al. (2015) focusing on stubble burning revealed that irritation in eyes and chest congestion were the two major problems faced by a majority of the household members, followed by respiratory allergy, asthma and bronchial problems as other smoke related diseases. Kumar et al. (2015) claim that health-related problems get aggravated during or shortly after harvest when burning of crop residues takes place. In the peak season, affected families had to consult doctor or use some home medicine to

get relief from irritation/itching in eyes, breathing problem and similar other smoke-related problems. On average, the affected members suffered at least half a month from such problems. In addition, cardiovascular diseases, pregnant women and small children are also likely to suffer from the smoke produced due to stubble burning. Similar alarming findings reports from other research teams (for example see, Abdurrahamn et al. 2020; Das et al. 2024; Mor et al. 2023). According to Singh et al. (2008), more than 60 % of the population in Punjab is exposed to air pollution due to stubble burning and are subject to health hazards. These adverse health impacts following stubble burning not only increase an individuals' disease mitigation expense but also affect their productivity at work (Novotny et al. 2015). Moreover, the smoke causing arising out of stubble burning results in loss of vegetation in the field (Kumar et al. 2015). Mentioned health hazards are some of the core factors in SGD 3[2] .

Particulate matter - a health risk in pregnant women, fetuses and children

The natural biological fragility in the growing body during childhood, makes the health hazards of air pollution even worse among children, as compared to adults with more robust bodies. Crop burning residues seems to affect the human health from before birth and along the whole life trajectory.

Crop burning residues generate air pollution in the form of particulate matter (PM), the smallest toxic components that hazards the health of pregnant women and her fetus (Johnsson et al. 2021). Isaevska et al. (2021) claim that exposure to air pollution creates harmful effects staring from fetus to the first years of life inform

[2]3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination. 3.9.d Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks.

of DNA changes at cellular level including the placenta as well as cellular responses to oxidative stress. Infants of PM-exposed mothers show health outcomes as lowered respiratory functions, less immune status, insufficient brain development and cardio functions (Johnsson et al 2021). A study by Saggu et al. (2018) including school children (10-16 years old) in Patiala, Fathegarh Sahib and Sangrur, during the crop burning residues period (September – December) shows significant associations between the children´s decreased lung functions and the increased level of PM. The concentration of PM and other toxic particulates (CO, NO2, O3, SO2) increase the hazard risk of cancer among children (Lee et al 2022).

The effects of stubble burning in India and other South Asian countries causes significant adverse impacts on human life, increased burden of disease and leads to prior death. For example, year 2012 air pollution caused around five million deaths in South Asia (Abdurrahamn et al. 2020).

OBJECTIVES

The overall objective of the research was to explore community perception, experience, social and psychological factors associated with stubble burning and to assess the pattern of health-related quality of life (HRQoL) of the population of Punjab region, India, who are living in the core areas of stubble burning in Punjab state, India. New understanding though the mapping of HRQoL with the air, water, and soil quality during stubble burning will help to create capacity building and community participation for preventing stubble burning.

Specific objectives (SO):

SO 1: To estimate the health and economic burden of stubble burning.

SO 2: To measure the (HRQoL) of the population living in the vicinity of stubble burning found by measuring the air, water and soil pollution with that of the average data.

SO 3: To measure the (HRQoL) of the agricultural migrated labourers.

SO 4: To explore the community awareness and perceptions of stubble burning and its health and socioeconomic effects.

SO 5: To assess the perceptions of the local policymakers such as neighbourhood leaders, village leaders, Block Development Officers (BDO), Sub-divisional officers (SDO) and agricultural officers, about stubble burning control.

METHODOLOGY

Sample and data: Socio-economic survey

For a collection of data related to health and other socio-economic characteristics of households affected by stubble burning, we carried out an extensive primary survey, and for that, we purposively selected four districts in the northern province of Punjab in India, where stubble burning is a recurrent annual problem. Based on official statistics on the incidence of stubble burning in the province of Punjab, we have chosen the districts of Moga, Sangrur, Ropar and Patiala as our sample (Figure 1). Out of these four sample districts, two are chosen from core areas of stubble burning, and the other two districts belong to control areas of stubble burning where the incidence of stubble burning is less prevalent. In particular, we have identified two sample districts, Sangrur and Moga, with relatively higher incidences of stubble burning and labelled these two districts as cases. The remaining two districts of Patiala and Ropar are identified as those with relatively lesser incidence of stubble burning and we label these two districts as the control. In each of the chosen sample districts, we have identified certain blocks, and in each block, we have identified certain villages for the purposes of our survey. The selection of blocks and the corresponding villages in each block in each sample district are decided in consultation with respective district administrative officials. In particular, in the district of Sangrur, we have identified four blocks Bhawanigarh, Sangrur, Dhuri and Lehergaga and the corresponding sample villages under these blocks are Sakroudi, Chote Sekhwan, Ghanour Kalan and Raidharana, respectively. In the sample district of Moga, the chosen blocks are Moga, Baghapurana, Dharakot and Nihal Singh Wala and the corresponding sample villages where the survey was conducted under this block are Buttar, Samalsar, Manawan and Himmatpura, respectively. In the district of Patiala, the sample blocks are Patiala, Samana and Nabha and the corresponding sample

villages are Challela, Lang, Kakrala and Mehas respectively. Finally, in the district of Ropar, we consider only one sample block, Chamkaur Sahib, and the sample villages under this block where the survey

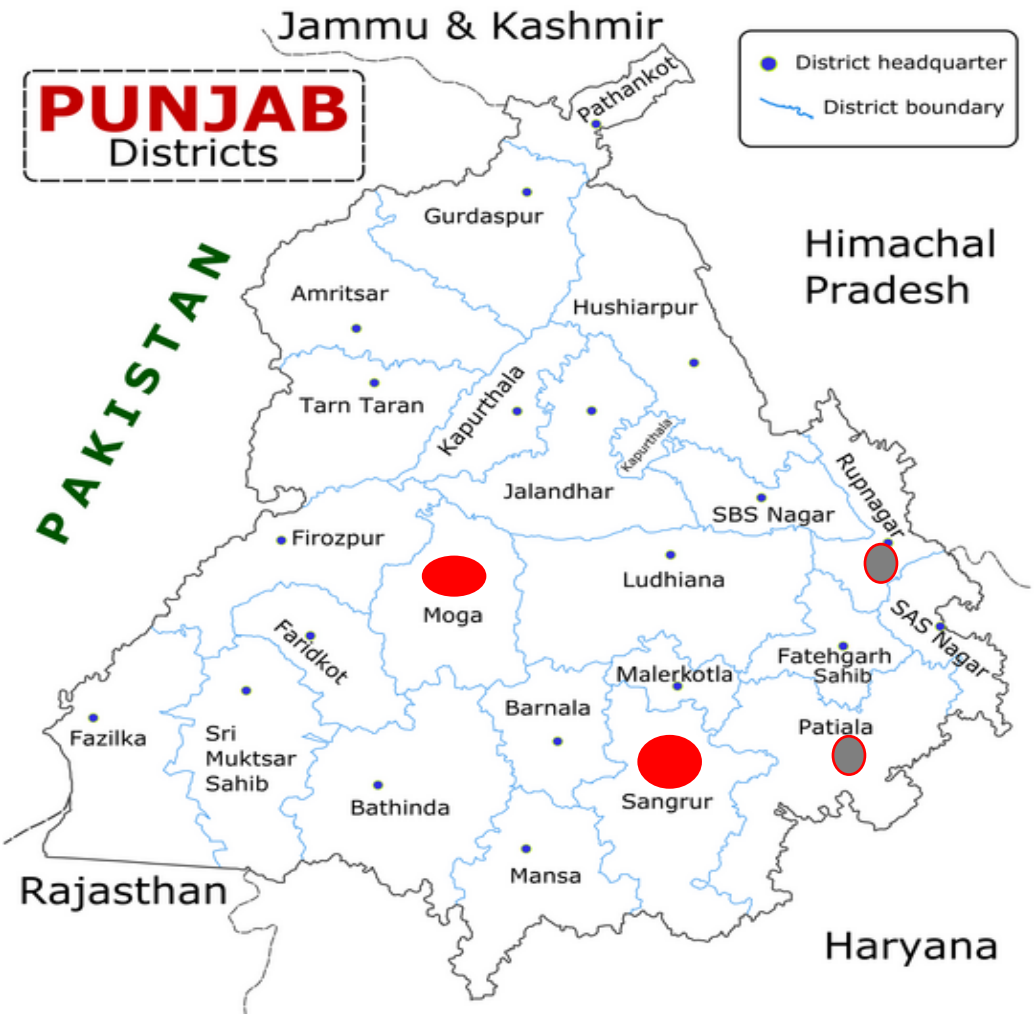


Figure 1. Study districts (Moga and Sangrur: Core areas for stubble burning, Patiala and Ropar/Rupnagar: Less prevalent areas of stubble burning)

Source of map: https://en.m.wikipedia.org/wiki/File:Punjab_district_map.png (under CC)

was conducted are Bela, Ferozepur, Makawal, and Phassa. In the district of Ropar, only one block was chosen per the district administration's recommendation as the remaining blocks are hardly affected by stubble burning.

For conducting survey and collection of primary data from the above mentioned sample villages in the chosen districts, we took necessary prior permission from all relevant authorities such as the district commissioners (DCs), Sub-divisional magistrates (SDM), Block Development Officers (BDO), agricultural officers (AO), and village leaders (Gram Pradhans). Prior to the survey, we also ensured adequate protection of the respondents who participated in informing their quality of health and different socioeconomic problems. Moreover, we followed the standard ethical guidelines while asking about their health related quality of life. As a part of the survey, we also took verbal as well as written consent of the participants for both quantitative and qualitative studies. For qualitative interviews also such as FGDs and Key informants Interview (KIIs), we took both verbal as well as and written consent. All participants were informed about the study both orally as well as in writing in Punjabi, Hindi and English languages.

As a part of our survey methodology, we also conducted Focus Group Discussions (FGDs) for exploring community perception and experience. FGDs were conducted in sample villages in certain districts and during FGDs, family head, women, young adults, elderly and pregnant women in the sample villages participated. All the FGD participants were given prior intimation via Panchyat Secretaries, before the meeting. The FGD started with a short presentation of the framework by the project leader. The entire FGD was recorded with due permission from the participants. We also took notes during the FGD. The entire recording of the FGD was transcribed at a later stage for further analysis.

We also collected health and other socio-economic characteristics from migrant labors who are observed to be come in the state of Punjab mainly from certain

other parts of northern India and these migrant labourers are socioeconomically vulnerable and migrate to Punjab for limited days. They join the workforce during crops planting and cutting seasons afterward they return back to their own places. In order to explore how the stubble burning affects their health and explore a new dimension of how the mainly illiterate, socioeconomically vulnerable people percept the pollution and health issues in relation to their income and subsistence.

Following the completion of our main survey and collection of primary data from the field in all of our sample districts, we conducted the Key informants interview (KII) for better understanding the views, perceptions and controlling issues about stubble burning and it's health impacts from policy makers' perspective. In all the KIIs, district pollution officer, village Sarpanchs, Block Development officers, Panchayat Officers, Sub-divisional officers, and district agricultural officers took part in the deliberations and discussions

As per our plan of the project, we have conducted this part of our survey in two phases: before and after stubble burning. In the first phase, we have collected survey data from 25 household units from each selected sample village with a total of 100 household units covering four villages in each sample block in a district. However, we have collected data of total 375 household units covering four districts before stubble burning[3]. In the second phase, post stubble burning, we have collected the data for total 350 household units[4]. Therefore, considering both the phases before and after stubble burning, we have collected data from total 725 household units. The collection of data is based on the suitably designed detailed questionnaire that consists of the relevant questions related to firm and household attributes, health related expenditure, awareness, general perception towards

[3] One village in the district of Sangrur, did not participate in the survey during pre stubble burning survey.
[4] 2 villages in the district of Moga did not participate in the survey, post stubble burning.

stubble burning and health status during stubble burning documented in five parts of the questionnaire (see the questionnaire, for details).

We also measure health related quality of life (HRQoL) by EQ-5D appropriate versions (e.g. EQ-5D-5L, EQ-5D-Y) for appropriate groups, before and after the stubble burning. EQ-5D is the most widely used generic measure for health-related quality of life. It has five dimensions (mobility, self-care, usual activities, pain and discomfort, and anxiety and depression) with three levels of attributes: severe disability, moderate disability or no disability. EQ-5D-3L covers 243 different disease states reported by the individual respondents/patients. EQ-5D also comes with a visual analogue scale (VAS) where the individual can mark her current health status on a scale of 0 to 100, where zero is the most imaginable worst case of health, and 100 is the best imaginable case of health or full health of the respondent.

Measurement of Air, Soil and Water quality during pre/ and post-stubble burning

As a part of our entire primary survey, we also measured the air, water and soil quality in all of our sample districts and the corresponding sample villages in all four districts before and after the farmers resorted to stubble burning in order to observe and analyse the environmental changes induced by the burning of agricultural residue. This comprehensive approach to studying the effects of stubble burning is aimed at capturing the variations in air, soil, and water quality across different regions affected by stubble burning in the state of Punjab. Our methodology in this part of our survey highlights how the data was gathered from multiple locations for air, water, and soil samples in different districts of Punjab and how we carried out further analysis based on that. Since burning of crop residues emits a significant quantity of the emissions of greenhouse gases, air pollutants (such as CO, NO, CH, CO, NH3, NOx, SO_2) and hazardous smoke in

the air, these lead to potential adverse consequences to human health along with other adverse consequences on soil and water. First, we conducted this survey before stubble burning in the year 2022, from October-November. Samples were collected before the burning season to establish baseline values.

Measurement of Air quality

For air samples, data was collected from three types of locations: farms (land where stubble burning typically occurs), houses (residences of the farmers, often located slightly away from the farms), and roadside (the road that is used by farmers connecting the residences and the farm lands) areas. Specifically, air samples were taken from Farm 1, Farm 2, House 1, House 2, Roadside 1, and Roadside 2, and therefore, we have 6 data points per village for pre-stubble burning. For each data point, measurements were taken three times, and an average was calculated for each value in order to mitigate any measurement error. In particular, for measuring air quality, we recorded data in six different locations in each location type in a village to capture the variations in data. These are near the main road of the village (ROADSIDE 1), far away from the main road in that village (ROADSIDE 2), near the field (FARM 1), far away from the field (FARM2), inside the residential house (HOUSE 1) and outside the residential house (HOUSE 2). The rationale behind this selection of the above locations is that the actual stubble burning takes place in the farm location, so we include two farm locations, the actual physical location of stubble burning. However, the farmers stay away from the farm in most cases. Thus, the effect in the periphery of their residences is also considered (house). Travel is done by road, and therefore, the roadsides are also included in the analysis. For measuring air quality, soil quality and water quality, we used Air quality Monitor, Soil meter and Water TDS and PH tester respectively. For air quality, we recorded PM 2.5 and PM 10. At each location, we measured six air pollutants both before and after stubble burning: PM2.5

(Particulate Matter with diameter less than 2.5 microns), PM10 (Particulate Matter with diameter less than 10 microns), AQI (Air Quality Index), CO (Carbon Monoxide), CO_2 (Carbon Dioxide), HCHO (Formaldehyde) and TVOV (Total Volatile Organic Compounds). Our objective was to assess how stubble burning impacts air quality in different environments. For the purposes of our analysis, the average of the two sets of measurements was calculated for each location (e.g., the average of Farm 1 and Farm 2, House 1 and House 2, Roadside 1 and Roadside 2). Accordingly, we used 3 average values based on 6 original data points per village for pre stubble burning. Therefore, for 16 villages covering all the four sample districts, we consider 48 data points. Similarly, we collected similar number data for post stubble burning, as well. Therefore, taking into account both pre and post stubble burning phases, we have 6 average values based on 12 original data points per village for air quality measurement. Since there are four sample villages in each of the four districts, the total number of averaged data values comes to be 96 (6*4*4). Since there are 7 measuring parameters for air quality as stated above, each air quality measurement (data point) consists of 7 values. Total sample for air quality measurement covering all the four districts turns out to be 2016[5]. Similarly, post stubble burning, we repeat the same procedure and we get 2016 sample data points.

Measurement of Soil quality

Similarly, for the measurement of soil quality, soil samples were collected from three different types of locations in each district: Roadside, House and Farm. For this purpose, we measured two parameters for the soil samples, both pre- and post-stubble burning: pH, which is considered to determine soil acidity or alkalinity, and the second parameter that is captured is the temperature in order

[5] For 6 locations in a village, we record 7 air quality parameters and therefore, we obtain 42 data points. We repeat this procedure 3 times and accordingly, we get 126 data points per village. For four villages in a district, we have 504 sample data points per district. For four sample districts, therefore, we collectively obtain 2016 values.

to detect potential changes in soil thermal conditions due to stubble burning. Similar to the air sample locations, soil samples were taken from 6 different locations in a village: Farm 1, Farm 2, House 1, House 2, Roadside 1, and Roadside 2. Again, each location was sampled three times, and the pH and temperature of the soil were measured. The data was averaged across the two sites for analysis at each location type (farm, house, roadside). Therefore, we have 3 average data values per village and therefore, for 16 villages covering 4 sample districts, we have 48 average values used in our analysis. The total number of sample data points for two soil parameters turns out to be 576[6]. For the post stubble burning phase of our survey of the soil samples, we also consider 576 original data points.

Measurement of Water quality

For measuring water quality, pH (Potential of hydrogen indicating acidity or alkalinity levels) and TDS (Total Dissolved Solids) levels in water were recorded during both the phases of our survey. The samples were taken at three different locations (Road side, Farm & House). For better accuracy, two different places for each location have been selected. We recorded pH and TDS levels based on samples collected from filter water, hand pump water, tap water and tubewell. Different samples were taken and the average of them has been calculated. Accordingly, we collected 6 samples for water for one village. Therefore, for 2 water parameters considered in our sample repeated 3 times, we have total 36 data points. Therefore, for 16 villages in 4 sample districts, our total sample size consists of 576 (36*16) samples. We repeated collecting these samples for post-stubble burning in all the sample villages in 4 districts.

The collected data described above is analyzed in order to determine the variations in air, water, and soil quality before and after stubble burning. Statistical

[6] For 6 locations in a village, for two soil parameters repeated 3 times, we finally obtain 36 readings (6*3*2). Therefore, for total 16 sample villages covering 4 districts, we have total 576 original data points.

techniques were employed to assess the significance of these changes, and finally, insights were made through graphs. The findings help us understand the environmental impact of stubble burning and provide insights into mitigation strategies. During the collection of all these primary data, we strictly followed ethical considerations by following environmental safety guidelines, ensuring minimal disturbance to the local environment and communities.

However, the study is limited to four Punjab districts, and the findings may not be generalised to the entire state or other regions that practice stubble burning. Additionally, the study focuses on selected environmental parameters, and further studies may explore additional aspects, such as biodiversity impact.

RESULTS

Respondents´ characteristics

Punjab residents:

The average age of the respondents is 46. The average family size is 5.26. The average land holding is 5.12 acres. Only 13% of the respondent's drink alcohol. Their average monthly expenditure is 16969.25 INR. Their average monthly health expenditure is 3987 INR.

Migrants:

The average age of the migrant laboureres is 47.70. Their average family size is 3.56. Migrant labourer's household expenditure when they ae in Punjab is 4152 INR while there earning per month is 10317 INR at the same month. They have almost no health expenditure while they temporarily work in Punjab fields.

Health related quality of life (HRQOL)

In general, the health related quality of life (HRQoL) for the entire Punjabi population is 76.05, while for the migrant labourers, HRQoL is 83.82 (Figure 2). This is a clear indication that long exposure to stubble burning has, in general, reduced the population's health-related quality of life. The migrant labourers are not exposed to stubble burning as they visit the rice fields just before the painting period (June -July). They are not there in the field during the harvesting period (October – November) and therefore are not exposed to stubble burning.

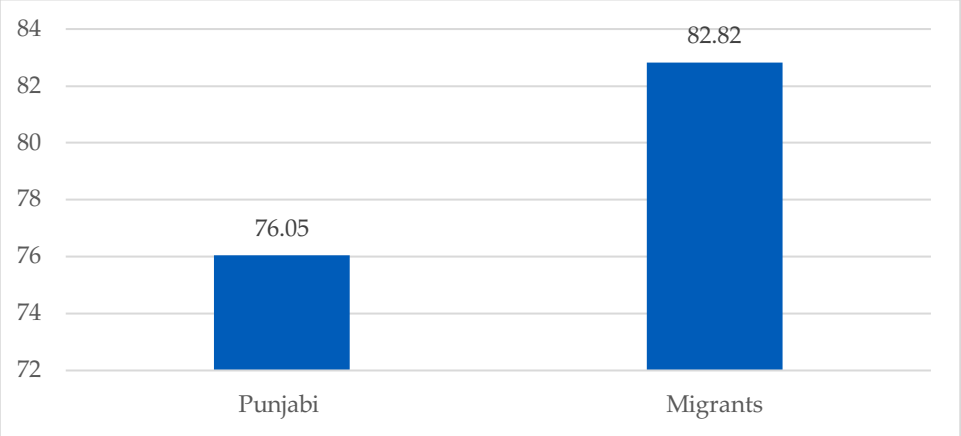


Figure 2. Health related quality of life (HRQOL) of the Punjab residents and migrants

The HRQoL significantly decreases after stubble burning in the Punjab population (Figure 3).

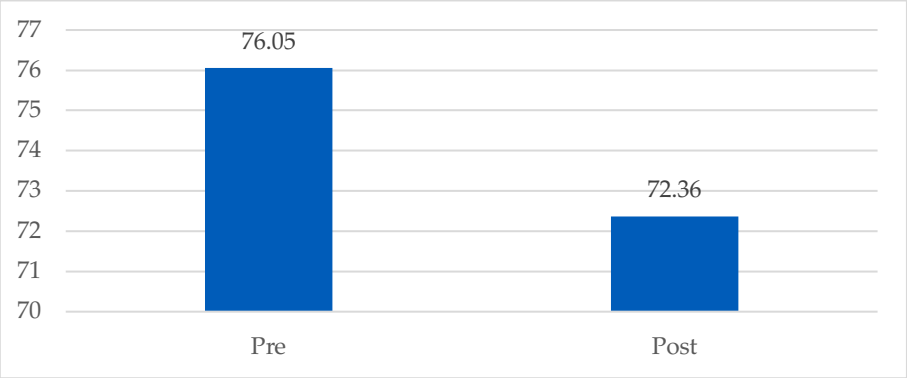
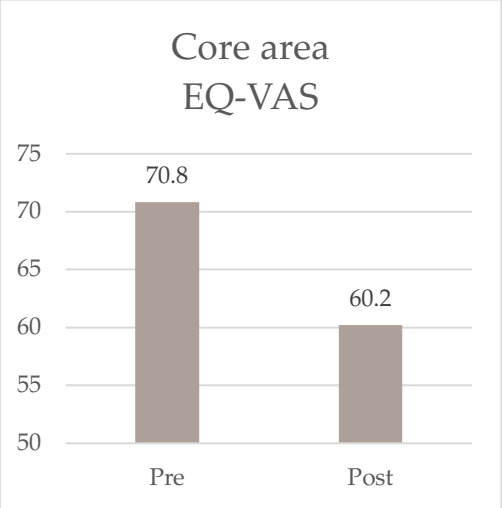


Figure 3. Health related quality of life (HRQOL) before and after the stubble burning

In the core areas of stubble burning, HRQoL decreases from 70.8 to 60.2, while in the less prevalent areas, it remains almost the same (Figures 4a & 4b).



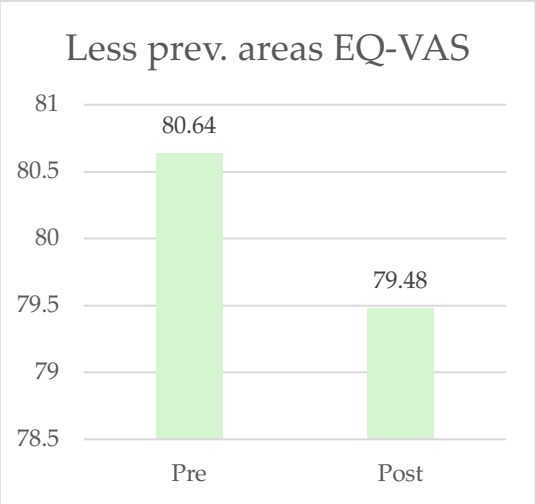


Figure 4a. FHRQoL in Core areas

Figure 4b. HRQoL in less prevalent areas

Health Expenditure

Average household expenditure in the core areas (Moga and Sangrur) is 21909 INR while in the less-frequent stubble burning areas (Ropar and Patiala) it is 12993 INR. Monthly health expenditure is 4219 INR in Core areas (Moga and Sangrur) and 3785 INR in Ropar and Patiala districts.

Catastrophic health expenditure due to stubble burning is very high (Figure 5). Almost 71 per cent of families have catastrophic health expenditure (CHE) where they spend more than 10% of their household expenditures on health.

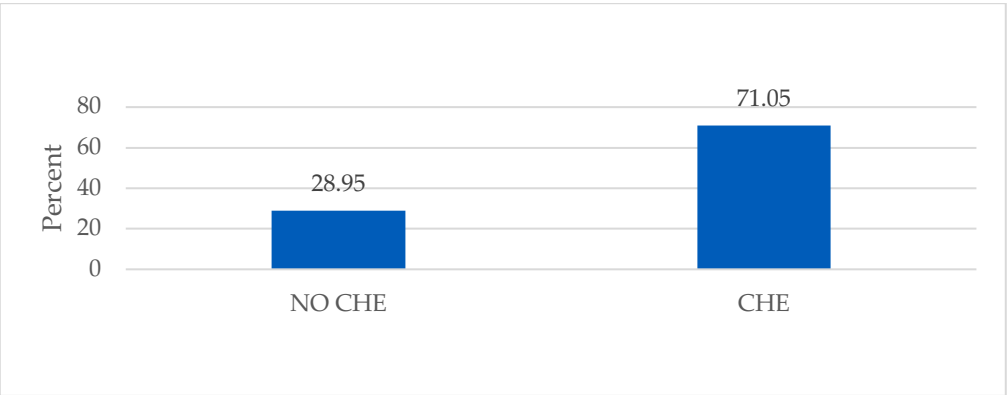


Figure 5. Catastrophic health expenditure (CHE) in the study areas

Awareness and Perceptions regarding stubble burning

This section presents an analysis of respondents' awareness, perceptions, and discussions regarding stubble burning and its associated consequences based on frequency figure. The findings are categorized by overall responses and district-specific variations, highlighting differences between areas with less and more prevalence of stubble burning. Key areas explored include levels of information about the negative and positive consequences of stubble burning, the importance assigned to this issue in family and community discussions, and the frequency of such discussions. Awareness of government schemes aimed at preventing stubble burning is examined to assess gaps in public knowledge. This analysis provides valuable insights into public engagement and knowledge levels surrounding a critical environmental and social issue.

The findings in Figure 6 indicate a relatively high level of awareness regarding the negative consequences of stubble burning among participants, with the majority (55.3%) feeling moderately informed. Additionally, 24.6% felt well-informed, and 3.2% felt very well-informed. However, 11.9% of participants still felt somewhat informed, and 5.0% reported being completely uninformed, suggesting that while awareness is fairly widespread, there is still a need to address the knowledge gaps in a portion of the population.

The regional differences further highlight varying levels of awareness. In districts with a lower prevalence of stubble burning (Figure 7), participants displayed notably higher levels of awareness, with 61.5% feeling moderately informed and 27.0% feeling well-informed. Only a small proportion (9.0%) felt somewhat informed, and 2.5% were not informed at all, suggesting that in areas with less stubble burning, there may be better access to information or more emphasis on its negative consequences.

In contrast, in districts with a higher prevalence of stubble burning (Figure 8), the awareness levels were slightly lower, with 48.3% feeling moderately informed and 21.9% feeling well-informed. A higher proportion (15.2%) felt somewhat informed, and 7.9% were not at all informed, which may reflect the normalization of stubble burning in these areas, leading to less emphasis on educating farmers about its negative impacts.

These regional variations suggest that targeted educational campaigns may be particularly beneficial in areas where stubble burning is more common to increase awareness and encourage more informed decision-making about the practice.

The data presented in Figure 9 reveal an overall need for more awareness about the positive consequences of stubble burning among farmers. While a majority (52.6%) felt moderately informed, this still indicates a significant knowledge gap. Only a small proportion of participants considered themselves well-informed (17.7%) or very well-informed (3.4%), which may suggest that information about these potential benefits is not effectively disseminated or understood.

The data further show regional differences in awareness levels. In districts with lower stubble-burning prevalence (Figure 10), a higher percentage (68.5%) of respondents reported feeling moderately informed, which could imply that in areas where stubble-burning is less common, there might be more opportunities for education on its benefits. In contrast, districts with higher stubble-burning prevalence (Figure 11) exhibited lower levels of awareness, with only 34.8% feeling moderately informed and 29.8% feeling well-informed. This discrepancy may reflect the normalization of stubble-burning practices in these areas, leading to less emphasis on promoting awareness of its potential positive outcomes.

This variation in knowledge between districts suggests that targeted interventions may be needed, particularly in regions where stubble burning is more prevalent,

to address the knowledge gaps and ensure farmers are better informed about all aspects of the practice.

As shown in Figure 12, stubble burning does not appear to be a significant topic of discussion within respondents' families. Most respondents (37.3%) rated the topic as neither important nor unimportant, while 28.0% considered it less important. Only 20.4% of respondents deemed it important, and a smaller proportion (3.7%) viewed it as very important. Additionally, 10.6% indicated that the topic was not at all important. These findings suggest that stubble burning is not commonly prioritized in family conversations.

In districts with less prevalence of stubble burning (Figure 13), family discussions were predominantly neutral, with 42.5% of respondents rating the topic as neither important nor unimportant. A significant proportion (39.0%) considered it less important, while only 12.0% rated it as important, and just 0.5% viewed it as very important. This indicates limited emphasis on stubble burning as a family discussion topic in these areas.

In contrast, family discussions in districts with a higher prevalence of stubble burning (Figure 14) showed a more balanced distribution. About 31.5% of respondents rated the topic as neither important nor unimportant, while 15.7% considered it less important. A notable 29.8% found the topic important, and 7.3% deemed it very important. These results suggest that stubble burning holds relatively greater importance in family discussions in high-prevalence districts compared to low-prevalence districts.

Community-level discussions on the importance of stubble burning reflected a similar trend across the overall sample (Figure 15). About one-third of the respondents (31.7%) rated the topic as neither important nor unimportant, while 29.6% considered it less important. A smaller proportion found it important (16.7%)

or very important (7.9%), and 14.0% viewed it as not at all important. These findings highlight a general need for prioritization of stubble burning in community discussions.

In districts with a low prevalence of stubble burning, the topic was primarily perceived as less important, with 41.5% of respondents choosing this option and an additional 41.0% rating it as neither important nor unimportant. Only 11.0% considered it important, while 6.5% viewed it as not at all important (Figure 16). These results suggest that stubble-burning features are less prominent in community-level discussions in these areas.

In districts with a high prevalence of stubble burning, a more significant proportion of respondents (23.0%) rated community-level discussions as important, and 16.9% considered them very important. However, 21.3% rated the topic as neither important nor unimportant, while 22.5% viewed it as not at all important (Figure 17). These findings suggest that community discussions around stubble burning are more valued in high-prevalence districts compared to low-prevalence areas.

When asked how often they discussed the negative consequences of stubble burning, nearly half of the respondents (48.4%) reported seldom engaging in such discussions, and 26.7% indicated discussing it sometimes. Only a small proportion reported discussing it often (10.6%) or very frequently (4.2%), while 10.1% mentioned never engaging in such conversations. These findings highlight those discussions on the negative consequences of stubble burning were generally infrequent (Figure 18).

In districts with a low prevalence of stubble burning, discussions were even less frequent, with 66.0% of respondents reporting seldom engaging in such conversations. About 20.0% indicated discussing the topic sometimes, while 12.0%

mentioned never discussing it. Only 2.0% of respondents reported often discussing the negative consequences, and none reported very frequent discussions (Figure 19).

In contrast, districts with a high prevalence of stubble burning exhibited greater engagement with the topic. About 34.3% of respondents reported discussing the negative consequences sometimes, and 20.2% indicated they discussed it often. Fewer respondents reported seldom engaging in such conversations (28.7%), and only 7.9% stated they never discussed the issue (Figure 20). These findings suggest that districts with a high prevalence of stubble burning are more active in discussing its negative impacts than low-prevalence districts.

Discussions about the positive consequences of stubble burning were relatively infrequent overall (Figure 21). Nearly half of the respondents (47.9%) reported seldom discussing the topic, and 20.1% mentioned discussing it sometimes. Fewer participants indicated engaging often (13.2%) or very frequently (5.8%) in such discussions. Additionally, 13.0% stated they never discussed the positive consequences, highlighting limited overall engagement.

In districts with a low prevalence of stubble burning, a majority (73.0%) reported seldom discussing the positive consequences, a figure significantly higher than the overall sample. A smaller percentage (11.5%) discussed it sometimes, and only 1.5% reported discussing it often. Additionally, 14.0% stated they never engaged in such discussions (Figure 22).

Conversely, engagement levels were higher in districts with a high prevalence of stubble burning. About 29.8% of respondents reported discussing the positive consequences sometimes, and 26.4% stated they often engaged in such discussions. A smaller proportion (19.7%) seldom discussed it, while 11.8% indicated they

never discussed it (Figure 23). These results suggest a greater frequency of discussions in high-prevalence districts compared to low-prevalence ones.

When asked about awareness of government schemes to prevent stubble burning, 47.9% of participants reported being moderately informed (Figure 24). A smaller percentage felt well-informed (21.7%) or very well-informed (6.6%), while 15.6% described themselves as somewhat informed, and 8.2% were not at all informed.

In districts with a low prevalence of stubble burning, respondents who felt moderately informed were slightly higher (50.0%) than the overall sample, and a larger proportion (27.0%) felt well-informed. However, fewer respondents in these districts described themselves as very well-informed (1.0%) or somewhat informed (12.0%). Those who reported being not at all informed accounted for 10.0% (Figure 25).

In contrast, 45.5% of respondents indicated being moderately informed in districts with a high prevalence of stubble burning, slightly lower than the overall sample and low-prevalence districts (Figure 26). A smaller percentage (15.7%) felt well-informed, though more respondents reported being very well-informed (12.9%) compared to low-prevalence areas. Additionally, 19.7% were somewhat informed, and 6.2% were not at all informed, reflecting slightly higher levels of awareness in the "very well-informed" category but lower in "well-informed" compared to low-prevalence districts.

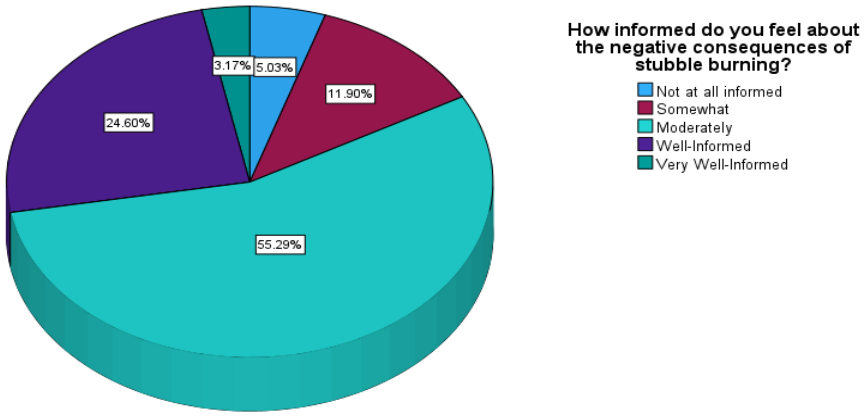


Figure 6. Awareness Levels About the Negative Consequences of Stubble Burning

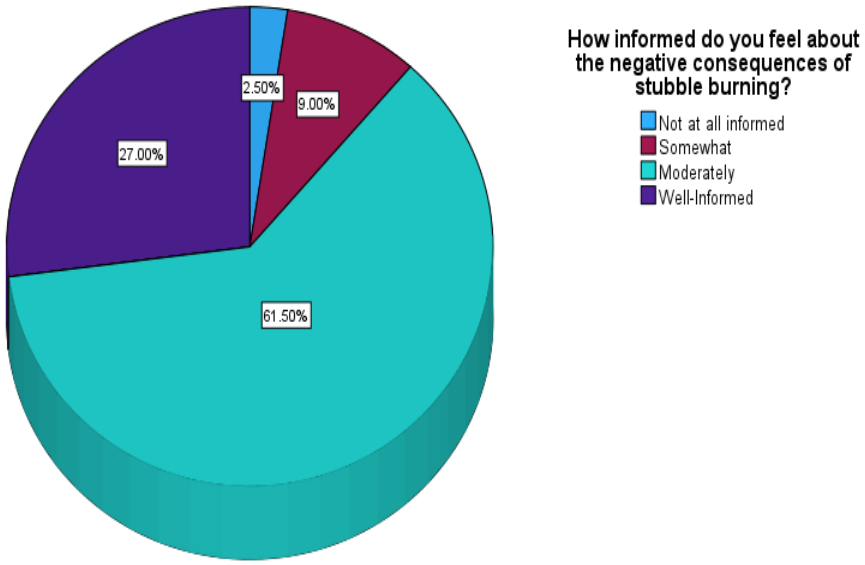


Figure 7. Awareness Levels About the Negative Consequences of Stubble Burning Among Residents of Districts with Fewer Cases of Stubble Burning.

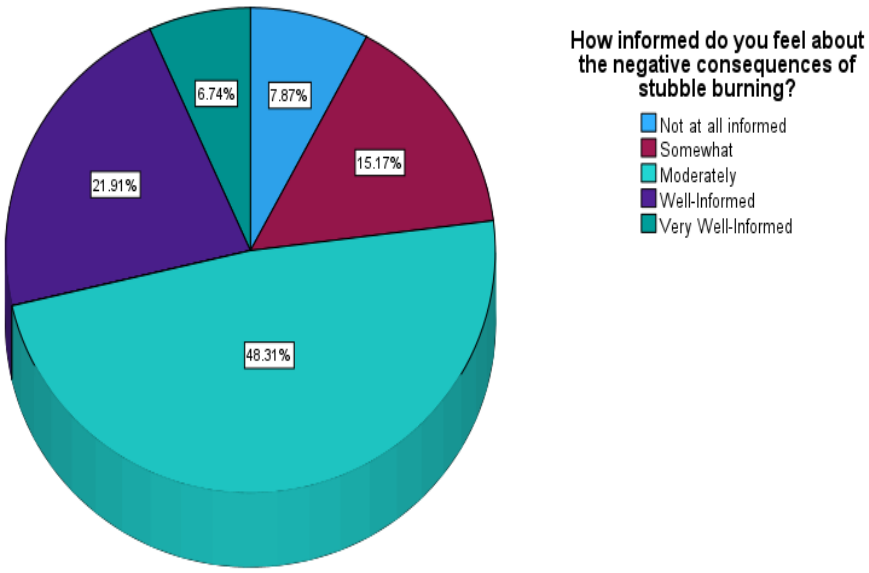


Figure 8. Awareness Levels About the Negative Consequences of Stubble Burning Among Residents of Districts with Higher Cases of Stubble Burning.

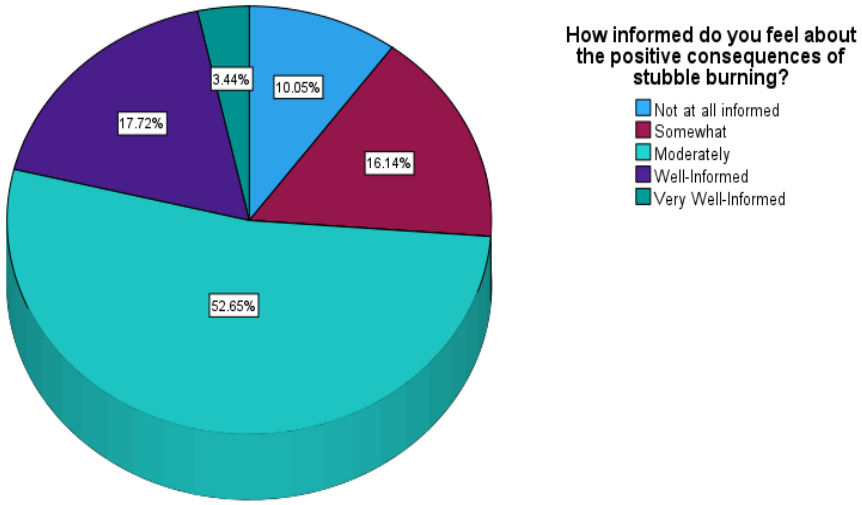


Figure 9. Awareness Levels About the Positive Consequences of Stubble Burning

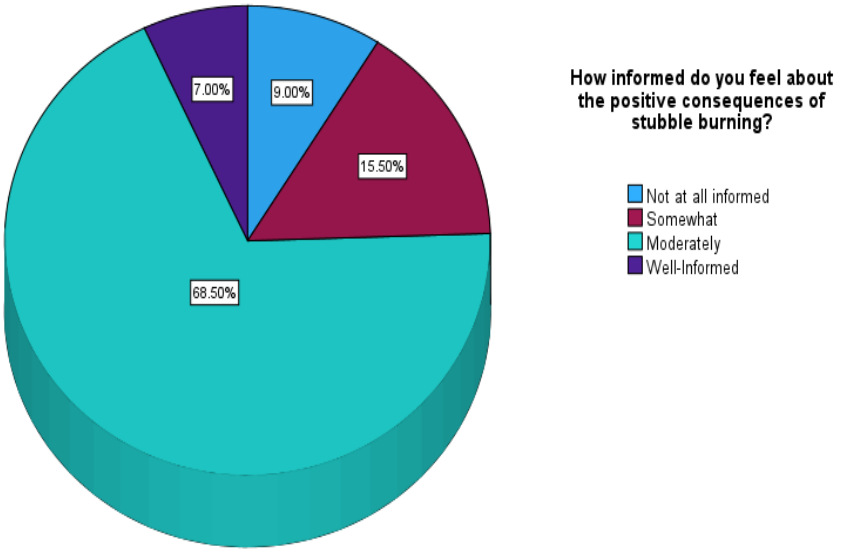


Figure 10. Awareness Levels About the Positive Consequences of Stubble Burning Among Residents of Districts with Fewer Cases of Stubble Burning

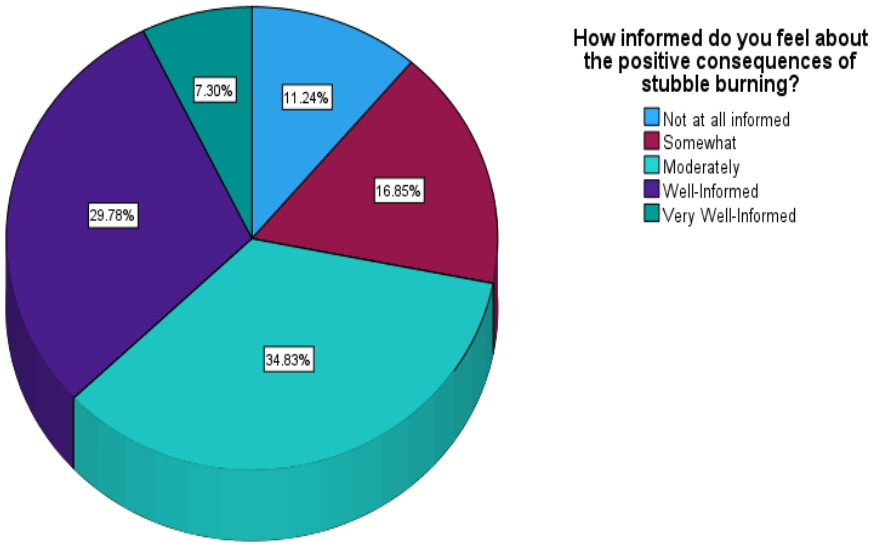


Figure 11. Awareness Levels About the Positive Consequences of Stubble Burning Among Residents of Districts with Higher Cases of Stubble Burning

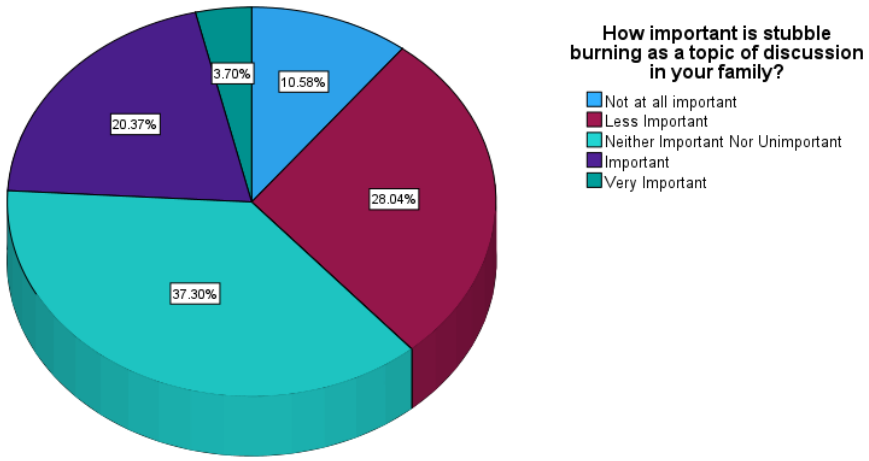


Figure 12. Importance of Stubble Burning as a Family Discussion Topic

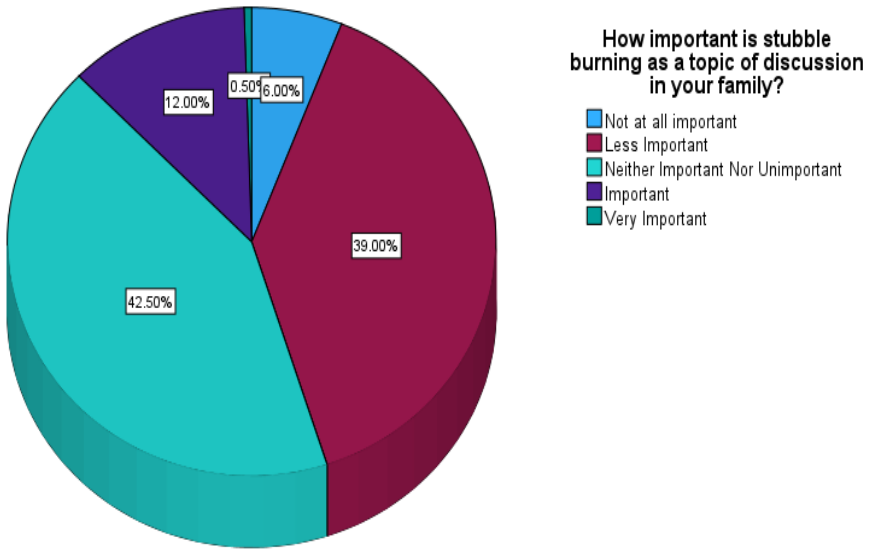


Figure 13. Importance of Stubble Burning as a Family Discussion Topic Among Residents of Districts with Fewer Cases of Stubble Burning

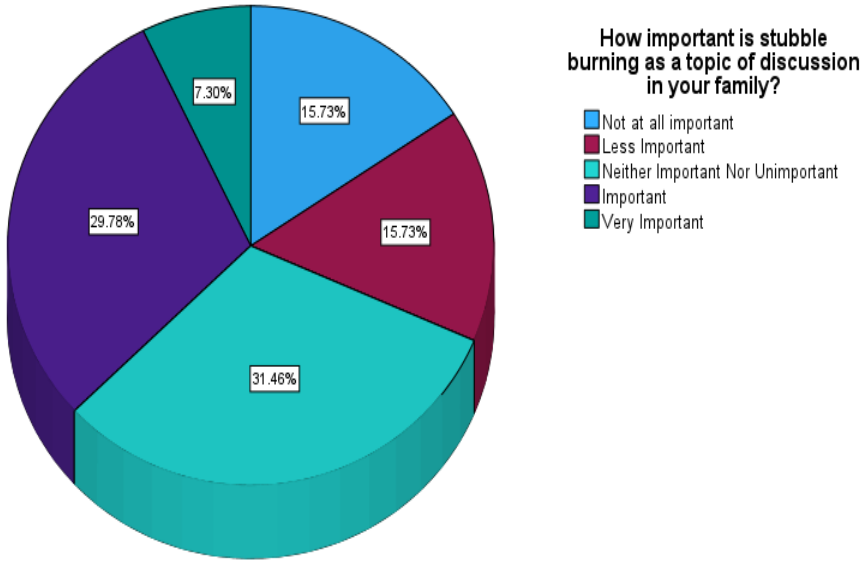


Figure 14. Importance of Stubble Burning as a Family Discussion Topic Among Residents of Districts with Higher Cases of Stubble Burning

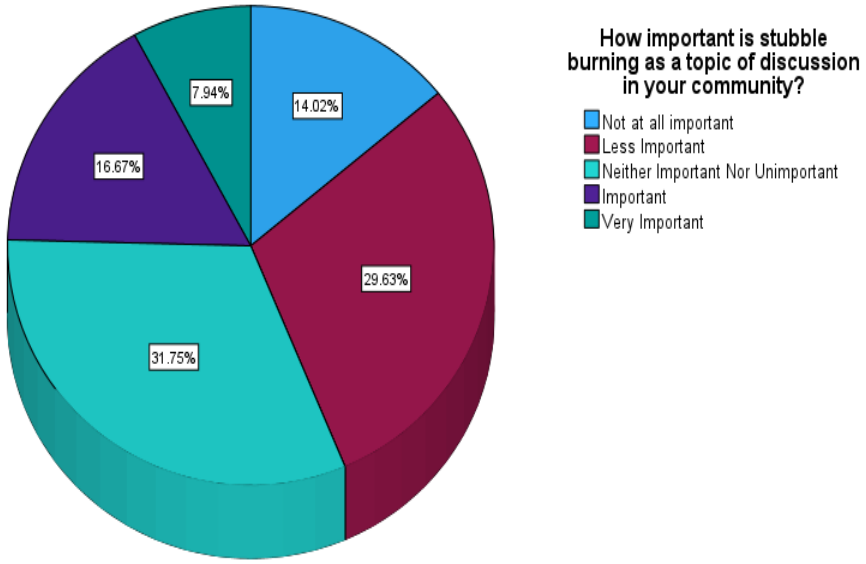


Figure 15. Importance of Stubble Burning as a Community Discussion Topic

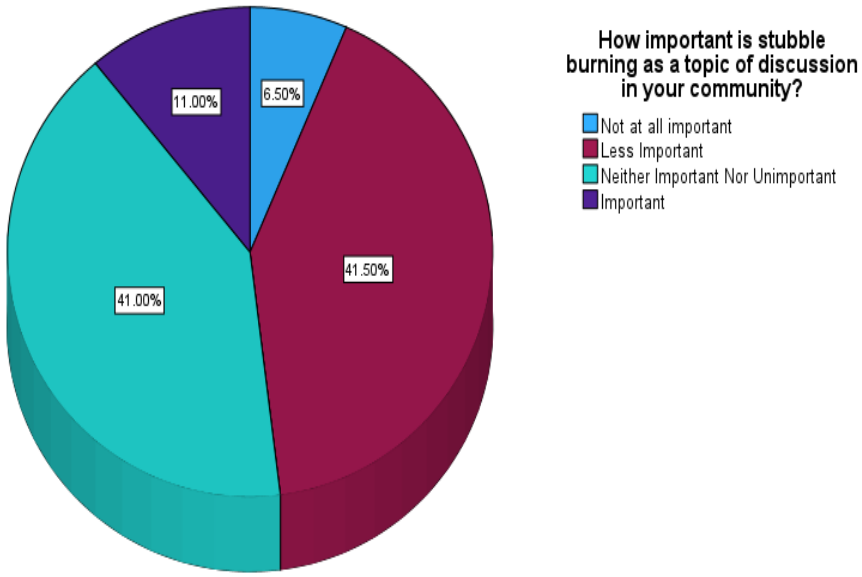


Figure 16. Importance of Stubble Burning as a Community Discussion Topic Among Residents of Districts with Fewer Cases of Stubble Burning

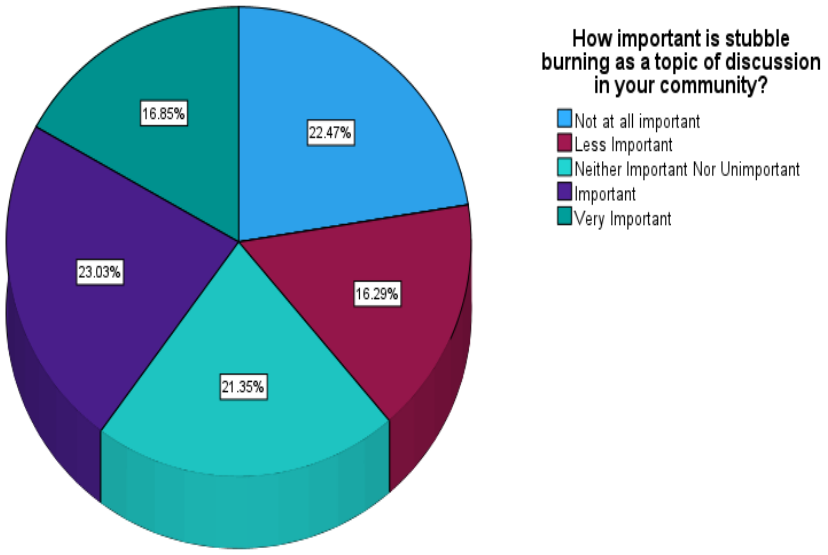


Figure 17. Importance of Stubble Burning as a Community Discussion Topic Among Residents of Districts with Higher Cases of Stubble Burning

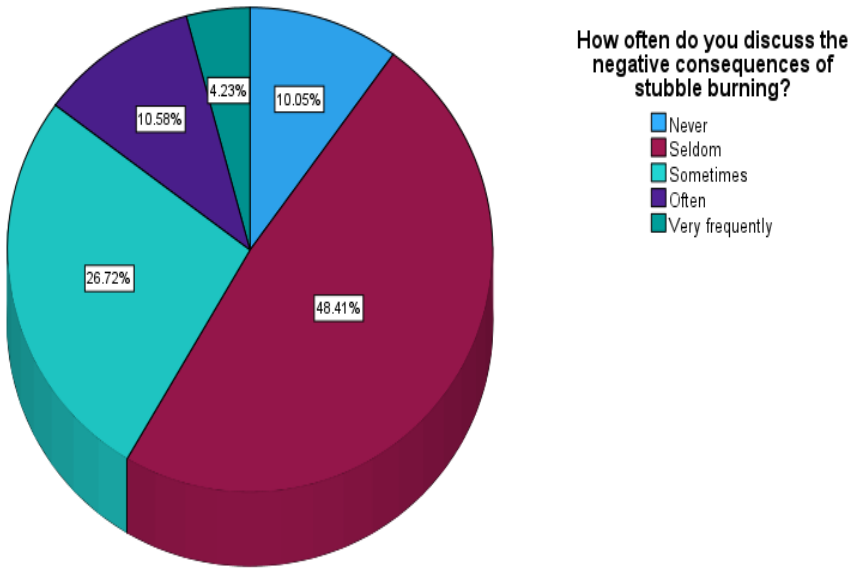


Figure 18. Frequency of Discussion on Negative Consequences of Stubble Burning

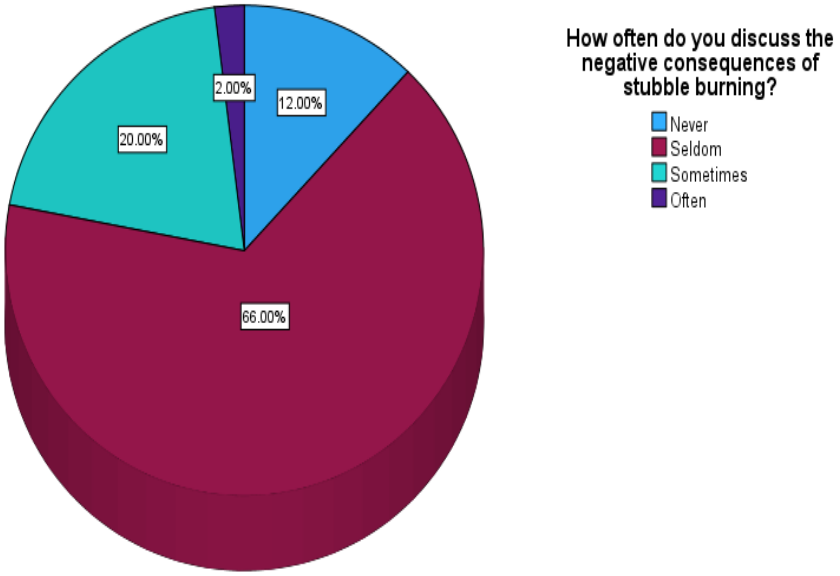


Figure 19. Frequency of Discussion on Negative Consequences of Stubble Burning Among Residents of Districts with Fewer Cases of Stubble Burning

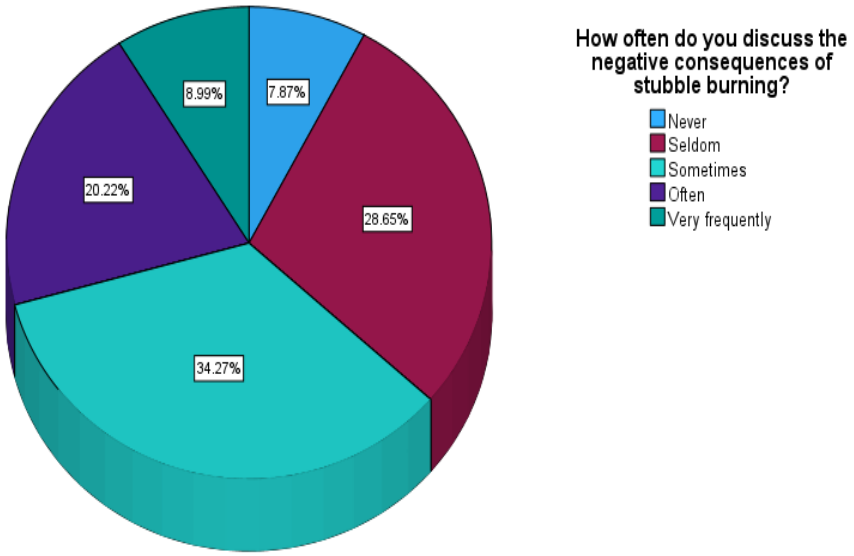


Figure 20. Frequency of Discussion on Negative Consequences of Stubble Burning Among Residents of Districts with Higher Cases of Stubble Burning

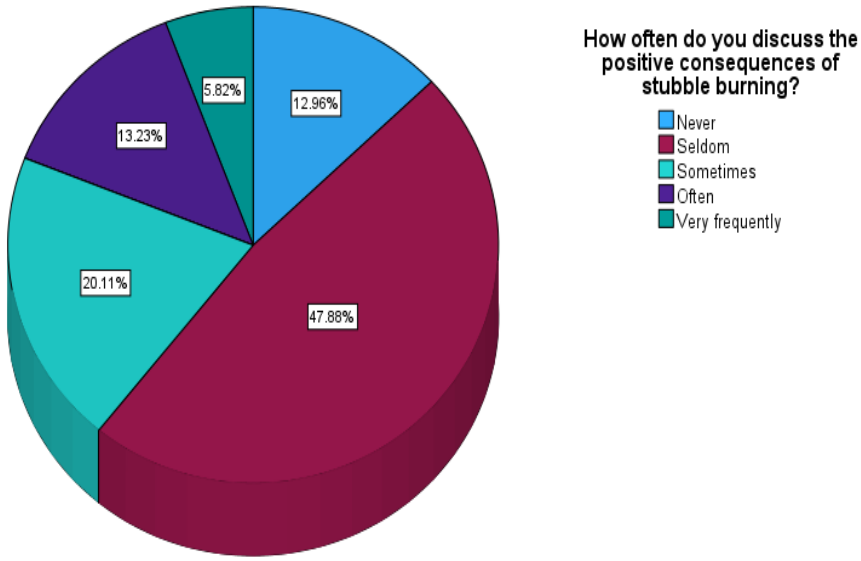


Figure 21. Frequency of Discussion on Positive Consequences of Stubble Burning

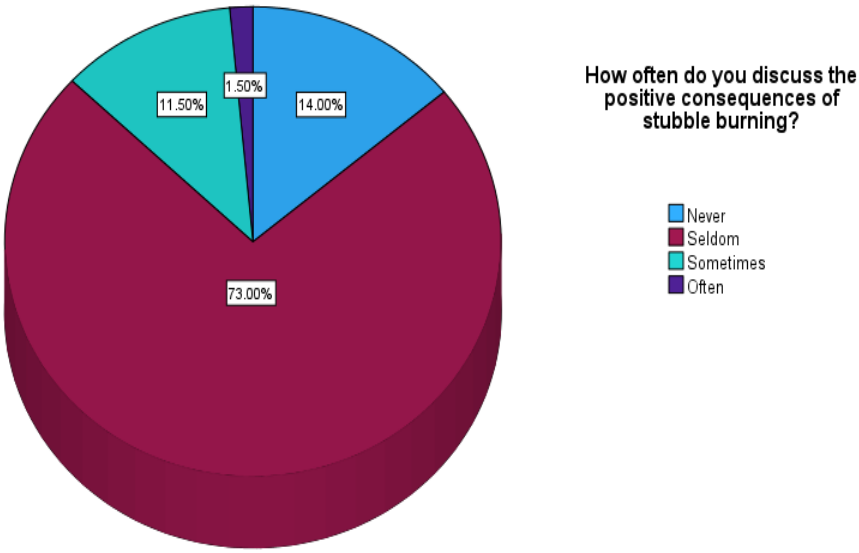


Figure 22. Frequency of Discussion on Positive Consequences of Stubble Burning Among Residents of Districts with Fewer Cases of Stubble Burning

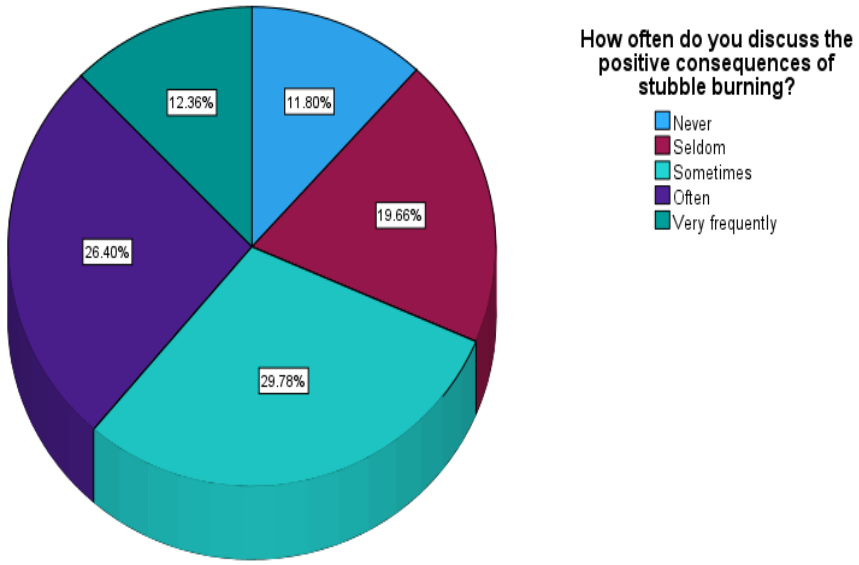


Figure 23. Frequency of Discussion on Positive Consequences of Stubble Burning Among Residents of Districts with Higher Cases of Stubble Burning

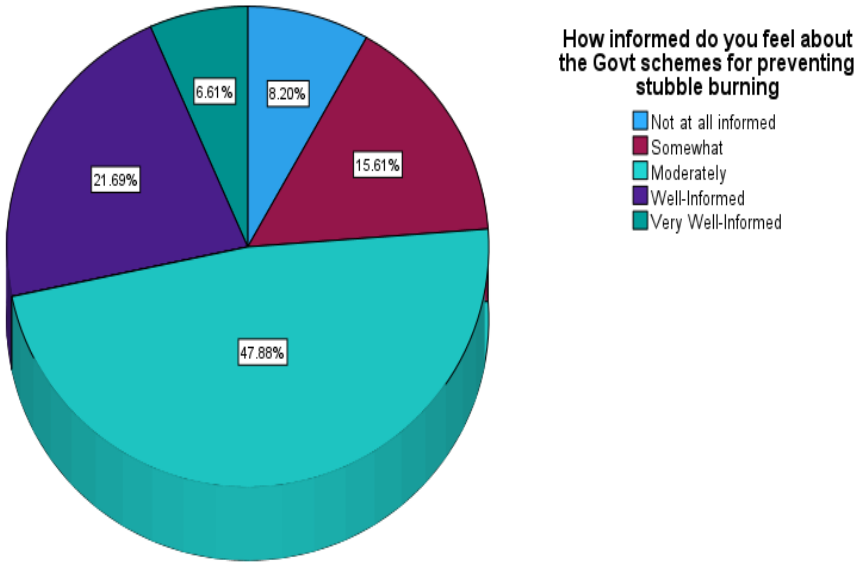


Figure 24. Awareness of Government schemes for Stubble Burning

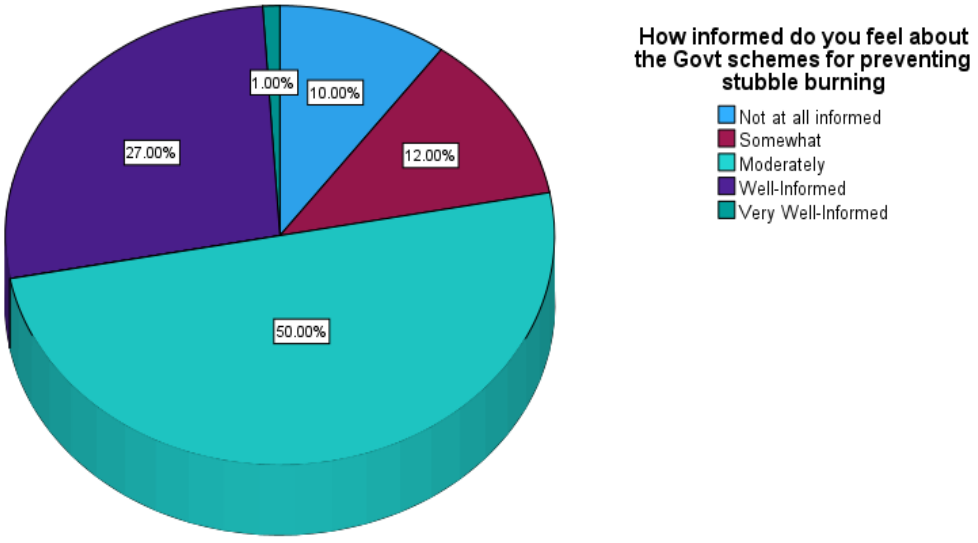


Figure 25. Awareness of Government schemes for Stubble Burning Among Residents of Districts with Fewer Cases of Stubble Burning

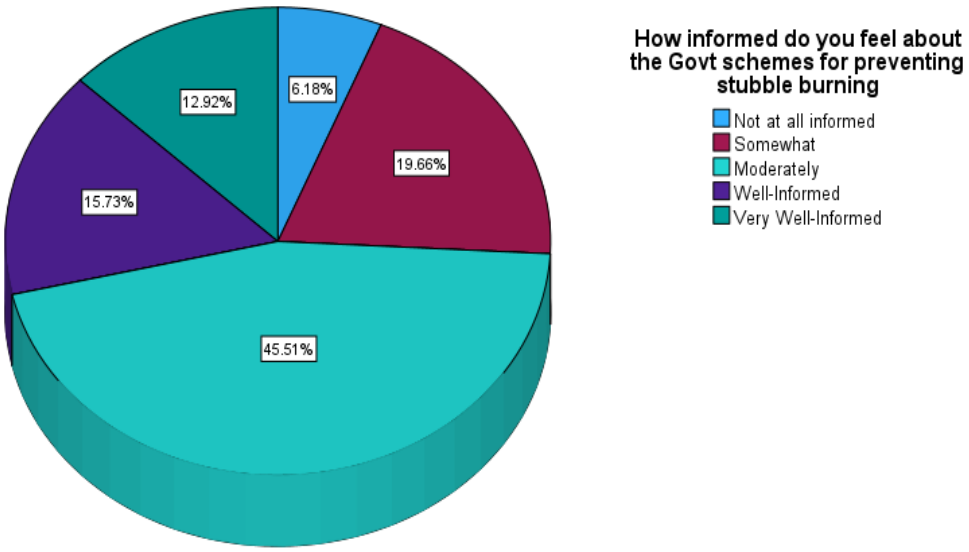


Figure 26. Awareness of Government schemes for Stubble Burning Among Residents of Districts with Higher Cases of Stubble Burning.

MIGRANT LABOURERS' AWARENESS AND PERCEPTIONS

More than two-thirds (69%) of the migrant labourers have opined that stubble burning has negative consequences (Figure 27)

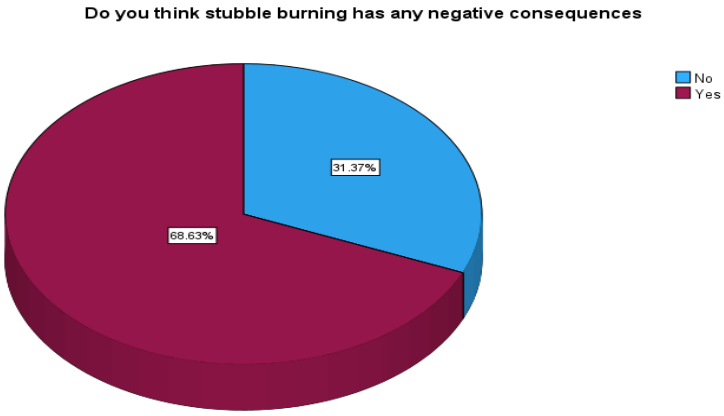


Figure 27. Perception of Negative Consequences of Stubble Burning Among Migrant Labourers

Majority of the migrant laboureres have thought that stubble burning has adverse health consequences (Figure 28)

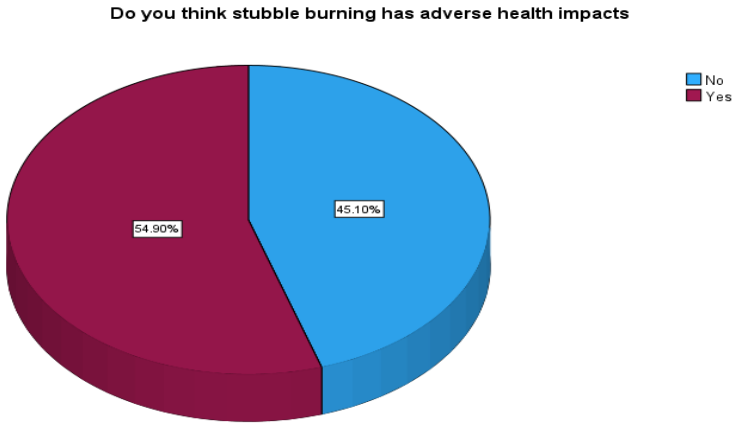


Figure 28. Perception of Adverse Health Impacts of Stubble Burning Among Migrant Labourers

POLLUTION: in relation to Stubble Burning

Accepted level of air ingredients

- **PM-2.5: (µg/m³):** Not more than 5 (annual), should not exceed 15 µg/m³ more than 3 - 4 days per year
- **PM-10: (µg/m³):** 15 annual mean, 45 24-hour mean.
- **AQI:** 0 - 50 Good
- **CO: (ppm)** 9-10 for no more than 8 hours; 25-35 for no more than 1 hour, 90-100 ppm for no more than 15 minutes
- **CO_2: (ppm):** less than 800 is good
- **HCHO:** less than 0.3 is good
- **TVOC:** less than 1 is good

Moga district: air quality

- **General Findings**:
  - Significant air pollution rise post-stubble burning in PM2.5, PM10, AQI, CO, CO2, HCHO, and TVOC.
  - Buttar and Himmatpura showed the highest pollutant increases.

- **PM2.5 & PM10**:
  - PM2.5 increase up to **153.5%**; PM10 increase up to **120.9%**.
- **AQI**:
  - Increase of **150%**, shifting from "Good" to "Moderate."
- **CO**:
  - Increase of up to **3047%**.
- **Other Pollutants**:
  - CO2 (+201.6%), HCHO (+1500%), and TVOC (+650%).
- **Health Risks**: High pollutant levels may cause severe respiratory and cardiovascular health issues.

Air Data		PM-2.5	PM-10	AQI	CO	CO_2	HCHO	TVOC
Roadside	Pre	103.75	163.625	2	12.125	523.75	0.02175	0.2
	Post	225	309.875	5	265.25	1563.75	0.254125	1.5
Inc/Dec		116.92	89.792	150	2134.862	198.568	1086.392	650
House	Pre	91.625	154.625	2	10.875	520.25	0.01925	0.2
	Post	216.375	306.75	5	261.375	1565.125	0.255	1.5
Inc/Dec		136.524	98.655	150	2342.889	200.841	1227.908	650
Farm	Pre	97.25	155.875	2	11.25	521.875	0.02	0.2
	Post	229.625	313.625	5	267.125	1571.125	0.2579	1.5
Inc/Dec		136.649	101.703	150	2337.384	201.052	1213.025	650

Inc = increment & Dec = decrement

Table 1. Moga district air quality : Roadside, House, Farm

Sangrur district: air quality

- **General Findings**:
  - Air quality degraded significantly post-stubble burning; highest impacts in Raidharana and Chatha Sekhwan.
- **PM2.5 & PM10**:
  - PM2.5 increase up to **127%**; PM10 increase up to **84.1%**.
- **AQI**:
  - Rise of **100-150%** across locations.

- **CO**:
  - Increase up to **3312.5%**.
- **HCHO & TVOC**:
  - HCHO increase up to **2759.2%**, and TVOC rise of **700%**.
- **Key Observations**:
  - Raidharana recorded the most severe pollutant increases, especially in CO and HCHO.

Air Data		PM-2.5	PM-10	AQI	CO	CO_2	HCHO	TVOC
Roadside	**Pre**	124.375	211.375	2	16.5	530.75	0.02525	0.2375
	Post	223.75	309.625	4.75	256	1561.25	0.256875	1.525
Inc/Dec		80.8242	47.65928	137.5	1554.457	194.2638	971.1859	562.5
House	**Pre**	109.875	200.25	2	12.875	521.75	0.02	0.2
	Post	212.375	303.125	4.75	294.375	1557.375	0.254875	1.4875
Inc/Dec		95.27424	53.33864	137.5	2296.578	198.5143	1224.917	643.75
Farm	**Pre**	115.375	204.5	2	13.75	523.75	0.019488	0.2
	Post	229.625	313	4.875	264.125	1566	0.26375	1.5125
Inc/Dec		101.9481	54.92526	143.75	1906.864	199.0468	1515.153	656.25

Inc = increment & Dec = decrement

Table 2. Sangrur district air quality: Roadside, House, Farm

Patiala district: air quality

- **General Findings**:
  - Major rise in all air pollutants (PM2.5, PM10, AQI, CO, CO2, HCHO, TVOC).
  - Highest increases recorded in **CO (up to 5897.5%)** and **TVOC (up to 650%)**.
- **PM2.5 & PM10**:
  - PM2.5 increase up to **127%**; PM10 increase up to **153.2%**.
- **AQI**:
  - Increase of **100-150%** across locations.
- **Notable Locations**:

- Mehas recorded the highest increases in CO (+1750%) and HCHO (+1068.2%).

Air Data		PM-2.5	PM-10	AQI	CO	CO2	HCHO	TVOC
Roadside	**Pre**	108.75	137.625	2	18.625	528.25	0.0285	0.2125
	Post	221.5	293.25	4.625	223	1532.75	0.2235	1.475
Inc/Dec		103.569	113.323	131.25	1126.747	190.1999	696.875	600
House	**Pre**	100	131.25	2	16.5	526.125	0.0265	0.2
	Post	214.75	260.375	4.375	221.5	1530.5	0.22025	1.4375
Inc/Dec		114.776	99.201	118.75	1283.072	190.9085	755.674	618.75
Farm	**Pre**	103.375	132	2	17.25	527.25	0.0269	0.2
	Post	227.125	298.375	4.625	478	1534.875	0.224	1.475
Inc/Dec		119.936	126.692	131.25	2484.807	191.129	754.516	637.5

Inc = increment & Dec = decrement

Table 3. Patiala district air quality: Roadside, House, Farm

Ropar district: air quality

- **General Findings**:
  - Notable pollutant rises across all locations, especially in Bela and Firozpur.
- **PM2.5 & PM10**:
  - PM2.5 increase up to **191.4%**; PM10 increase up to **107.1%**.
- **AQI**:
  - Rise of **100-150%**, indicating serious air quality deterioration.
- **CO**:
  - Increase up to **1900%**.
- **HCHO & TVOC**:
  - HCHO increase up to **1064.5%**, and TVOC rise of **550-600%**.
- **Critical Locations**:
  - Bela experienced the highest overall deterioration.

Air Data		PM-2.5	PM-10	AQI	CO	CO_2	HCHO	TVOC
Roadside	**Pre**	87	152.625	2	12.125	519.25	0.021	0.2
	Post	180.75	267.5	4.375	173.75	1479.625	0.169	1.3
Inc/Dec		109.423	78.530	118.75	1349.668	184.921	700.764	550
House	**Pre**	82.25	147.75	2	10.75	516.375	0.0181	0.2
	Post	177.125	266.125	4.25	174.125	1507.125	0.175	1.3
Inc/Dec		118.464	83.945	112.5	1523.72	191.858	866.966	550
Farm	**Pre**	85.5	148.75	2	10.125	515.875	0.018	0.2
	Post	193	281.5	4.5	185.25	1519.875	0.17425	1.3375
Inc/Dec		129.490	92.346	125	1759.474	194.5871	882.399	568.75

Inc = increment & Dec = decrement

Table 4. Ropar district air quality: Roadside, House, Farm

Air Data		PM-2.5	PM-10	AQI	CO	CO2	HCHO	TVOC
Roadside	Pre	105.9688	166.3125	2	14.8438	525.5	0.024188	0.2125
	Post	212.75	295.0625	4.6875	229.5	1534.344	0.225969	1.45
% Increment		100.7667	77.41451	134.375	1446.105	191.9779	834.2377	582.3529
House	Pre	95.9375	158.4688	2	12.75	521.125	0.020969	0.2
	Post	205.1563	284.0938	4.59375	237.8438	1540.031	0.22625	1.43125
% Increment		113.8436	79.2743	129.688	1765.441	195.5205	978.9866	615.625
Farm	Pre	100.375	160.2813	2	13.0938	522.1875	0.021091	0.2
	Post	219.8438	301.625	4.75	298.625	1547.969	0.229969	1.45625
% Increment		119.0224	88.18483	137.5	2180.668	196.4393	990.3838	628.125

Table 5. All four districts (Punjab) air quality: Roadside, House, Farm

PM-2.5 and PM-10:

- Significant increases are observed in PM-2.5 and PM-10 levels across all locations post-stubble burning.
- PM-2.5 levels nearly doubled, highlighting the drastic impact of burning activities on fine particulate matter.

Carbon Monoxide (CO):

- CO levels showed a drastic rise post-burning, with concentrations increasing by more than 15 times on average. This indicates a substantial release of incomplete combustion by products.

Carbon Dioxide (CO2):

- CO2 concentrations more than doubled post-burning, emphasizing the large-scale carbon emissions from the practice.

Variations by Location:

- Farms displayed the highest increases in PM-2.5 and CO2 levels, indicating the proximity to burning fields contributes to elevated pollution.
- Houses showed slightly lower increments but remained significantly impacted, emphasizing how air quality deteriorates even in residential areas.

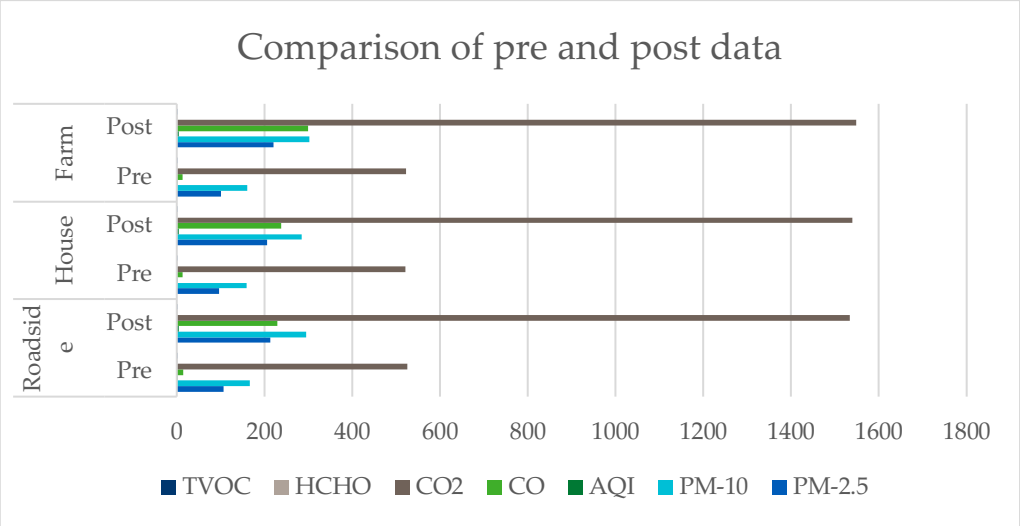


Figure 29. Values of 7 pollutants for pre and post stubble burning for different locations

Here's the bar graph illustrating the percentage increase in various air quality parameters (PM2.5, PM10, AQI, CO, CO2, HCHO, and TVOC) across the four districts of Punjab (Moga, Patiala, Ropar, and Sangrur) post-stubble burning.

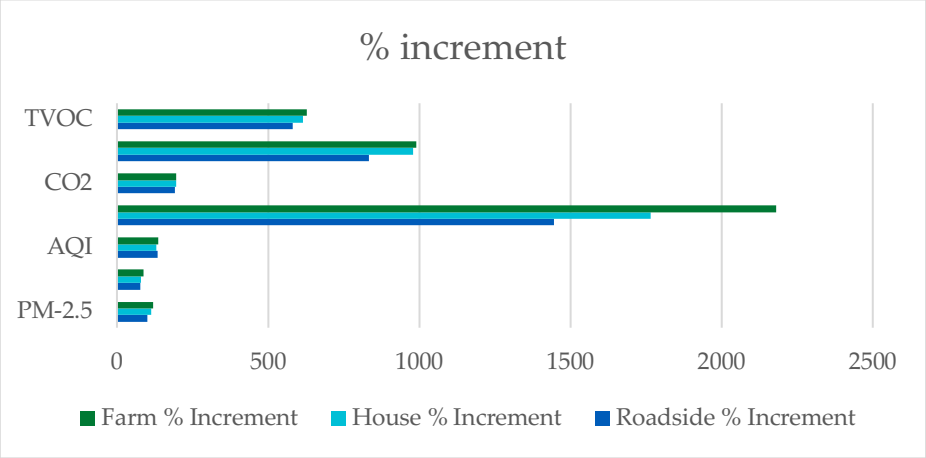


Figure 30. Percentage increase of the 7 pollutants pre and post stubble burning at different locations

Health problems

The breating, irritation, skin rashes, cough, resperitory allergies, other lungs/ heart related diseases, idigestation, loss of appetite and nose throat irritations significantly incrtease during stubble burning.

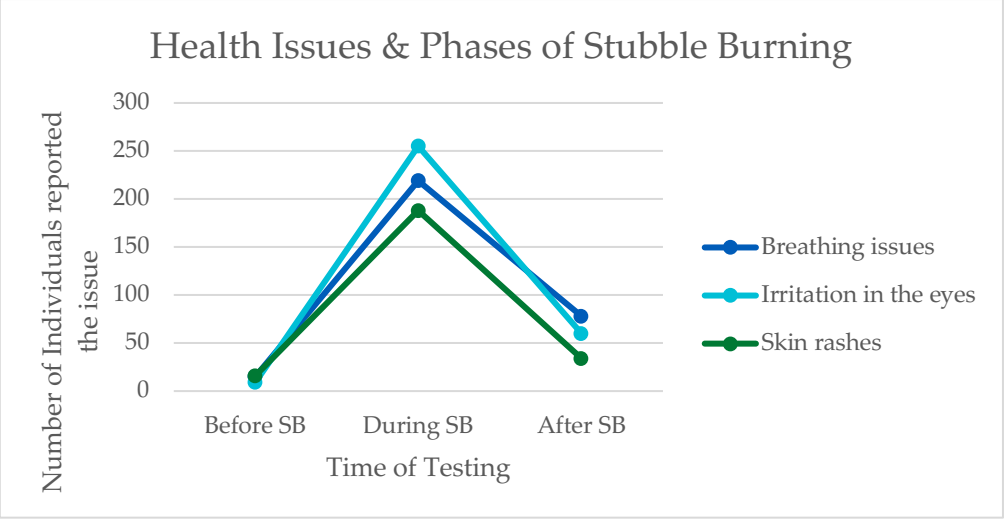


Figure 31a. Health problems pre-during-after stubble burning

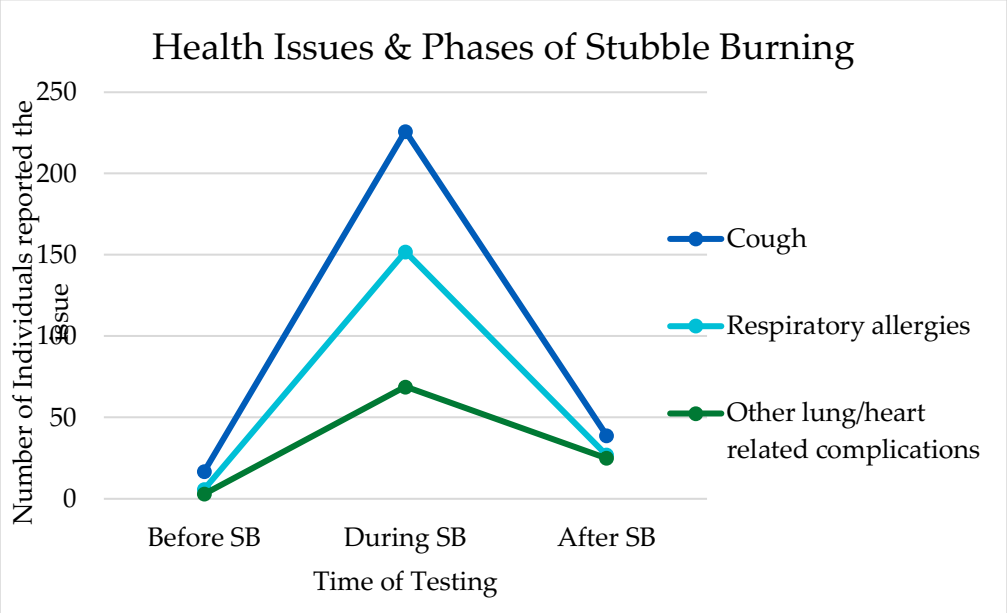


Figure 31b. Health problems pre-during-after stubble burning

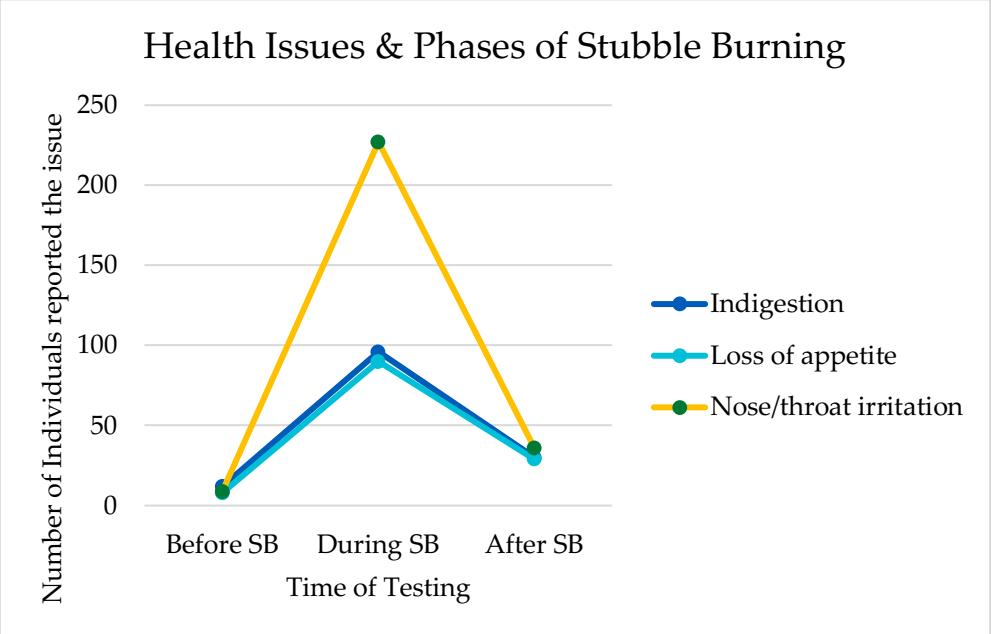


Figure 31c. Health problems pre-during-after stubble burning

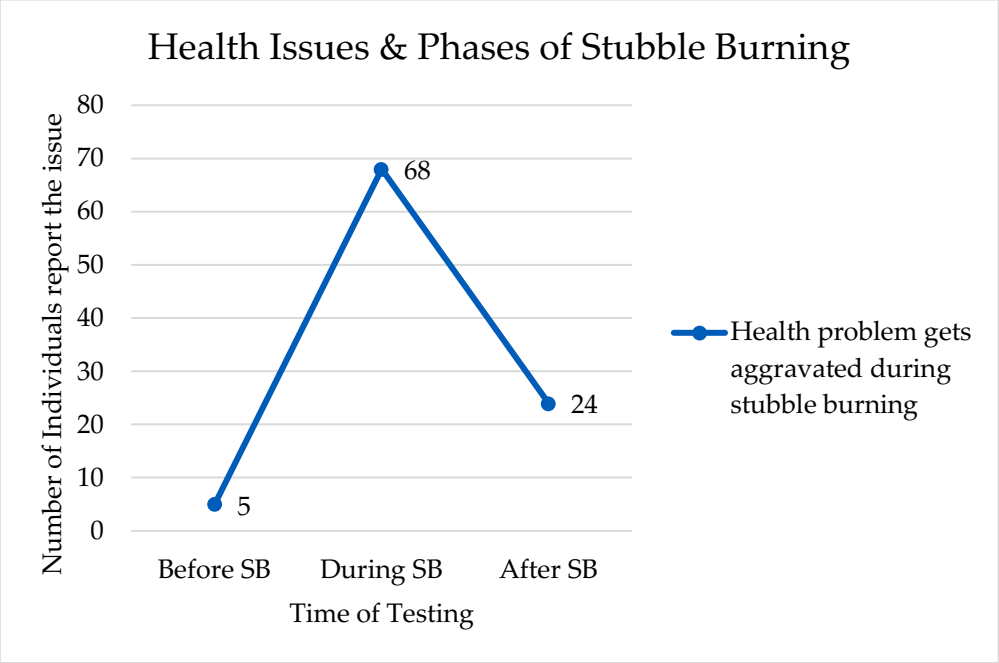


Figure 32. Health problems pre-during-after stubble burning

Filed Photos

Photo 1. **Rice stubbles**

Photo 2. **Paddy filed after stubble burning**

Photo 3. Stubble burning

Photo 4. Stubble burning

Photo 5. **Just after stubble burning**

Photo 6. **Measuring air quality during stubble burning**

Qualitative results

Rice Straw is the problem

The focus group discussions with the villagers have revealed that rice straws are the problem. Rice straws are not good food for domestic animals such as cows and buffalos. Cows produce minimal milk with rice straws. Therefore, it is difficult for the farmers to sell rice straws. On the other hand, transporting rice stubble from the field to another place costs a lot. The farmers are not economically solvent to carry the stubbles. Therefore, the easiest way is to burn the rice stubbles.

> *" …….it costs too much to cut the rice straws and stems and then transport them to somewhere else. It does not provide any resale value. Therefore, it is a total loss project……."* (FGD 1)

Villagers in the study areas have almost the same opinion. Burning rice stubble is the easiest economic way to save money. Farming costs are increasing daily. The rice sale price is not high enough to bear the extra economic burden of handling rice stubbles ecologically and scientifically.

> *"…..my whole family's survival will be in problem if I pay the costs for handling the rice stubbles after the crop-cutting. I have no other way but to burn out the stubbles….."* (FGD 2)

The stubble burning in Punjab has multifold problems. Now, the farmers are trying to have three-time crops. Wheat straws are not the problem. Rice stubbles have no economic value. Scientists and policymakers urgently need to create a commercial and/or economic value for rice stubbles.

> *"……..you, the educated persons, can help us by making the rice straws and stubbles economically viable. So, we can earn extra money from it instead of*

paying for negative investment. Otherwise, such stubble burning shall continue. We can not stop it……" (FGD 3)

Basmati rice straws are the best alternative

Rice straws are a problem for economic losses. The farmers and villagers have alternative experiences. The farmers who cultivated Basmati rice, instead of other rice have economic benefits. Basmati rice straws are good for cows and buffalos as they produce more milk. Therefore, the cattle owners prefer Basmati rice straws. Also, Basmati rice production needs less water, and the sale price is much higher than that of the coarse rice variety. Overall, Basmati rice cultivation and marketing are economically more attractive to farmers. However, the initial investment for Basmati rice cultivation is relatively higher for the farmers, especially for low- and middle-income cultivators.

" We need more planning and government support for cultivating basmati rice. It is both profitable for the pocket and for the environment. It is eco-friendly. We need support for basmati rice plating." (FGD 2)

Time-bound seeding schedule by the authorities

Kharif (autumn: mid-May up to November) and Ravi (spring: November to April) are two major harvesting seasons in Punjab and India. In Punjab, rice and wheat are the main agri-products during the Kharif and Ravi seasons, respectively. Major crops grown during the Kharif season are rice, cotton, maize, and sugarcane.

During Ravi seasons, major crops are Wheat, Rapeseed and mustard and Potato. Farmers and families in Punjab are concerned about Kharif harvesting period restrictions. Government restrictions give farmers a short time frame for harvesting rice and wheat. Some villagers found the restrictions also led to stubble burning.

"We can not start rice harvesting before 10th of June. So the time between rice cutting and wheat harvesting is only two weeks. Do you think that in two weeks we manage the stubble? No. So, we burn it. Simple. We have no time, no money and no other resources. Stubble burning saves money, resource and time." (FGD 4)

Teenaged Villagers

The young villagers from the stubble-burning core areas are very much concerned about the issues and problems. They are especially concerned about their health. They believe that stubble burning is disturbing their health and wellbeing. However, when they observe the struggle of their parents and family members, the young generation of Punjab gets very much jeopardized. On one hand, they know that stubble burning is harmful to them and to the environment. On the other hand, they are stuck in a dilemma of the struggle of their parents and family members for the costs and expenses of ecologically managing the rice stubbles, which also brings more economic burden to their family.

> *"My eyes and parts of face burn during stubble burning. What else can I do except this suffering?....."* (FGD 2)

> *"You know, I can not study. My eyes are full of water all the time, especially during the stubble burning; it is worse. The air quality is very bad. I feel it. My eyes, palms and face itch during the burning session. The senior people must understand it……." (FGD 2)*

> *" It is not only residue burning, as you think. I help my father with cultivation with chemicals. The soil is very bad and there are no insects. How can we*

produce better without chemicals? We are in a bad situation. The air is so poor. Soil is unnatural with so much burnt ashes. Water? I don't know. Overall, the basic living conditions are not favourable for us to live better. " (FGD 4)

" The harmony between soil, air, water, insects, cows, buffalos, and humans is very much necessary. By burning rice stubble, we destroyed it. Now we are suffering so much for health and wellbeing. But we are not learning; rather, we are still continuing with it. (FGD 2)

"Our greed kills us. We are thinking that we are saving money by burning stubbles. No! We are losing our health and wellbeing. In my class, we all have problems with watering our eyes, itching, runny nose, burning sensations in the stomach, irritations, and so many health problems. Why? I think it is because of stubble burning and excessive chemical use. " (FGD 2)

Students in higher education

The college and university students have serious concerns about stubble burning and their future. They are frustrated and worried about their health issues.

"I want to join the military or police. I have been practising long-distance running for several years, starting in my early teenage years. Now it is becoming very difficult to run at a stretch. I feel short of breath. My running capability is not getting improved. I may not qualify for the military or police job as it is a

mandatory examination for the entry threshold. My lungs are getting damaged by stubble burning. I am worried about my future" (FGD 2)

" My concern is the rural-urban migrations for jobs. We youth groups from the villages are migrating from villages to big cities. The labour force in agricultural fields is decreasing compared to our parents' generation. So, they are getting trouble to collect and manage stubbles. The residue burning occurs. It is a bad cycle. I don't know the solutions to get out of these annual problems. But we all are suffering." (FGD 2)

"Happy seeder costs 2500 INR per acre to plough rice crop residues and seeding. It costs too high. But at the end of the day yield is lower than normal procedure. The whole process is less economically productive. Why will the poor farmers go for it? They have no other alternative. So, they set fire on crop residues." (FGD-2)

Pregnant Women

Pregnant women are seriously concerned about stubble burning. They are worried about their health and more anxious about their fetus and infants. They have several physical and mental health problems during and after stubble burning. They are also concerned about their infants and children.

"Stubble burning might save some money. But it is harmful to the baby inside me. I can not breathe properly. I can not eat properly. I can not live my normal life during stubble burning. How can my baby inside me can be well?" (FGD 1)

"My asthma could affect my baby inside me. I am taking so much medicine. I have so many health problems due to stubble burning. I am worried about my baby's health. " (FGD 1)

"If I cough all the time, how will my baby inside me be well? If I can not eat and drink properly, feeling nauseous all the time, how will my baby inside me grow properly and be healthy? I am now seven months pregnant. It is my precious child as I conceive first after many years of our marriage. I am always worried about my baby's development and wellbeing. We want a healthy baby……..." (FGD 1)

Middle-aged Villagers

The middle-aged (approximately 45 to 60 years old) villagers are very concerned about the future of their health, their family's health, their well-being, and the environment.

" We live in a bad generation. We have extended families, including children and children, parents and even some grandparents. Stubble burning is affecting all. Every year, it is the same problem. However, the health toll has been over the years. There is a high burden of so many diseases on our families. We are getting poorer by means of health and money……..." (FGD 3)

" The biggest problem is infertility. I think the stubble burning has increased infertility in our villages. Now, there are 'infertility clinics' everywhere. It has become a booming big business now in Punjab. Why? It is mainly due to stubble burning. The air, water, soil, and ecosystem are all destroyed by the name of either money saving or money earning. We do not care about health. Only money! Cancer and infertility are there which are mainly caused by the stubble burning" (FGD 4)

"Our health and economy both are in danger. We spend money on health expenditure. We save money by stubble burning. What is the meaning? Health is wealth. Once we lose health, we lose all. But we do not think it. We try to save money by stubble burning. But spend more money on health. This is not justifiable……" (FGD 4)

"The combine harvester cuts the rice straws up to certain level. They machine operators are cautious if the blade gets damaged from stones of other hard ground objects. The repairing costs a lot. The operators asked farmers that they will cut it not from ground. At least 10-12 inches above the ground. The farmers agreed. The 10-12 inches crop residues including stems and roots remained there. Happy seeders costs 2200 – 2500 INR to manage those residues. But we do not have money to pay the at costs. We burn it knowing the bad effects of stubble burning." (FGD 4)

Old and experienced Villagers

The old people have different opinions on stubble burning. They blame the young and middle-aged people. They are also very frustrated with the young generations' health behaviour and attitude for short-run gains.

"Infertility has increased up to 90% during the last two decades. Look at the Punjab healthcare scenario: how many infertility clinics are there? Infertility clinics are in every corner. They are the most profitable business here. Why? Because of infertility. Why is it so high infertility? Just because of stubble burning. Yes, it is due to stubble burning. No one cares. This is the irony of us." (FGD 4)

"The young generation is very lazy. They are busier with mobile phones, friends, and motorcycles than our generation, who put more labour in the field. We also had crop residues. We cut them by hand and saved the nature and ecology. They are using machines and not labourious like us. They should understand and put labour on the crops….." (FGD 4)

Village leaders and Decision-making authorities

Stubble burning became a tradition. One factor is the delay in paddy cutting and the urgency of preparing the field for wheat harvesting. The other factor is that the farmers also have a short period of time when they need funds. Therefore, they resort to setting fire to their rice crop waste. Agricultural officers vividly described the problem.

"To quickly prepare their fields for wheat harvesting, the farmers burned the rice crop residues" (Respondent 4)

"The relatively rich farmers with large acres of land holding manage wisely and generally do not burn stubbles. They use machines and rice

stubbles for economic opportunity generations, as they can invest money. The small and medium-level farmers lack money. The rice stubbles are a real burden to them. They also have other time-consuming opportunities. However, the farmers take the shortest way with minimum investment to burn the crop residues……..” (Respondent 11)

“We are trying our best with the police. However, it is getting more and more hide-and-seek game between us and the farmers.” (Respondent 8)

“…….You know, the farmers are very smart. To save money, they mainly burn the stubbles at dusk or in early morning time. Do you know why? To cheat the surveillance system…...” (A senior official)

DISCUSSIONS

The results from this study show a decrease in health-related quality of life (HRQoL) and significantly increased household expenditures on health in the Punjabi population after stubble burning exposure. This is in line with earlier research (e.g., Kumar et al. 2015; Novotny et al. 2015), but the present study's design renders results that extend previous research.

A comparison of HRQoL before and after stubble burning in less prevalent areas was almost the same, while the same comparison in core areas showed a significant decrease. The consequences for the families in the core areas were not only health related but also had consequences for catastrophic health expenditure, which was more than twice as much in core areas.

Stubble burning was related to negative health and to the economic situation of the families in the area.

Stubble burning has consequences for air, water and soil pollution (refs) and data were collected in the four regions in different locations such as road, farm and house.

We look at several pollution measures to highlight the differences in pollution before and after stubble burning in the different regions. We observe that even if two of the districts were chosen as controls (Patiala and Ropar), they were not unaffected by stubble burning. All measures of pollutants in the four regions increased, but the rise in Moga and Sangrur was exceptional, reaching levels that could cause severe respiratory and cardiovascular health issues. An exception was Patiala, where the CO increased by almost 5900 per cent, which was the highest figure among the four regions. Even Ropar, being a less prevalent region in terms of stubble burning, increased also experienced CO levels of 1900 per cent, reaching levels that have severe consequences for health.

The results from the analysis of the district-wise air quality, pre and post stubble burning, show that all the measures (PM-2.5, PM-10, AQI, CO, CO2, HCHO, TVOC) were significantly higher on roadside, house and farm, post stubble burning in Moga and Sangrur as well as in the districts of Patiala and Ropar, chosen as less prevalent areas in relation to stubble burning.

Some of the toxic components needs extra attention, such as PM-2,5 and PM-10, as children and pregnant women are more sensitive to Particulate Matter with diameter less than 10 microns, and the consequences can affect also the fetus severely (Isaevska et al. 2021).

It is well known that stubble burning causes health problems such as respiratory diseases and cardiovascular diseases (Kumar et al. 2015). The results in the present study showed that breathing issues were the most common problem followed by irritation in the eye, cough and also indigestion.

The increased rate of indigestion is less recognized in the literature, but could be due to the deteriorated quality of the water and soil after stubble burning (Thakur et al. 2022).

Health issues were measured during three phases: before, during and after stubble burning in the four regions. The analysis not only show that the health issues increased during the stubble burning period, but also that the health issues were more prevalent after stubble burning, and not returned to the pre stubble burning level. It indicates that health issues become aggregated and that stubble burning has long term consequences for health in the population. The adverse health impact causes problems for the individuals and can lead to increased household expenditures on health, as the present study shows, but it can also affect their

productivity at work (Novotny et al. 2015) which, in the long term, affect the prosperity in the whole community.

Other long-term consequences are those affecting particularly pregnant women, foetuses and children.

The migrant labourers were more or less the same age as the Punjab residents, but their earnings were lower. Migrant workers also belong to a socioeconomically vulnerable group and many of them are illiterate. From a socioeconomic perspective, it could be expected that the migrant workers' health status would be lower than the general population in the area, as health is related to socioeconomic position (Fuhrer et al. 2002). On the contrary, the health of the migrants was more positive, likely due to the fact that they had not been exposed to stubble burning.

This shows the importance of including migrant workers as participants in the study, as few people in the Punjab region are unaffected by stubble burning.

There are laws against stubble burning in India and policies that provide necessary solutions to stubble burning. There are also scientific and technological solutions to the problem with stubbles from rice and crops, but farmers are not ready to change their behaviour unless they have enough knowledge and awareness of the problems (Mor et al., 2023) or have better economic conditions to cope up with the issues of stubble burning. A more inclusive approach could reduce the stubble burning.

A comparison between the regions with a high and low degree of stubble burning, respectively, shows that the awareness of the negative consequences is higher in

regions with less stubble burning. A suggestion is, therefore, to increase knowledge about the negative consequences in regions where it is more common.

The same relationship between the regions was shown in relation to the positive aspects of stubble burning indicating that there is a need to increase general awareness of stubble burning and its health consequences, , particularly in regions with more stubble burning.

Discussions about stubble burning in the family in less prevalent areas of stubble burning was overall, not a prioritized subject, but it seemed to be more prevalent in family discussions in high prevalence districts.

The community level is important as discussions at that level have the potential to affect discussions in the family. It was observed as more important to have discussions at the community level in high-prevalent district compared with less prevalent districts, indicating that there is a susceptibility to initiate more discussions at the community level in these districts.

Even if the health hazards of stubble burning were extensive and serious discussions of the negative consequences were rare at the community level, it was more common in high prevalence districts. It is possible that there is a higher readiness for discussions of negative consequences of stubble burning in high-level districts.

As stubble burning is prohibited by the law, but shows a low compliance in rural areas, we asked about the awareness of government schemes. Interestingly, a higher degree of respondents reported being well-informed in high prevalence districts compared to low prevalence districts.

Many of the migrants who work in the chosen sample districts were, unexpectedly, aware of the negative consequences of stubble burning and a majority thought that it has adverse health consequences, i.e. they seemed to be more informed than the people who live in the area.

The interviews with the different respondents deepened the understanding of the problems the farmers and their families face in relation to stubble burning.

Even if the farmers burn stubbles, they seemed to understand the problems it causes, but they also suggested some possible solutions. It is learnt from the interactions that Basmati rice is more eco-friendly, the production needs less water and it is digestible for cattle, who also produces more milk when they eat the stubbles from Basmati compared to other food.

For those who cannot afford to take care of the stubbles, they requested innovations to make effective use of rice stubbles to create economic values, otherwise they need economic support for getting rid of the stubbles and transport them to another place. They also talked about the government restrictions, i.e. structural factors, that lead to stubble burning as the restrictions do not give them any choice.

Teenagers and students in higher education were highly affected by the stubble burning and the chemicals used in the cultivation. They could see the consequences for health and other problems, such as young people leaving rural areas. They seemed to perceive it as a vicious circle that needed to be changed, although they did not have any influence on the situation. Even if the families save money when they burn the stubbles, they lose money on the other end through high costs for health expenditures.

Pregnant women were more worried about their unborn child and their children than about their own health, and they seemed aware of the fact that they are more sensitive to different health hazards than adults (Isaevska et al. 2021).

At the same time, as there are more risks for foetuses and children, the villagers thought that infertility was a significant problem in the villages, and they blamed the stubble burning. There is, so far, no scientific evidence for such a causality, but there are studies showing that air pollution could affect fertility among women (Conforti et al. 2018), and it is, therefore, likely that there also is an increased risk for infertility due to stubble burning. Future studies should also include men in the analysis as air, water and soil pollution could also affect their reproductive organs.

While people living on the farms could see structural factors that increased the risk for stubble burning, village leaders and decision-making authorities discussed it more from an individual perspective, even if they also understood that the lack of money is part of the problem.

In sum, the analysis of the qualitative data informs us of the high awareness of the problems with stubble burning but also that changes in governmental restrictions and some financial support could break a vicious cycle, where the burning of stubbles lead to the saving of money in the short perspective and not are taken away as catastrophic health expenditures, which have far more long term adverse health consequences.

One of the advantages of our study is the collection of data in the rural areas where the stubble burning occurs, as the health hazards are more prevalent than in urban areas.

Conclusions

Stubble Burning severely impacts air quality in Moga District, substantially increasing harmful air pollutants across all four locations studied. Health risks increased due levels of pollutants like CO, CO2, PM2.5, and HCHO, which pose significant health risks, especially to sensitive groups (e.g., children, elderly, and those with respiratory issues). All locations in Patiala District show significant increases in air pollution indicators after stubble burning, with the most notable increases in **CO** and **CO2**. The highest increases in all parameters post-stubble burning were experienced **in Bela** village. The **Air Quality Index (AQI)** and pollutants like **CO, CO2, HCHO, and TVOC** showed extreme increases, indicating a significant deterioration in air quality. **PM2.5** and **PM10** levels were elevated across all sites, with **Makowal** and **Phassa** showing notable rises in particulate matter.

The health-related quality of life (HRQoL) was found to decrease in the Punjab population. Stubble burning influenced the health of villagers including children, elderly and pregnant women, and seasonal workers such as migrant labourers on agricultural fields. Participants reported increase of several types of severe health problems during periods of stubble burning, such as breathing issues, respiratory allergies, lung diseases, indigestion, eye irritations, and skin rashes, but also infertility. The economic cost for households increased due the health problems.
The economic conditions affect how farmers manage crop residues in the fields.

Those who had larger land areas could invest in machines to work effectively with crop residues, while those with less financial resources continued with the tradition of stubble burning, despite the health risks, to save time to quickly get started the next harvesting period.

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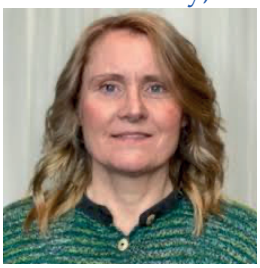

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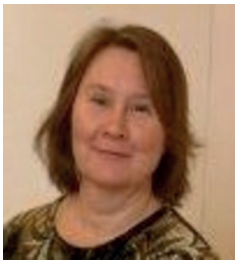

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