Quantify the temporal carbon, water and energy fluxes in selected land use systems in Himalayas

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Quantify the temporal carbon, water and energy fluxes in selected land use systems in Himalayas"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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SYMBOLS AND ABBREVATIONS

%	Percentage
μ mol	Micro mol
μ mol m^{-2} s^{-1}	Micro mol metre per second
°C Yr^{-1}	Degree Celsius per year
K/Year	Kelvin per Year
A	Area
A_E	Ecosystem carbon assimilation
C	Carbon
C flux/Cf	Carbon flux
cm	Centimetre
CO_2	Carbon dioxide
C Stock	Carbon Stock
DNDC	DeNitrification-Decomposition Model
E	East
EC	Electrical conductivity
EDW	Elevation dependent warming
ET_0	Reference crop evapotranspiration
FAO	Food and Agricultuture Organization
FAS	Ferrous ammonium sulphate

FRI	Forest Research Institute
FSI	Forest Survey of India
g	Gram
$g\ cm^{-2}$	Grams per centimeter square
g/cm^3	Gram per cent meter cube
GHG	Green House Gas
GPP	Gross Primary Production
Gt	Giga ton
HCl	Hydrochloric acid
H_2O	Water
IHR	Indian Himalayan Region
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
IRGA	Infra Red Gas Analyzer
Kg C/ha/Year	Kilogram carbon per hector per year
Kg/ha	Kilogram per hector
LBA	Large Scale Biosphere-Atmosphere Experiment in Amazonia
LAI	Leaf Area Index
Msl	Mean Sea Level

mg CO_2 m^{-2} hr^{-1}	milligram carbon dioxide per metre per hour
mg H_2O m^{-2} hr^{-1}	milligram water vapor per metre per hour
min	minute
mm	milli metre
MMK	Mann-Kendall Test
MSU	Microwave Sounding Unit
mm/day	millimetre per day
m s^{-1}	Meter per second
N	North/Nitrogen
NEE	Net Ecosystem Carbon Exchange
NOAA	National Oceanic and Atmospheric Administration
N_2O	Nitrous oxide
NPP	Net Primary Production
Pg C/ Year	Petagram of carbon per year
PgC	Petagram of carbon
ppm	Parts per Million
PMW	Pettitt-Mann Whitney
PPED	Photosynthetically Active Photon Flux Density
PPA	Portable Photosynthesis Analyzer
PVC	Polyvinyl chloride

R_E	Ecosystem respiration
R_s	Soil respiration
R_n	Heterotrophic respiration
RCP	Representative concentration pathway
RMP_s	Recommended management practice
SOC	Soil organic carbon
TgC/Yr	Teragram per Year
TSEB	Two Source Energy Balance
$t\ ha^{-1}$	Ton per hector
V	Volume
VMC	Volumetric constant
$WJ\ m^{-2}\ hr^{-1}$	Watts joule per metre per hour
Wm^{-2}	Watts per metre square

INTRODUCTION

CHAPTER 1

INTRODUCTION

In India, next to agriculture, forests have the largest land-use area. As per Indian State of Forest Report – 2017, the total forest cover of the country is 708,273 km^2 which is 21.54% of its total geographic area (FSI, 2017). In the Indian Himalayan Region (IHR), the forest is the major land cover category. It covers about 41% of the geographical area in IHR.

Each year roughly about one-seventh of the total atmospheric CO_2 passes into vegetation. In the absence of human intervention, this large CO_2 flux from the atmosphere to the terrestrial biosphere is balanced by the counter respiration fluxes (Cox *et al.*, 2000). Because of the key role played by forest to remove deposited carbon dioxide in the atmosphere, the forest has a great potential in mitigating climate change. The largest significant carbon storage pool in the forest ecosystem is the soil having a potential of 662 TgC/Yr (Black and Ferrel, 2006). Forest safely traps and store CO_2 in soil and wood products. The sequestration potential of forest land is high, and hence it is good to undertake systematic studies for interpreting mitigation strategies in terms of forest types. The carbon stocks in the forest in India and the tree cover have increased in an annual increment of 38 million tons of CO_2. This CO_2 is sufficient to neutralize 11.25 % of India's total greenhouse gas emissions at the 1994 level (Kumar, 2011). This knowledge will help us to improve management efficiency by restoration and through conservation measures.

The rise in temperature can harmfully make a severe impact on snow reserves, ice and water in the high mountains, which supplies water to rivers over downstream. More importantly, the great Himalayas play an important role in monsoon circulation patterns. Variations in temperature will drastically affect the global circulation pattern, which would harm the cultivation. The varied ecological and microclimatic condition leads to rapid change in soil characters. Soil is an integral compound of the global carbon cycle as they take up and release a large amount of carbon (C) over short periods (C flux) or accumulate it over longer periods (C stock).

The IPCC (2007) estimated that during the last century, the global mean surface air temperature increased on an average of 0.74°C, but this increasing trend varies from place to place. These changes in temperature influence the microbial activity, and it affects the carbon, water and heat flux of respective soil surface. The critical role of soils in determining global carbon cycle dynamics is essential because they serve as the link between the ocean, atmosphere and vegetation. At 2 meter depth, up to 2500 Gt soil carbon pool is estimated globally and within this soil organic carbon pool comprises 1550 Gt, the soil inorganic carbon, as well as the elemental pools, fills up the remaining 950 Gt (Batjes, 1996).

Compared to atmospheric pool (760 Gt), soil carbon pool are 3.3 times greater and 4.5 times than biotic pool (560 Gt). In cold regions, soil organic carbon pool at 1m soil ranges from 50-150 tons/ha (Lal, 2004). Hence soil is considered as a sink and source of greenhouse gases (GHG) in the terrestrial ecosystem with larger capacities.

To obtain reliable global budgets, we have to use precise quantifications, that are necessary for land use management concerning global change and would be used for climate research (Oertel *et al.*, 2016). The annual accumulated CO_2 in the atmosphere is far larger than the amount which can be balanced by present natural ecological processes helping to remove CO_2 from the atmosphere (Clarke *et al.*, 2007). Coming to the terrestrial ecosystem, soil microbes act on a different substrate and oxidize or decompose and produce degraded components, one of them is CO_2. For soil nutrient recycling, microbial biomass composed of organic and inorganic concentrations has an important role. Soil environment will affect the microbial performance and active rate. In a terrestrial ecosystem, carbon sequestration is possible due to the microbial activities, and it mostly depends upon the soil characters. Due to soil respiration, more than 2.5 to 2.9 times carbon had been released from the soil surface, compared to the input of carbon to the system in aboveground litterfall in the forest (Raich and Schlesinger, 1992). Darker soil absorbs more heat and dry soil experience high heat. In soil, heat moves analogously to that of water. Microbial activity will be high with temperature up to 25-30°C, and if it is greater than this range, the activity gets decreased (Pietilcainen *et al.*, 2005; Qiu *et al.*, 2005; Jae *et al.*, 2010). It shows a positive correlation with CO_2 efflux and the microbial growth rate (Barros *et al.*, 1995). Because of the higher water and nutrient holding capacity and increased microbial biomass, fine-textured soil has high CO_2 efflux compared to coarse-textured soil (Valpassos *et al.*, 2001). If temperature changes do occur, and if converted into higher soil temperatures, then we can expect an increase in soil respiration rates. Because of the rising temperature, precipitation patterns will also be expected to change. Warming enhances soil carbon fluxes to and from the soil.

The land-climate feedback remains as one of the uncertainties in models and in projections. Especially in Earth System Models, this feedback restricts the capacity to develop carbon emissions targets that are compatible with specific climate change scenarios. Hence direct measurements of warming-induced changes in soil carbon stocks from fields are urgently needed to be increased.

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Rising atmospheric CO_2 concentration, air and land surface temperature, simulation in humidity, changes in patterns of precipitation, radiation and other meteorological and land-use changes, have been the reasons for attracting numerous studies on coupling and response of carbon, water and energy fluxes in various land-use systems and its feedback to change in climate or environmental or microclimatic circumstances (Baldocchi *et al.*, 2004; Singh, 2017). The functioning of various ecosystems of Himalayan and its foothill and the potential changes in their carbon, water and energy budgets are of particular importance because of their large extent and presumed sensitivity to climatic variability and anthropogenic manipulations and disturbances (IPCC, 2003; 2007).

Therefore, accurate quantification of carbon, water and energy fluxes is of great importance for a wide range of ecological, agricultural, forestry and meteorological applications. Hence it is significant to estimate the monitor carbon, water, and heat flux in various land use. Keeping the above-mentioned views, the present study has proposed the following objectives:

Objectives

- ❖ To quantify the temporal dynamics of carbon fluxes in various land-use systems.
- ❖ To investigate temporal changes of water fluxes in various land-use systems.
- ❖ To study temporal variations of energy fluxes in various land-use systems.
- ❖ To develop interlinking between carbon, water and energy fluxes and in-situ measured microclimatic variables.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

2.1 Importance of Climate change on the Himalayas

Shrestha *et al.* (1998) studied the annual and seasonal temperature distribution trends. Warming rates were found in high elevation regions of middle mountains and Himalaya while southern regions showed a cooling trend. From 1971 to 1994 maximum temperature from 49 stations in Nepal gave warming trends after 1977 which it ranged from 0.06 °C to 0.12 °C yr-1 in middle mountains. The Himalayas and southern plains showed warming trends less than 0.03 °C yr-1. The subset records from 14 stations back to the early 1960s suggested the recent warming showed similar cooling trends. This behaviour gave the sensitivity of mountainous regions to climate change. Spatial temperature distribution and seasonal temperature trends highlighted the influence of monsoon circulation.

Bhutiyani *et al.* (2007) confirmed that the north-western Himalayan region had a significant rise in air temperature about 1.6°C in the last century. Warming rate was faster during winter, and diurnal temperature range showed an increasing trend due to the rise in minimum and maximum temperature where maximum temperature increased more rapidly.

Basistha *et al.* (2009) undertook a study with the help of 80-year data from 30 rain gauge stations established by India Metrological Department (IMD) for examining the changes in rainfall pattern in the Indian Himalayas. Mann-Kendall Test (MMK) and Pettitt –Mann Whitney (PMW) test was applied for detecting trend and possible shift and found that rainfall decreased in the Indian

Himalayas. It was noted that in Uttarakhand state rather than a gradual trend, a sudden shift occurred. An increasing trend in rainfall was noted during the period 1902-1964, whereas a reversal was noted during the 1965-1980 period.

Prasad *et al.* (2009) observed atmospheric temperature by using the Microwave Sounding Unit (MSU) because of less availability of ground measuring stations. Based on their study MSU showed warming trends for over 30 years in the lower and middle troposphere in the mid-latitude regions at Northern Hemisphere. Mid troposphere showed an increase by 0.048±0.026 K/Year with a statistical significance of 95 % and showed positive month to month warming trends over six months (December to May). They concluded that this warming trend was due to the increased amount of aerosols. MSU obtained mean monthly lower troposphere temperature trend over Indo-Gangetic plains and dust sources regions such as Sahara desert, Middle East Arabian region, Afghanistan-Iran-Pakistan and Thar desert regions where it showed similar six months to statistically significant month oscillation. Warming trends during winter and pre-monsoon months accelerated glacial melt.

From the analysis conducted by Shekhar *et al.* (2010), the Western Himalayan region showed an increase in seasonal mean, minimum and maximum temperatures by 2 °C, 1°C and 2.8°C respectively. Within Western Himalaya, three mountain ranges showed increasing trend of seasonal maximum and minimum temperature and Karakasam range showed decreasing trend in cloud cover and precipitation, whereas no trend in annual frequency of Western disturbances was found. Number of snowfall days decreased during the peak snowfall months (January-March). More regional climate modelling studies are required over the Western Himalaya for making a robust relationship between global warming and its regional impacts.

Rangwala and Miller (2012) carried out studies on the Swiss Alps, the Colorado Rocky Mountains, the Tibetan Plateau/Himalayas and the Tropical Andes for knowing the sensitivity of climate change to surface elevation at different time scales. Elevation depended climate response modelling studies showed that some mountain regions experienced more seasonal warming than land average. The result from several studies took a global generalization but suggested seasonality to elevation depended responses occurred for minimum temperature increase during the cold season and maximum temperature during the warm season.

Kattel *et al.* (2012) conducted a study on temperature lapse rate on the Southern Central Himalayan slope on a monthly, seasonal and annual basis. Based on 56 stations, meteorological data of 20 years (1985-2004) were collected and analyzed using a linear regression model. It was found that the maximum temperature lapse rate obtained during the pre-monsoon period assisted with strong convection. The second maximum occurred during the post-monsoon period with a relatively small thermal forcing after the rainy summer. Least lapse rate and strong radiative cooling during winter made cold air over low-elevated areas. Over the high elevations due to minimum latent heat, the summer lapse rate solar heating was lower at the lower elevation.

According to Negi *et al.* (2012), Himalayan mountain ecosystem is very vulnerable. Several works were carried out on a different aspect of Western Himalayan Mountain ecosystem, but it failed to correlate with climate change. Climate change data were insufficient and needed to be strengthened. Available data did not follow the uniform methodology and standard instrumentation without quality control. Since crude methods of data collection were employed, the reliability of data was uncertain. Impact of climate change needs to be classified based on climatic events such as rainfall, temperature and CO_2 concentration. Adaptation and mitigation efforts were required for the vulnerable mountain ecosystem and communities as they are likely to face higher climate change risk. Indigenous methods of adaptation also need to be documented and researched.

Kattel and Yao (2012) examined recent surface air temperature changes across 13 mountain stations with the help of surrounding regional studies and annual maximum, minimum and average trends of 30 years time series (1980 to 2009). A significant warming trend was found for the majority of the stations. The highest maximum temperature was observed over Chainpur station on the southern slope of the central Himalayas, while minimum temperature trend showed greater variability among stations. Based on this study, they concluded that on Tibetan plateau greater increase in minimum temperature than that of maximum temperature occurred.

Hence this difference at Tibetan Plateau was considered due to anthropogenic climate change. The maximum and average temperature from 1997 to 2009 clearly showed the sharp shift in temperature from the central-southern slope of the Himalayas which experienced warming for the last decades. The difference in topography influenced the Interannual fluctuations and variability for the minimum temperature trends.

Studies by elevation-dependent warming (EDW) working group Pepin *et al.* (2015), says that warming rate is amplifying with elevation compared to low elevation. High mountain environments experience a more rapid change in temperature. Snow albedo, surface heat loss and temperature changes and aerosols contribute to EDW. They also discussed future need to improve knowledge of temperature trends in the mountains and thus controlling mechanisms by improved observations, satellite-based remote sensing and model simulators.

2.2 Soil Physical Properties and its significance

2.2.1 Organic Carbon

Lal (2004) found that the atmospheric concentration of CO_2 at the observed rate of 1990 was 3.2 Pg C/year, and continued to increase at the rate of 20-26 Pg C/year even with carbon sequestration. Observed rate of soil carbon sequestration rate by adopted recommended management practices (RMPS) give a range of 50 to 1000 kg/ha/year. This showed how important proper of soil management practice of soil in maintaining sequestration potential of soil.

Bhattacharyya *et al.* (2008) performed a study to explain the importance of soils as natural resources in enhancing carbon capture and storage. They generated thematic maps on soil carbon stocks along the Himalayan zone. When compared between the western and the eastern sides of Himalaya, organic carbon percentage was greater for the Eastern Himalayan zone (3.56 %) at 0-30m depth. Within Gangetic plains, upper Gangetic plains showed higher organic carbon than that of lower-middle and trans-Gangetic plains. Soil characteristics in the southern plateau/hills gave 5.50 % of soil organic carbon.

Zhang *et al.* (2019) conducted a study by using the DeNitrification-DeComposition (DNDC) model on eastern China for quantifying soil organic carbon changes by introducing changes in temperature and precipitation in uplands. The stimulated model indicated that by the combined effect of increased temperature and simulated increase or decrease in precipitation on carbon sequestration rate was less than the sum of their individual effects. They found that when temperature increased by 2°C and precipitation decreased or increased by 20 %, the sequestration rate projected to be 332 or 318 kg C/ha-1year-1 from 2010 to 2039, where it was 3.07 % or 5.36 % lower than the sum of their individual effects. Depending on upland soil groups, the soil organic carbon changed due to the combined effects of temperature and precipitation because of soil heterogeneities and its physiochemical conditions and fertilizer application. From the study, a nonlinear pattern of soil organic carbon changes was noticed in response to individual and simultaneous global change.

2.2.2 Soil Texture

Rastogi *et al.* (2002) stated that soil texture had a great significance for microbial, fungal and bacterial activation through the supply of soil moisture and air, resulting in the production of CO_2. Water percolation and gaseous diffusion rate are also greatly influenced by soil texture.

Edwards *et al.* (2018) examined nitrous oxide and carbon dioxide emission in sandy loam soil with drip irrigation and concluded that nitrous oxide emission was less evident, but seasonal carbon dioxide emission was greater than N_2O emission and concluded that apart from soil moisture, soil texture plays a great role in gaseous emission.

Muhammad *et al.* (2019) studied carbon, nitrogen emission with the cover crop concerning soil texture. Silty loam and sandy clay loam performed low CO_2 and N_2O emission without cover crop compared to clay loam and silty clay loam soil and concluded that soil texture had a great role in soil respiration.

2.2.3 Coarse Fragment

Parajuli *et al.* (2017) explained about the importance of bulk stony-soil and its water retention characteristics and stated that less porosity of stone makes a reduction in water retention capacity, by high volumetric stone content.

Naseri *et al.* (2019) measured the effect of stones on the hydraulic properties of two textured soil (sand and sandy loam) by simplified evaporation method and noted with a high volumetric stone content reduction in water and hydraulic conductivity. The data suggested that the presence of coarse fragment in soil widely affects pore size distribution.

2.2.4 Bulk Density

Osumbitan *et al.* (2005) studied the influence of tillage in bulk density and hydraulic property and suggested soil bulk density decreased with increase in time after cultivation. This led to a higher percolation capacity of water.

Chaudhari *et al.* (2013) suggested that dynamic soil properties varied with profile depth and found clayey soil tend to have low bulk density and higher porosity than sandy soil. The results showed a negative correlation with silt content, clay content, organic matter, Micro and macro nutrient contents except for sand content. And concluded there is a high degree of correlation between organic matter and bulk density of soil.

Kuscu *et al.* (2018) stated that bulk density differed in the soil at 0-5 m depth. High bulk density affected infiltration and surface flow, making the soil more compact, and it varied concerning human and animal intervention to the soil.

Sharma *et al.* (2018) analysed the microbial activity and influence of earthworm on dynamic soil properties. The increase in soil porosity in the organic system reflected a decrease in soil bulk density which promoted soil microbial activity.

2.3 Impact of Microclimate on Soil

Rastogi *et al.* (2002) discussed about several influencing CO_2 production and emission from the soil. It was estimated that a 1°C increase in temperature created a loss of 10% of soil organic carbon with an annual mean temperature of 5°C. For the dry soil, respiration rate will be maximum and for wet soil, both day and night gives similar respiration rate. Temporal variability of CO_2 efflux was mostly controlled by soil temperature. Spatial variability of soil respiration occurred at 15cm depth due to the improved root development. It was concluded that atmospheric pressure is inversely proportional to soil respiration.

Xu *et al.* (2004) observed that ecosystem respiration was an exponential function of soil temperature and respiration rate reached its maximum during the wet winter season. It was concluded that carbon loss from the system after a few summers was relatively high.

Emmett *et al.* (2004) discussed litter decomposition, respiration, net N mineralisation and nitrification in shrubland in warming drought conditions. The study indicated soil respiration was largely temperature-dependent. The data predicted an increase in respiration of 0.003 g cm^2 ha^1 in response to a 1 °C rise in temperature in the treatments. The primary productivity showed changes due to reduction in water availability.

Fan and Dool (2004) produced a 0.5 ° × 0.5 ° monthly global soil moisture increment with atmospheric temperature data set for 1948 to 2004. The Land Model used global monthly precipitation as input and developed a one-layer Water Balanced Model. The data showed that global soil moisture had an impact on long-term trends in precipitation on both regional and global scales.

Hasler and Avissar (2006) concluded that evapotranspiration (ET) would increase during summer (June-September) and decrease during the wet season (December-March), and stated net radiation was the primary factor which influenced ET. Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) was used to provide spatial variability of temporal evapotranspiration cycle.

Fischer and Seneviratne (2007) studied the intensity and persistence of the 2003 European summer heatwave. Summer atmospheric circulation, as well as the anomalous dry continental-soils, played an important role in summer heatwaves. Dried soil and precipitation deficit reduced the soil moisture and lead to an extreme summer event along with clear sky condition, which enhanced evapotranspiration rate throughout summer and autumn in 2003. Soil moisture perturbations could influence circulations on a continental scale and showed positive feedback between them.

Anjileli *et al.* (2009) studied variations of soil respiration under various hydro-climatic conditions with temperature using the help of a probabilistic model in a semi-arid ecosystem in southern California. It was observed that the soil respiration increased below~ 18°C, and decreased up to~ 27 °C with increased soil temperature. At selected two temperature ranges of (14°C) and (17°C) annual mean soil respiration increased by 33 % and declined by 35 % between (20°C) to (23°C).

Lamberty and Tomson (2010) constructed a database of worldwide soil respiration (Rs) observations and showed similarity with high-resolution historical climate data. Air temperature anomaly had a positive correlation with 98±12 PgC and increased by 0.1 $PgCy^{-1}$ between 1989 and 2008 as a response to the increasing air temperature.

Suseela *et al.* (2012) conducted a field study to examine the response of heterotrophic respiration (Rn) and its temperature sensitivity to global warming and altered precipitation. Heterotrophic respiration was noted excluding plant root and litter inputs. Rn responded strongly to precipitation and shapely decreased when volumetric soil moisture dropped below~15% or exceeded~26 %.

Jiang and Weng (2016) conducted a study for determining urban land surface temperature. Daily and hourly evapotranspiration (ET) and soil moisture were examined. Two Source Energy Balance (TSB) method was used to generate ET and found soil moisture fluctuated from 15% to 20%. The ET changed concerning the vegetation and soil.

2.4 Carbon, Water and Heat Flux

Idson *et al.* (1975) experimented with loam soil at 10cm. Net radiation, soil heat flux, incoming and reflected solar radiation, and soil water content was measured. The soil heat flux on net radiation changed as the soil dried and the net radiation-soil heat flux difference for the soil in an air-dry state was only about one half of that on the day after irrigation.

Hollinger *et al.* (1999) examined carbon dioxide, water vapour and sensible heat fluxes within and above a boreal forest in the USA. Compared to other coniferous forests, summer midday CO_2 uptake was high on an average of -13μmol CO_2 m^{-2} s^{-1}. Respiration averaged at nocturnal summertime was approximately above six μmol CO_2 m^{-2} $s^{-}$with a mean temperature of 15°C. But during April, it reduced due to autumn frost. CO_2 exchange was regulated mostly by the incident Photosynthetically Active Photon Flux Density (PPED) and concluded forest was a strong carbon sink, storing about 2.1tCha^{-1}.

Ogee *et al.* (2001) presented work for estimating soil heat flux in south-west of France, where it was estimated using the null alignment method using soil temperature, bulk density and water content measurements from the soil surface at a depth of 1m. Throughout the investigated year and at 30 min time scale, the soil heat flux represented 5-10 % of incident net radiation which means 30-50 % of the net radiation over the understory. The heat stored in a forest floor was not negligible under the canopy as the flux represented up to 50 % of midday net radiation. The source of variation in the heat flux was due to soil water content.

Baldocchi and Wilson (2001) performed an exercise using eddy covariance flux measurements with the help of a biophysical model and examined interannual variability of mass and energy exchanges by validating micrometeorological records. They estimated a 5 to 6 year of CO_2 and water vapour exchange associated with EL-Nino phenomena. Infrared absorption gas analyser having open-path was used to measure carbon dioxide and water vapour fluctuations. It was found out that at each increment day, changes in the length of the growing season altered the net ecosystem CO_2 exchange at a rate of 5.9 gCm^{-2}.

Santanello and Friedl (2003) discussed the diurnal behaviour of soil heat flux as a function of net radiation on bare and sparse cover conditions, along with soil moisture and soil type. Field data information was compared with the diffusion-based soil model with multilayer stimulations. The result was attained, showing that the soil moisture played an important role between net radiation and soil heat flux. The relation between them was affected by evaporation processes. Integration of the effect of soil type and moisture on diurnal surface temperature could be used to predict the behaviour and magnitude of soil heat flux and net radiation in varying soil conditions.

Smith *et al.* (2018) reviewed the interaction between soil biological and physical processes and the production and consumption of greenhouse gases in soils. CO_2 respiration/release from soil organic matter generally increased with an increase in temperature. They examined the temperatures at different depths from both field experiments of some arbitrarily chosen depth. In general, for CO_2 flux, they concluded that greater the swing in temperature, greater would be the mean respiration rate, even though they mean temperature was the same. This would apply for a different location as well as to varied depths at the same point in the landscape. Hence they predicted soil exposed in a sunny climate, but with the same mean diurnal temperature as a shaded forest, experience high respiration in the surface layers where moisture content was not limiting.

Jian *et al.* (2018) modelled carbon dioxide flux increase with temperature. Examined CO_2 flux between 1960 and 2014 found an increase of 0.05 Pg C/Yr.

Concerning RCP 8.5, 3°C of global warming would accelerate CO_2 efflux to 0.12 Pg C/Yr. Further increases in GHGs would lead to more CO_2 flux rate in an enhanced rate.

Chatterjee *et al.* (2018) experimented using eddy covariance to study both above and below ground CO_2 and H_2O fluxes along with sensible heat and latent heat energy. Soil CO_2 flux measurement was undertaken from four soils and, CO_2 flux chambers (LI- 8100A, LI-COR, USA) were installed on the forest floor. Mean CO_2 flux above the canopy gave a value of 2.8± 6.5 μmol m-2S^{-1} which was higher than within the canopy, with a value of 0.6 ± 0.1 μmol m-2S^{-1}. Only at afternoons, the values of CO_2 flux gave positive values within the canopy, and the flux increased with soil CO_2 flux. H_2O flux was high above the canopy after precipitation and soil CO_2 emission increased at the same time when canopy emitted more water vapour to the atmosphere. The high altitudes in eastern Himalayan coniferous forests acted as a net sink of CO_2 having a net ecosystem exchange of -656.5 g of CO_2 m-2 during the spring season.

2.5 Significance of Selected Land use to Climate Change

2.5.1 Mixed Forest

Ralch and Nadelhoffer (1989) estimated above ground and below ground carbon allocation in a forest ecosystem in carbon rising scenario. The litterfall carbon ranged from 70 to 500 gm-2 yr^{-1}. And belowground allocation decreased from 3.8 to 2.5, which was related to carbon increase from 200 to 500 gm-2 yr^{-1}.

Couteaux *et al.* (1995) stated tropic forest primary productivity was expected to change and the concentration of Nitrogen in a litter with the response to temperature rise, in boreal and temperate forest decomposition of organic matter increased and enhanced C and N mineralization. The larger soil carbon reservoirs per unit surface area were indicated at higher latitudes and tropical regions compensated this storage ability by high primary productivity.

Fearnside (2000) estimated soil carbon from tropical forest. The annual decomposition processes emitted 2.1×109 tonnes of C. It was found that an additional emission of 0.8×109t C year^{-1} by tropical land-use changes. Total net emission of carbon indicated a warming potential due to land use.

Melillo *et al.* (2002) discussed about soil warming experiment in the mid-latitude hardwood forest and stated that warming in soil accelerated soil organic matter decomposition and release of CO_2 as CO_2 flux to the atmosphere. Warming had enough potential to enhance storage potential, but the projected climate model (Three Dimensional Carbon-Climate Model) gives a prediction of the long-term release of soil carbon.

Clark (2014) examined how tropical rain forests respond to changing climate. CO_2 enrichment in the atmosphere did not show great influence in above-ground biomass and average global temperature rise in the atmosphere led to the mortality of trees. It was indicated that the old tropical forest had a significant role in carbon sequestration potential. While temperature continued to rise a reduction in Net Primary Production (NPP) is found and suggested that tropical old-growth forests would be acting as a net source.

2.5.2 Chir Pine (*Pinus roxburghii*) Forest

Usman *et al.* (1999) estimated fine root production of Chir pine (Pinus roxburghii) with broad-leaved forest and obtained high fine root production in the broad-leaved forest of Quercus leucotrichophora (banj Oak) which decreased with depth having a value of 3631 kg ha-1 year-1 and Pine with 2508 kg ha^{-1} year^{-1}.

Sheikh *et al.* (2012) evaluated C stock of forest floor of (*Pinus roxburghii*) along with elevation at three sites and concluded that *P. roxburghii* forest was a sink of a large amount of atmospheric carbon and noticed above and below biomass increased with a decrease in elevation.

Pant and Tewari (2013) determined biomass and carbon sequestration potential of Chir pine (*Pinus roxburhghii*) on the southern and northern aspect with different girth classes. The result showed greater biomass and carbon sequestration at the northerly aspect, even the tree density was lower. This is because of the sequestration potential of mature trees in the northern aspect.

Shah *et al.* (2014) studied soil carbon reserves in a subtropical pine forest. The total ecosystem carbon density was 247.87 t ha^{-1}, and 190.89 t ha^{-1} was stored in the soil layer.

Singh *et al.* (2014) showed the link of albedo dynamics in Chir pine over subtropical ecosystem with soil moisture and Leaf Area Index (LAI). A strong coupled energy balance with water budget was existing and brought out the link between the degree of variability in South West Monsoon rainfall and variability of pre Monsoon sensible heat fluxes.

Sharma *et al.* (2016) studied the allelopathic effect of *Pinus roxburghii* on *Bidens pilosa* through laboratory and greenhouse experiment and found extracts of needle and bark of *Pinus roxburghii* inhibited the germination, initial growth and root initiation of *Bidens pilosa* and the soil was found to be rich in phenolics.

Kumar and Pandey (2016) estimated loss of biomass and carbon from Chir pine forest due to felling. Before felling, carbon and biomass were already taken. Estimated above-ground biomass of trees were 266.16 t ha^{-1} with total carbon stock of 119.77 t ha^{-1}. When 50 trees/ ha were removed, an estimated loss of carbon from the patch was 40.46 t ha^{-1}, meaning 0.81 t carbon was lost from the respective tree removed areas.

Gupta *et al.* (2017) examined soil organic carbon stock in coniferous as well as broad-leaved forest of Uttarakhand. The data obtained showed that the organic carbon stock in the coniferous forest was 79.21 t/ha, and in broad-leaved

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forest it was 71.06 t/ha. While the total SOC stock for the coniferous forest was 40.60 million tons, this variation was because of the large area occupied by broad-leaved forest, around 13,10,503.32 ha but coniferous had only 524,180.86 ha area.

Jasrotia and Raina (2017) studied the temporal variations of carbon storage and carbon biomass between 1995-96 and 2015-16 in Jammu & Kashmir in *Pinus roxburghii* (Chir pine) forest. The total carbon stock declined to 4.39 lack tones from 5.90 lack tones.

Amir *et al.* (2018) examined the sequestration potential of Chir pine (*Pinus roxburghii*) forest withstanding age. Forest age classification ranged from (< 50 years) young stand, (50-75) mature and (>75 years) over matured. The result showed an increased carbon sequestration trend in stand-in living biomass and a decreasing trend in soil carbon.

2.5.3 Grassland

Scurlock and Hall (1998) discussed Net Primary Productivity (NPP) data of grasslands. They showed grassland significance on climate change and suggested for temperate grassland using the CCGRASS model where elevated CO_2 lead to an increase in the carbon loss worldwide from grasslands.

Genxu *et al.* (2002) compared respiration rate of grassland soil on Tibetan Plateau and China and obtained 1.17 Pg C year-1 in Tibetan Plateau which accounted for 26.4 % of China's total soil respiration but released from 16.9 % compared to China's soil area. Tibetan Plateau grassland carbon cycle had a significant impact on global atmospheric CO_2 concentration changes. Due to the degradation of carbon emission from grassland soil on plateau totalled 3.02 Pg C year^{-1} and with an emission rate of 1.27 Pg C year^{-1}.

Hunt *et al.* (2002) examined carbon dioxide emission from grassland in New Zealand and observed during summer high ground temperature resulting maximum CO_2 release of 4.9 μ mol m-2s-1per day has been reported, which substantiated grassland ecosystem switched into the sink to source more carbon dioxide is released than sequestered. The short rainfall followed by drought increase the source strength.

Liukang and Baldocchi (2003) presented carbon dioxide flux over annual grassland in California and noted the seasonal trends in Gross Primary Production (GPP) and ecosystem respiration with LAI. Ecosystem respiration peaked after rain events on non- growing season. The comparison of two seasons based on the data collected showed that the start of the wet season and rainy events had a great impact on GPP and ecosystem respiration.

Novick *et al.* (2004) assed Net Ecosystem Carbon Exchange (NEE) with Ecosystem Carbon Assimilation (AC) and Ecosystem Respiration (RE). After the harvesting of grassland, it become a net source of carbon to the atmosphere but rapidly maintained and became a carbon sink during summer by recovering in LAI at that period with AC (-1.202 g C m^{-2} a^{-1}) and RE (1,299 g C m^{-2} a^{-1}) when the soil moisture was (< 0.2 m^3). In the absence of soil moisture grassland acted as a sink of~ 65 g C m^{-2} a^{-1}showing the importance of hydrological parameter in the grassland ecosystem.

Baldocchi *et al.* (2004) focused abiotic, biotic and edaphic factors which modulated energy exchange over annual grassland and oak and obtained observation in net energy exchange over seasonal evaporation and sensible heat exchange of 380mm per year on woodland and 300mm per year on grassland.

Conant *et al.* (2017) examined management practice and carbon stock in grasslands. Conversion of native forest to grassland led to a loss in soil carbon both in temperate (-0.84 Mg C ha^{-1} yr^{-1}) and in tropical regions (-0.13 Mg C ha^{-1} yr^{-1}).

2.5.4 Bamboo Forest

Ben-Zhi *et al.* (2005) reviewed ecological functions of bamboo forest and explained about net primary production and growth rate of bamboo was high hence more carbon was sequestered.

Liu *et al.* (2011) examined soil CO_2 efflux on subtropical site over 12 month period between conventionally managed broad-leaved evergreen forest and intensively managed bamboo forest. The maximum efflux was obtained at summer and minimum in winter. There was no significant change in total annual soil CO_2 efflux between the conventionally managed bamboo forest and broad-leaved evergreen forest. High CO_2 efflux was shown by intensively managed bamboo forest. Other than soil moisture soil temperature had a great impact on soil CO_2 efflux.

Duking *et al.* (2011) reported that old bamboo forest act as a source among above and belowground storage, clubs present in above ground carried great carbon accumulation potential. When it is was added to soil rhizomes and root system, it made the bamboo forest as a source. Mature bamboo exhibit CO_2 intake and release in an equilibrium state and old bamboo showed a decline in carbon storage.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The present study **entitled "Quantify the temporal carbon, water and energy fluxes in the selected land-use system in the Himalayas"** was conducted at the Forest Research Institute, Dehradun. This institute is located in a lush green estate, which spreads over 450 hectares in the Doon valley, with the outer Himalayas in its backdrop. It falls under subtropical climate, with many seasonal variations over the year. Himalayan foothills constitute the valley in the north and Shivalik hills to the south, which adds to its peculiar sub-tropical climatic characteristics lying in the geographical limits of latitude 30°20'42"N and longitude 77°59'59"E and with an elevation of 653m. The mean monthly air temperature of the experimental site averaged for twenty years varies between 11.47˚C to 26.82˚C with the lowest in January and the highest during June. The details of the materials used ad methods adopted during the investigation are described in this chapter.

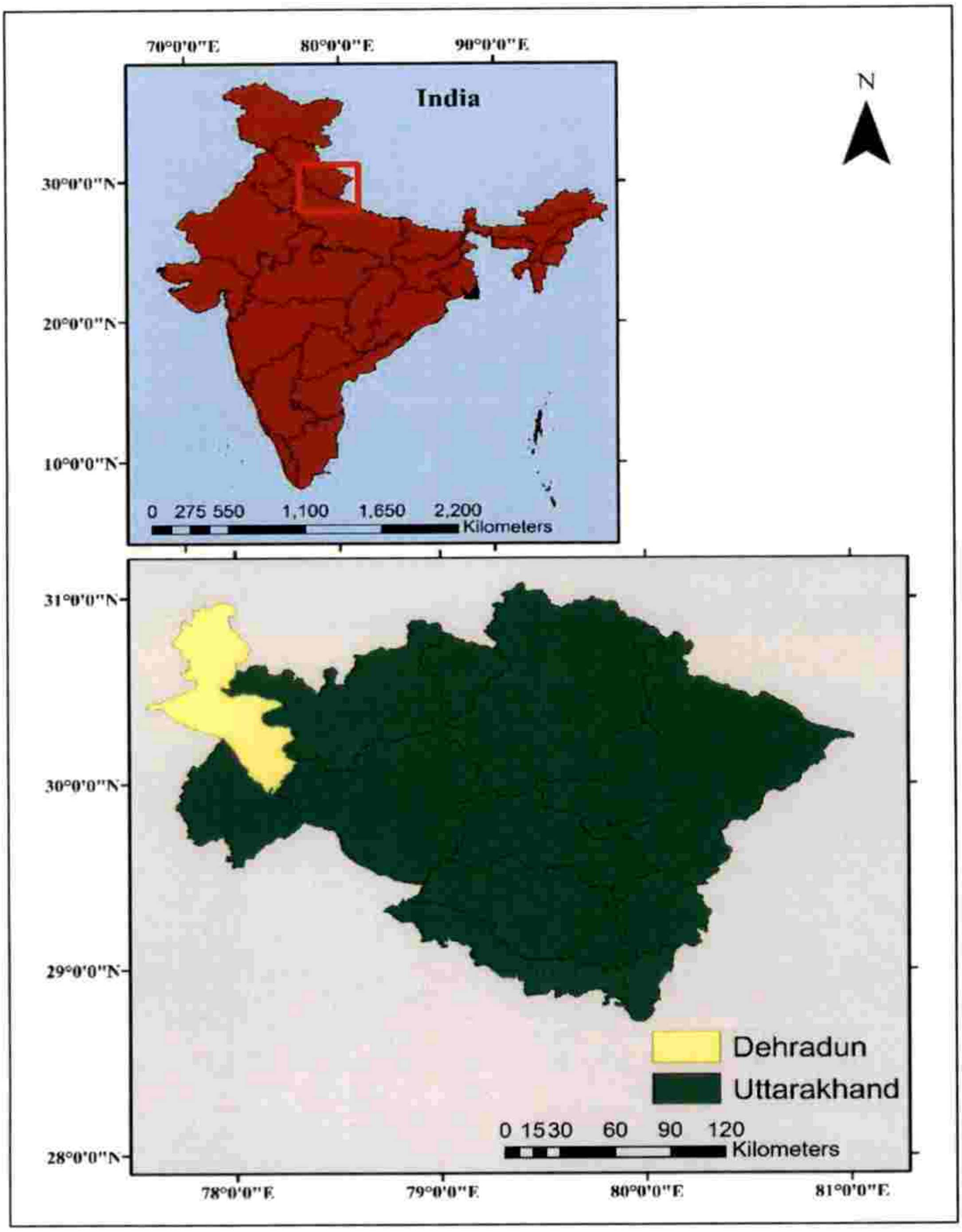

Plate 1: Uttarakhand (Dehradun)

Plate 2: Forest Research Institute (Dehradun)

3.1 EXPERIMENTAL SITE

3.1.1 Mixed Forest

Matured mixed forest is dominated by Sal (*Shorea robusta*) and teak (*Tectona grandis*) planted by British during 1906 and later developed into the mixed forest. With latitude 30°20'30.97" N, and longitude 78°00'19.08" E total area comes under mixed forest is 630,197 m^2.

Plate 3: Mixed forest with Sal (*Shorea robusta)* and Teak(*Tectona grandis*)

Plate 4: Mixed forest floor

3.1.2 Chir pine (*Pinus roxburghi*) Forest

The experiment was set up in uniform Chir pine (*Pinus roxburghii*) plantation. It was established in 2002 inside FRI. Having latitude 30˚20'4" N, longitude 78˚00'01" E and with an elevation of 640.08 MSL. The gross area of the plantation is 14,641 m^2.

Plate 5: Chir pine forest

Plate 6: Pine floor till March (2019) beginning

Plate 7: Floor of Chir pine (*Pinus roxburghii*) along April-May (2019)

3.1.3 Grassland

Undisturbed natural grassland with a total area of 6,234 m^2 having latitude 30°20'04.99"N, and longitude 77°59'56.81" E.

Plate 8: Grassland till February

Plate 9: Grassland in March-April

Plate 10: Grassland in May

3.1.4 Bamboo Forest

The bamboo plantation was established in 2008 with (*Dendrocalamus strictus*) having an area of 11,779 m^2 with latitude 30°20'03.77"N, and longitude 77°00'02.81" E.

Plate 11: Bamboo forest in December-February (2018-2019)

Plate 12: Bamboo field from mid March and April (2019)

Plate 13: Bamboo floor in April (2019)

3.2 Soil

The soil of the present study area was sandy clay loam. Soil samples were collected from 0-15 and 15-30 cm layer of the soil.

3.3 Season

The experiment was conducted during winter to the summer season, (from December 2018 to May 2019).

Table 1: Chemical properties of the soil

Sl. No.	Fields	Parameters	0-30cm	Procedure Adopted
1	Mixed forest Pine forest Grassland Bamboo forest	Organic carbon (%)	1.43 1.16 1.56 1.17	Walkely and Black (1934)
2	Mixed forest Pine forest Grassland Bamboo forest	Organic carbon pool (PgC)	203 162 271 122	Penman *et al.* (2003)

Bulk density of the soil from each field in two depths was obtained by Hakson and Lipiec (2000) method.

Table 1(a): Bulk density (Mg m^3)

Fields	Depth (0-15cm)	Depth (15-30cm)
Mixed forest	1.35	1.38
Pine forest	1.23	1.13
Grassland	1.22	1.27
Bamboo forest	1.17	1.34

Bouyoucos hydrometer method is adopted for determining soil texture and resulted in sandy clay loam in all fields,

Table 1(b): Textural composition of the soil

Fields	Sand (%)	Slit (%)	Clay (%)
Mixed forest	56.66	17.5	25.84
Pine forest	56.16	15.75	28.09
Grassland	61.91	14.25	22.39
Bamboo forest	59.91	16.75	23.34

The highest percentage of soil texture is occupied by sand, followed by clay, and the least percentage in all collected and tested samples was slit. Among that grassland carried high sand percentage with (61.91 %), pine forest soil showed least sand percentage of (56.16 %), and silt is high in bamboo forest soils (16.75 %), low in grassland (14.25 %). High clay content was in pine soils (28.09 %) and low in grassland (22.39 %).

Coarse fragment of the soils from each field in two depths is obtained by the method proposed by Wild *et al.* (1964) and the obtained data is given in Table 1(c).

Table 1(c): Coarse fragments (%)

Fields	Depth (0-15cm)	Depth (15-30cm)
Mixed forest	1.71	3.79
Pine forest	2.41	2.22
Grassland	2.63	2.55
Bamboo forest	2.03	2.21

3.4 Weather

The monthly maximum and minimum temperatures, relative humidity, wind velocity and sunshine hours are given in Appendix III for each field at respective dates, readings obtained and graphically presented in Fig. 1a. (Mixed forest), Fig. 2b. (Pine forest), Fig. 3c. (Grassland) and Fig. 4d. (Bamboo forest).

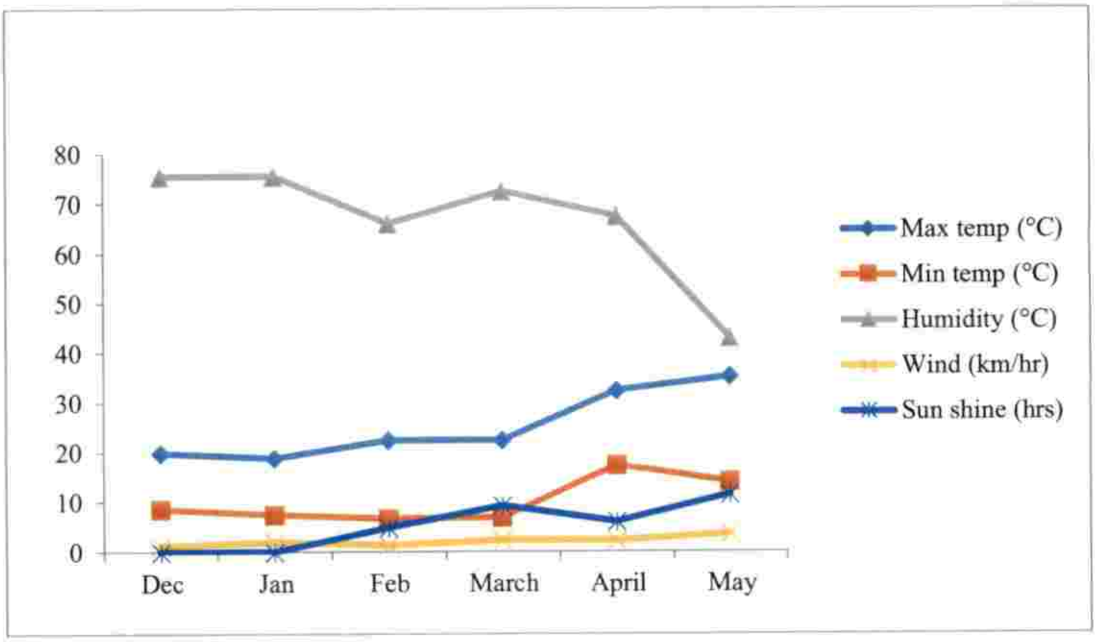

Fig 1a: Weather parameters of mixed forest at the date of 6th in all respective months (Dec 2018-May2019)

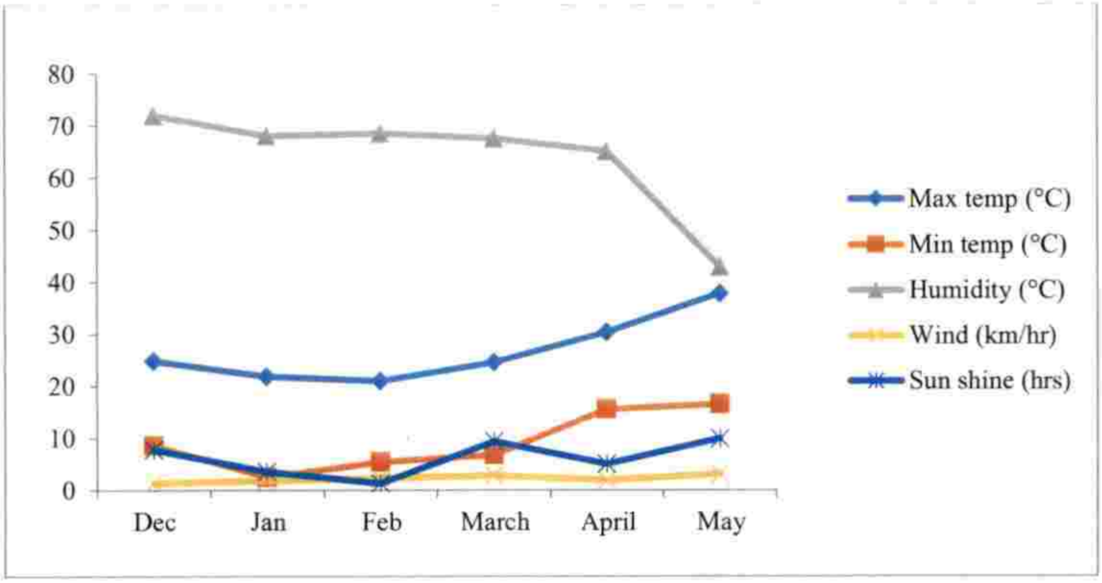

Fig. 1b: Weather parameters of pine forest at the date of 10th in all respective months (Dec 2018-May2019)

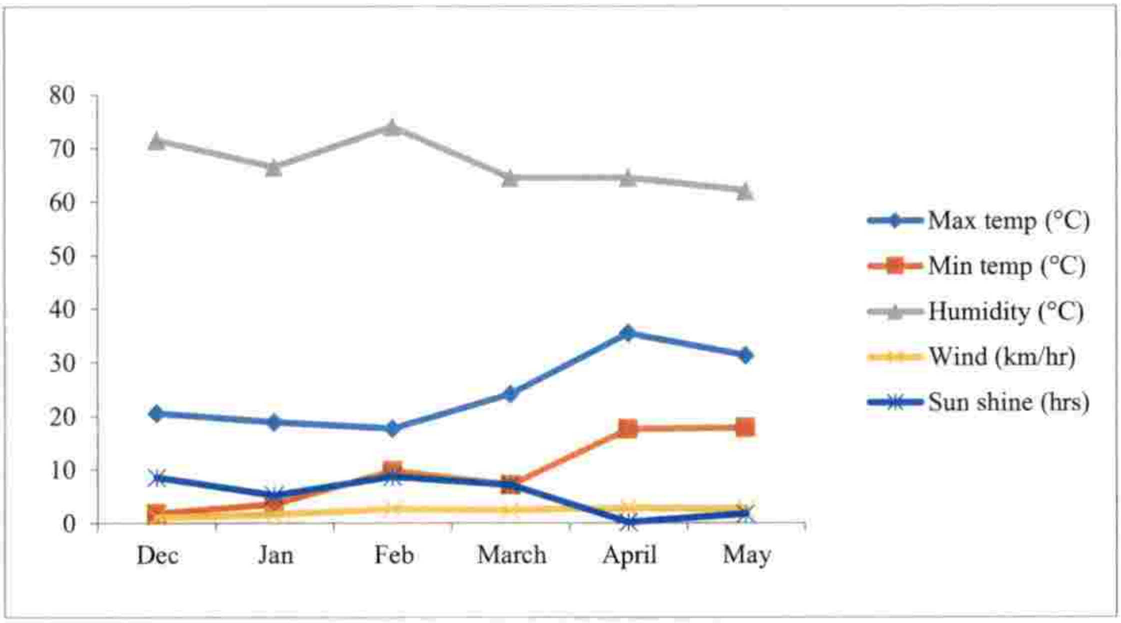

Fig. 1c: Weather parameters of grassland at the date of 16th in all respective months (Dec 2018-May2019)

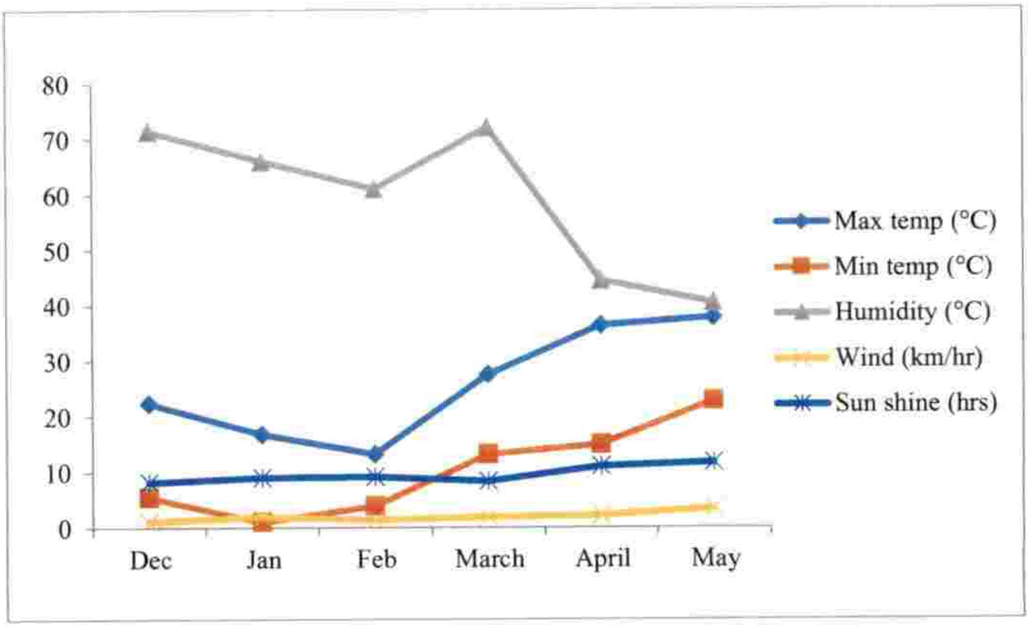

Fig. 1d: Weather parameters of bamboo forest at the date of 28th in all respective months (Dec 2018-May2019)

3.5 Outline of the technical programme

Two seasons were taken winter and summer (2018 December-2019May). Two sites were selected within the field and among each field 0-15cm and 15-30cm were analyzed for soil physical parameters.

Replication	: 4	
Plot size (m^2)	**:Mixed Forest**	630,197
	:Pine Forest	14,641
	:Grassland	6,234
	:Bamboo Forest	11,779

3.2 Methodology

3.2.1 Soil respiration/CO_2 flux measurement by using IRGA chamber connected to Portable Photosynthesis Analyzer (PPA)

For determining CO_2 respiration from the soil surface, a transparent sheet of PVC chamber having 20cm×20cm×20cm size and with 80 – 85% transmission level of light is used. The measurement of soil respiration from the field is possible with this chamber by connecting it with Portable Photosynthesis Analyzer (PPA) (LI-COR-6400 XT, Lincoln, USA) with a reference pipe. Then the chamber is inserted into 2cm depth into the soil, and air tightened with the help of surrounded soil manually. The chamber which is connected to PPA helps to visualize the change in CO_2 concentration, and it is displayed on the screen. The initial reading is taken immediately just after placing the chamber, after 15 minutes final CO_2concentration is taken and saved as a log file in the Portable Photosynthesis Analyzer (PPA). The CO_2 respiration from the soil per unit time (mg CO_2 m^2/hour) and it is calculated by subtracting initial value from the final value of CO_2 concentration and with the area of the chamber along with the time taken between the initial and final concentrations of CO_2. This method of soil respiration/ CO_2 flux is carried out in two sites within the fields for six months (Singh, 2017).

$$\textbf{Carbon flux (C)} = \frac{(Cn - C_0)}{Tn} \times \frac{V}{A}$$

Where,

Cn is the final CO_2 concentration, C_o is the initial concentration, and Tn represents the time between Cn and C_o, V and A are the respective volume and area of reference chamber.

Plate 14: Taking soil respiration with IRGA chamber

3.2.2 Measuring H_2O flux using Portable Photosynthesis Analyzer (PPA) connected to IRGA chamber

For estimating the water flux the same PVC transparent 20cm×20cm×20cm chambers are used, and it is placed on the field as like measuring CO_2 respiration. The chamber is inserted 2cm depth from the soil surface and covered with removed soil, and air tightened. The initial reading is taken suddenly after placing the chamber and final reading after a gap of 15 minutes. This is obtained with the help of reference pipe connected from the chamber to (LI-COR-6400 XT, Lincoln, USA) Portable Photosynthesis Analyzer (PPA) and it is saved. Here the water efflux per unit time (mg H_2O/m^2/hour) which is calculated by subtracting final H_2O concentration with initial concentration and by considering the size of the chamber along with the time taken between this two readings. This estimation method is followed in two sites within the fields for six months (Singh, 2017).

$$\textbf{Water flux (H)} = \frac{(Hn - H_0)}{Tn} \times \frac{V}{A}$$

Where,

Hn is the final H_2O concentration, H_0 is the initial concentration and Tn represents the time between Hn and H_0, V and A are the respective volume and area of reference chamber.

Plate 15: Monitoring soil moisture by attaching reference pipe

3.2.3 Onsite measurement of soil temperature and soil moisture

For taking soil temperature and soil moisture measurements an instrument called ProCheck-12, TEROS-12 (formally known as the GS3 sensor) is used it helps in measuring water content, temperature and electrical conductivity (EC). Apart from gravimetric measurements, soil moisture sensor indirectly measures the electric resistance, dielectric constant and neutron interactions. For taking the readings within the field, a suitable pit of 30cm is made with the help of an auger. Sensor connected to the ProCheck-12 device having the probe is inserted

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horizontally at a depth of 15cm and 30cm. Three readings are taken from each side of the pit in two depths. The connected probe having sensor helps to display soil moisture in % VMC, soil temperature in °C and electrical conductivity in ds/m from the respective depths which is automatically saved within the device (Singh, 2017).

Plate 16: ProCheck device and insertion probe with soil moisture sensor

Plate 17: Taking reading from installed probe at 15cm

3.2.4 Determination of Energy Flux (Heat Flux)

The soil heat flux (G), is the conduction of energy per unit area concerning a temperature gradient. G is positive when the soil system is warming while negative when soil system is cool. The soil heat flux was expressed as WJ/m^2/hr.

And equation for heat flux,

$$\mathbf{G_{hr}} = C_d \times R_n$$

Where,

G_{hr} is the heat flux

C_d Canopy density with respective land use and Rn net radiation.

For short grass, canopy density, (Cd) 0.1, for Mixed forest,(Cd) 0.02, Bamboo forest,(Cd) 0.06 and for Pine forest, Soil heat flux during the day, (Cd) 0.04 (Allen *et al*., 1998).

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Rn (W/m2) represents net radiation on a daily or hourly basis (Maximum and minimum daily temperature is obtained from FRI meteorological observatory, with the help of CROPWAT 8.0 developed by Land and Water Development Division of FAO, net radiation is derived every month).

3.2.5 Crop Evapotranspiration ET₀ (mm/day)

Evaporative demand of atmosphere was derived from weather data. It was obtained with the help of CROPWAT 8.0 developed by the Land and Water Development Division of FAO. Weather parameter such, as maximum and minimum temperature, relative humidity, wind speed and sunshine hours were obtained from FRI observatory

3.2.6 Statistical analysis

Data obtained from the field were compiled, tabulated and analyzed by IBM SPSS Statistics 20 package; one – way ANOVA, correlation and regression are performed for the evaluation of obtained data.

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RESULTS

CHAPTER 4

RESULTS

An investigation titled "Quantify the temporal carbon, water and energy fluxes in selected land-use systems in the Himalayas" was conducted to understand the link among fluxes in various land use with meteorological parameters. The results obtained from the present experiment are presented below.

4.1 MONTHLY FLUX DATA FOR SELECTED LAND USE

4.1.1 Soil carbon flux

Monthly Carbon flux obtained from selected land use is given in Table 4.1. Carbon flux showed significant influence with seasonal variation (winter-summer) and made a relation between air temperature. Most carbon flux is shown from grassland soil and low in pine forest soil..

Table 2.1: Soil carbon flux for respective months in selected land use

Parameters	**Months**	**Mixed forest**	**Pine forest**	**Grassland**	**Bamboo forest**
	December	1.21	1.3	1.89	1.22
	January	1.86	1.22	1.76	1.43
Carbon Flux ($mgCO_2\ m^{-2}hr^{-1}$)	**February**	2.72	2.11	2.09	2.01
	March	3.58	3.21	4.69	3.82
	April	3.86	3.51	4.67	4.12
	May	4.32	3.54	4.89	4.67

4.1.2 Soil water flux

Water exchanged from selected fields to the atmosphere obtained from six months showed a gradual increasing pattern from December to May. Among the four land use, grassland showed high water flux, and minimum flux is experienced in pine forest soil.

Table 2.2: Soil water flux for respective months in selected land use

Parameters	Months	Mixed forest	Pine forest	Grassland	Bamboo forest
Water Flux ($mgH_2O\ m^{-2}hr^{-1}$)	December	10.02	10.06	13.42	11.52
	January	10.89	11.04	11.32	12.34
	February	11.21	11.17	12.47	13.21
	March	21.67	25.32	32.89	27.62
	April	21.58	26.78	36.23	29.87
	May	26.46	27.67	88.51	32.01

4.1.3 Soil energy flux

Energy/heat flux obtained from selected land use showed a significantly increased pattern. High energy flux was experienced by grassland, and minimum energy flux was shown by mixed forest soil. All observed fluxes were evaluated with mean air temperature every month, and it increased with months.

Table 2.3: Soil energy flux for respective months in selected land use

Parameters	Months	Mixed forest	Pine forest	Grassland	Bamboo forest
	December	0.25	0.48	1.67	0.82
	January	0.27	0.61	1.86	0.70
Energy Flux (MJ m^{-2} hr^{-1})	**February**	0.34	0.69	1.72	0.87
	March	0.34	0.60	2.19	1.15
	April	0.33	0.53	2.27	1.24
	May	0.33	0.67	2.79	1.61

4.2 SOIL PHYSICAL PROPERTIES

4.2.1 Soil moisture (%VMC)

Obtained soil moisture data for the four fields from two depths (15-30cm) examined with the help of ProCheck showed increased rate from December. Soil moisture is high in lower depth.

Table 3: Monthly soil moisture obtained at two different depths of selected land use

Months	Mixed forest		Pine forest		Grassland		Bamboo forest	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Dec	19.5	20.8	15.2	16.2	16.3	19.3	16.1	18.5
Jan	18.6	21.1	16.7	17.4	15.2	17.1	20.3	24.1
Feb	19.5	20.1	14.2	18	16	18	15.3	17.2
March	17.2	19.2	15.5	18.7	21.3	22.4	25.3	28.2
April	19.4	20.5	28.7	30.5	19.1	22	19.3	20.4
May	20.1	22.3	24.3	28.5	17.6	18.3	18.2	19.2

4.2.2 Soil temperature (°C)

Monitored six months of data with the help of ProCheck is given in Table 4.5. Soil temperature decreased concerning depth.

Table 4: Monthly soil temperature obtained at two different depths of selected land use

Months	Mixed forest		Pine forest		Grassland		Bamboo forest	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Dec	16.1	14.5	12.3	10	12	10.3	17.1	12.4
Jan	15.3	12.2	11.1	10.3	12.4	10.6	15.2	13.2
Feb	16.3	13.4	14.1	12	12.3	10.2	16	15.1
March	22.5	18.1	29	27.3	32	29	20.2	19.2
April	24.2	21.1	23	21.5	27.3	25	24.5	22.1
May	28.6	23	33.3	29	32.6	25	26.3	23.7

4.2.3 Reference crop evapotranspirtion (ET₀)

Reference Crop evapotranspiration was computed using CROWAT 8.0 with the help of weather data inputs obtained from FRI observatory. The results are shown in Table 4.6. It is expressed as ET_0 and unit mm/day. ET_0 rose every month and high ET_0 is experienced from bamboo forest and least in the pine forest.

Table 5: Monthly reference crop evapotranspiration of respective fields

Months	Mixed forest	Pine forest	Grassland	Bamboo forest
Dec	1.23	1.04	2.13	2.41
Jan	1.25	1.09	2.25	2.3
Feb	2.24	1.11	2.01	2.42
March	3.34	1.25	2.22	2.63
April	3.26	1.22	3.95	2.92
May	3.27	1.57	4.63	5.18

4.2.4 Mean air temperature

The mean air temperature was obtained from FRI observatory itself, and for each field, one date is fixed for the data collection and the mean air temperature obtained is represented in Table 4.7. Mean air temperature increased from December till May (Winter-summer).

Table 6: Monthly mean air temperature of respective fields (°C)

Months	Mixed forest (At the date of 6th in all months)	Pine forest (At the date of 10th in all months)	Grassland (At the date of 16th in all months)	Bamboo forest (At the date of 28th in all months)
Dec	11.2	11.4	11.3	14.5
Jan	11.5	11.3	11.9	13.6
Feb	11.6	11.7	12.01	12.9
March	24	26.9	27.3	23.1
April	23.4	25.7	25.4	25.4
May	25.4	27.3	26.9	26.1

4.3 STATISTICAL SIGNIFICANCE

With the help of IBM SPSS Statistics 20 tool, One-Way ANOVA is performed. The obtained result showed that carbon and water flux between four fields have no statistical variance. Heat flux (G_{hr}) in mixed and pine forest falls under one group, grassland and bamboo in other separate groups. Reference crop evapotranspiration in the mixed forest comes as separate and all others grouped under one category (Appendix-I).

4.3.1 Analysis of variables in selected land use

By using IBM SPSS Statistic 20 relationship between variables (Correlation) and dependence of independent and dependent variable (regression) is Performed, correlation analysis of carbon, water, heat fluxes and reference crop evapotranspiration with air temperature from selected land use showed a positive correlation.

4.3.1.1 Mixed Forest

Carbon and water flux in the mixed forest showed significant values with air temperature. High correlation is experienced by heat flux and reference crop evapotranspiration (Appendix-II).

4.3.1.2 Pine Forest

Correlation analysis performed in pine forest showed a high correlation between carbon flux and water flux with air temperature and a high positive correlation is experienced between carbon and water flux (Appendix-II).

4.3.1.3 Grassland

Analysis obtained from the data collected from grassland showed that carbon water and heat flux is highly positively correlated with air temperature (Appendix-II).

4.3.1.4 Bamboo Forest

Bamboo forest data analysis for determining relationships between variables with the help of IBM SPSS Statistics 20 software showed a highly positive correlation in air temperature with carbon water and heat flux, and they are correlated with each other (Appendix-II).

4.3.2 Regression Analysis

Regression analysis is carried out for each selected land use, and relationships are determined separately with independent and dependent variables. The results are given below;

4.3.2.1 Carbon flux (Cf) variation with air temperature in mixed forest

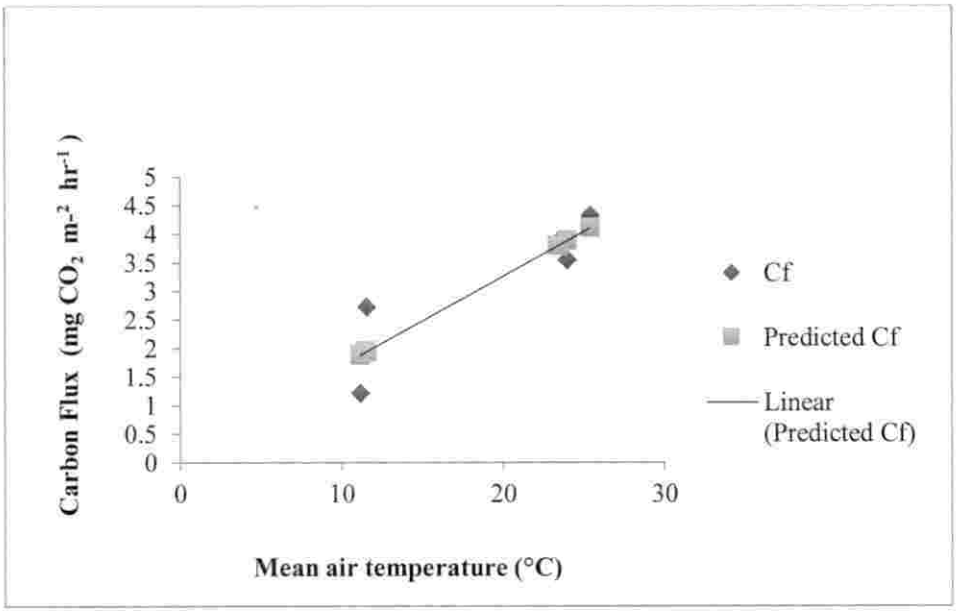

Fig. 2: Regression line obtained for carbon flux in mixed forest

R^2 value for the regression analysis is 0.8322

And the fitted equation is; y = m x + c (where, m- significance value from ANOVA, x- Air temperature, c- Intercept value)

Carbon flux = 0.0112× 0.2537+ 1.977

Carbon flux expected for next month = 1.9798 mg CO_2 m^{-2} hr^{-1}

4.3.2.2 Water flux (Wf) variation with air temperature in mixed forest

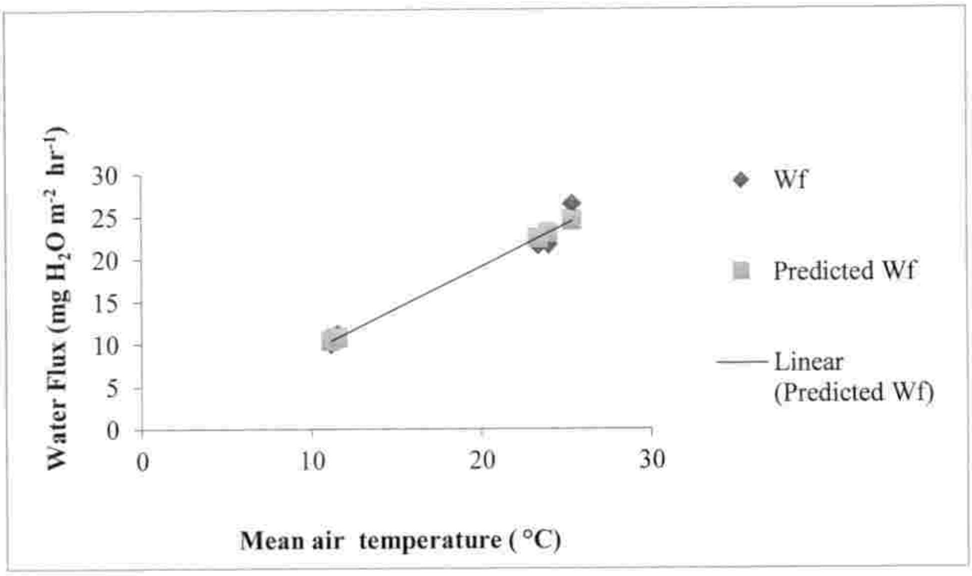

Fig. 3: Regression line obtained for water flux in mixed forest

Obtained R^2 value for the regression analysis is 0.9717

And the fitted equation is; y = m x + c

Water flux = 0.0003× 1.225+ 3.740

Water flux expected for next month = 3.7403 mg H_2O m^{-2} hr^{-1}

4.3.2.3 Reference crop evapotranspiration (ET) in mixed forest with air temperature

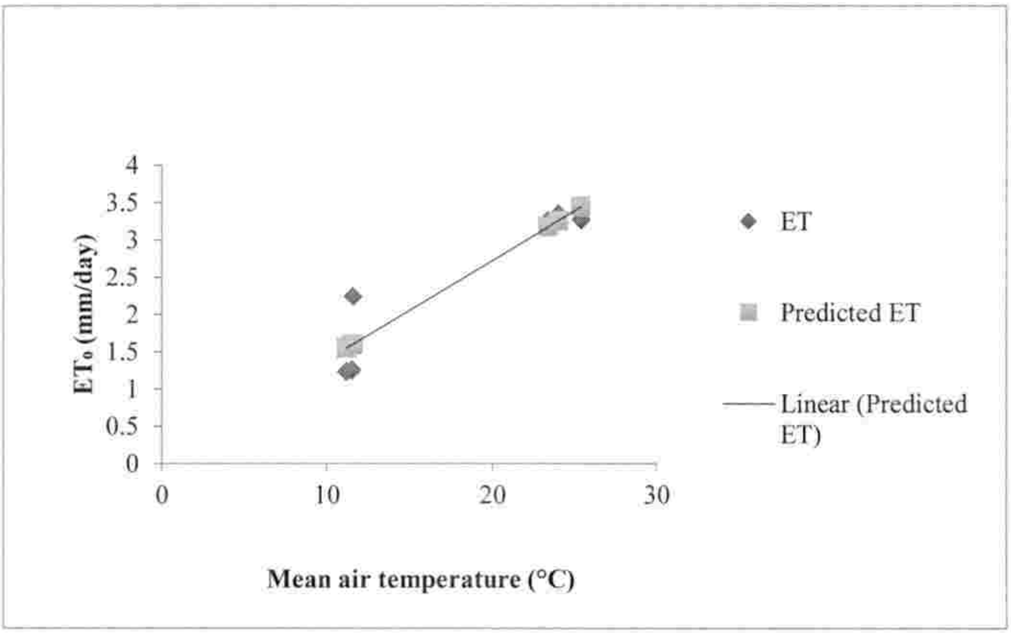

Fig. 4: Regression line obtained for reference crop evapotranspiration in mixed forest

R^2 value for the regression analysis is 0.869

And the fitted equation is; y = m x + c

Reference crop evapotranspiration = 0.0067× 0.2051+ 1.4166

Expected reference crop evapotranspiration for coming month = 1.4179 mm/day

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4.3.2.4 Carbon flux (Cf) variation with air temperature in the pine forest

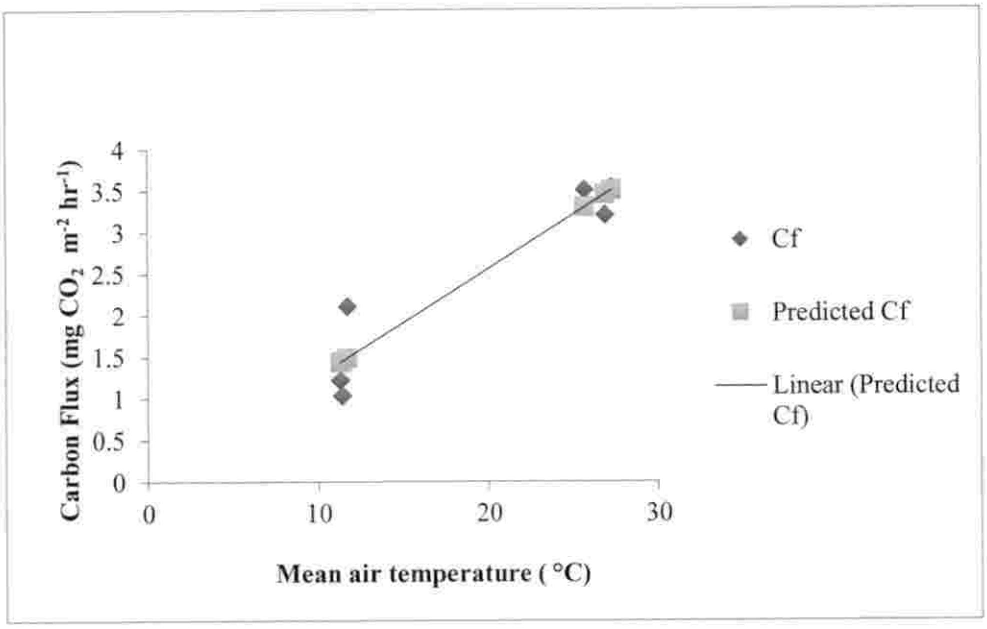

Fig. 5: Regression line obtained for carbon flux in the pine forest

R^2 value obtained with the help of SPSS Software for the regression analysis is 0.8906

And the fitted equation is; y = m x + c

Carbon flux = 0.0047× 0.1926+ 1.2612

Expected carbon flux for the month of June 2019 = 1.2621 mg CO_2 m^{-2} hr^{-1}

73

4.3.2.5 Water flux (Wf) variation with air temperature in the pine forest

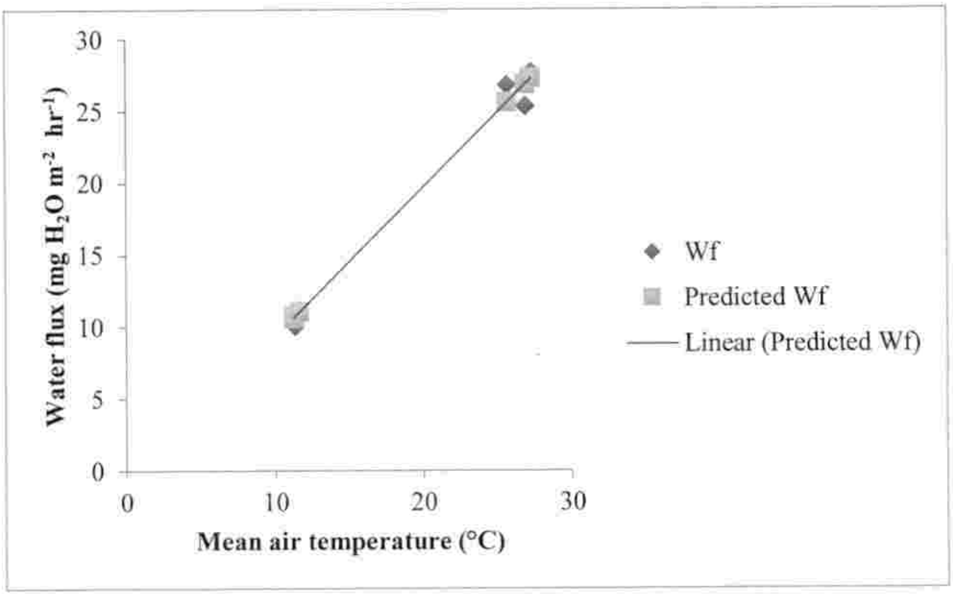

Fig. 6: **Regression line obtained for water flux in the pine forest**

R^2 value for the regression analysis is 0.9881

And the fitted equation is; $y = m x + c$

Water flux = $0.002\times 1.1991 + 2.1086$

Expected water flux for next month in 2019 = 2.1109 mg H_2O $m^{-2}hr^{-1}$

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4.3.2.6 Water flux (Wf) variation with air temperature in grassland

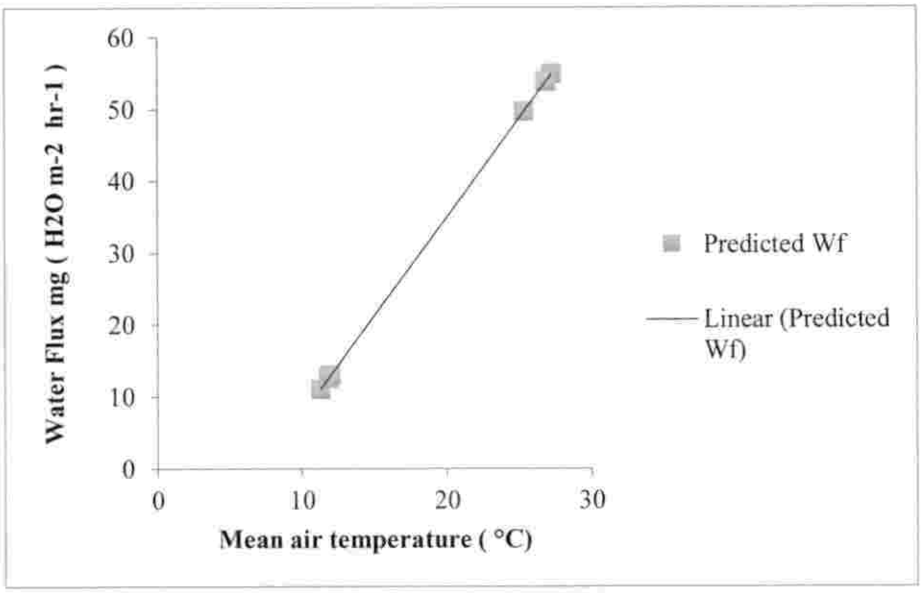

Fig. 7: Regression line obtained for water flux in grassland

R^2 value for the regression analysis is 0.9902

And the fitted equation is; y = m x + c

Carbon flux = 0.005× 0.2171 + 0.2228

Expected carbon flux for the month of June 2019 = 0.2238 mg CO_2 $m^{-2}hr^{-1}$

4.11.4.1 Carbon flux (Cf) variation with air temperature in the bamboo forest

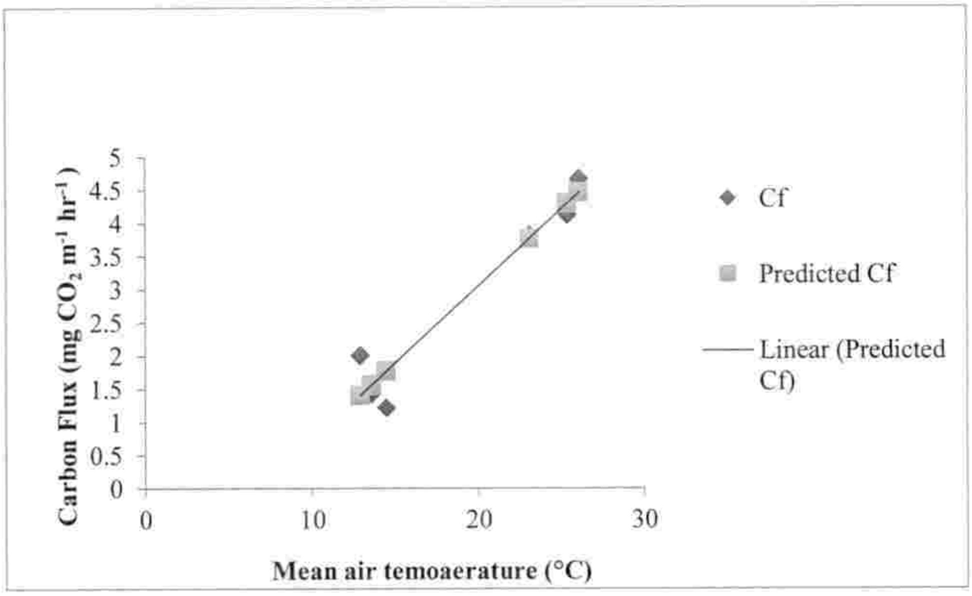

Fig. 8: Regression line obtained for carbon flux in the bamboo forest

R^2 value for the regression analysis is 0.9313

And the fitted equation is; $y = m x + c$

Carbon flux = $0.0018 \times 0.3195 + 0.1645$

Expected carbon flux for June 2019 = 0.16507 mg $CO_2m^{-2}hr^{-1}$

4.11.4.2 Water flux (Wf) variation with air temperature in the bamboo forest

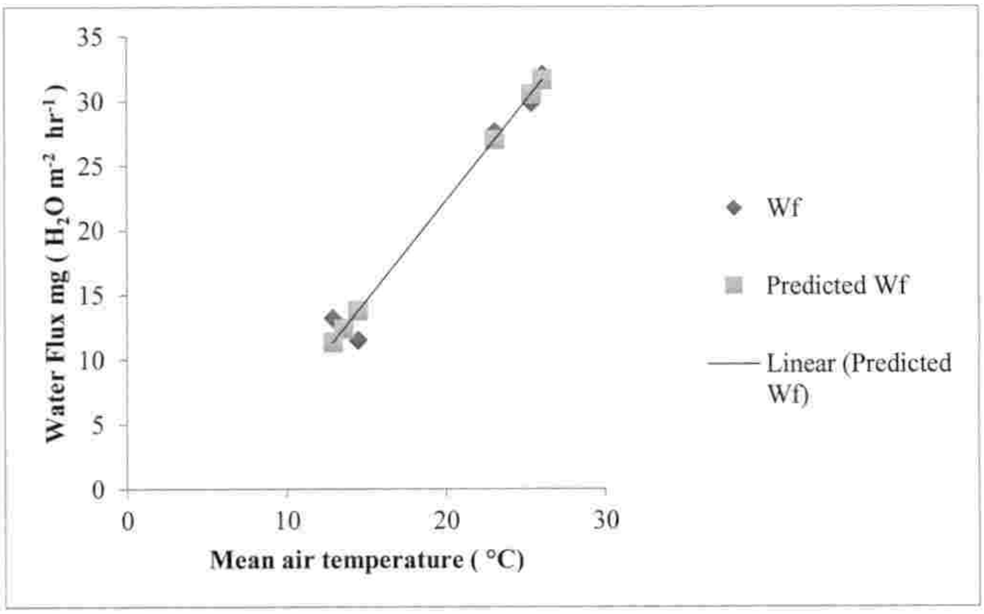

Fig. 9: **Regression line obtained for water flux in the bamboo forest**

R^2 value for the regression analysis is 0.869

And the fitted equation is; y = m x + c

Reference crop evapotranspiration = 0.0067× 0.2051+ 1.4166

Expected reference crop evapotranspiration for June = 1.4179 mm/day

4.11.4.3 Heat flux (Hf) variation with air temperature in bamboo forest

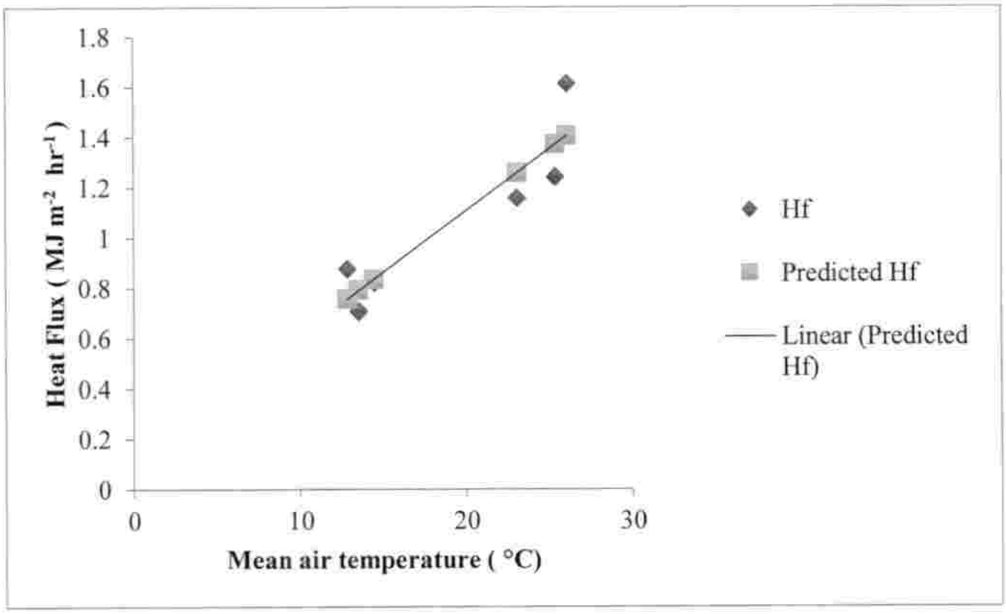

Fig.10: Regression line obtained for heat flux in bamboo forest

R^2 value for the regression analysis is 0.8377

And the fitted equation is; y = m x + c

Heat flux = 0.0105× 0.0794+ 0.7256

Predicted heat flux for June 2019 = 0.7264 MJ m^{-2} hr^{-1}

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DISCUSSION

CHAPETR 5

DISCUSSION

The present investigation entitled **"Quantify the temporal carbon, water and energy fluxes in the selected land-use system in the Himalayas"** was conducted at the Forest Research Institute (FRI), Dehradun, during September 2018 – May 2019. The experiment was conducted in four selected land use, i.e., mixed forest, pine forest, grassland and bamboo forest. Carbon, water, energy fluxes, reference crop evapotranspiration and soil physical properties were examined in two seasons, winter and summer, along six months. The result of the study is discussed in the following sections.

In general, from the study conducted, carbon, water and heat fluxes increased concerning mean air temperature rise as (Dold *et al.*, 2019) reported. In the case of CO_2 flux due to available soil temperature and moisture for microbes and root respiration, carbon flux of respective land increased (Pietilcainen *et al.*, 2005; Qiu *et al.*, 2005). The readings were taken from December to May as it was the transitional period between winter to summer and that the change in atmospheric temperature would be highly expressed. Soil texture in all respective land use was sandy clay loam (Table. 3) with high sand percentage and high porosity.

5.1 Mixed Forest

Carbon flux examined on mixed forest showed an increasing pattern from December to May (Fig. 11). Mean air temperature also showed the same pattern (Fig.14). This gives the relation between temperature and CO_2 release from the respective soil surface. Water flux showed similar pattern of increasing trend from December to May (Fig. 12), flux from soil surface increased in relation with air temperature, water flux gets dropped during April to (21.58 mg $H_2O/m^2/hr$) because of the reduction in mean air temperature to (23.4°C) from March (24°C). Heat flux in the mixed forest showed an increasing trend from December and maximum in March (0.34 $MJ/m^2/hr$) (Fig. 13). It is mostly related to soil temperature and air temperature (Santanello and Friedl, 2003). Soil moisture increased with depth (Table. 3). At 30cm soil moisture was higher than 15cm (LU *et al.*, 2018).

During March, moisture dropped due to the increased rate of evapotranspiration (ET_o) (Jiang and Weng 2016) (Fig. 15), soil temperature decreased with depth (Table. 4) because of less contact to solar radiation (Pavelka *et al.*, 2007). Soil experienced high temperature during May due to air temperature rise. Crop evapotranspiration rate increased with mean air temperature (Bisquert *et al.*, 2016), High rate shown in March (3.34 mm/day) with a mean air temperature of (26°C). Bulk density increased with depth (Table.1a) (Lu *et al.*, 2019). Organic carbon percentage of the mixed forest gave 1.43 % (Fig. 36). Coarse fragment percentage was 2.41% at 15cm and 2.22% at 30cm (Table. 1c). Lesser coarse fragment percentage obtained at lower depth due to high tillage performed by various roots in different depths (Baker *et al.*, 2007). Soil organic pool from mixed forest made 203 PgC (Fig. 37).

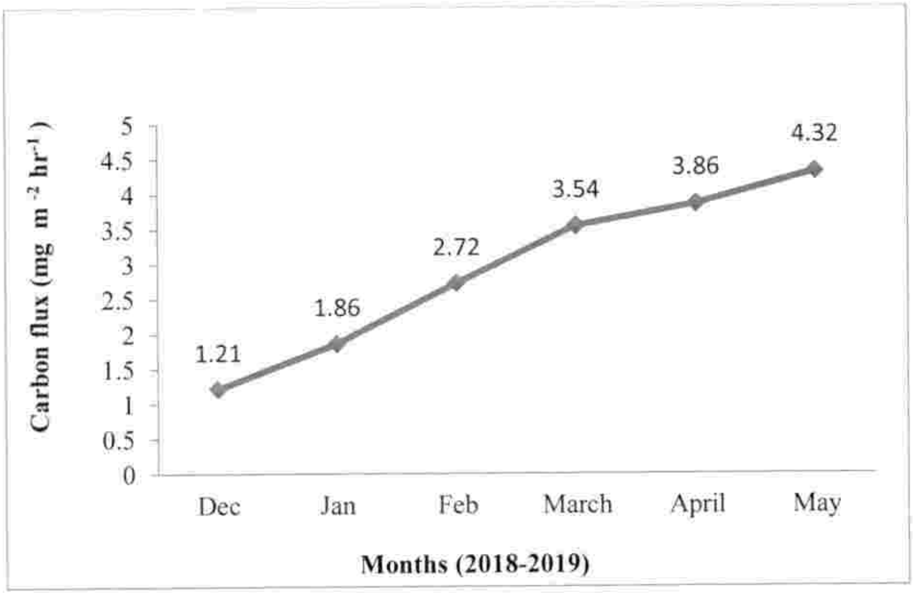

Fig. 11: Carbon flux in mixed forest from Dec-May (2018-2019)

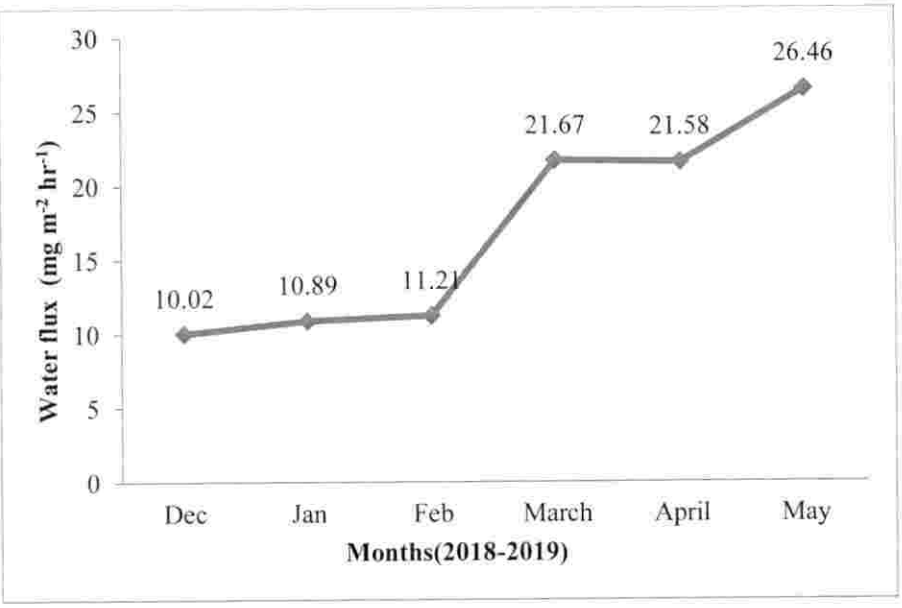

Fig.12: Water flux in mixed forest from Dec-May (2018-2019)

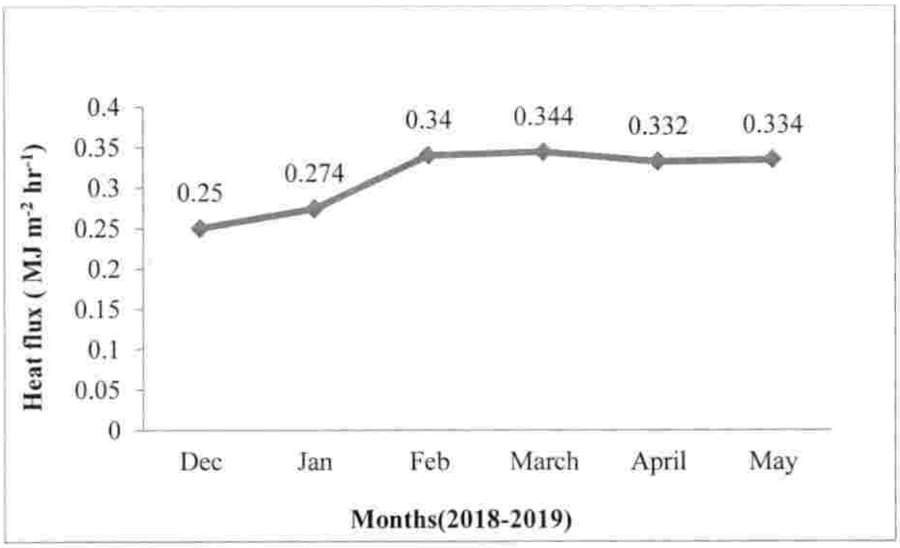

Fig. 13: Heat flux in mixed forest from Dec-May (2018-2019)

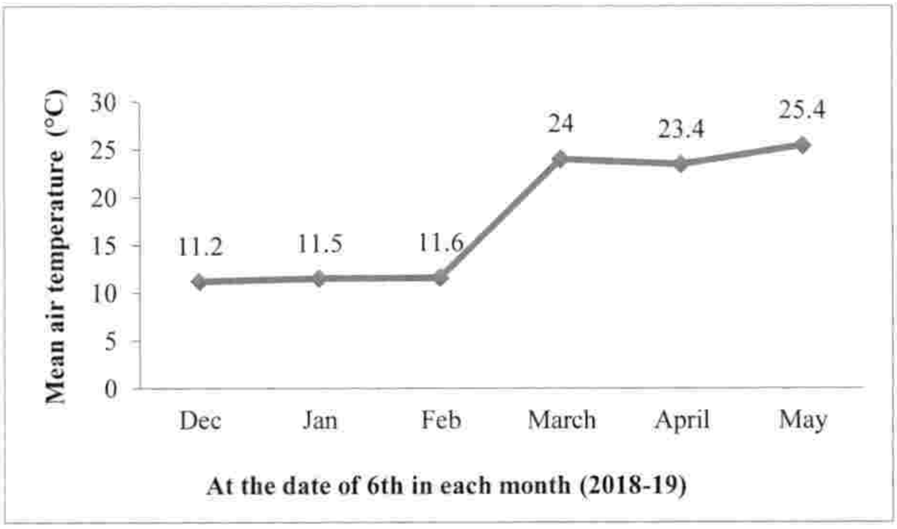

Fig. 14: Mean air temperature of mixed forest from Dec-May (2018-2019)

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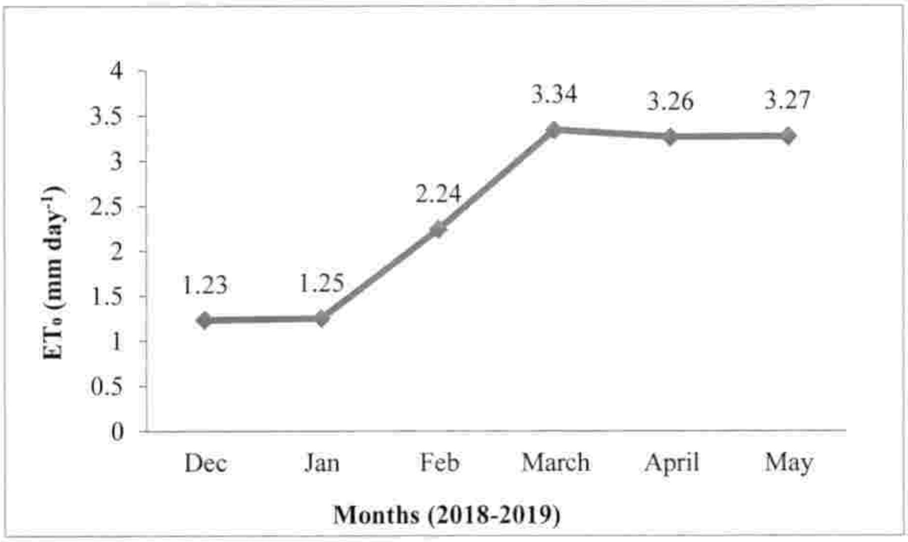

Fig. 15: Reference crop evapotranspiration in mixed forest from Dec-May (2018-2019)

5. 2 Pine Forest

Along the observed six months (December-May) data of pine forest carbon, flux has risen with air temperature (Fig. 16). February, March and April showed a decreased trend in heat flux (Fig. 18). This is due to high litterfall of pine needles; soil moisture gets retained their itself because of the thick layer formed by litterfall (Fig. 7) (Chen and Chen 2018). Hence mean air temperature has risen from December to May (Fig. 19). Soil temperature also increased (Table. 4) (Rahman *et al.*, 2018).

Crop evapotranspiration in pine field showed increasing pattern from December to May, between February and April, March has shown high vales due to high air temperature (Fig. 19) (Moura *et al.*, 2018). Apart from March and May, ET_0 dropped in April to 1.22 mm/day due to litterfall (Plate. 7)

(Zhang *et al.*, 2018). Bulk density increased with depth (Table. 1a) due to less intervention (Owoyemi and Awojobi 2016). Less organic carbon is experienced by pine forest (Fig. 78) because of less decomposition rate due to limited microbial performance in pine litter (Sharma *et al.*, 2016). Coarse fragment percentage is high in 30cm; it increases with depth (Table. 1c) (Kumar *et al.*, 2016). Soil texture exhibited by pine forest is sandy clay loam (Table. 1b). Soil Organic Carbon Pool is less in a pine forest (Fig. 37) due to less microbial activity inhibited by the presence of high phenol content in the litter (Sharma et al., 2016).

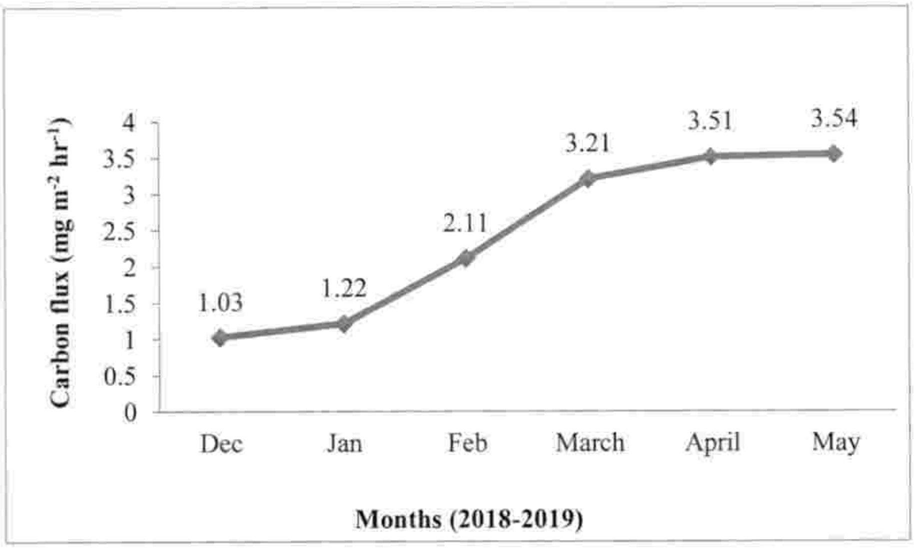

Fig. 16: Carbon flux in pine forest from Dec-May (2018-2019)

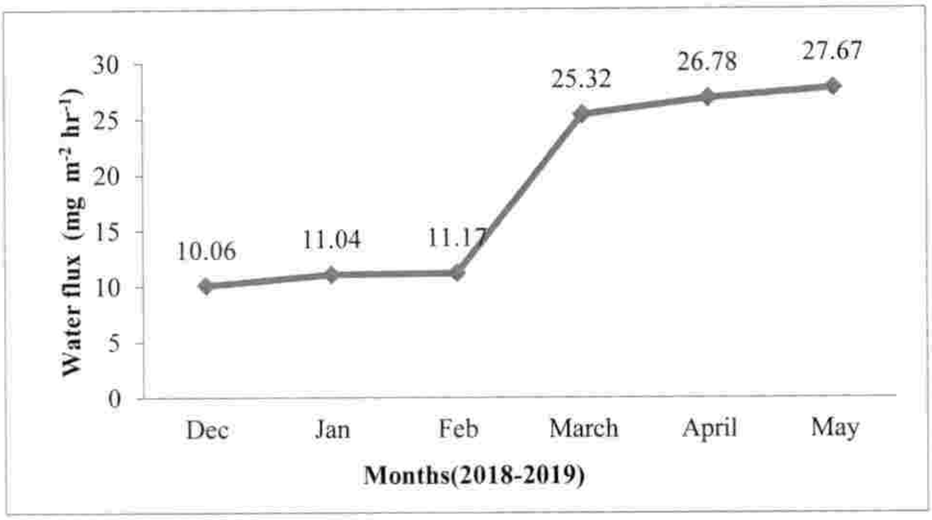

Fig. 17: Water flux in pine forest from Dec-May (2018-2019)

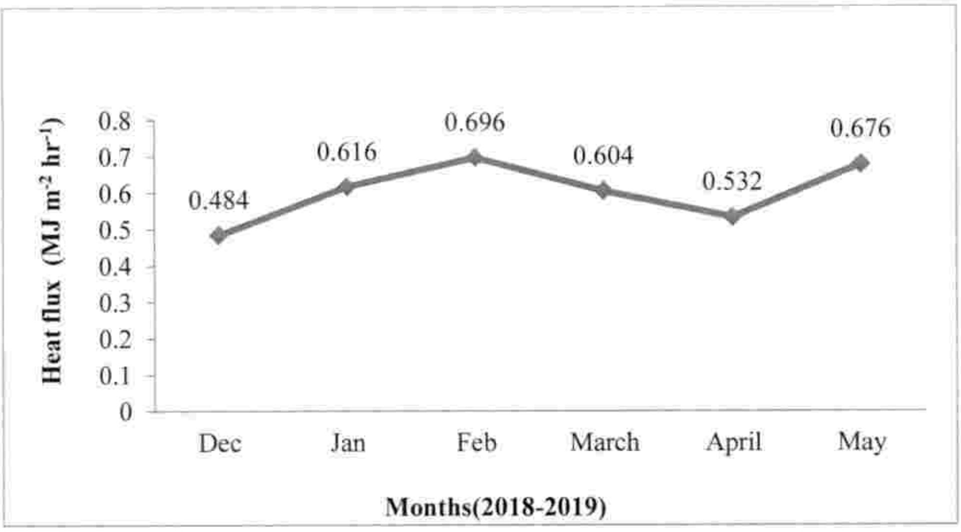

Fig. 18: Heat flux in pine forest from Dec-May (2018-2019)

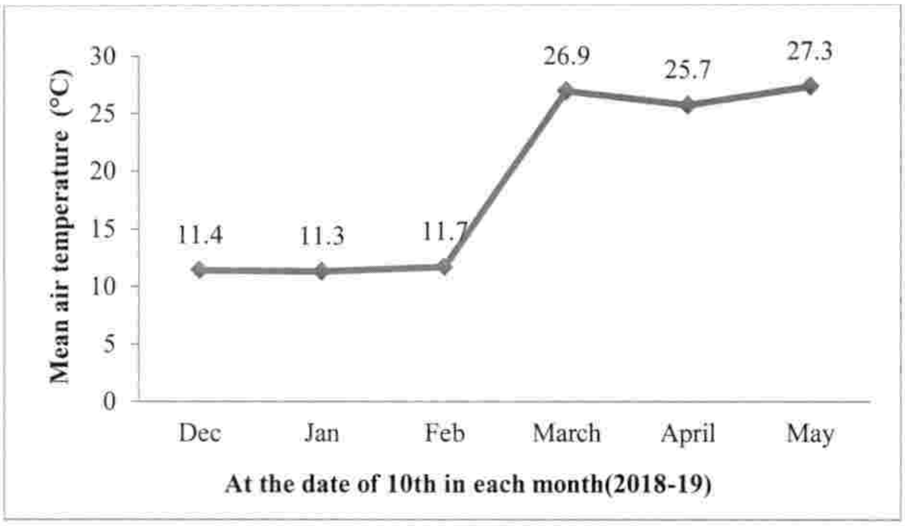

Fig. 19: Mean air temperature of pine forest from Dec-May (2018-2019)

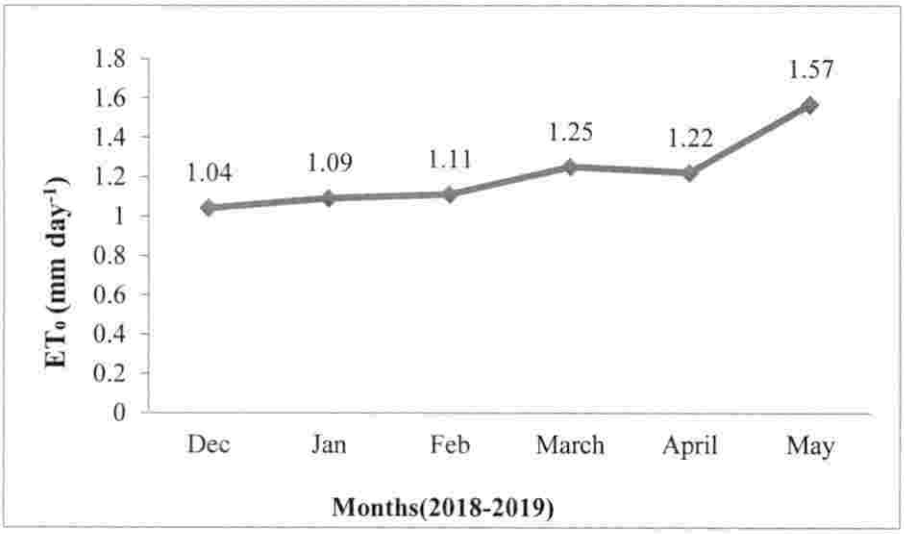

Fig. 20: Reference crop evapotranspiration in pine forest from Dec-May (2018-2019)

5.3 Grassland

Carbon flux in grassland increased with months and showed a peak rate during March due to the peak rise in air temperature from February (Fig. 21). A reduction in CO_2 flux in April due to fall in air temperature is also evidently shown. Water flux also showed the same trend of increment concerning air temperature rise (Fig. 22). Soil heat flux increased with monthly wise but reduced from March to April then increased (Fig. 23). This is due to soil temperature drop (Dhillon *et al.*, 2015). Soil moisture decreased from March due to evapotranspiration (Table. 3) (Purdy *et al.*, 2018). In May, a reduction in soil moisture was by drying up of grassland (Plate.10) (Almagro *et al.*, 2015). Soil temperature rose monthly, except April due to mean air temperature fall (Fig. 66). Reference crop evapotranspiration increased from December to May concerning air temperature along with soil temperature (Fig. 25) (Hargreaves *et al.*, 2019). Mean air temperature rose from December to May because of the transition between winter to summer (Fig. 24). Bulk density of grassland was slightly high in 15-30 cm than 0to15cm (Table. 1a). Organic carbon is high in grassland (Table.1) due to soft leaf tissue digestion and due to high active microbe presence (Riggs *et al.*, 2015). Coarse fragment increased with depth (Table. 1c) (Harrington *et al.*, 2017). Soil texture was under sandy slay loam with high sand percentage (Table. 1b). Soil organic carbon pool is high in grassland (Fig. 37) due to the activity of the microbial community (Puissant *et al.*, 2017)

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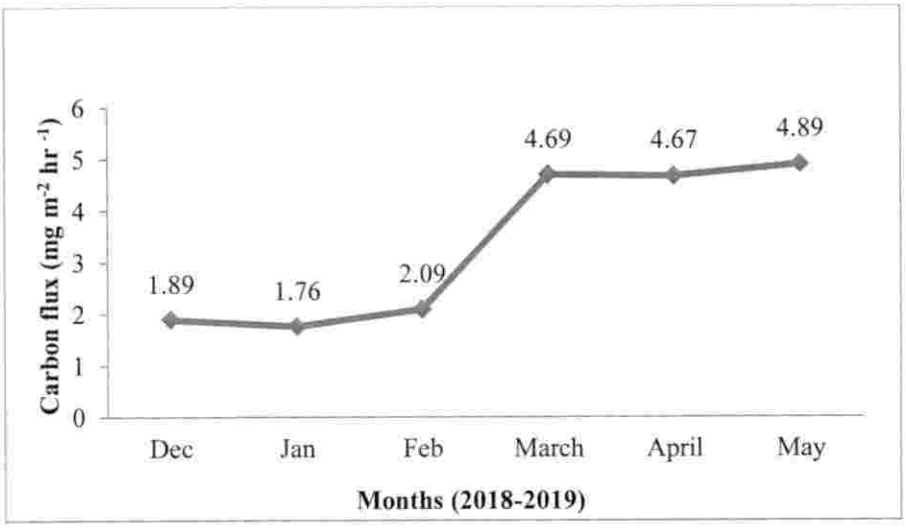

Fig. 21: Carbon flux in grassland from Dec-May (2018-2019)

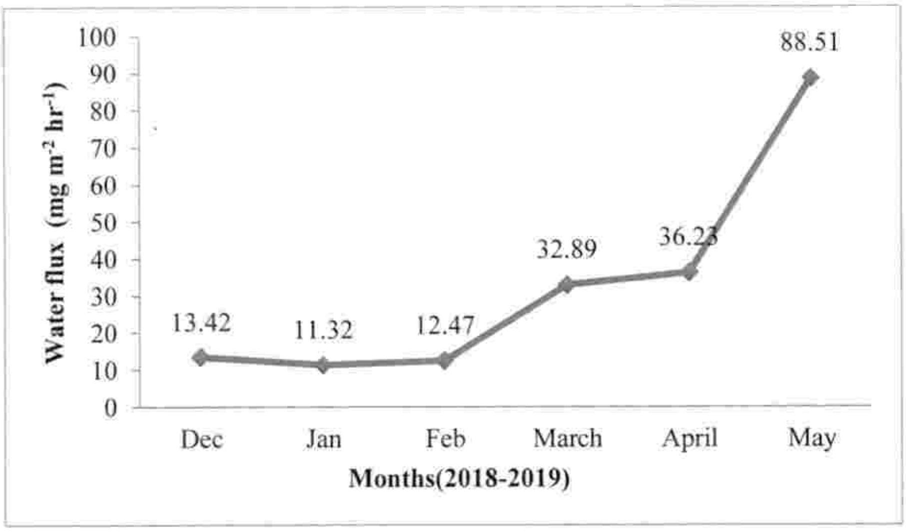

Fig. 22: Water flux in grassland from Dec-May (2018-2019)

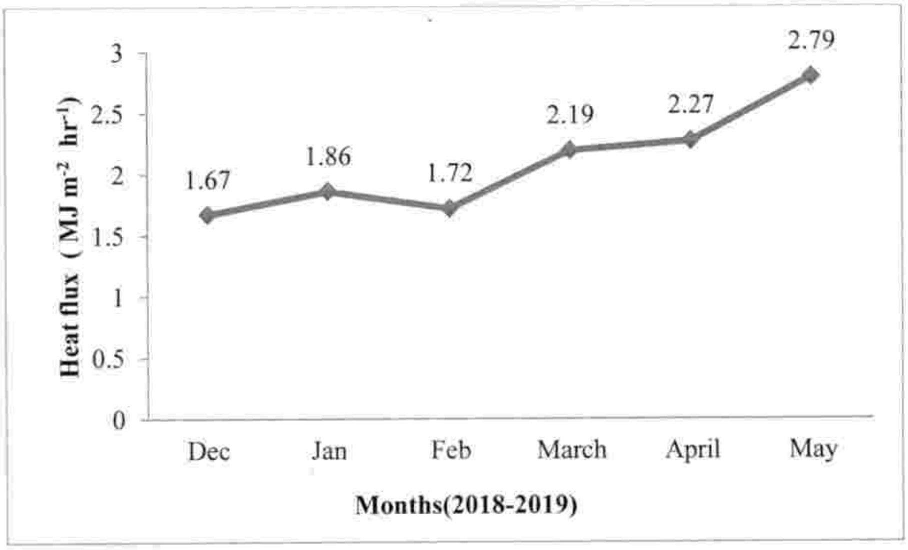

Fig. 23: Heat flux in grassland from Dec-May (2018-2019)

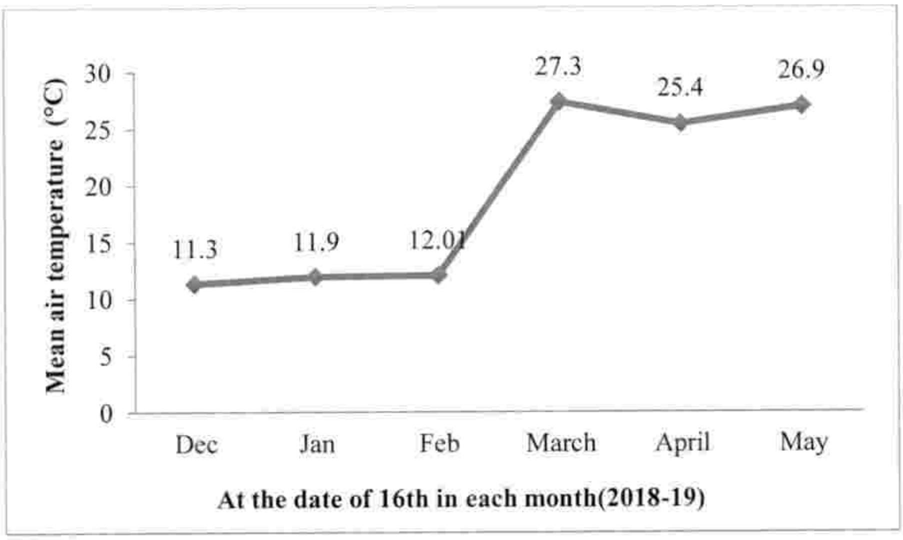

Fig. 24: Mean air temperature of grassland from Dec-May (2018-2019)

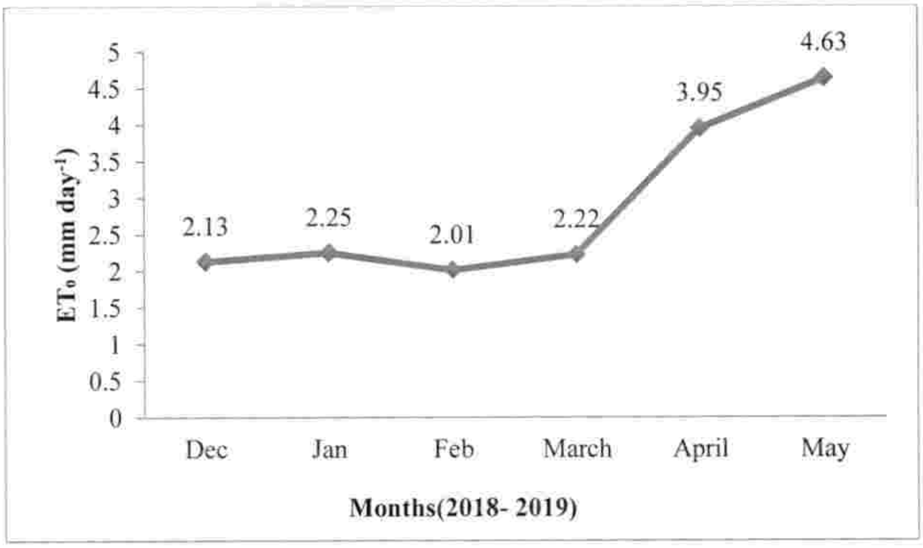

Fig. 25: Reference crop evapotranspiration in grassland from Dec-May (2018-2019)

5.4 Bamboo Forest

During the selected six month period, carbon flux in the bamboo forest showed an increasing trend (Fig. 26) concerning air temperature, (Fig. 29) April showed a reduction in CO_2 release due to the fall in soil moisture (Table. 3) (Kumar *et al.*, 2016). Water flux in the bamboo field gradually rose and increased rapidly from March due to the peak rise in mean air temperature (Fig. 27).

Heat flux is closely related to mean temperature; hence it also increased from December to May (Fig. 28). Soil moisture decreases with air temperature rise, but in March, it showed high value because of litter cover (Plate. 12). Soil moisture reduces soil temperature due to litter drying (Barnes *et al.*, 2015). Evapotranspiration exhibited an increasing rate with month similar to mean air temperature (Fig. 30). Bulk density increased with depth because of fewer disturbances (Table.1a) (Singh *et al.*, 2016). Organic carbon is less due to the high fibre content in the litter (Table. 1), (Zhang *et al.*, 2015). Compared to lower layers coarse fragment percentage was high in the surface layer (Table. 1c) (15cm), leading to a reduction in the water holding capacity (Poeplau *et al.*, 2017). Soil texture class was sandy clay loam with sand in high percentage making water infiltration high (Table.1b).

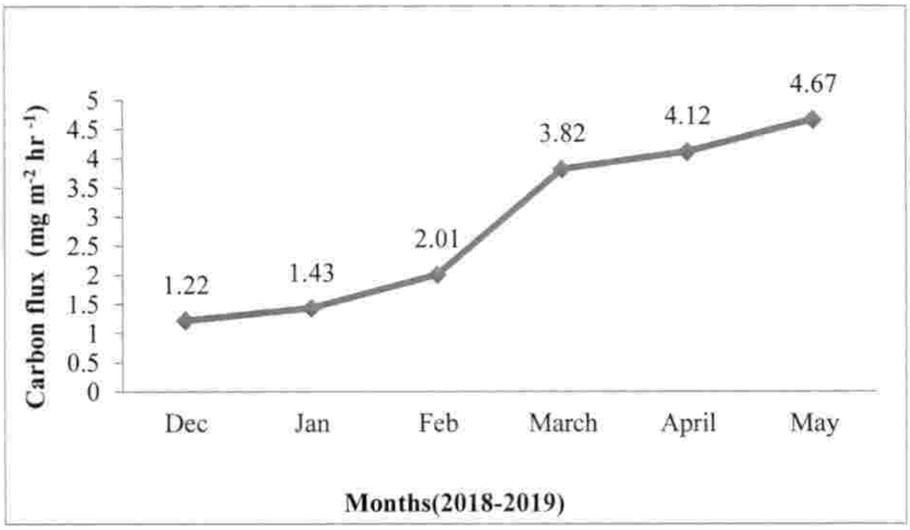

Fig. 26: Carbon flux in bamboo forest from Dec-May (2018-2019)

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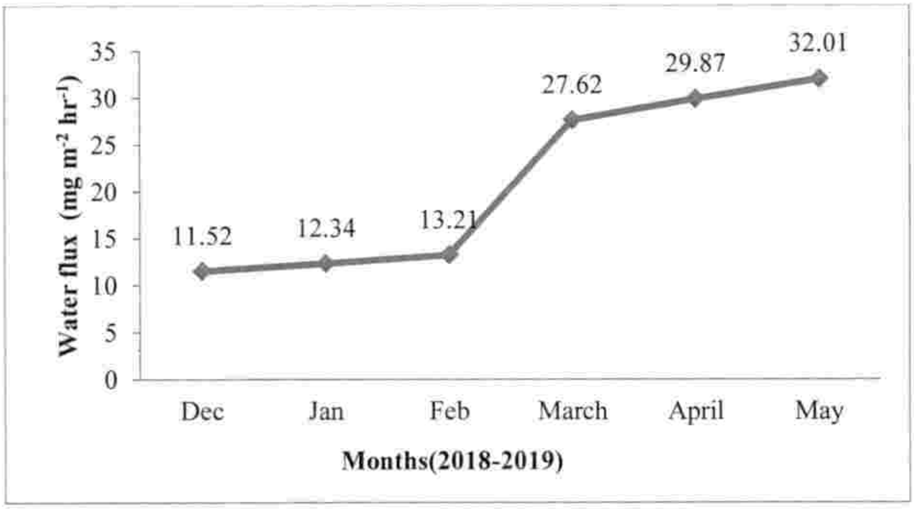

Fig. 27: Water flux in bamboo forest from Dec-May (2018-2019)

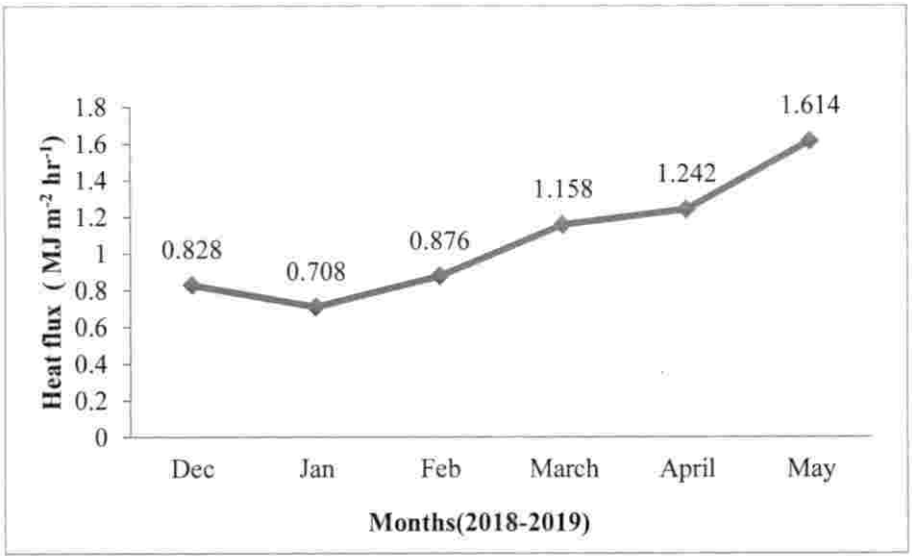

Fig. 28: Heat flux in bamboo forest from Dec-May (2018-2019)

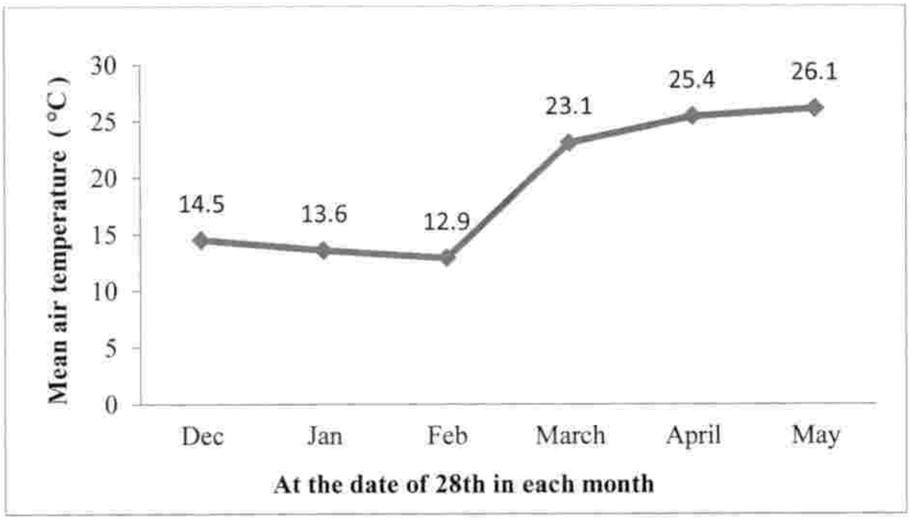

Fig. 29: Mean air temperature of bamboo forest from Dec-May (2018-2019)

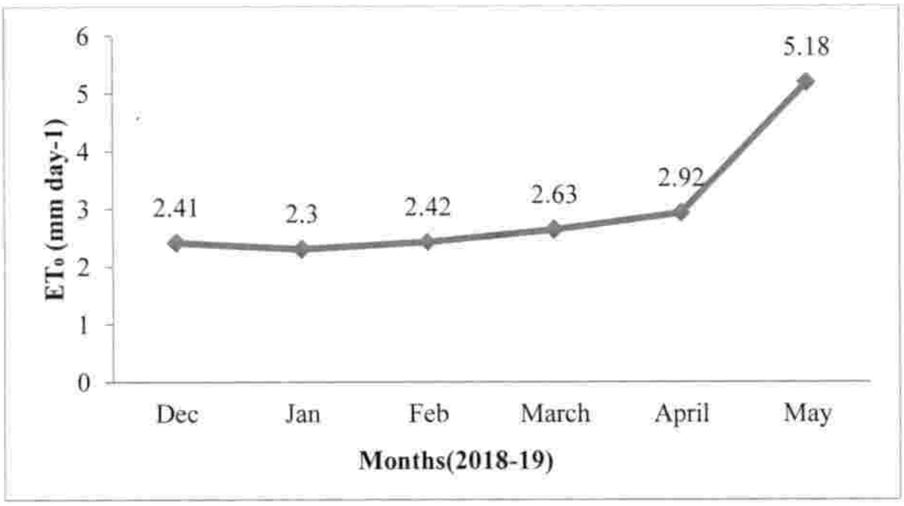

Fig. 30: Reference crop evapotranspiration in bamboo forest from Dec-May (2018-2019)

From the six-month data collection, grassland showed high flux rates from selected land use. This is due to high microbial respiration and decomposition rate concerning increased temperature and soil moisture (Hunt *et al.*, 2002). Less CO_2 flux shown by pine forest is due to the limited/low microbial activity (Frey *et al.*, 2004). Lowest carbon flux is experienced by pine

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forest, and the highest is in grassland the difference between their carbon flux during December was 45% and during May 27%.

The above difference in fluxes can be attributed to the availability of mean air temperature of respective days selected for data collection and microbial activity enrichments (DeLuca *et al.*, 2006). Water flux in respective soils from four fields also showed a greater value in grassland. This might be due to the fast degradation of land use (Roy *et al.*, 2016). Compared to all fields mixed forest showed low average water flux (Fig. 32) due to different root zone character possessed by diverse tree species making soil available water to lock with in macro soil pores, disallowing the water to get the release to the atmosphere (Neary *et al.*, 2009). During December, 25% higher flux rate was experienced by grassland compared to the mixed forest, and in May 70 % increase was experienced. In the case of heat flux also grassland occupied the highest value (Fig. 33) this is due to grassland degradation, by short term grasses making the soil more exposed to direct solar radiation (Emerson *et al.*, 2018). Heat flux rate in the mixed forest is low because reduced evapotranspiration. They shed leaves and added to the forest floor and reduce the direct impact of sunlight (Wolfe *et al.*, 2016), 56% increment in December and 74% higher value is experienced by grassland with mixed forest. Soil moisture decreases with air temperature increase, but due to high litter fall in bamboo (Plate.12) and pine (Plate. 7), the forest makes the soil to retain to soil surface layers itself (Chaudhuri and Chakraborty 2019). Variation in soil moisture is gradually occurring in the mixed forest compared to other land use because of heterogeneous tree species and their root zones and permanently maintained forest floor mechanism (Bruijnzeel 2004).

Soil temperature in all fields increased with air temperature (Decker et al., 2003). Reference crop evapotranspiration (ET_0) increased all fields along with mean air temperature rise, except leaf/needle shedding months (Kergoat *et al.*, 2002). Mean air temperature increased from December-May due to the shift in season from winter to summer. Reference crop evapotranspiration in all selected land use increased from March due to air temperature rise, and bamboo forest showed the highest value, and pine forest showed less because of the variation in above-ground biomass within selected land use (Piouceau *et al.*, 2014) the difference of bamboo forest with pine forest in evapotranspiration rate during December is 25% and 91% at May. Bulk density increased with depth except in mixed forest (Table. 1a). This is due to high root penetration compared to other selected land use (Baker *et al.*, 2007). Organic carbon is rich in grassland due to high fine root with microbial population (Fig. 37) (Soussana *et al.*, 2004) and low in pine due to high chemical content in pine soil than other land use, microbial association and active rate is reduced instead of this (Pandey *et al.*, 2018).

Soil texture in all field comes under sandy clay loam with high sand percentage making the soil more porous to water (Edwards *et al.*, 2018). Soil organic carbon pool is high in grassland due to high decomposition and addition of organic matter continuously because of fast degradation and regeneration compared to other fields (Schiedung *et al.*, 2019).

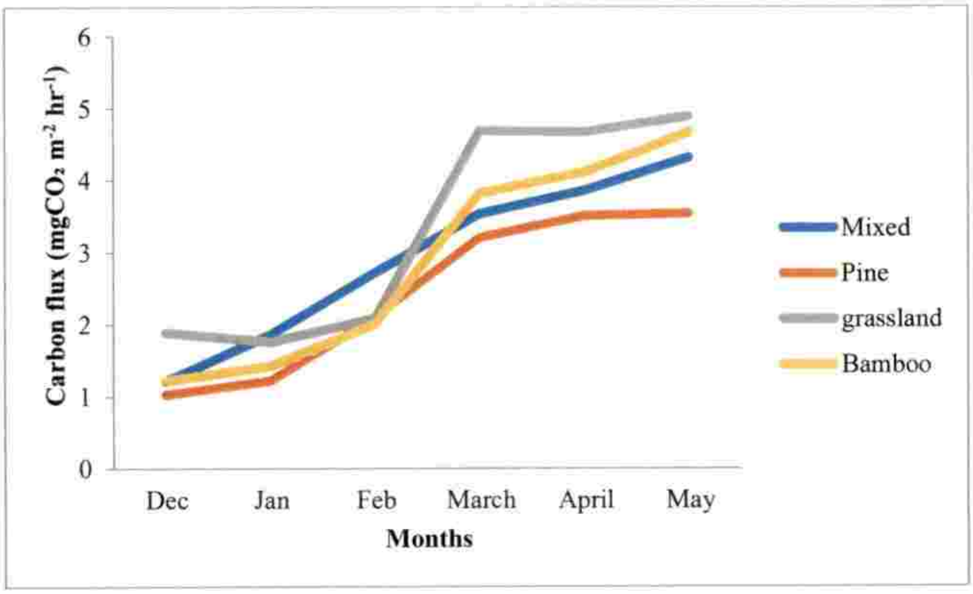

Fig. 31: Carbon fluxes from selected land use during Dec-May (2018-2019)

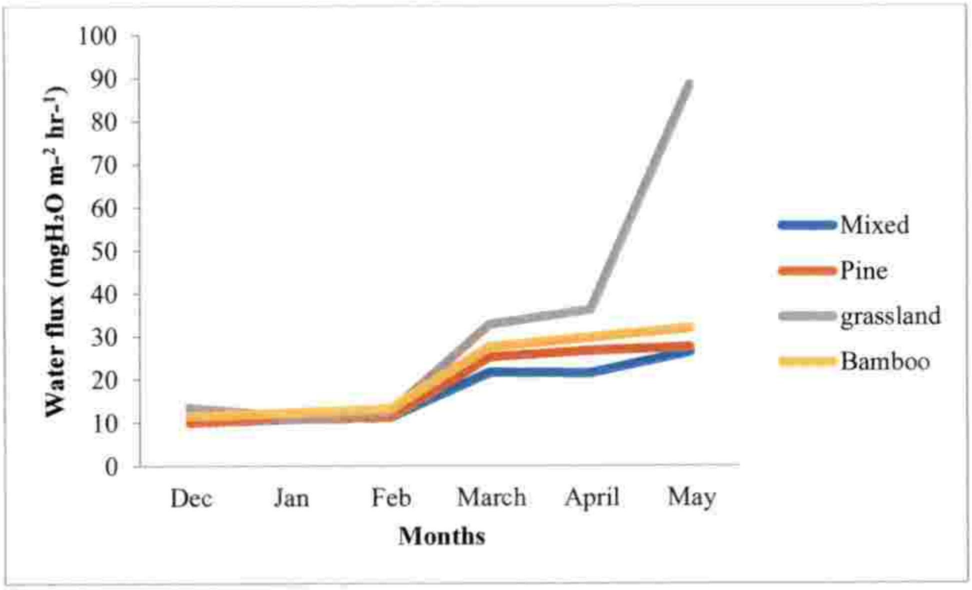

Fig. 32: Water fluxes from selected land use during Dec-May (2018-2019)

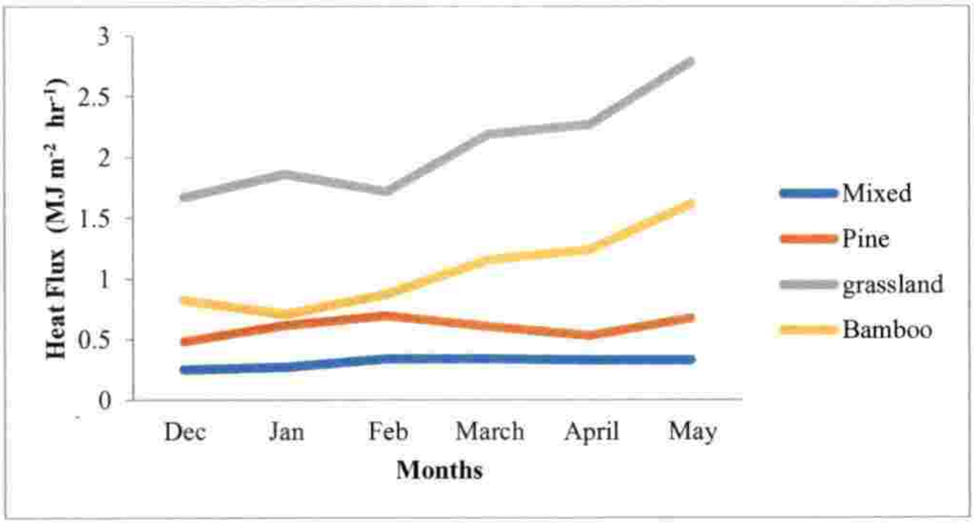

Fig. 33: Heat flux from selected land use during Dec-May (2018-2019)

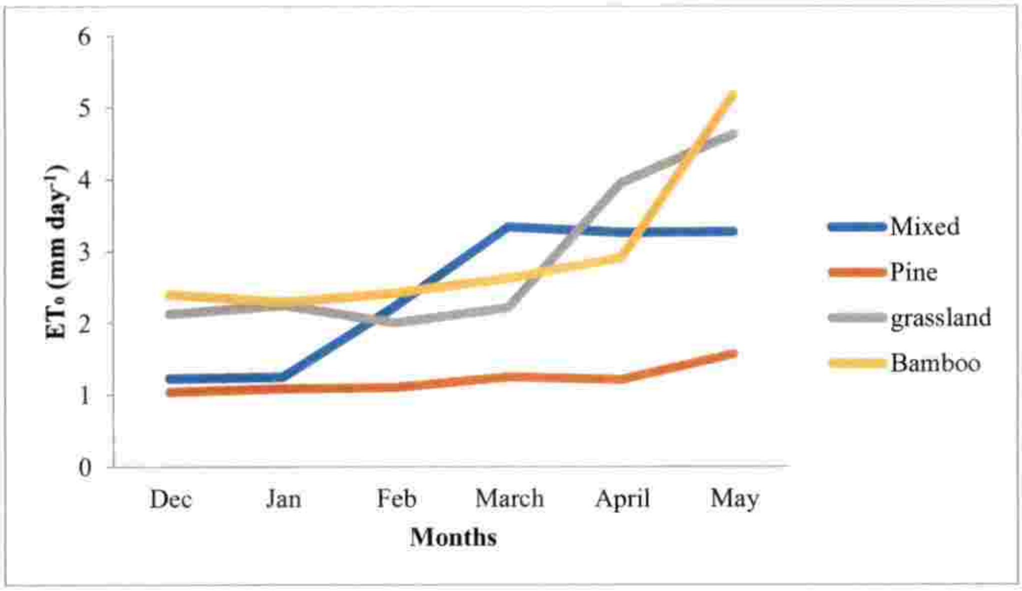

Fig. 34: Reference crop evapotranspiration (2018-2019)

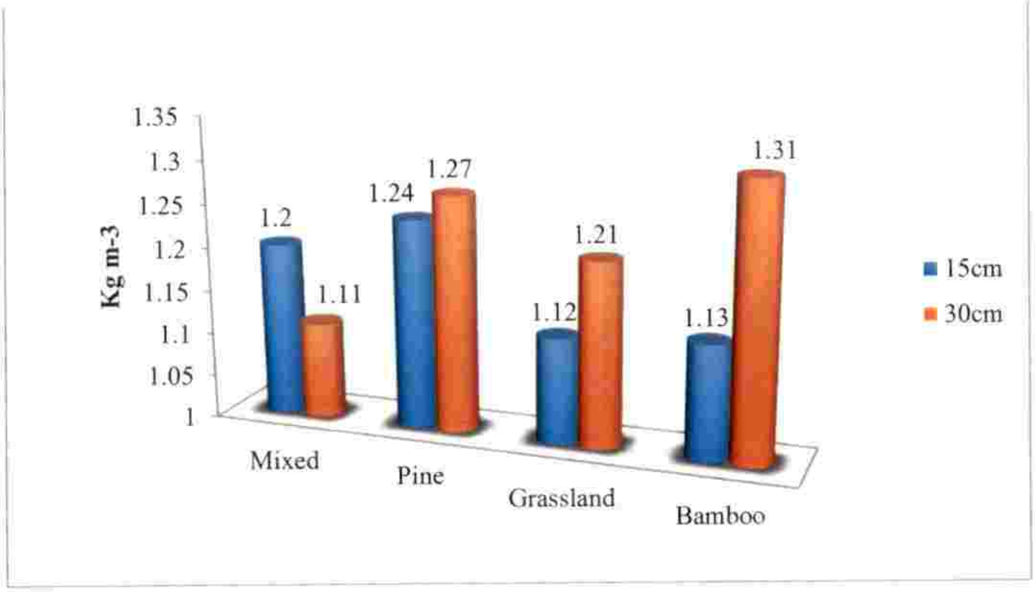

Fig. 35: Bulk density of soil in 0-15 and 15-30 cm

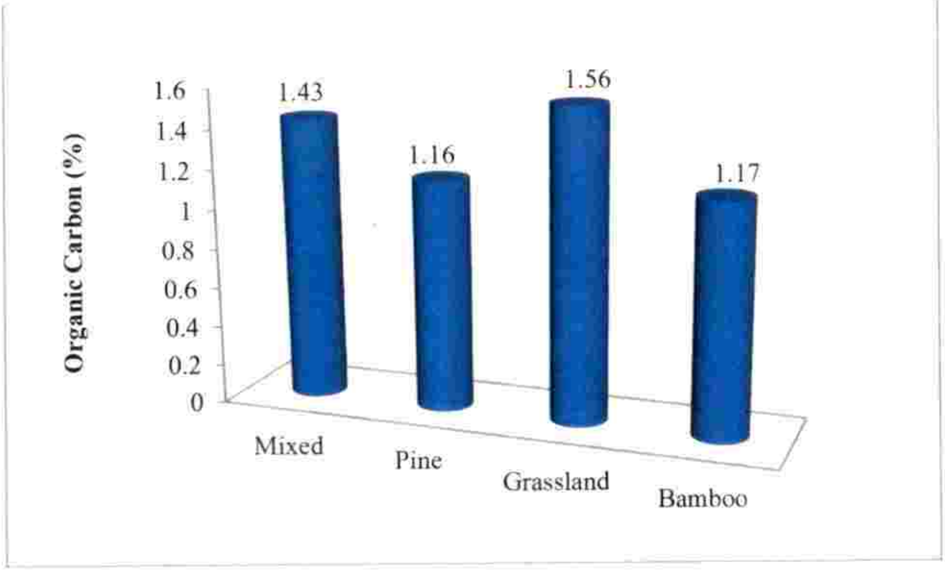

Fig. 36: Organic carbon in selected land use (%)

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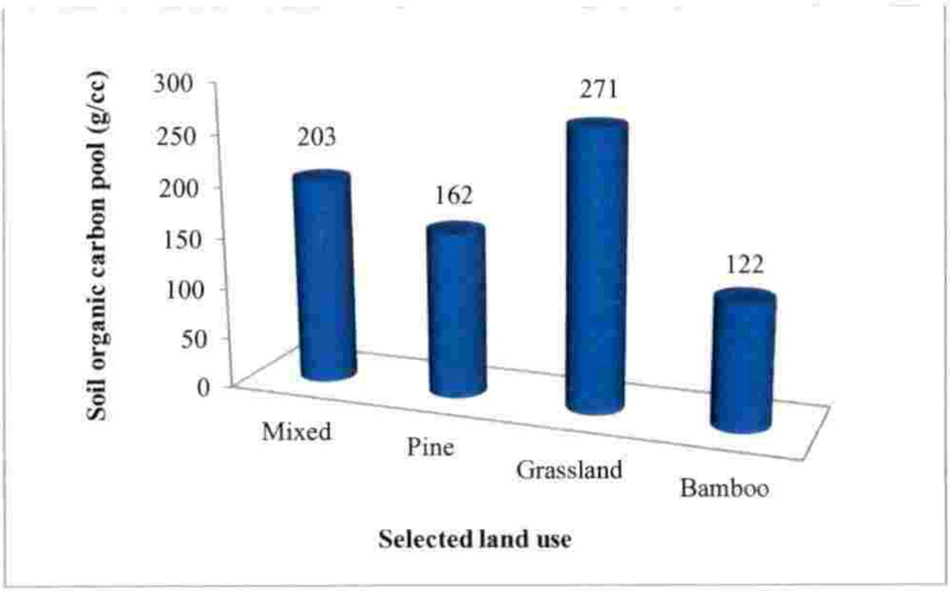

Fig. 37: Total SOC pool of selected land use

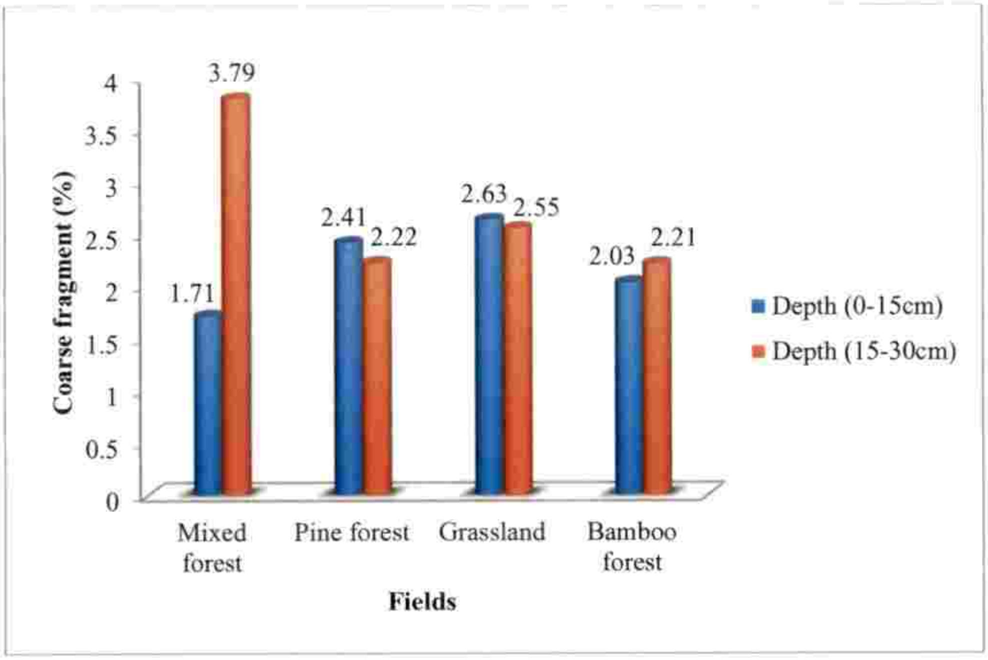

Fig. 28 Coarse fragment percentage of selected land use in two depths

SUMMARY

CHAPETR 6

SUMMARY

A field experiment was conducted at the Forest Research Institute (FRI), Dehradun, from December 2018 to May 2019 to determine the interlinking between carbon, water and energy fluxes and climatic variables.

The experiment was carried out in four fields within FRI campus. Four replications were taken within one field, and for soil analysis, two depths were considered, 0-15cm and 15-30cm.

The salient findings of the investigation are summarized below.

- Along six months (December-May), all flux rates increased with air temperature. Within four selected land use, grassland showed maximum values in all respective fluxes.
- The flux rate increase was significantly related to mean air temperature.
- Litterfall influenced soil moisture and temperature. Even though the mean monthly temperature gets rise, epically pine and bamboo forest floor experienced more soil moisture and reduced temperature due to this.
- Carbon flux in grassland showed 45% and 25 % increment in December and May with pine forest. .
- Mixed forest showed minimum water and heat/energy flux, and maximum flux was experienced in grassland. In December 25 % and in May 70% increment in water flux with the mixed forest was observed. Heat flux in grassland reached with a value of 56% in December and 74% May.

- Reference crop evapotranspiration was high in bamboo while less in pine and their differences are 25 % and 91% in December and May.
- Soil textural class of all fields is sandy clay loam.
- Organic carbon and soil organic carbon pool were high in grassland and low in pine forest soil.
- Microbial activity was especially significant for carbon flux, and it is related to minimum and maximum temperatures.
- From the result, it can be summarized that pine forest system fluxes are relatively low; hence it safely traps good quantity of greenhouse gases entering into this system for a long time.
- Mixed forest, in all case, gives a gradual rise concerning air temperature, which means the heterogenic type of land use can manage the present atmospheric condition in a better way.
- The study indicated that all examined fluxes are significantly related to air temperature. Hence future climate was expected to rise it will make our existing green cover to enhance climate change by releasing greenhouse gases like carbon dioxide and water vapour. For quantifying this net sequestration and emission from each land use must be considered and examined regarding their flux exchanges.

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APPENDIX-I

Sites	Carbon flux (mg CO_2 m^{-2} hr^{-1})	Water flux (mg H_2O $m^{-2}hr^{-1}$)	Heat flux (WJ $m^{-2}hr^{-1}$)	Evapotranspiration (mm/day)
Mixed	2.436^a	16.97^a	0.31^c	1.21^b
Pine	2.878^a	18.67^a	0.6^c	2.43^a
Grassland	2.918^a	21.09^a	1.07^b	2.86^a
Bamboo	3.331^a	32.47^a	2.08^a	2.97^a
P-Value	0.733	0.383	0.05	0.015

One Way ANOVA values for Selected land use a, b and c denotes the respective groups in homogeneous subsets, where mean sample size = 6.000.

APPENDIX-II

Mixed Forest

	Air temperature	Carbon Flux	Water Flux	Heat Flux	Evapotranspiration
Air temperature	1				
Carbon Flux	0.912^{*}	1			
Water Flux	0.649	0.855^{*}	1		
Heat Flux	0.986^{**}	0.932^{**}	0.645	1	
Evapotranspiration	0.932^{**}	0.96^{**}	0.868^{*}	0.913^{*}	1

Pine Forest

	Air temperature	**Carbon Flux**	**Water Flux**	**Heat Flux**	**Evapotranspiration**
Air temperature	**1**				
Carbon Flux	**0.944****	**1**			
Water Flux	**0.994****	**0.956****	**1**		
Heat Flux	**0.078**	**0.089**	**0.089**	**1**	
Evapotranspiration	**0.79**	**0.802**	**0.802**	**0.446**	**1**

Grassland

	Air temperature	Carbon Flux	Water Flux	Heat Flux	Evapotranspiration
Air temperature	1				
Carbon Flux	0.995**	1			
Water Flux	0.755	0.956**	1		
Heat Flux	0.869*	0.876*	0.962**	1	
Evapotranspiration	0.688	0.73	0.881*	0.892*	1

Bamboo Forest

	Air temperature	Carbon Flux	Water Flux	Heat Flux	Evapotranspiration
Air temperature	1				
Carbon Flux	0.965**	1			
Water Flux	0.990**	0.991**	1		
Heat Flux	0.915**	0.944**	0.928**	1	
Evapotranspiration	0.683	0.721	0.694	0.892*	1

APPENDIX-III

Weather data obtained for each field at specific date for the experimental period

(December 2018-May 2019 –Monthly Data)

Months	Max temp (°C)	Min temp (°C)	Relative humidity (%)	Wind velocity (Km/hr)	Sunshine (hrs)
06-12-2018	19.8	8.6	75.5	1.2	0
06-01-2019	18.8	7.4	75.5	2	0
06-02-2019	22.4	6.7	66	1.3	4.8
06-03-2019	22.5	6.9	72.5	2.4	9.2
06-04-2019	32.4	17.4	67.5	2.3	6
06-05-2019	35.2	14	43	3.6	11.5

Mixed forest

Months	Max temp (°C)	Min temp (°C)	Relative humidity (%)	Wind velocity (Km/hr)	Sunshine (hrs)
10-12-2018	24.8	8.6	72	1.4	7.8
10-01-2019	21.8	2.5	68	1.8	3.6
10-02-2019	21	5.4	68.5	2.3	1.3
10-03-2019	24.5	6.8	67.5	2.8	9.4
10-04-2019	30.4	15.5	65	2	5
10-05-2019	37.8	16.5	43	3.1	9.9

Pine forest

Months	Max temp (°C)	Min temp (°C)	Relative humidity (%)	Wind velocity (Km/hr)	Sunshine (hrs)
16-12-2018	20.6	1.9	71.5	1.1	8.6
16-01-2019	18.9	3.5	66.5	1.6	5.2
16-02-2019	17.7	9.8	74	2.7	8.7
16-03-2019	24	7.1	64.5	2.5	7.1
16-04-2019	35.4	17.6	64.5	2.9	0.2
16-05-2019	31.2	17.8	62	2.7	1.8

Grassland

Months	Max temp (°C)	Min temp (°C)	Relative humidity (%)	Wind velocity (Km/hr)	Sunshine (hrs)
28-12-2018	22.4	5.4	71.5	1.1	8.2
28-01-2019	16.8	1	66	2	9
28-02-2019	13.2	4	61	1.4	9.1
28-03-2019	27.6	13.2	72	2	8.4
28-04-2019	36.4	15	44.5	2.2	11
28-05-2019	37.8	22.8	40.5	3.5	11.7

Bamboo forest

Quantify the temporal carbon, water and energy fluxes in selected land use system in Himalayas

by

ARYA M. S

(2014 - 20 - 128)

THESIS ABSTRACT

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Faculty of Agriculture
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ABSTRACT

An investigation entitled "Quantify the temporal carbon, water and energy fluxes in selected land use system in Himalayas" was conducted at Forest Research Institute (FRI), Dehradun, during 2018 December to May 2019. The experiment was conducted in two seasons winter (December-February) and summer (March-May) with four land use i.e.; mixed forest, pine forest, grassland and bamboo forest. Soil physical properties are also considered at the depth of 0-15cm and at 15-30cm. The study aimed to give an insight of carbon, water and energy flux variations along micrometeorological observations.

The results revealed that during summer season (air temperature increased) all the respective observed fluxes significantly rose, among selected land use. Grassland showed high flux release from the system to the atmosphere. While mixed forest, soil experienced gradual rise in flux exchange, but pine forest system stores greenhouse gases like carbon dioxide in a long time period in a safe manner.

Apart from flux, soil temperature and soil moisture were also examined and obtained data showed a decrease in moisture and increase in soil temperature with air temperature rise except leaf shedding months. As the study show that different land use had evident impact on variability in climatic conditions and hence more than considering the green covers, specific land use flux exchange monitoring is required for all terrestrial land use.