Final Techenical Report

Scheme: Provision of Technical Studies on Impacts of Climate Change on Agriculture, Forestry and Land-use Sector

Study Title: Spatio-temporal Dynamics of Greenhouse Gas Emissions from Soil under Various Forest Types of Pakistan

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ABSTRACT

Intergovernmental Panel on Climate Change (IPCC) has reported with high confidence that increases in the atmospheric concentration of greenhouse gases (GHG's) have led to changes in the earth's climate. These increases are mainly attributed to increased fossil fuel use, rapid land-use changes especially conversion of forests to agriculture. However, GHG emissions from forest soils account for ~24% of the total emissions of the world. Soil processes directly contribute in climate change through the production and consumption of Carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). Forest management and land-use, influence the role of soil to act as a source and sink of GHG's. On the other, climatic change will influence soil processes through imposed changes in soil temperature, soil moisture and soil nutrient regime. In natural systems, the long-term impact of increased CO_2 on ecosystem sustainability is not known. These changes may also result in altered CO_2, CH_4, and N_2O exchange with the soil. Because of large temporal and spatial variability in the soil-atmosphere exchange of GHG's, the measurement of quantity and prediction is still difficult. In recent years, much progress has been made in decreasing the uncertainty of field scale measurements and efforts are being directed to large scale field and modeling studies. Soil under different forest types respond in dissimilar manners under varying climatic conditions. Present study was focused on determining GHG emissions from soil under three major forest types of Pakistan. In addition, the impact of spatio-temporal factors on the emission patterns was also be investigated. Scientific investigation indicated that CO_2 and N_2O emissions from the soil of moist temperate forests were higher compared to subtropical chir pine forests and scrub forests. It is worth mentioning that CH_4 was not detected at any sampling site in three forest types studied. It was also concluded that soils

with higher moisture content, higher organic matter and higher nutrient ratio produces more GHG emissions than those soils having lower values of these attributes.

Present study will help in understanding relationships of tree-species and soil characteristics. This will be useful for developing National Forest Reference Emission levels (FREL) for REDD+ implementation under Paris agreement.

1.1 INTRODUCTION

Greenhouse gases (GHGs) absorb infrared radiations in the atmosphere, trapping heat and warming the surface of the Earth. This process is performed under the phenomenon of greenhouse effect. The important GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are directly associated with agriculture and forests (Snyder *et al.*, 2009). The average temperature of the Earth's surface would be about −18 °C (NASA GISS., 2016) without greenhouse gases, rather than the present average of 15°C (Karl and Trenberth, 2003; Treut *et al.*, 2007). The Earth's average temperature is maintained due to the balance between absorbed and reflected solar radiations. The state of equilibrium is maintained till the concentration of greenhouse gases and the sun energy remains constant. However, the advancement in industrialization in twentieth century disturbed global energy balance. The disturbance in the state of equilibrium was caused due to increased atmospheric concentration of GHGs resulting in global warming. Human activities, including clearing of land for agriculture and unsustainable forest harvesting have increased emissions of GHGs to the extent that scientists are predicting an average increase in global temperature of 2-4°C by the middle of the next century (IPCC, 2014*a*). Political agendas of individual countries and international initiative proclaim GHG neutral by the year 2050 (Kirton, 2015; Law and Harmon, 2011). International initiatives such as the United Nations Framework Convention on Climate Change and the Kyoto Protocol require countries to estimate national inventories of their greenhouse gas emissions. The emissions of CO_2, CH_4 and N_2O have significant impacts on global warming. Carbon dioxide accounts for 65%, CH_4 for 20% and N_2O for 6% of greenhouse warming (Table 1). Globally, climate change is currently high on public agenda and poses threats to public health, the environment, agriculture, and the economy (IPCC, 2007; Patz *et al.*, 2005; Patz *et al.*, 2007; Stern 2008).

Landscape sources of CH_4 are estimated to contribute ~86% of all CH_4 emissions, some 58% coming from anthropogenic sources: landfills and wastes, ruminants, rice growing and biomass burning (Denman *et al*. 2007). The remainder comes from natural sources: wetlands and termites. Forests might be the substantial sources of CH_4 but the mechanism of CH_4 formation and the magnitude of the forest source are unclear (Denman *et al*., 2007).

Table 1. Major greenhouse gases and linkage to climate change

Greenhouse gas	Basic human sources	Contribution to climate change (%)
Carbon dioxide (CO_2)	Fossil fuel use, human influence on land such as deforestation	65
Methane (CH_4)	Rigorous livestock agri-business, fossil fuel production	20
Halogenated compound	Industrial activities, consumer product, aerosols spray	10
Nitrous oxide (N_2O)	Land clearance, fossil fuels production	6

Reproduced from: IPCC, 2014(b)

The increasing GHG concentrations have raised concerns about global warming and the possible positive feedback is increasing fluxes between soil and atmosphere (Rustad *et al*., 2000). The escalating concentrations of greenhouse gases on the Earth are causing enhanced greenhouse effect (Allison, 2010). Greenhouse gases are about 1% in the atmosphere but have strong potential to disturb global energy balance. New production technologies and processes were introduced due to rapid scientific development. Agriculture was converted to intensive farming approach, burning of fossil fuels increased due to increased human population. These processes are increasing concentration of GHGs in the atmosphere leading to further warming.

Human activities are the major cause of enhanced GHGs. Present-day concentrations of GHGs in the atmosphere are the highest compared to the past three million years and have been increasing since the dawn of the industrial revolution (Van *et al*., 2011). Under normal conditions, GHGs are being produced and released from natural sources. However, additional amounts (due to industrialization) lead to more heat being trapped on the planet. This extra heat creates an impact by distorting weather patterns and triggering climate change.

The measurement of GHG emissions from different sources is important because by knowing current emission tendencies, predictions about the future trends of climate change can be made with more confidence and reliability. Soils are recognized as major source of GHGs. The emissions from soil need to be better quantified for global budgets. The increased soil emissions are mainly CO2, CH_4 and N_2O, due to industrialization and intensive agriculture practices (Forster *et al*., 2007). Soil GHG emissions is a key topic of research for agricultural and forestry management under the scenario of climate change. It is important to improve our understanding of soil processes in order to gain more confidence in projections about future changes in the global atmospheric GHG concentrations (Drewitt *et al*., 2002; Merino *et al*., 2004). The production of GHGs from soil depend on many factors such as fertilization, irrigation, soil moisture regime, soil temperature, and land use type (Gundersen and Rasmussen, 1990; Venterea and Rolston, 2000; Khalil., 2003) among which land use history has been identified as one of the most significant factor to influence GHGs production and release to the atmosphere (Ishizuka *et al*., 2002; Merino *et al*., 2004).

The accurate and reliable quantification of GHG sources and sinks is required for reliable global budgets, necessary for sustainable land-use management (agriculture and forestry) and for studies related to climate change mitigation (Rochette *et al*., 2008).

Present study was designed to estimate and compare GHG emissions from soil under major forest types of Pakistan. Key objectives of the study were as under:

- Develop a profile of GHG emissions from soil under three major forest types of Pakistan.
- Develop empirical models for prediction of GHG emissions under three major forest types of Pakistan.

2.1 MATERIAL AND METHODS

2.1.1 Study Area

Forests in Pakistan are classified on the basis of climate and physiography. Among total nine forest types, three occupy almost 74% of the total forest area of Pakistan. These are scrub, sub-tropical chir pine and moist temperate forests. Sub-tropical chir pine and moist temperate forests are collectively named as coniferous forests. These are mainly evergreen forests along with the mixture of some deciduous broad leave trees.

2.1.2 Scrub Forests

Scrub forests are classified as arid and semi-arid forests. These are short, open and noticeably xerophytic forests in which thorny leguminous species dominate. This forest type spreads over the whole of the Indus plain excluding the driest parts. Altitude of the scrub forests varies between 300-1500m. These are low forests of branchy trees, varying in density from complete closure under the most favorable conditions to scattered single trees or groups on the dry sites with a fair amount of shrubs. These forests are generally found in Potohwar region i.e. districts of Chakwal, Jhelum, Rawalpindi and Islamabad. The temperature varies between below freezing point in winter to 45ºC in summers. Winds blow all through the summer. Mostly erratic precipitation is received in July and August and again in January and February. Precipitation range is 250-1250mm. Sometimes, there are long periods of drought. The species are mostly thorny and often with small evergreen leaves. The main tree species are *Olea ferruginea, Acacia modesta, Tecoma undulata*, while *Dodonaea viscosa, Capparis aphylla,* and *Zizyphus* spp.

2.1.3 Subtropical Chir Pine Forests

These are high forests in which *Pinus roxburghii* (Chir) forms practically the whole of the top canopy up to 120 ft. These are evergreen and nearly even-aged forests. Chir pine forests present in Western Himalayas within the range of summer monsoon. There is heavy needle fall in May and wildfires are common unless special protective measures are taken. Chir pine is also important for resin tapping. These forests are also valuable watershed of Simli and Rawal dam Islamabad. Natural existence of these forests within the elevation range of 3000-5500 feet and usually temperature ranges between 12-32ºC. Annual precipitation spans 750-1250 mm. Generally, soil is loamy, light sandy and well drained. These forests are found in Tehsil Murree, district Rawalpindi. Common species are *Pinus roxburghii* (Chir pine) and *Quercus inacana* (oak, Rin) and Berbaris.

2.1.4 Moist Temperate Forests

These are evergreen coniferous forests and are similar to those of other parts of temperate regions in the world like Europe and America. These forests in Pakistan are mainly due to altitude not due to latitude. Deciduous broad-leaf species are also present in these forests but in small number. Their under growth is rarely dense mostly sparse. These types of forests are further classified into lower and upper zones in each of which specific species of conifers and or oaks dominate. In the lower zone deodar, blue pine, fir and spruce are main species with increasing altitude with *Quercus incana* at lower altitude and *Quercus dilatata* above 7000ft. In upper zones *Abies pindrow* and *Quercus semecarpifolia* are dominant tree species. Moist temperate forests are important watersheds of Pakistan due to high precipitation.

These forests are important because of recreation resorts, medicinal plants, wildlife and timber species. These forests are managed under selection system in which dead, drying and diseased trees are felled. The elevation range is 900-3000m, rainfall is 750-1750mm while mean annual temperature range is 13 and 22.2ºC. Gallies in district Abbotabad and Jhika Gully are covered by this forest type. Main species are *cedrus deodara* (deodar, diar), *pinus wallichiana* (blue pine), *abies pindrow* (fir), *picea smithiana* (*spruce*), *pinus roxburgii* (*chir pine*).

Table 2. Area under different forest types of Pakistan

Forest type	Total Area (000ha)	Percentage
Coniferous	1913	45.30
Irrigated Plantation	103	2.43
Riverain	173	4.10
Scrub	1191	28.19
Mangrove	207	4.9
Linear plantation	16	0.38
Farmland trees	466	11.03
Misc. Planting	155	3.66
Total	**4224**	**100**

Source: Siddiqui, 1997

2.2 METHODS

2.2.1 Forest Stratification

A strong sampling strategy is critical to obtain representative data. Forest stratification was realized based on climatic conditions and physiographic attributes. These factors have been demonstrated to be useful substitute for the spatial distribution of species and forest productivity (Butterbach-Bahl *et al*., 1997). Altitude is the foremost controlling factor in vegetation growth and in most cases limits its spatial distribution at local and regional scales (Jin *et al*., 2008). Moreover, topographic factors also control soil structure, moisture and species existence. Geographic Information System (GIS) efficiently provides this information using Digital Elevation Model (DEM). Conventional forest types (developed by GM Khattak) were taken into account and strata's were developed within each type based on altitude range. Sub-strata's within each stratum were created based on fundamental characteristics of forest structure: stocking and species composition.

2.2.2 Site Selection

The study was focused on three forest types: scrub, subtropical and moist temperate forests of Pakistan. The sampling sites were chossen in districts of Abbottabad, Islamabad, Rawalpindi and Chakwal covering three forest types. Sites within the substratum were randomly selected keeping in view forest characteristics. Figure 1 demonstrates sampling strategy. Sampling sites in each forest type were evenly distributed to cover all stocking classes and species compositions. Sampling sites for each forest type in four districts including Islamabad Capital Terriotry are shown in Figures 2-6.

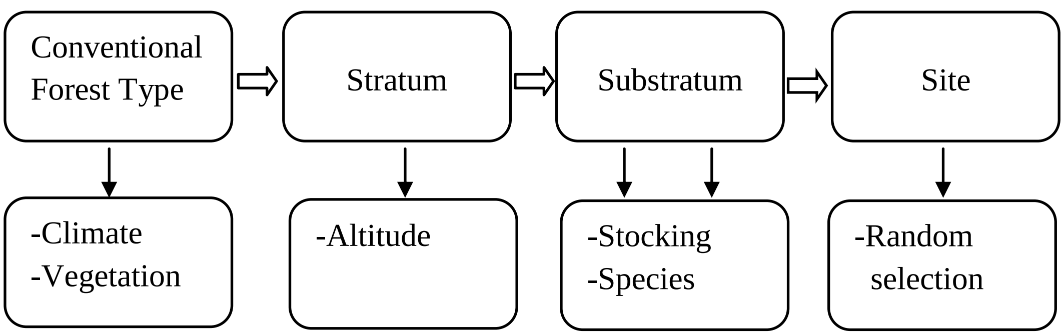

Figure 1. Illustration of sampling strategy adopted in this study

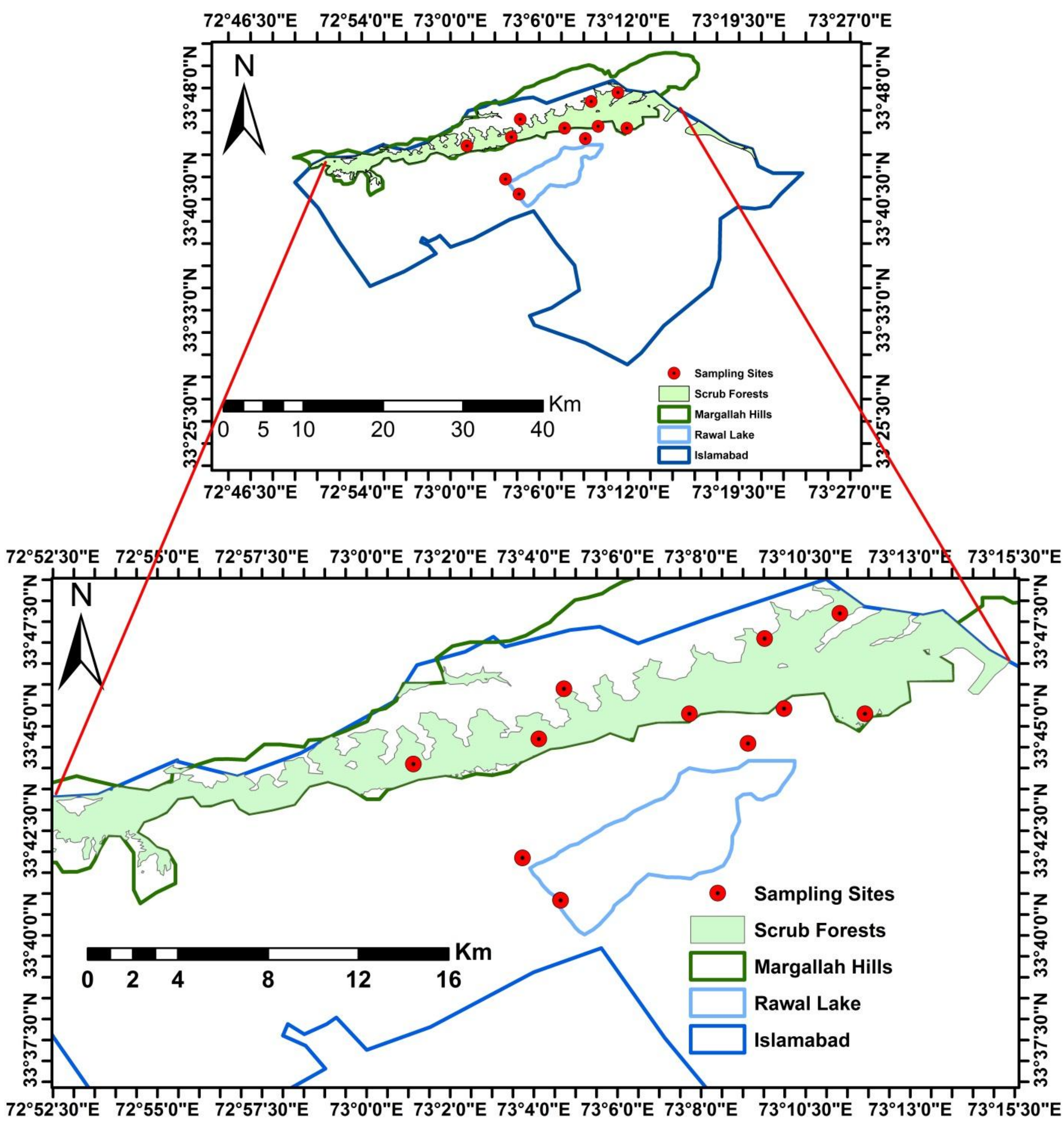

Figure 2. Geographic locations of sampling sites in Islambad Capital Terriotry

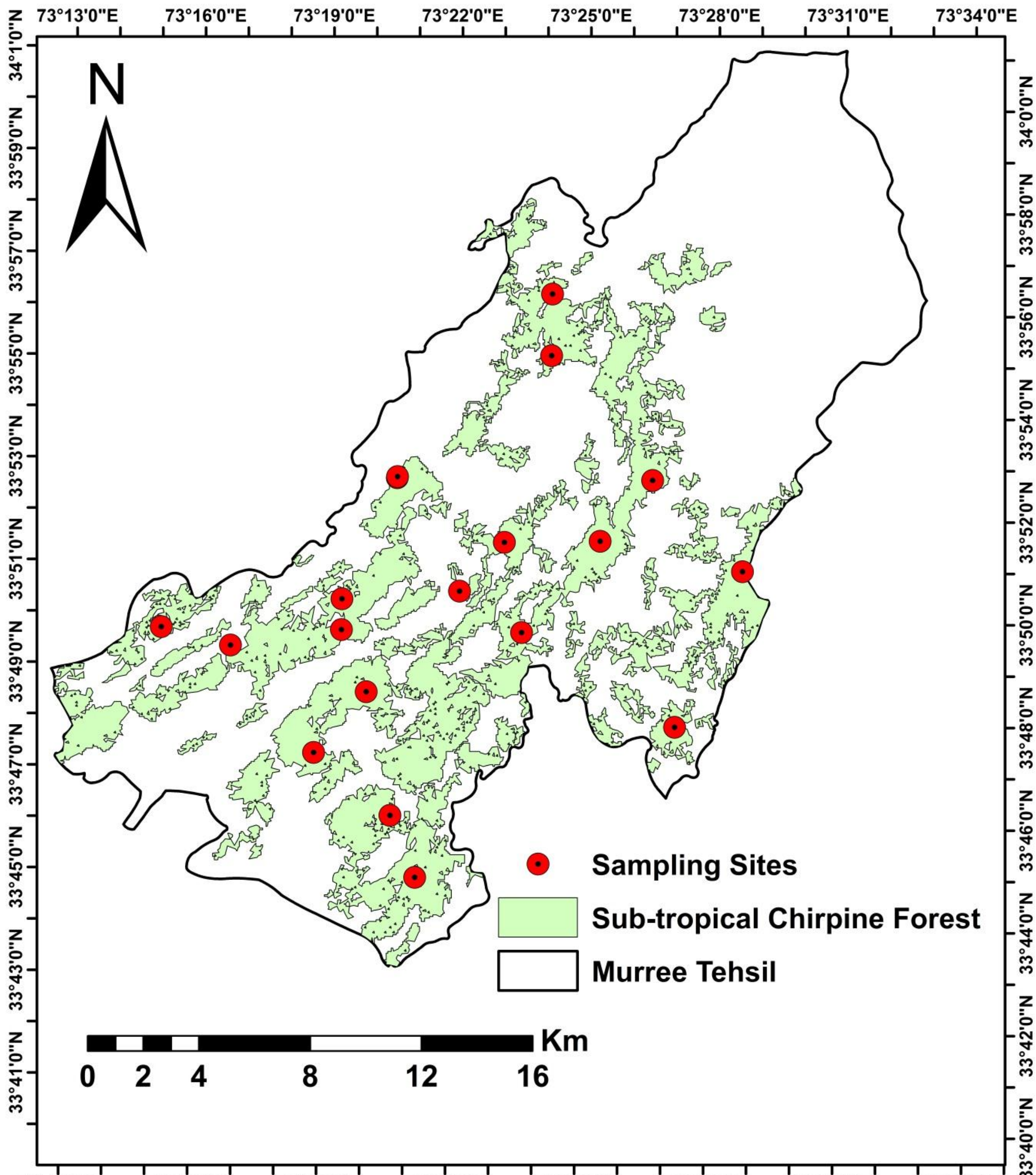

Figure 3. Geographic locations of sampling sites in Murree (District Rawalpindi)

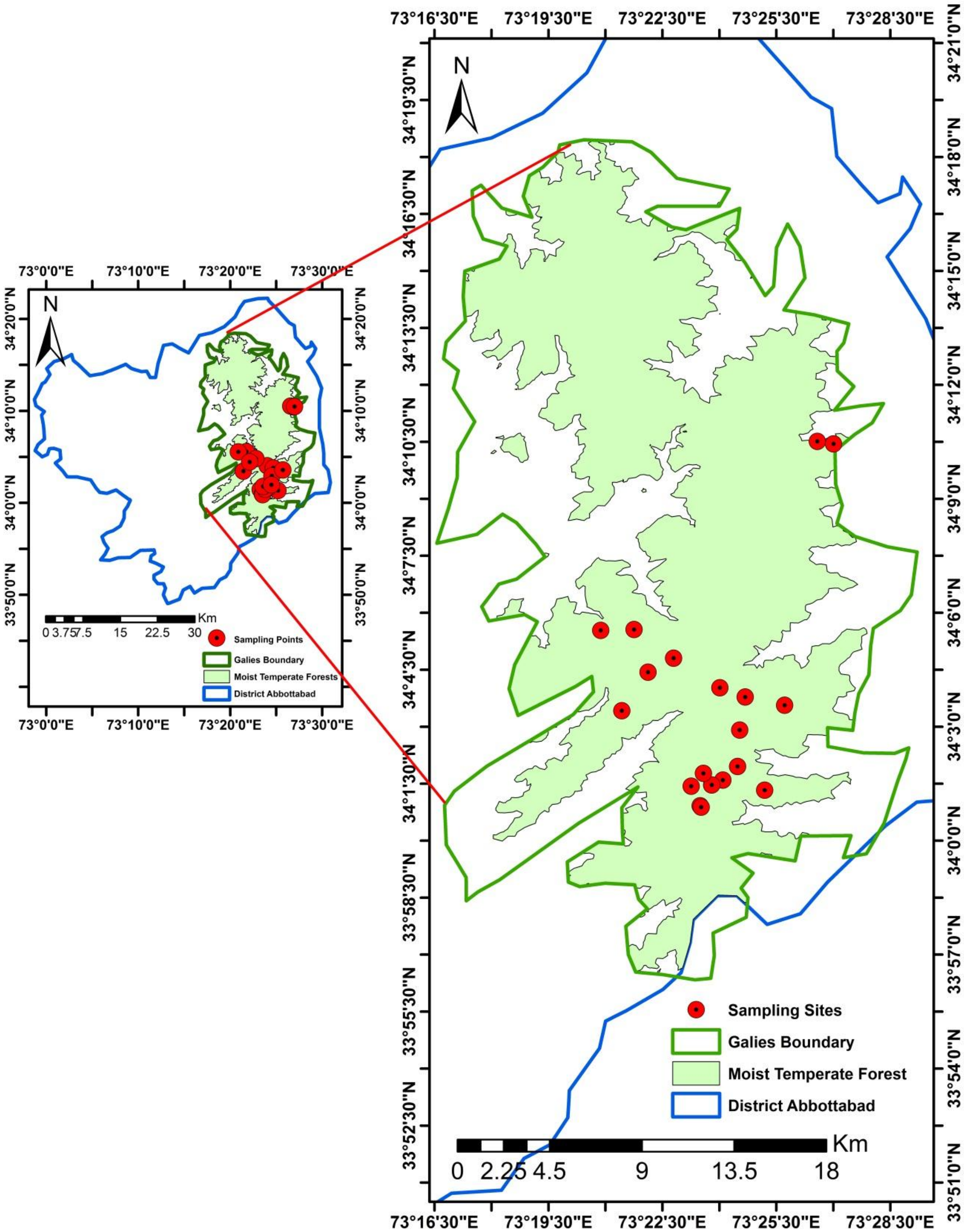

Figure 4. Geographic locations of sampling sites in District Abbotabad

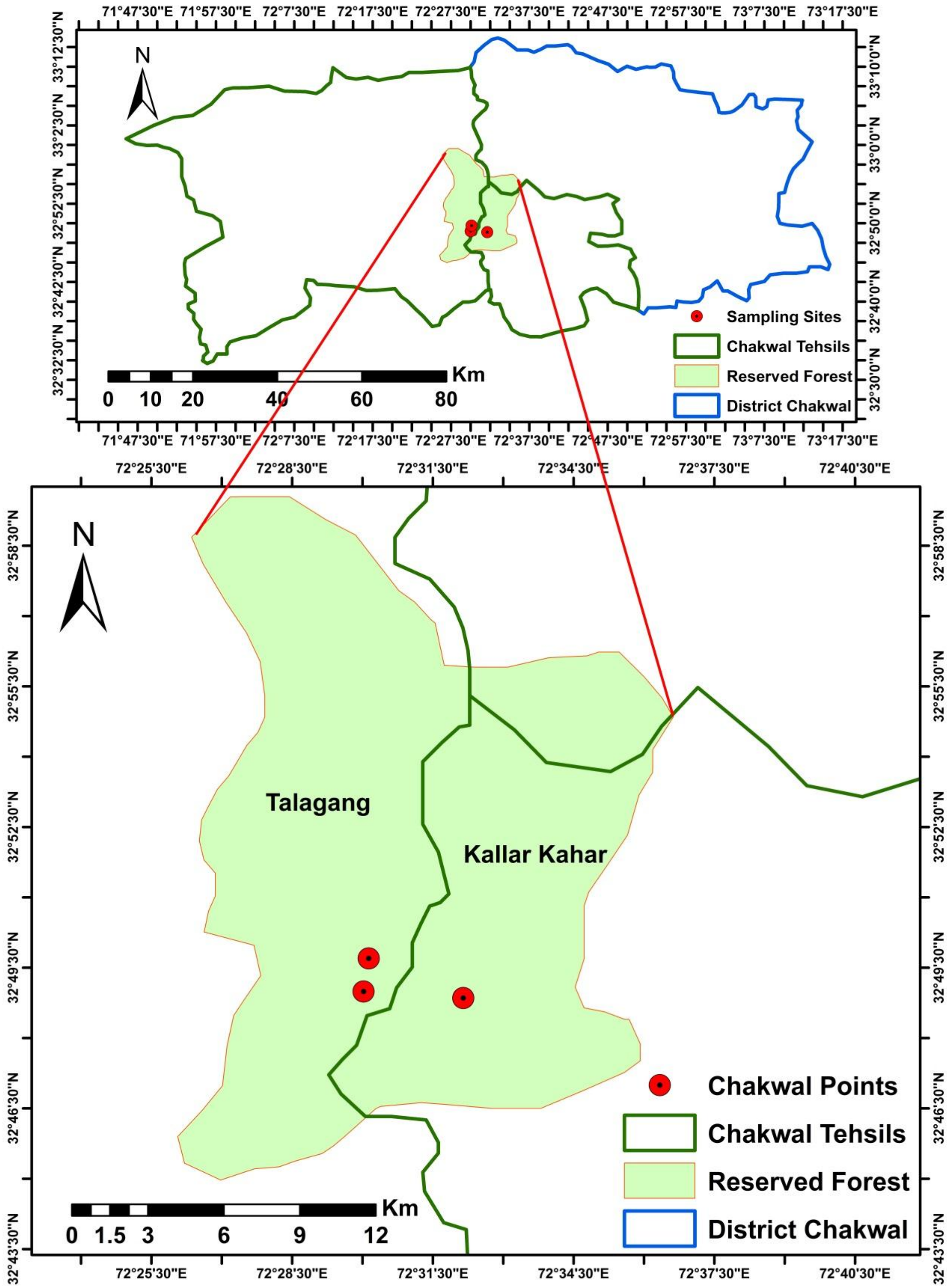

Figure 5. Geographic locations of sampling sites in District Chakwal

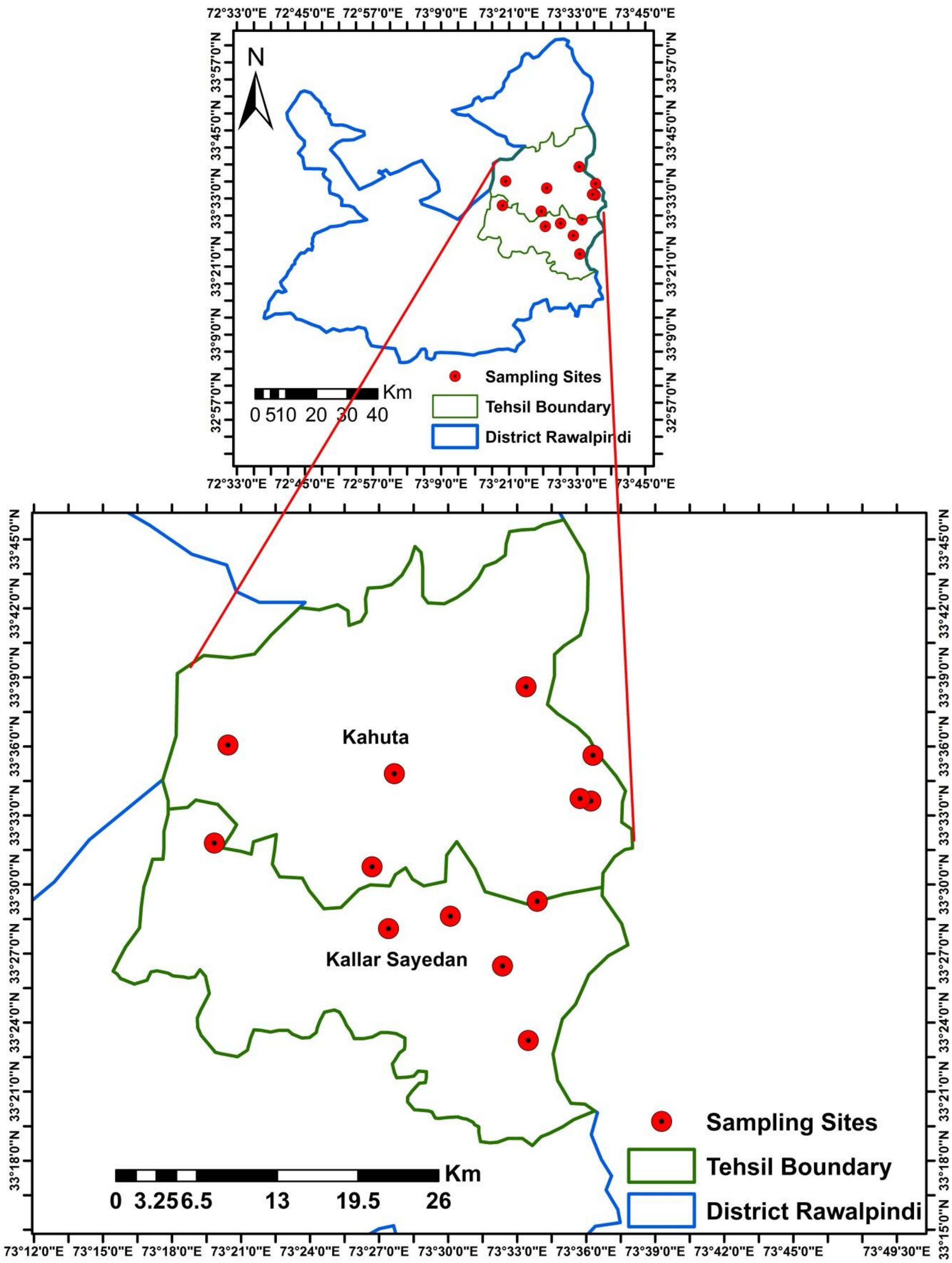

Figure 6. Geographic locations of sampling sites in District Rawalpindi

2.3 DATA COLLECTION

After the selection of sampling sites in each forest type, the data for site characterization and GHG inventory were collected. Following factors were taken into account for site characterization:

- Soil distal drivers: soil temperature and moisture
- Soil proximal drivers: EC, pH, nutrients (Phosphorus and Potassium), texture, organic matter and saturation

Soil samples were collected by composite sampling method, packed in air tight polythene bags and brought to laborarty for analysis.

Closed chamber technique was used to measure gas accumulation in a chamber of size: length 2 feet, width 2 feet and height 1 foot. Furthermore, gas samples were collected in the mid-morning between 9-12 am (Alves *et al*. 2012). Temporal factor was considered with two aspects: (1) seasonal (summer and winter) and (2) gas accumulation time. Four readings were taken from a site at the intervals of 0, 10, 20, 30 minutes in triplicate to avoid any biases and errors. Composite and repeated sampling is helpful in collection of accurate and precise data. Portable gas analyzers for CO_2, CH_4 and N_2O were used to estimate gas concentration. These analyzers measure gas concentration based on electrochemistry principles with an accuracy/resolution of 0.01ppm. Soil moisture and temperature was measured on the spot.

2.4 DATA ANALYSIS

The collected data was subject to analysis for pattern recognition and association between influencing factors and ghg emissions. Furthermore, development of empirical models need wide range of data, at least two season data is required. The models for prediction of GHG emissions will be developed after collection of winter season data. The flow of data in this study is shown in Figure 7.

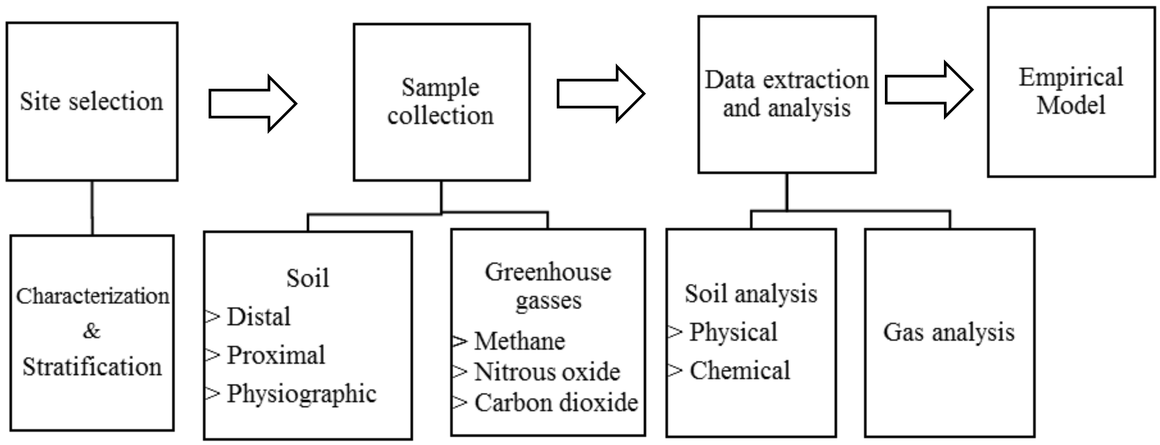

Figure 7. Data flow in this study

3.1 RESULTS AND DISCUSSION

The data for the summer season was collected during the month of June and July 2019. Results of soil analysis and information regarding topographic characteristics are presented in Table 3. The elevation range of sampling sites was 448-832 meters for scrub forest, 535-1637 meters for subtropical chir pine and 2035-3493 meters for moist temperate forests as detected by Garmin E30X GPS. Similarly, mean elevation of sampling sites was the lowest for scrub forests whereas the highest for moist temperate forests.

3.1.1 Soil Analysis

Results of soil analysis are presented in Table 3. The mean soil temperature recorded was the highest (36.49^{o}C) for scrub forest sampling sites whereas the lowest (23.42^{o}C) for moist temperate forests. The soil moisture percentage was the lowest (28.57%) for scrub forest and the highest (68.76%) for moist temperate forests. Soil moisture is the single most important soil parameter for soil gas emissions, since it controls microbial activity and all related processes. Soils with less water-filled pore space (WFPS) show higher emissions by nitrification, with a maximum at 20% WFPS (Ludwig *et al.*, 2001). Generally, our results were according to the described limits of soil temperature and moisture in past studies.

Table 3. Soil analysis and topographic information collected from sampling sites

	Elevation (m)		Soil								
Forest Type	**Mean**	**Range**	**Temp (^{o}C)**	**Moisture (%)**	**EC** (dSm^{-1})	**pH**	**OM** (%)	**P** (mg Kg^{-1})	**K** (mg Kg-1)	**Saturation** (%)	**Texture**
Scrub	626	448-832	36.49	28.57	0.72	7.42	0.55	2.97	84.75	41.40	Loam
Sub-tropical	1073	535-1637	31.63	40.11	0.70	6.94	0.58	3.53	83.69	42.31	Loam
Moist-temperate	2298	2035-2493	23.42	68.76	0.71	7.18	0.60	3.25	84.22	41.86	Clay loam

Soil electrical conductivity (EC) is a measure of the amount of salts in soil (salinity of soil). It is an important indicator of soil health. Soil EC for all forest types were according to the standard limits for non-saline soils. Soil EC is an important indicator as it affects plant growth, plant nutrient availability, and activity of soil microorganisms which influence key soil processes including the emission of GHGs such as nitrogen oxides, methane, and carbon dioxide. Excess salts hinder plant growth by affecting the soil-water balance.

Soil pH is a measure of the acidity or alkalinity of soil. It can be used as a general guide for determining nutrient availability and therefore, the species that may grow on a given site. Table 3 indicates pH values for three forest types. The soil of sub-tropical chir pine forest was slightly acidic (pH: 6.94) whereas moist temperate forest soil was slightly alkaline (pH: 7.18). However, soil of scrub forest was alkaline (pH: 7.42).

Soil organic matter (SOM) influence physical and chemical properties of soil and regulate many soil processes and functions. The emissions from soil are also influenced by the amount of organic matter. The highest SOM (0.60) was found in moist temperate forests whereas the lowest was in scrub forests (0.55). The highest value of phosphorus was found in sub-tropical forests whereas the highest value of potassium was in scrub forests. Generally, soil texture of scrub and subtropical forests were loamy and of moist temperate was clay loam.

3.1.2 Greenhouse gases accumulation

Figure 8 shows accumulation of CO_2 in the chamber over time. The highest concentration of CO_2 at 0 minutes was 510 ppm for subtropical chir pine forest whereas the lowest was 472 ppm for moist temperate forests. The CO_2 concentration increased over time accordingly. The measurement at 30 minutes indicated the highest value of 804 ppm for moist temperate forests and the lowest value of 674 ppm for subtropical chir pine forests. The initial reading (0 minutes) is an indication of air concentration whereas later measurements tell about accumulation of CO_2 from soil. The highest soil emissions of CO_2 from moist temperate forests are logically justified in presence of higher SOM, higher soil moisture and higher nutrient ratio. These results are in line with the findings of Čuhel *et al.*, (2010) who observed the highest CO_2 emissions at neutral pH values.

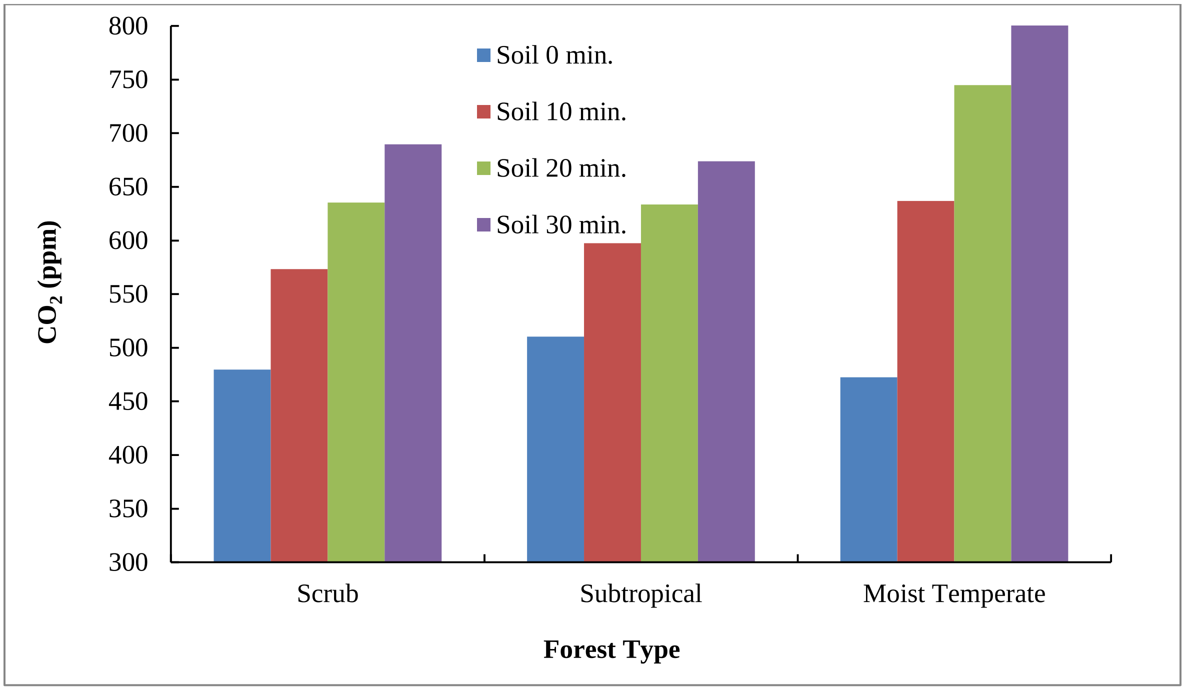

Figure 8. Accumulation of CO_2 in chamber over time in different forest types of Pakistan

Generally, the highest emissions of N_2O were observed for moist temperate forest which increased over time (Figure 9). The lowest emissions were observed for scrub forests which generally decreased over time. In chamber during 30 minutes, the concentration of N_2O varied between 0.21 and 0.41 ppm for moist temperate forests, 0.06-0.17 for subtropical chir pine forests and 0.05-0.10 ppm for scrub forests.

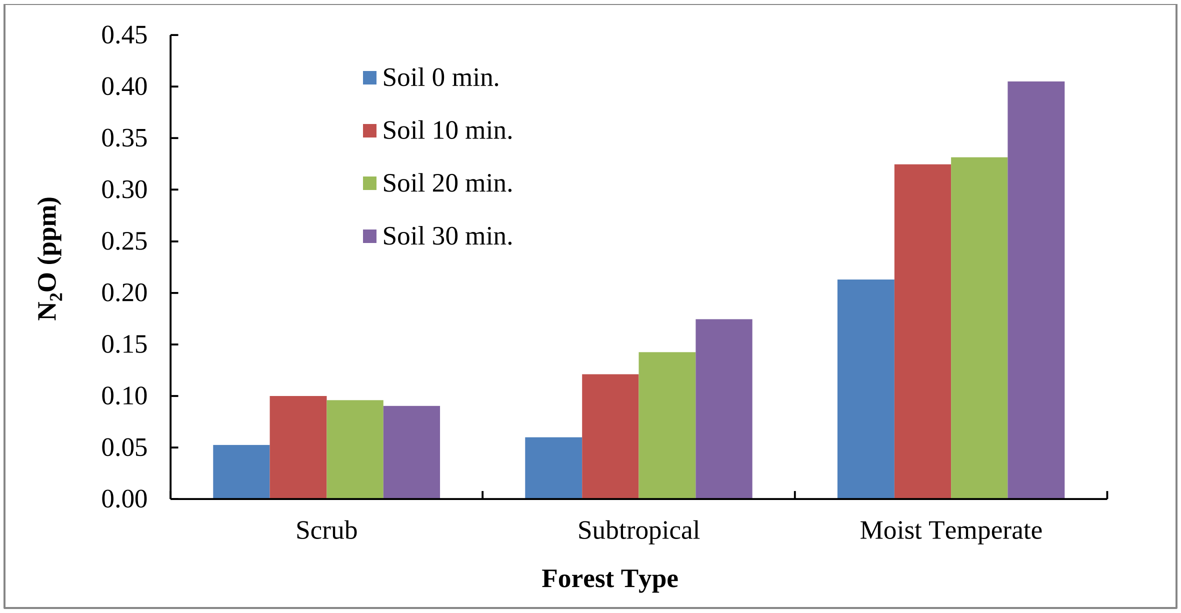

Figure 9. Accumulation of N_2O in chamber over time in different forest types of Pakistan

CONCLUSION

Methane, an important greenhouse gas is not being produced by forest soils in scrub, subtropical and moist temperate forest systems of Pakistan. Scientific investigation indicated that CO_2 and N_2O emissions from soils of moist temperate forests were more compared to subtropical chir pine forests and scrub forests. It was also concluded that soils with higher moisture content, higher organic matter and higher nutrient ratio produces more GHG emissions than those soils having lower values of these attributes.

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