**“Mapping of Green House Gases Emissions from Agriculture Residue Burning in Madhya Pradesh”**

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Abstract: *The Greenhouse Gases makes up about less than 0.1 % in the Total Atmosphere. The main Greenhouse Gases include: Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), Sulphur Hexafluoride (SF6), Hydro Fluorocarbons (HFCs), Per Fluorocarbons (PFCs), as well as Ozone Depleting Chlorofluorocarbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) these latter two gases are not covered under the Kyoto Protocol. Among all, Carbon Dioxide is the most dominant and leading Greenhouse Gas. Greenhouse Gases (GHGs) Traps Heat in the Atmosphere, causing the Earth's Surface Temperature to rise. To reduce Greenhouse Gas (GHGs) Emissions, there is an urgent need to identify where the emissions are coming from, so to develop a plan to reduce them. This paper covers* ***Madhya Pradesh GHGs Emission*** *rate data with respect to Kharif and Rabi Crops that causes major Crop Residue Burning and also ensure future work so that emissions are actually reduced. This research paper aims to identify some of the key points of GHGs inventory preparation and mitigation strategies after the crops are harvested, crop residues are produced in Madhya Pradesh which emits Greenhouse Gases annually as a result of Burning Crop Residue, of which approximately* ***5291.045 Gg/yr of Carbon Dioxide****,* ***19.427 Gg/yr of Methane****, and* ***0.33059 Gg/yr of Nitrous Oxide*** *are released annually. Additionally, the effects of various Greenhouse Gases are compared over a 20-year period. These gases generate global warming, often known as the greenhouse effect, which can lead to Climate Change.*

Keywords: *Crop Residue Burning, GHGs, Climate Change, Global Warming, GHGs Emissions.*

**I. INTRODUCTION**

The *Greenhouse Gases* are toxic to life on *Earth* because of their ability to act like a blanket, trapping some of this *Infra-Red Radiation* and preventing it from escaping back into space, without this process the *Temperature* on the *Earth’s* surface would be very much colder. This concentration of *Greenhouse Gases* in the *Atmosphere* has developed as a result of *Human Activity* and this process would appear to be disturbing the natural balance between *Incoming* and *Outgoing Energy*. A layer of *Greenhouse Gases* are primarily water vapor and much smaller amounts of Carbon Dioxide, Methane and Nitrous Oxide absorbing *Heat* and *Warming* the surface and act as a thermal blanket on the *Earth*. The influence of Burning Agricultural Residue on Greenhouse Gas Emissions and Climate Change in Madhya Pradesh is the main topic of this work. Greenhouse Gases (GHGs), such as Carbon Dioxide (CO2), Methane (CH4), and Nitrous Oxide (N2O), are released when Agricultural or Crop Waste is Burned. ***Madhya Pradesh*** emits around of greenhouse gases annually as a result of burning crop residue, of which approximately 5291.045 Gg/yr of Carbon Dioxide, 19.427 Gg/yr of Methane, and 0.33059 Gg/yr of Nitrous Oxide are released annually. Additionally, the effects of various greenhouse gases are compared over a 20-year period. The Greenhouse Effect, or Global Warming, which might lead to Climate Change, is caused by these gases. During burning activities, different air pollutants are released depending on the crop and the weather.

 *Awasthi et al. (2011)* noted that burning rice stubble frequently contributes more to PM2.5 than PM10 and reported a greater proportion of PM2.5 of around 55% to 64% of total RSPM during this time. In their 2010 study, Singh et al. *(2011)* examined the greater levels of organic tarry matter in the ambient air during the burning of *Rice* and *Wheat Crop Residues* in Patiala compared to the Non-Burning Period. They found that burning Rice Stubble had more organic tarry matter than burning Wheat Stubble. *Hays et al. (2005)* investigated the physical and chemical characteristics of particle-phase emissions from stimulated open burning of agricultural biomass and discovered that while particulate matter Emissions from Rice are primarily composed of Carbonaceous Matter (~84%), those from Wheat are enriched in K+ and Cl- (~31% and ~36%). *According to Tang et al. (2013)*, during the open Agricultural Residue Burning period in central eastern China, ozone levels increased by 39% on sunny days and 27% on wet days. *Kharol et al. (2012)* studied the Concentration of Black Carbon (BC) in Patiala, India, and found that the agricultural burning activities enhanced the aerosol loading and BC concentration.

 Global Warming is due to Greenhouse Effect that results when the atmosphere Traps/Absorbs *Heat Radiation* from *Earth* towards space. Certain *Gases* in the atmosphere behave like the glass in *Greenhouse*, allowing *Sunlight* to enter, but blocking *Heat* from *Escaping Out*. Gradual Rise of the *Earth's* *Surface Temperature* causes by the *Greenhouse Effect*. The Snow-White surface of a glacier reflects a significant portion of *Solar Radiation* back into space, thereby minimizing *Surface Heating* on the *Ice*. In contrast, Dark Soil absorbs *Solar Radiation Intensively*, contributing to significant warming of the surface and Emitted Radiation. Additionally, *Cloud* cover influences the *Greenhouse Effect* by reducing both the amount of Solar Radiation reaching the *Earth's* surface and the amount of radiant energy emitted into space. This process influences the *Climate*, causing changes in weather patterns, sea levels, and other aspects of the *Environment*. Combating *Climate Change* involves reducing *GHGs Emissions* and exploring *Sustainable Solutions* for the *Future*.

Agriculture: *Burning Agricultural Residue*, *Raising Livestock*, and growing rice are three practices that increase carbon emissions. *IPCC* techniques were used to assess emissions from the agriculture sector. “The emissions from burning agricultural residue for the year 2005–06 were calculated taking into account the standard crop residue ratio [20], Dry Matter Fraction, Percentage Actually Burned, Fraction Oxidized, CH4 *Emission Factor*, CO *Emission Factor*, and CO2 *Emission Factor*.

Table 1: Emission Factors (g kg-1Dry Matter Burnt) for various types of Burning. (Source: https://www.ipcc-nggip.iges.or.jp/)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Category  | CO2  | CO  | CH4  | N2O  | NOX |
| Savanna and Grassland  | 1613 ± 95  | 65 ± 20  | 2.3 ± 0.9  | 0.21 ± 0.10  | 3.9 ± 2.4 |
| Agricultural Residues  | 1515 ± 177  | 92 ± 84  | 2.7  | 0.07  | 2.5 ± 1.0 |
| Tropical Forest  | 1580 ± 90  | 104 ± 20 | 6.8 ± 2.0 | 0.20 | 1.6 ± 0.7 |
| Extra Tropical Forest  | 1569 ± 131  | 107 ± 37  | 4.7 ± 1.9  | 0.26 ±0.07  | 3.0 ± 1.4 |
| Biofuel Burning  | 1550 ± 95  | 78 ± 31  | 6.1 ± 2.2  | 0.06  | 1.1 ± 0.6 |

 Key Gas Emissions from different *Biomass Burning Operations* are compared in the table above. Savanna and Grassland had the highest CO₂ emissions, with 1613 ± 95, whereas agricultural residues have somewhat lower amounts. Strong greenhouse gas CH₄ maxima in biofuel burning (6.1 ± 2.2) and tropical forests (6.8 ± 2.0). The greatest CO emissions are seen in Tropical Forest (104 ± 20) and Extra Tropical Forest (107 ± 37). Even though N2O is a major greenhouse gas, it is only released in trace levels; the greatest value (0.26 ± 0.07) is found in Extra Tropical Forest. Savanna and grassland have the highest NOₓ emissions (3.9 ± 2.4), whereas burning biofuel produces the lowest (1.1 ± 0.6).

 In addition to contributing significantly to the *Global Warming Potential (GWP)*, *Soil Emissions* are essential for comprehending and reducing the effects of agricultural activities on *Climate Change*. 21% of nitric oxide (NO), 53% of *N2O*, 35% of *CO2*, and 47% of *CH4* are emitted by soil, which greatly contributes to *GWP* and emphasizes how crucial it is to measure these emissions precisely for global budgets. Anaerobic conditions are necessary for the soil to produce *CH4*. Additionally, it is affected by elements like bulk density and carbon content. With a *GWP* of 265 over a 100-year period, *N2O* is produced via nitrification and denitrification processes, with nitrification being enhanced by soil transitions from wet to dry and denitrification being promoted by soil rewetting. By applying cover crops, lowering soil disturbance, increasing carbon absorption, applying sustainable tillage techniques, and developing soil structure can all help reduce emissions from agricultural soils. A low GWP can thus be achieved by reducing *N2O* emissions. Using *Sustainable Agricultural Techniques* *Including Organic Farming, Site-Specific Nutrient Management*, and *Fertilizer Optimization* can help lower soil emission. In addition to lowering GHG emissions, these techniques improve crop yields, strengthen soil health, and foster the development of *Sustainable* *Agriculture*.

 Both a source and a sink of *Greenhouse Gases*, agricultural soils have the capacity to retain large amounts of *Organic Carbon*. The soil has a significant role in GHG emissions, since around 10% of atmospheric CO2 travels through it each year. Agriculture is a major source of greenhouse gas emissions, accounting for almost 80% of N2O emissions and 70% of *Ammonia* (*NH3*) Emissions from Human Activities.

Moreover, *Enteric Fermentation* in *Agricultural Processes* accounts for almost 40% of anthropogenic *CH4* emissions. In fact, the exchange of greenhouse gases with the atmosphere and the global carbon cycle both heavily depend on the soil. Thus, this study's goal is to provide a thorough explanation of how *Agricultural Residue*has increased the atmospheric burden of *Greenhouse Gases (GHGs)*, as well as the main causes of *GHG* emissions. More importantly, though, is to show how future sustainable management practices can aid in lowering the amount of *GHGs* that accumulate in the atmosphere, which is covered in the next section.

 The primary “*Greenhouse Gas* in the earth's atmosphere is *Carbon Dioxide (CO2),* whose emissions are thought to make up 55% of the atmosphere. This is quite low when compared to the concentrations recorded in 2015 and 2018. Comparing data from 2015 and 2018, the concentrations of *Methane (15%)* and *Nitrous Oxide (6%)*, in addition to CFC and other substances (7%), are likewise low.

 Regular Burning Reduces the Soil's ability to hold Carbon and Nitrogen, kills off the beneficial microflora and Fauna, and further removes a large amount of Organic Matter. Burning crops completely upsets the Carbon-Nitrogen Balance of the Soil. According to NPMCR, when one ton of Straw is Burned, all of the Organic Carbon, 5.5 kg of Nitrogen, 2.3 Kilogram of Phosphorous, 25 kg of Potassium, and 1.2 kg of Sulfur are destroyed. 20% Potassium (K), 50% Sulfur (S), 25% Phosphorus (P), and 80% Nitrogen (N) are commonly found in crop residue from a variety of crops. If left in the ground, the *Agricultural Waste* can enhance the *Soil*.

II. Literature Review

To address this issue, *Kabange, N. R., Kwon, et al. [****10****]* proposed policy measures and the use of technological interventions that have been overlooked for years. “Among them, it can mention stringent policy measures such as (i) By banning crop residues; (ii) By promoting the technologies for optimum utilization and in-situ management of crop residue, to prevent loss of valuable nutrients or diversify uses of crop residue in industrial applications; (iii) By developing and promoting appropriate crop machinery in farming practices such as modification of the grain recovery machines (harvesters with twin cutters to cut the straw); (iv) By providing discounts and incentives for the purchase of mechanized sowing machinery such as the happy seeder, shredder and baling machines; (v) By using satellite-based remote sensing technologies to monitor crop residue management, involving the designated government agencies; and (vi) By providing financial support through multidisciplinary approach and fund mobilization for innovative ideas and project proposals.

According to *Devi, S et al. [****5****],* aerobic well-drained soils are generally a sink for CH4, due to the high CH4 diffusion rate into such soils and subsequent oxidation by methanotrophs. The capacity of soils to uptake CH4 varies with land use, management practices [**14**], and soil conditions [**15**]. In contrast, large CH4 emissions are usually observed in anaerobic conditions, such as wetlands, rice paddy fields, and landfills. Warm temperatures and the presence of soluble carbon provide optimal conditions for CO2 production and incompletely oxidized substrates, thus enhancing the activity of methanogens. Likewise, a close relationship between the increase in atmospheric CO2 levels and the subsequent increase in CH4 emissions has been proposed. In this regard, studies suggested intermittent drainage to reduce the activity of anaerobic methanogens in the soil, especially in flooded crop cultivation systems, which may have a direct impact on the amount of CH4 produced and released by up to 80%. Although in-season or intermittent drainage can result in a significant reduction in CH4 production and emissions, this crop management technique aiming to mitigate CH4 emissions can cause increased N2O emissions, even if the overall warming potential remains lowered [**9**].

*Bhuvaneshwari et al (2019)* observed the effects of Soil Moisture, Temperature, Bulk Density and Particle Density on CO2 Emission and CH4 uptake from Old-Growth Forest Soils in Boreal Coniferous Forest, Temperate Needle-Broad Leaved Mixed Forest, Subtropical Evergreen Broad Leaved Forest and Tropical Monsoon Rain Forest along Eastern China. Apart from that, they also highlighted that, Soil CO2 and CH4 Fluxes were driven by many Environmental Factors including availability and amount of C Substrates, Temperature, and Soil Water Content, Redox Potential and Aeration, Diffusion, Soil Texture, Soil pH, Salinity, Ion Deficiencies and Toxicities and Elevated CO2 and atmospheric N Deposition.

*Badarinath, K (2006)* explained CH4 Emission from Wetland and CH4 Uptake in Upland Soil. Moreover, Yan et al. (2008) concluded that soil CH4 is Influenced by Soil Moisture and Inversely Correlated by *Soil Temperature*. Three Treatments were set in the *Studied Field*: (A) Litter-Free, (B) with Litter, and (C) with Litter and Seedling. A Strong Positive Relationship occurred between CH4 Fluxes and Soil Moisture in all the Three Treatments, and Weak Relationship between CH4 Fluxes and Soil Temperature for Treatment B and Treatment C. The N2O Fluxes Correlated with Soil Temperature for all the *Three Treatments*.

*Alvarado et al. (2011)* observed Soil Respiration and Methane Flux from Adjacent Forest, Grassland and corn field by using the *Closed Chamber* method from June to November 2019. The Forest Soil absorbed *Methane* at a rate range from -0.12 to -0.02 mg C m-2h-1 , while the Grassland Soil Emitted Methane at the range from Undetectable Levels to 0.18 mg C m-2h-1. Linear Regression Analysis demonstrated that the Methane Flux Rate was Positively Correlated with the Soil Water Filled Pore Space and Negatively Correlated with Gas Diffusion Coefficient and Air Filled Pore Spaces. The Soil Respiration Rate is Positively Correlated with the Soil Temperature at all there sites.

# 2.1 Problem Formulation

Trends shows that increasing in emission of GHGS causes various environmental problems are mainly responsible for climate change adverse effect hence it is important to minimize it emission. For incressing in emission trends various human activity is responsible, hence in this study we have focused on emission increased due to agricultural burning of residue in mp region which may be helpful in identifying the area responsible for adverse impact and easy for formulation of agricultural management policy.

The correlation between air pollution due to agricultural residue burning and respiratory problems in vulnerable population is studied by Agarwal et al. (2012) and highlighted that air pollution influences the respiratory symptoms. The association between pollutant emissions from rice straw burning and daily hospital admission due to asthma was investigated by Agarwal et al. (2012) and reported that with increase in burning activities risk of asthma hospital admission increases. Agarwal et al. (2012) studied the health effect of exposure of rice and wheat stubble burning in 50 healthy subjects in rural agricultural area and highlighted that increase in particulate concentration during burning period had significant effect on pulmonary function tests and children are more vulnerable to the elevated pollutant concentrations.

III. RESEARCH METHODOLOGY

This section illustrates the flow of *Proposed Methodology*.

### 3.1 Agricultural Activity Data

From 2011 to 2020, *Crop Statistics* were sourced from the Crop Production Statistics Information System (https://www.aps.dac.gov.in). The *Statistical Data* includes information on the area under Cultivation, Yield, and Production of Crops Cultivated in MP for each of the relevant *Seasons*. We have chosen crops with CRB potential based on *IPCC* Guidelines, Existing Research, and Ground Surveys because not all Agricultural Residue is Burnt (IPCC, 2006).

 Five Crops—Wheat, Rice, Soybean, Maize, and Groundnut—are identified as important contributors to CRB because of their *High Production* potential Residue-to-Crop Ratio and the Dearth of Alternative, Reasonably Priced Residue Management Techniques. District-by-District seasonal inventories for 2011–2020 have been created for the five crops selected for further research. We estimated the *Crop-Wise Contribution* of total ABA by using Census Data to calculate the percentage of area under cultivation for each crop.

### 3.2 ABA Extraction from MODIS BA

In order to extract ABA from Existing Global-BA products, we employed the Deshpande et al. (2022b) technique. “The Cloud Computing Platform of Google Earth Engine is used for the study (Gorelick et al., 2017). In order to produce monthly BA at 500 m resolution, the MCD64A1 Global BA product combines MODIS *Surface Reflectance Data* (500 m) with MODIS Active Fire observations (1 km). Analyzing the two main agricultural seasons, Kharif and Rabi. This is because most agricultural fields in MP grow crops during the two main growing seasons, while CRB often occurs in areas that are Double-Cropped (or more).

 The MOD13A1.061 Terra and MYD13A1.061 Aqua Vegetation Indices products, which are available at 16-Day Intervals, were used to produce these Phenologies using NDVI (500 m). Following the application of our masks, we were able to create Seasonal ABA Products by combining our monthly ABA Estimates. We created a *State-Wise Crop Calendar* based on state cultivation calendars, GoI-recommended sowing dates, and a literature assessment in order to provide regionally-appropriate ABA seasonal data. Table 2 displays the specifics of the seasonal separation for the CRB that was employed in this investigation. The final products are retrieved at the district level between 2011 and 2020. For instance, the Kharif burning season is when crop leftovers from Kharif crops are burned, the Rabi burning season is when residues from Rabi crops are burned, and so on with other seasons. The burning season is called after the cultivation season in which the crop wastes are burned.

### 3.3 Validation for ABA Extraction Methodology

Using *High-Resolution* (3 m) estimates of BA obtained from Madhya Pradesh's PlanetScope data, we verified the ABA extraction process. For this study, we chose 40 sample polygons bigger than 55 ha to represent Madhya Pradesh's burnt and unburned lands. We then used these data to train and validate a Random Forest Classifier in GEE. We did not collect burn scars 500 meters or less from forested areas to avoid forest fires influencing our training and validation data. Through hyperparameter change, the optimal number of decision trees was found to be 150, and a 70:10:20 ratio was created for classifier training, validation, and hyperparameter tweaking.



Figure 1: Study Area Map.

### 3.4 Determining Emissions estimation

We computed district-wise CO, CO2, CH4, and N2O Emissions from Burning Agricultural Residue over MP for the Kharif and Rabi seasons 2011–2020 using the IPCC (2006) inventory preparation criteria and worldwide fire emissions estimates for 1997–2016 (IPCC, 2006). The Global Warming Potential of CO2e was also computed using CO2, CH4, and N2O (IPCC, 2024) (Table 2).

Table 2: Global Warming Potentials of Pollutant.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Compound Name | Formula | Source | Application |  | GWPs |
| Carbon Dioxide | CO2 | Natural | Human Respiration  |  | 1 |
| Methane | CH4 |  | Bacterial Activity |  | 273 |
| Nitrous oxide | N2O |  | Fertilizers Wastes |  | 310 |

CO, CO2, and CH4 are used to determine *Carbon Content (CC),* assuming that these gaseous pollutants account for the majority of carbon emissions during burning. The following formula is used to estimate the emission of various pollutant species, Espec (in Gigagrams, *Gg*), from CRB:

*Espec* **=** *RpAaba* *FcultFdm* *Eb* *Femiss*  (1)

where *Rp* is the crop-specific residue production (kg/ha), *Aaba* is ABA (ha) extracted from the MODIS BA products, *Fcult* is the fraction of crop-specific area out of the total area under cultivation for all selected crops, *Fdm* is a dry matter fraction specific to the crop that accounts for the moisture content of the residue during harvesting, *Eb* is burn efficiency for which a constant value of 0.90 has been used, and finally *Femiss* is the emission factor in grams per kg of agricultural DMB, which is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant”. All the conversion factors have been listed in Table 3.

Table 3: List of Conversion Factors used in the present study.

|  |  |  |
| --- | --- | --- |
| *(A) Crop-wise convection factor for calculating Dry matter burned* |  | *(B) Species-specific emission fractions* |
|  |  |  |  |  |  |  |
| *Crop* | *Fresd* | *Fdm* | *Eb* |  | *Pollutants* | *Femiss (g/kg)* |
| Rice  | 1.40 (1.30–1.50) | 0.86 | 0.90 |  | CO  | 102 |
| Wheat | 1.60 (1.50–1.70) | 0.83 (0.78–0.88) | 0.90 |  | CO2 | 1585 |
| Maize | 1.50  | 0.88 | 0.90 |  | CH4 | 5.82 |
| Groundnut | 2.00 | 0.80 | 0.90 |  | CC | 480.352 |
| Cotton | 3.00 | 0.80 | 0.90 |  | N2O | 0.1 |
| Jute | 3.00 | 0.80 | 0.90 |  | Carbon Content (CC) was estimated from CO2, CO, and CH4 |
| Soyabean | 1.8 | 0.87 | 0.90 |  | EFs[e](https://www.sciencedirect.com/science/article/pii/S0048969723055699%22%20%5Cl%20%22tf0025) |  |

Residue production (*Rp*) is estimated using the following equation:

 Rp=Pcrop×Fresd (2)

 Acult

where F*resd* is the crop-specific production to residue ratio, A*cult* is the crop area under cultivation, and P*crop* is the total crop production (in *Kilograms*) for each district. A comprehensive review of the literature was done to determine the optimal F*resd* values for each crop that was selected (IPCC, 2006; Venkataraman et al., 2006). We have looked at two selection criteria for these numbers from the literature: the mean value from a maximum-minimum range or the value that is most well known in the literature”.

### 3.5 Comparison with other Emission Inventories

We computed “MP *District-level Agricultural Residue Burning Emissions (DARBE)* annual emissions for 2011–2020 and contrasted them with current worldwide inventories. Using the agricultural land type masks used to build DARBE, we computed emissions from the inventory data that were only caused by burning agricultural residue at a resolution of 0.10.

# 3.6 Data Analysis

### Report of Actual Burning Area (ABA) 2011-2020 in Hectare

**Table 3: Crop Statistics for Actual Burning Area (ABA) 2011-2013 in Hectare.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| FID | **District** | **Rabi1011** | **Rabi1112** | **Rabi1213** | **Kharif1011** | **Kharif1112** | **Kharif1213** |
| 1 | Agar Malwa | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Alirajpur | 987.8319852 | 621.1069281 | 0 | 0 | 0 | 0 |
| 3 | Anuppur | 22.92705156 | 0 | 0 | 0 | 0 | 0 |
| 4 | Ashoknagar | 294.9283797 | 135.6761125 | 1244.379114 | 0 | 0 | 0 |
| 5 | Balaghat | 115.62465 | 138.7662641 | 0 | 0 | 0 | 0 |
| 6 | Barwani | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Betul | 4669.528142 | 6536.31242 | 0 | 0 | 0 | 0 |
| 8 | Bhind | 958.4656875 | 1181.344136 | 378.9303828 | 0 | 913.9418359 | 0 |
| 9 | Bhopal | 6911.702263 | 7030.025732 | 4495.928719 | 0 | 0 | 0 |
| 10 | Burhanpur | 5053.249255 | 5545.095882 | 0 | 0 | 0 | 0 |
| 11 | Chhatarpur | 3776.979476 | 6259.869826 | 1143.031313 | 0 | 0 | 0 |
| 12 | Chhindwara | 3165.896372 | 1159.747116 | 45.35241134 | 0 | 138.2390438 | 0 |
| 13 | Damoh | 9740.0718 | 14121.95907 | 3790.646419 | 0 | 45.69095 | 0 |
| 14 | Datia | 156.7702734 | 2330.189484 | 2769.744595 | 134.3818281 | 0 | 0 |
| 15 | Dewas | 15132.01906 | 10696.12801 | 3948.289812 | 0 | 0 | 0 |
| 16 | Dhar | 19986.36645 | 3547.672468 | 5774.397342 | 0 | 68.76484531 | 0 |
| 17 | Dindori | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | Guna | 2352.634688 | 4111.99595 | 1976.671485 | 0 | 0 | 407.7599594 |
| 19 | Gwalior | 12608.41683 | 9494.85433 | 14878.41038 | 447.8087172 | 7477.912004 | 4053.097088 |
| 20 | Harda | 56466.60314 | 54750.86202 | 10329.63522 | 0 | 0 | 0 |
| 21 | Hoshangabad | 161893.7266 | 166574.4136 | 52002.37246 | 0 | 183.7150047 | 0 |
| 22 | Indore | 18878.90201 | 12328.79352 | 10632.50783 | 0 | 0 | 0 |
| 23 | Jabalpur | 162.314229 | 4974.537351 | 1091.591252 | 1462.021413 | 6195.328816 | 9221.585803 |
| 24 | Jhabua | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | Katni | 1184.08028 | 5317.738816 | 1328.670027 | 0 | 0 | 168.4186073 |
| 26 | Khandwa | 9183.267257 | 27968.74569 | 4483.833044 | 0 | 0 | 0 |
| 27 | Khargone | 2963.082593 | 1181.630123 | 1475.305706 | 0 | 0 | 0 |
| 28 | Mandla | 965.9787469 | 528.9816391 | 0 | 0 | 0 | 0 |
| 29 | Mandsaur | 1107.209278 | 208.46204 | 170.8660795 | 0 | 0 | 0 |
| 30 | Morena | 0 | 0 | 44.58875313 | 0 | 45.6731298 | 0 |
| 31 | Narsinghpur | 3276.778712 | 1920.225813 | 7.622033597 | 0 | 0 | 894.6387016 |
| 32 | Neemuch | 791.9903234 | 3438.877445 | 1390.508642 | 1560.828997 | 0 | 0 |
| 33 | Panna | 2015.162529 | 12375.5163 | 7661.815575 | 0 | 0 | 0 |
| 34 | Raisen | 75287.28071 | 75645.13688 | 39713.23453 | 618.4554359 | 0 | 0 |
| 35 | Rajgarh | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | Ratlam | 0 | 91.42719531 | 45.54990469 | 0 | 0 | 0 |
| 37 | Rewa | 0 | 1685.640325 | 48.5342841 | 0 | 0 | 0 |
| 38 | Sagar | 3604.062616 | 6226.39618 | 535.832023 | 0 | 363.1149781 | 0 |
| 39 | Satna | 342.284584 | 2086.323666 | 2207.101483 | 0 | 0 | 0 |
| 40 | Sehore | 29769.88189 | 33951.6534 | 8875.787327 | 0 | 0 | 0 |
| 41 | Seoni | 13966.34074 | 13740.27643 | 6077.666567 | 0 | 0 | 0 |
| 42 | Shahdol | 478.7951578 | 0 | 0 | 0 | 0 | 0 |
| 43 | Shajapur | 98.72687159 | 251.0538656 | 296.7661734 | 0 | 0 | 0 |
| 44 | Sheopur | 5811.245333 | 31637.2443 | 17193.92218 | 2513.352222 | 3592.178145 | 3524.208102 |
| 45 | Shivpuri | 361.0696934 | 941.1200094 | 302.5864694 | 0 | 44.81754063 | 0 |
| 46 | Sidhi | 295.724525 | 19.25737279 | 0 | 0 | 0 | 0 |
| 47 | Singrauli | 356.396824 | 478.9467147 | 0 | 0 | 136.1787844 | 0 |
| 48 | Tikamgarh | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | Ujjain | 9894.838797 | 6993.628656 | 5780.883591 | 0 | 0 | 0 |
| 50 | Umaria | 660.9163766 | 1343.071033 | 0 | 0 | 0 | 0 |
| 51 | Vidisha | 26186.93428 | 25983.18273 | 17596.78003 | 591.4322141 | 0 | 0 |
| 52 | Niwari | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 4: Crop Statistics for Actual Burning Area (ABA) 2018-2020 in Hectare.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **FID** | **District** | **Rabi1718** | **Rabi1819** | **Rabi1920** | **Kharif1718** | **Kharif1819** | **Kharif1920** |
| 1 | Agar Malwa | 501.1288406 | 491.4986696 | 4071.418085 | 0 | 0 | 0 |
| 2 | Alirajpur | 0 | 145.0393788 | 0 | 0 | 0 | 0 |
| 3 | Anuppur | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Ashoknagar | 476.1070203 | 8911.291654 | 9153.172824 | 0 | 0 | 0 |
| 5 | Balaghat | 0 | 23.03300156 | 185.2639938 | 0 | 0 | 0 |
| 6 | Barwani | 0 | 0 | 0 | 0 | 4.805306054 | 115.2519906 |
| 7 | Betul | 8307.817773 | 1666.269283 | 0 | 0 | 0 | 0 |
| 8 | Bhind | 1047.278055 | 2259.998082 | 643.5312439 | 0 | 0 | 1082.85342 |
| 9 | Bhopal | 12453.52187 | 15737.37262 | 13178.54849 | 251.3440484 | 45.718875 | 0 |
| 10 | Burhanpur | 17858.94167 | 208.8031141 | 486.527975 | 0 | 0 | 0 |
| 11 | Chhatarpur | 4010.632953 | 6121.967704 | 3828.040254 | 0 | 0 | 0 |
| 12 | Chhindwara | 1868.237772 | 1574.77907 | 514.0612988 | 0 | 0 | 0 |
| 13 | Damoh | 11800.2652 | 7150.694655 | 4915.536304 | 227.3269 | 0 | 0 |
| 14 | Datia | 7448.605018 | 26285.97474 | 27449.91591 | 67.09347188 | 3266.679353 | 4488.730055 |
| 15 | Dewas | 7946.911314 | 8717.937726 | 17675.70382 | 137.6140531 | 0 | 0 |
| 16 | Dhar | 1830.342024 | 8063.881074 | 50275.61575 | 0 | 46.00523125 | 0 |
| 17 | Dindori | 137.4115719 | 0 | 0 | 0 | 0 | 0 |
| 18 | Guna | 0 | 22159.30637 | 13398.57252 | 1313.907338 | 0 | 0 |
| 19 | Gwalior | 2553.119508 | 22154.575 | 38826.22189 | 0 | 851.0151047 | 6718.708072 |
| 20 | Harda | 28314.99505 | 22208.39506 | 23799.45776 | 0 | 0 | 0 |
| 21 | Hoshangabad | 148709.177 | 153911.2825 | 139399.2063 | 3330.567497 | 2709.773756 | 4646.644133 |
| 22 | Indore | 16928.64499 | 27377.9424 | 50592.58813 | 0 | 0 | 0 |
| 23 | Jabalpur | 5367.994222 | 18748.19973 | 6331.240128 | 14392.11665 | 13269.38436 | 5141.144994 |
| 24 | Jhabua | 68.7329 | 152.9709422 | 0 | 0 | 0 | 0 |
| 25 | Katni | 2590.55337 | 1042.335046 | 435.2729213 | 0.089521765 | 145.2023922 | 296.749021 |
| 26 | Khandwa | 12691.45444 | 10936.55638 | 4205.461988 | 0 | 0 | 0 |
| 27 | Khargone | 5673.937919 | 1776.49122 | 408.0694895 | 0 | 0 | 0 |
| 28 | Mandla | 1311.25902 | 1802.264776 | 2564.40782 | 206.84655 | 0 | 0 |
| 29 | Mandsaur | 0 | 0 | 590.6571359 | 0 | 909.0823 | 0 |
| 30 | Morena | 535.2800078 | 357.0333672 | 191.8290279 | 445.8126672 | 0 | 937.295575 |
| 31 | Narsinghpur | 2536.280541 | 8466.031396 | 3677.161659 | 61.51865178 | 0 | 102.7118232 |
| 32 | Neemuch | 996.3651031 | 2127.150411 | 0 | 0 | 0 | 0 |
| 33 | Panna | 12473.2843 | 4791.330558 | 3542.324685 | 0 | 0 | 0 |
| 34 | Raisen | 86149.18176 | 109521.311 | 90728.70504 | 503.7429891 | 229.1071844 | 0 |
| 35 | Rajgarh | 0 | 22.73129219 | 40.24989248 | 0 | 0 | 0 |
| 36 | Ratlam | 925.7896387 | 4507.07966 | 4740.888612 | 0 | 0 | 0 |
| 37 | Rewa | 972.4900074 | 492.4535376 | 0 | 0 | 0 | 0 |
| 38 | Sagar | 1292.385145 | 4544.804197 | 4251.921537 | 0 | 0 | 0 |
| 39 | Satna | 4165.629649 | 4824.959864 | 6676.714473 | 0 | 0 | 0 |
| 40 | Sehore | 32390.05551 | 34779.4361 | 38204.47741 | 1451.569268 | 0 | 964.1495578 |
| 41 | Seoni | 19208.65756 | 30205.44909 | 42195.74439 | 3638.16622 | 2325.35817 | 0 |
| 42 | Shahdol | 501.6341703 | 410.2471922 | 0 | 0 | 0 | 0 |
| 43 | Shajapur | 0 | 182.6464125 | 3763.781832 | 22.87410156 | 0 | 0 |
| 44 | Sheopur | 17746.07823 | 34663.44187 | 45776.3185 | 20537.1803 | 27026.03075 | 44903.35357 |
| 45 | Shivpuri | 224.3912344 | 2977.828935 | 6496.158956 | 0 | 0 | 0 |
| 46 | Sidhi | 249.5948416 | 0 | 22.6632 | 0 | 0 | 0 |
| 47 | Singrauli | 1294.50602 | 0 | 0 | 113.5037078 | 0 | 0 |
| 48 | Tikamgarh | 0 | 356.6876099 | 1491.543958 | 0 | 0 | 0 |
| 49 | Ujjain | 9873.878074 | 24151.95692 | 51608.03608 | 0 | 0 | 0 |
| 50 | Umaria | 1481.799866 | 137.0054766 | 22.75143906 | 0 | 0 | 0 |
| 51 | Vidisha | 30953.68449 | 59228.86365 | 76741.28472 | 0 | 0 | 0 |
| 52 | Niwari | 0 | 61.47919249 | 367.5139302 | 0 | 0 | 0 |

### 3.7 Report of Uncetainty Analysis: from 2011-2020 (in Hectare) for Kharif and Rabi Crops

***Espec = Rp×Aaba×Fcult×Fdm×Eb×Femiss*** *(Deshpande et al., 2023)****(1)***

**Table 5: Emission Factors (Akagi et al., 2011).**

|  |  |  |  |
| --- | --- | --- | --- |
| Species | Femiss  | Uncertainty | % Uncertainty |
| CO2 | 1585 | 100 | 6 |
| CO | 102 | 33 | 32 |
| CH4 | 5.82 | 3.56 | 61 |
| N2O | 0.1 | x | x |

**Table 6: % Uncertainty (Deshpande et al., 2023).**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Crop | Pcrop (%) |  Acult(%) |  Fcult(%) | Fresd(%)  | Aaba(%) | Fdm(%) | Eb(%) |
| Wheat | 0.1 | 0.1 | 0.2 | 10 | 27 | 5 | X |
| Rice | 0.1 | 0.1 | 0.2 | 10 | 27 | 5 | X |
| Maize | 0.1 | 0.1 | 0.2 | 10 | 27 | 5 | X |
| Groundnut | 0.1 | 0.1 | 0.2 | 10 | 27 | 5 | X |
| Cotton | 0.1 | 0.1 | 0.2 | 10 | 27 | 5 | X |
| Jute | 0.1 | 0.1 | 0.2 | 10 | 27 | 5 | X |
| Soyabean | 0.1 | 0.1 | 0.2 | 10 | 27 | 5 | X |

Total % Uncertainty considering the variables of eq. (1) are Independent

**Utotal = √(*U*2*(Pcrop)+U2(Acult)+U2(Fcult)+U2(Fresd)+U2(Aaba)+U2(Fdm)+U2(Femiss))***

**Table 7: Total % Uncertainty.**

|  |  |  |  |
| --- | --- | --- | --- |
| Crop | CO2 (%) | CO (%) | CH4 (%) |
| Wheat  | 30 | 43 | 68 |
| Rice | 30 | 43 | 68 |
| Maize | 30 | 43 | 68 |
| Groundnut | 30 | 43 | 68 |
| Cotton | 30 | 43 | 68 |
| Jute | 30 | 43 | 68 |
| Soyabean | 30 | 43 | 68 |

Total % Uncertainty considering the variables of eq. (1) are correlated

Utotal, max = *U(Pcrop)+U(Acult)+U(Fcult)+U(Fresd)+U(Aaba)+U(Fdm)+U(Femiss)*

**Table 8: Total % Uncertainty.**

|  |  |  |  |
| --- | --- | --- | --- |
| Crop | CO2 (%) | CO (%) | CH4 (%) |
| Wheat  | 48 | 74 | 103 |
| Rice | 48 | 74 | 103 |
| Maize | 48 | 74 | 103 |
| Groundnut | 48 | 74 | 103 |
| Cotton | 48 | 74 | 103 |
| Jute | 48 | 74 | 103 |
| Soyabean | 48 | 74 | 103 |

IV. RESULTS AND DISCUSSIONS

Descriptive Statistics (Minimum, Maximum, Mean and Standard Deviation) of each data set of parameters are performed in this chapter.

### 4.1 Average GHG Emission

**Table 9: Average GHG Emission (CO2 Eq\_Gg/yr).**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  | **AVG GHG EMISSION(CO2 Eq\_Gg/yr 2011-2013** |  |  |
| **S.NO** | **DiVISION** | **AVG RICE** | **AVG MAIZE** | **AVG GROUNDNUT** | **AVG COTTON** | **AVG JUTE** | **AVG SOYABEAN** | **AVG WHEAT** | **TOTAL** |
| 1 | BHOPAL | 0.4679224 | 0.668598554 | 0.070372098 | 0 | 0 | 38.26302 | 567.0413 | 606.5112 |
| 2 | CHAMBAL | 19.296332 | 0.509877292 | 0.422592822 | 0.061706466 | 0 | 27.66478 | 167.5876 | 215.5429 |
| 3 | GWALIOR | 20.171092 | 0.553683247 | 0.212415143 | 2.28537E-05 | 0 | 48.43841 | 119.2422 | 188.6179 |
| 4 | INDORE | 0.0002247 | 0.016342119 | 0.001484393 | 0.016689619 | 0 | 10.98853 | 267.7039 | 278.7272 |
| 5 | JABALPUR | 18.224117 | 1.398296295 | 0.106776356 | 0.027229305 | 0 | 22.91107 | 85.44315 | 128.1106 |
| 6 | NARMADAPURAM | 0.2213735 | 0.006494974 | 0.000469661 | 0 | 0 | 12.76802 | 1471.198 | 1484.194 |
| 7 | REWA | 0.034925 | 0.030148817 | 9.64806E-05 | 0 | 0 | 0.000271 | 11.61837 | 11.68381 |
| 8 | SAGAR | 0.1377744 | 0.106487166 | 0.035144112 | 0 | 0 | 80.0579 | 95.35346 | 175.6908 |
| 9 | SHAHDOL | 0 | 0 | 0 | 0 | 0 | 0.117831 | 2.329659 | 2.44749 |
| 10 | UJJAIN | 0.001061 | 1.887103589 | 0.180995395 | 2.05448E-05 | 0 | 81.54168 | 106.3209 | 189.9318 |
|  | **TOTAL** | **58.554822** | **5.177032052** | **1.030346459** | **0.105668788** | **0** | **322.7515** | **2893.838** | **3281.458** |
|  |  |  | **AVG GHG EMISSION(CO2 Eq\_Gg/yr 2018-2020** |  |  |  |
| **S.NO** | **DIVISION** | **AVG RICE** | **AVG MAIZE** | **AVG GROUNDNUT** | **AVG COTTON** | **AVG JUTE** | **AVG SOYABEAN** | **AVG WHEAT** | **TOTAL** |
| 1 | BHOPAL | 5.404145 | 0.726654214 | 0.02355666 | 6.93369E-06 | 0 | 26.59533 | 1396.614 | 1429.364 |
| 2 | CHAMBAL | 201.92173 | 2.087260982 | 1.842989921 | 0.041750653 | 0.000359 | 110.9301 | 312.9852 | 629.8094 |
| 3 | GWALIOR | 21.066833 | 2.254955788 | 1.134620877 | 1.95001E-05 | 8.26E-05 | 11.34332 | 490.546 | 526.3459 |
| 4 | INDORE | 4.134E-05 | 0.166105065 | 0.006878152 | 0.032249705 | 6.58E-07 | 1.169324 | 619.7889 | 621.1635 |
| 5 | JABALPUR | 48.888211 | 6.918744686 | 0.054150288 | 0.000127046 | 0.00013 | 3.311883 | 383.0946 | 442.2678 |
| 6 | NARMADAPURAM | 16.04745 | 1.795831705 | 0.001013493 | 0 | 0.014931 | 23.94614 | 1617.654 | 1659.46 |
| 7 | REWA | 0.1414899 | 0.043849868 | 0 | 0 | 0 | 0 | 43.34593 | 43.53127 |
| 8 | SAGAR | 0.2287725 | 0.011404119 | 0.003455794 | 0 | 0 | 1.034321 | 141.1437 | 142.4217 |
| 9 | SHAHDOL | 0 | 0 | 0 | 0 | 0 | 0 | 4.179525 | 4.179525 |
| 10 | UJJAIN | 0.0004703 | 1.87052654 | 0.174630769 | 0.013489727 | 0 | 12.6362 | 363.1058 | 377.8012 |
|  | **TOTAL** | **293.69914** | **15.87533297** | **3.241295954** | **0.087643565** | **0.015503** | **190.9666** | **5372.459** | **5876.344** |

Wheat consistently contributes the highest emissions across divisions, with a significant increase from 2011–2013 (2893.838 Gg/year) to 2017–2020 (5372.459 Gg/year), indicating increased production or burning practices. Soybean is the second-largest contributor, although emissions dropped from 322.7515 Gg/year to 190.9666 Gg/year between the two periods. Rice emissions surged notably, from 58.554822 Gg/year to 293.69914 Gg/year, particularly in Chambal, Gwalior, and Jabalpur. Narmadapuram reported the largest increase in wheat emissions (from 1471.198 Gg/year to 1617.654 Gg/year), emphasizing the region's dependence on wheat cultivation.

 Chambal and Jabalpur witnessed significant increases in rice emissions, suggesting expanding cultivation or intensified residue burning practices. Gwalior and Indore saw notable increases in maize emissions over time, indicating a shift in cropping patterns. From 2011–2013 to 2018–2020, there has been a significant overall rise in GHG emissions across most crops, especially wheat, rice, and maize. Certain crops like soybean and groundnut have shown declines, suggesting improved management or reduced cultivation. Cotton and Jute contribute minimally to GHG emissions, likely due to limited cultivation areas in the state. Divisions like Shahdol have consistently reported negligible emissions, indicating less reliance on residue-burning practices or lower agricultural activity”.

Figure 4: Average GHG Emission (CO2 Eq\_Gg/yr 2011-2013 & 2018-2020).

Figure 5: Average GHG Emission Division Wise (CO2 Eq\_Gg/yr 2011-2013 & 2018-2020).

V. CONCLUSION

Total GHG emissions increased significantly from 3281.458 Gg/yr (2011–2013) to 5876.344 Gg/yr (2018–2020), indicating a growing trend in agricultural emissions.

* It is found that GHGs emission has increased 79.07% from 2011-2013 to 2018-2020. Soybean production contributed significantly in regions like Chambal and Ujjain. Wheat remained a dominant factor across all divisions, particularly in Bhopal, Narmadapuram, and Indore.
* Narmadapuram consistently recorded the highest emissions in both periods, rising from 1484.194 Gg/yr to 1659.46 Gg/yr, mainly due to wheat production. Jabalpur’s Emissions increased from 128.1106 Gg/yr to 442.2678 Gg/yr, with only 7.5% contribution in GHGs.
* Emissions in Indore grew from 278.7272 Gg/yr to 621.1635 Gg/yr, reflecting an increase in wheat production. Emissions increased from 128.1106 Gg/yr to 442.2678 Gg/yr, with wheat as a major contributor. Emissions in Rewa and Shahdol remained among the lowest but showed slight increases to 43.53127 Gg/yr and 4.179525 Gg/yr, respectively.
* The data reflects an overall increasing trend in agricultural GHG emissions, particularly from wheat and soybean production, highlighting the need for sustainable practices in high-emission regions like Narmadapuram, Bhopal, and Chambal.

# 5.1 Future Work

Resulting from this work has identified knowledge gaps and needs for future studies such as: Future efforts should focus on sustainable agriculture, technological innovations, and policy interventions to reduce GHG emissions while maintaining agricultural productivity. Prioritizing high-emission divisions and promoting farmer education will be critical to achieving long-term emission reductions.

#

# REFERENCES

1. Akagi, S. K., Yokelson, R. J., Wiedinmyer, C., Alvarado, M. J., Reid, J. S., Karl, T., &Wennberg, P. O. (2011). Emission factors for open and domestic biomass burning for use in atmospheric models. *Atmospheric Chemistry and Physics*, *11*(9), 4039-4072.
2. Badarinath, K. V. S., Chand, T. K., & Prasad, V. K. (2006). Agriculture crop residue burning in the Indo-Gangetic Plains–a study using IRS-P6 AWiFS satellite data. *Current Science*, 1085-1089.
3. Bhuvaneshwari, S., Hettiarachchi, H., &Meegoda, J. N. (2019). Crop residue burning in India: policy challenges and potential solutions. *International journal of environmental research and public health*, *16*(5), 832.
4. Dutta, A., Patra, A., Hazra, K. K., Nath, C. P., Kumar, N., &Rakshit, A. (2022). A state of the art review in crop residue burning in India: Previous knowledge, present circumstances and future strategies. *Environmental Challenges*, *8*, 100581.
5. Devi, S., Gupta, C., Jat, S. L., &Parmar, M. S. (2017). Crop residue recycling for economic and environmental sustainability: The case of India. *Open Agriculture*, *2*(1), 486-494.
6. Erenstein, O., & Thorpe, W. (2011). Livelihoods and agro-ecological gradients: A meso-level analysis in the Indo-Gangetic Plains, India. *Agricultural Systems*, *104*(1), 42-53.
7. Grover, D., & Chaudhry, S. (2019). Ambient air quality changes after stubble burning in rice–wheat system in an agricultural state of India. *Environmental Science and Pollution Research*, *26*, 20550-20559.
8. Giglio, L., Boschetti, L., Roy, D. P., Humber, M. L., & Justice, C. O. (2018). The Collection 6 MODIS burned area mapping algorithm and product. *Remote sensing of environment*, *217*, 72-85.
9. Jain, M., Mondal, P., DeFries, R. S., Small, C., & Galford, G. L. (2013). Mapping cropping intensity of smallholder farms: A comparison of methods using multiple sensors. *Remote Sensing of Environment*, *134*, 210-223.
10. Jain, N., Bhatia, A., & Pathak, H. (2014). Emission of air pollutants from crop residue burning in India. *Aerosol and Air Quality Research*, *14*(1), 422-430.
11. Kabange, N. R., Kwon, Y., Lee, S. M., Kang, J. W., Cha, J. K., Park, H., ... & Lee, J. H. (2023). Mitigating Greenhouse Gas Emissions from Crop Production and Management Practices, and Livestock: A Review. *Sustainability*, *15*(22), 15889.
12. Jethva, H., Torres, O., Field, R. D., Lyapustin, A., Gautam, R., &Kayetha, V. (2019). Connecting crop productivity, residue fires, and air quality over northern India. *Scientific Reports*, *9*(1), 16594.
13. Mittal, S. K., Singh, N., Agarwal, R., Awasthi, A., & Gupta, P. K. (2009). Ambient air quality during wheat and rice crop stubble burning episodes in Patiala. *Atmospheric Environment*, *43*(2), 238-244.
14. Ramulu, C., Pateriya, R. N., Naik, M. A., Vishwakarma, D. K., Kuriqi, A., Al-Ansari, N., &Mattar, M. A. (2023). A residue management machine for chopping paddy residues in combine harvested paddy field. *Scientific Reports*, *13*(1), 5077.
15. Reddy, M. S., Boucher, O., &Venkataraman, C. (2002). Seasonal carbonaceous aerosol emissions from open biomass burning in India. *Bull. Indian Aerosol Sci. Technol. Assoc*, *14*, 239-243.
16. Shurpali, N., Agarwal, A. K., & Srivastava, V. K. (2019). Introduction to greenhouse gas emissions. *Greenhouse Gas Emissions: Challenges, Technologies and Solutions*, 1-5.
17. Sonwani, S., & Saxena, P. (2022). Introduction to greenhouse gases: Sources, sinks and mitigation. In *Greenhouse Gases: Sources, Sinks and Mitigation* (pp. 1-7). Singapore: Springer Nature Singapore.
18. Filonchyk, M., Peterson, M. P., Zhang, L., Hurynovich, V., & He, Y. (2024). Greenhouse gases emissions and global climate change: Examining the influence of CO2, CH4, and N2O. *Science of The Total Environment*, 173359.
19. Miller, C. A., & Gage, C. L. (2011). Potential adverse environmental impacts of greenhouse gas mitigation strategies. In *Global Climate Change-The Technology Challenge* (pp. 377-415). Dordrecht: Springer Netherlands.