CHAPTER 4
RESULTS

4.1. Seasonal variations of soil physicochemical parameters across the ecosystems:

4.1.1. Soil texture

The particle size distribution characteristics of the soil revealed a silty loam texture of the studied ecosystem. Both grassland (sand 36.2%, silt 54.1%, clay 9.7%) and forestland (sand 37.8%, silt 53.3%, clay 10.9%) ecosystem recorded similar textural composition. However, the wetland ecosystem contains a higher percentage of clay (16.5%) and silt (75.1%) compared to grassland and forestland ecosystem (Figure 4.1A).

The textural composition of soil in grassland and forestland ecosystem did not differ significantly with depth.

4.1.2. Soil pH

The soil pH of the studied ecosystems falls under strongly acidic to neutral range (5.14-6.90). In the grassland ecosystem, the soil pH ranged from 6.65 to 6.90. Similarly, the pH values recorded in the forestland ecosystem ranged from 6.55 to 6.80. Whereas, in the wetland ecosystem it ranged from 5.14 to 5.59 (Figure 4.1B). Soil pH exhibited significant seasonal variation ($p \leq 0.05\%$) across the three ecosystems. Regardless of the ecosystems, the higher pH value (6.90) was obtained during the monsoon season, while the lowest value (5.14) was observed during the pre-monsoon season.

Irrespective of the seasons, soil pH varied significantly ($p \leq 0.05$) with depth in both grassland and forestland ecosystem. Higher pH values were recorded in the topsoil (6.90) of grassland ecosystem. Whereas lower values of the same were noted in the subsoil of forestland ecosystem (6.55).

4.1.3. Soil Electrical Conductivity (EC)

The electrical conductivity (EC) of soil in the studied ecosystems ranged from 0.03 to 0.16 $dScm^{-1}$ (Figure 4.1C). The recorded soil EC of grassland, forestland and wetland ecosystem was 0.06 to 0.15 $dScm^{-1}$, 0.03 to 0.10 $dS\ cm^{-1}$ and 0.14 to 0.16 $dS\ cm^{-1}$ respectively. Soil EC showed significant seasonal variation ($p \leq 0.05$) during the study period. During monsoon, an increase of soil EC (12.5-25.5%) was noted in all the three ecosystems compared to pre-monsoon season.

Furthermore, soil EC differed significantly ($p \leq 0.05$) with soil depth in grassland and forestland ecosystem. Irrespective of the seasons, the subsoil of the forestland ecosystem had lower soil EC (0.03 dScm^{-1}) than the topsoil of the grassland ecosystem (0.16 dScm^{-1}).

4.1.4. Soil Moisture

Figure 4.1D depicts the soil moisture content of the studied ecosystems of Kaziranga National Park across the seasons. Recorded soil moisture ranged from 12.10 to 53.05 %. Wetland ecosystem had the highest soil moisture, followed by grassland and forestland ecosystem. Season had a significant effect ($p \leq 0.05$) on soil moisture content. Monsoon season recorded the highest soil moisture percentage (53.05%) in all the three ecosystems while the lowest (12.10%) of the same was observed during the pre-monsoon season.

Similarly, soil depth has a significant impact ($p \leq 0.05$) on soil moisture content, with higher values obtained in grassland topsoil (23.06-33.81%) and lower values were observed in forestland subsoil (12.10-17.60%) across the three seasons.

4.1.5. Soil organic carbon (SOC)

The spatiotemporal variation of soil organic carbon ranged from low to high (0.36-2.00%) (Figure 4.2A). The highest SOC content was found in wetlands (1.84 - 2.00%), followed by grasslands (0.54 - 1.95%). Throughout the three seasons, the forestland ecosystem had the lowest SOC content (0.36-1.45%). Soil organic carbon exhibited significant seasonal variation ($p \leq 0.05\%$) in all the ecosystems. Regardless of the ecosystems, monsoon season recorded an increase (1.10-1.33-fold) in SOC content as compared to pre-monsoon season.

Similarly, soil depth influences SOC content significantly ($p \leq 0.05$). Across the three seasons, higher SOC values of 1.84-1.95% were noted in the topsoil of the grassland ecosystem, while subsoil of the forestland ecosystem recorded the lowest value of 0.36-0.48% for the same.

4.1.6. Total Nitrogen

Spatiotemporal variation of total nitrogen in the experiment sites are presented in Figure 4.2B. It ranged from 0.03 to 0.25% in the three ecosystems. Grassland and forestland ecosystem recoded lower (0.03- 0.21%) total soil nitrogen compared to wetland ecosystem (0.12 – 0.25 %). Across the studied ecosystems, total soil nitrogen content varied significantly ($p \leq 0.05\%$) with season. Higher value (0.25%) of total soil nitrogen was recorded during the monsoon season and a lower value (0.03%) of the same was found during the pre-monsoon season.

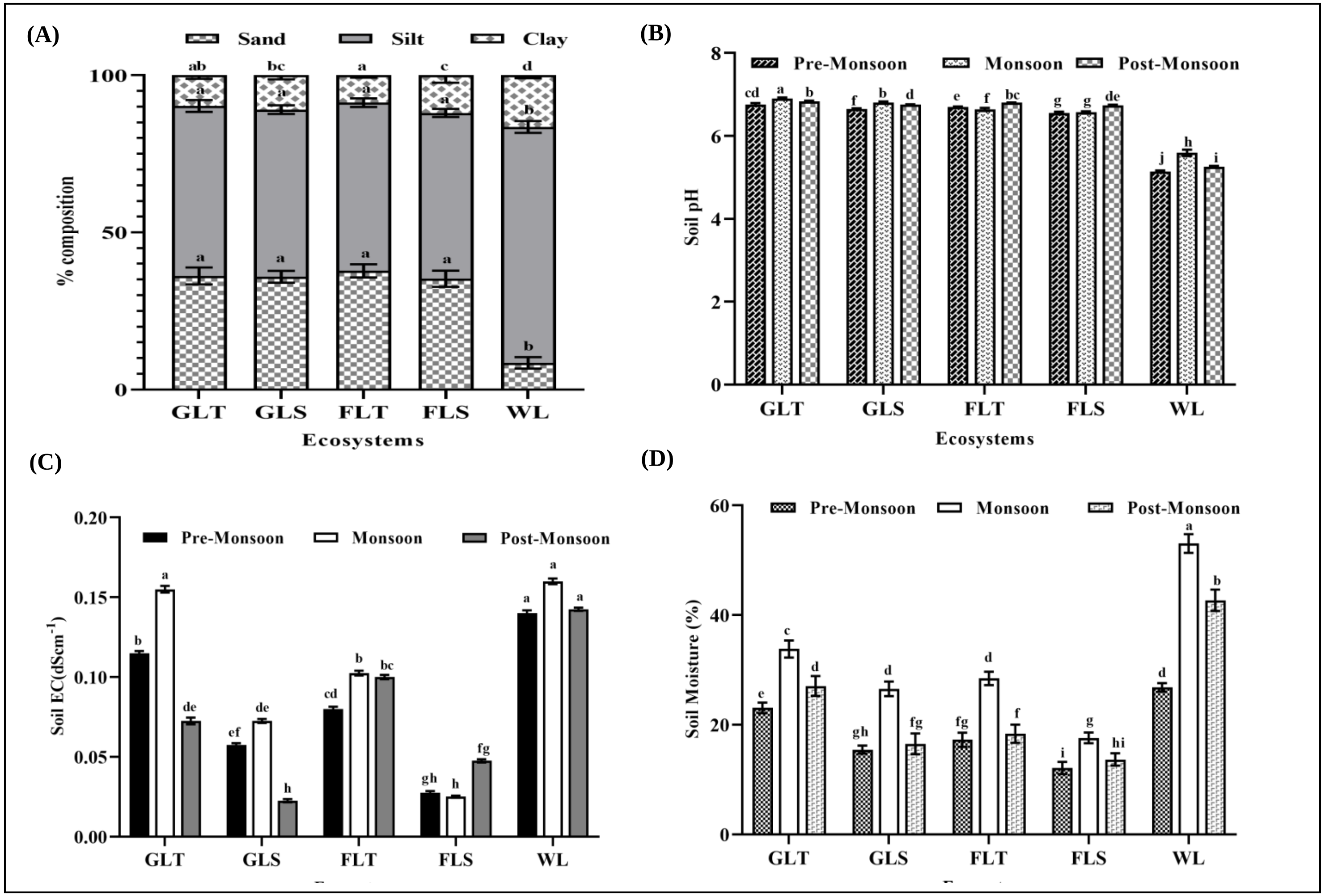


Figure 4.1. (A) Soil textural composition (B) Soil pH (C) Soil EC (D) Soil moisture of the studied ecosystems across the seasons. Data shown are mean ± S.D. (n = 5).GL denotes grassland ecosystem; FL denotes forestland ecosystem and WL denotes wetland ecosystem. T and S denotes topsoil and subsoil, respectively. Bars sharing the same letter, for each parameter, don't differ significantly according to the Duncan's multiple range test ($p \leq 0.05$).

Furthermore, soil depth has a significant effect ($p \leq 0.05$) on total soil nitrogen content. Topsoil of the grassland ecosystem recorded higher total soil nitrogen content (0.08-0.21%) and the lower values (0.03-0.05%) of the same was found in subsoil of forestland ecosystem.

4.1.7. Soil available P

Available P of soil in the studied ecosystems ranged from 22.1 to 39.9 kg/ha (Figure 4.2C). The recorded soil available P in grassland, forestland and wetland ecosystems was 22.9-39.6 kg/ha, 22.3- 38.9 kg/ha and 22.1 - 24.3 kg/ha respectively. The seasonality induced a significant variation ($p \leq 0.05$) in soil available P content with higher values of 24.3-39.6 kg/ha during the monsoon season and lower values of 22.1-29.5 kg/ha during the pre-monsoon season across the ecosystems.

Similarly, soil available phosphorus varied significantly ($p \leq 0.05$) with the soil depth. Regardless of the season, the topsoil of the grassland ecosystem recorded higher soil available P (29.5-39.6 kg/ha), while the subsoil of the forestland ecosystem recorded the lowest value (22.3-26.6 kg/ha).

4.1.8. Soil available K

Soil available K ranged from 136.9 to 282.7 kg/ha across the ecosystems as presented in the Figure 4.2D. The wetland ecosystem recorded the highest soil available K (205.5 – 282.7 kg/ha) compared to the grassland (136.9- 217.8 kg/ha) and forestland (123.9–197.6 kg/ha) ecosystems. Across the studied ecosystems, soil available K content varied significantly ($p \leq 0.05$) among the seasons. Monsoon season recorded higher values of soil available K (144.22-282.73 kg/ha) whereas the lowest of the same (123.9-205.5 kg/ha) was recorded in pre-monsoon season.

Regardless of the season, a significant difference ($p \leq 0.05$) in soil available K was observed at different soil depths. The topsoil of the grassland ecosystem had higher soil available K content (143.4-217.8 kg/ha). Whereas, the subsoil of the forestland ecosystem recorded the lowest (123.9-144.2 kg/ha) values for the same.

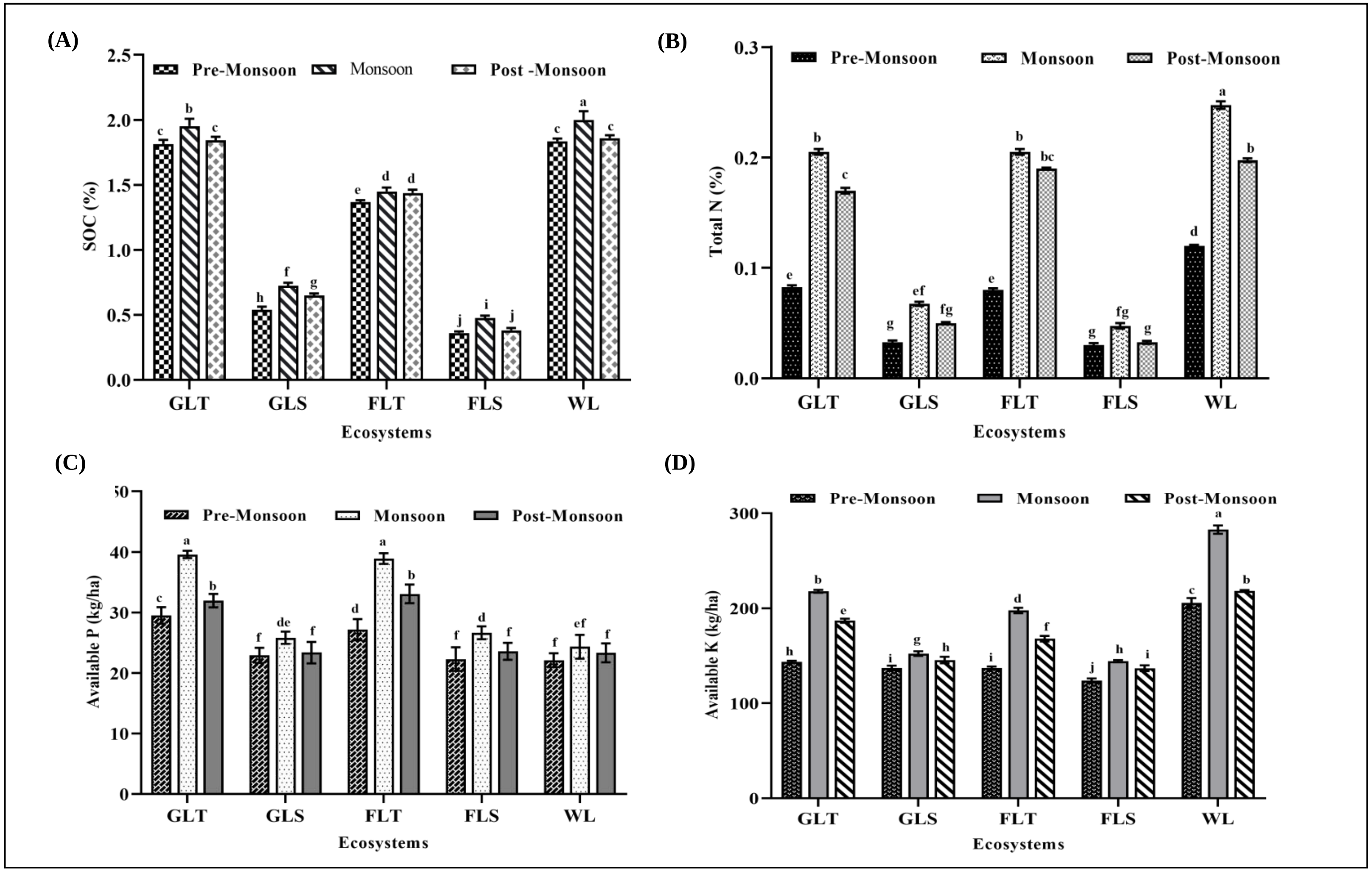


Figure 4.2. (A) Soil organic carbon (SOC) (B) Total Nitrogen (C) Soil available phosphorus (D) Soil available potassium of the studied ecosystems across the seasons. Data shown are mean ± S.D. (n = 5).GL denotes grassland ecosystem; FL denotes forestland ecosystem and WL denotes wetland ecosystem. T and S denotes topsoil and subsoil, respectively. Bars sharing the same letter, for each parameter, don’t differ significantly according to the Duncan’s multiple range test ($p \leq 0.05$).

4.2.Seasonal variations of soil biological parameters across the ecosystems:

4.2.1. Soil *β*- D glucosidase activity

β- D glucosidase activity of the soil across the ecosystems and seasons are presented in the Figure 4.3A. It ranged from 4.03 to 6.24 μg PNP g^{-1} h^{-1}. Significant variation (*p≤0.05*) in *β* - D glucosidase activity is obtained among the seasons and ecosystems. Wetland ecosystem recorded the highest *β* - D glucosidase activity (4.99-6.24 μg PNP g^{-1} h^{-1}) followed by grassland ecosystem (4.06-5.04 μg PNP g^{-1} h^{-1}). The lowest activity of the soil enzyme was observed in the forestland ecosystem (4.03-4.86 μg PNP g^{-1} h^{-1}). The seasonality induced a significant effect on soil *β* - D glucosidase activity across the studied ecosystems. When compared to the pre-monsoon season which recorded the lowest activity of soil *β* - D glucosidase, the monsoon season had a 1.95-20.03% increase of the same.

Similarly, regardless of the seasons or ecosystems, soil depth showed a significant difference (*p≤0.05*) in *β* - D glucosidase activity. The topsoil of the grassland ecosystem had higher *β* - D glucosidase activity (4.50-5.04 μg PNP g^{-1} h^{-1}) while the subsoil of the forestland ecosystem had the lowest (4.03-4.11 μg PNP g^{-1} h^{-1}) activity of the soil enzyme.

4.2.2. N-acetyl glucosaminidase activity

Figure 4.3B depicts the N-acetyl glucosaminidase activity of soil across the ecosystems and seasons. The enzyme activity varied significantly (*p≤0.05*) among the ecosystems. Regardless of seasons, the highest activity of N-acetyl glucosaminidase was noted in wetland ecosystem (5.50-7.12 μg PNG g^{-1} h^{-1}) while, forestland ecosystem noted the lowest activity (4.49-5.79 μg PNG g^{-1} h^{-1}) for the enzyme. Significant variation (*p≤0.05*) in N-acetyl glucosaminidase activity was documented between the seasons. Monsoon season recorded the highest activity of 5.35-7.11 μg PNG g^{-1} h^{-1} and lower values of 4.47-5.50 μg PNG g^{-1} h^{-1} was obtained in the pre-monsoon season across the studied ecosystems.

Soil N-acetyl glucosaminidase activity varied significantly (*p≤0.05*) with the soil depth. Regardless of season, the topsoil of the grassland ecosystem had higher N-acetyl glucosaminidase activity (4.82-5.87 μg PNG g^{-1} h^{-1}) than the subsoil of the forestland ecosystem (4.49-5.49 μg PNG g^{-1} h^{-1}).

4.2.3. Acid phosphatase activity

Acid phosphatase activity differed significantly ($p \leq 0.05$) across the seasons and ecosystems as represented in Figure 4.3C. Both wetland and grassland ecosystem had the highest acid phosphatase activity (11.49-20.99 μg PNP $g^{-1}h^{-1}$), while the forestland ecosystem noted the lowest (6.19-7.05 μg PNP $g^{-1}h^{-1}$) value. The seasonality brought a significant impact ($p \leq 0.05$) on acid phosphatase activity in all three studied ecosystems. The activity of soil acid phosphatase increased by 12.20-45.26% during the monsoon season as compared to the pre-monsoon season which documented the lowest activity.

Similarly, regardless of season or ecosystem, soil depth showed a significant variance ($p \leq 0.05$) in acid phosphatase activity. The topsoil of the grassland ecosystem had the highest acid phosphatase activity (10.03-20.58 g PNP $g^{-1}h^{-1}$) while the subsoil of the forestland ecosystem had the lowest (6.19-7.05 g PNP $g^{-1}h^{-1}$).

4.2.4. Microbial Biomass Carbon (MBC)

Seasonal variation of soil MBC was significant ($p \leq 0.05$) during the study period (Figure 4.3D). It ranged between 110.1 to 401.9 mg kg^{-1}. Monsoon season recorded the highest MBC (142.41-401.91 mg kg^{-1}), while pre-monsoon season recorded the lowest (110.1-300.8 mg kg^{-1}). MBC also varied significantly ($p \leq 0.05$) across the ecosystems, with the highest value in the wetland (300.6-401.9 mg kg^{-1}) than grassland (120.9-272.2 mg kg^{-1}) and forestland (110.1-263.9 mg kg^{-1}) ecosystem.

Furthermore, the soil depth also significantly influenced ($p \leq 0.05$) the MBC content. Maximum microbial biomass carbon was observed in the topsoil of the grassland ecosystem (191.4-272.2 mg kg^{-1}) and a minimum value of the same was observed in the subsoil of forestland ecosystem (110.1-142.4 mg kg^{-1}).

4.3.Soil metagenomics

4.3.1. Relative abundance of bacteria across the ecosystems of KNP in different seasons

The KRONA plot visually depicts the bacterial annotation analysis result. The inner and outer circles represent distinct taxonomic ranks, and the area of the sector represents the percentage of different operational taxonomic unit (OTU) annotation results. The KRONA graphs for the three studied ecosystems of KNP across the seasons are shown in Figure 4.4 A, B, C. A total of 47, 46, and 45 phyla were observed across the ecosystems during the

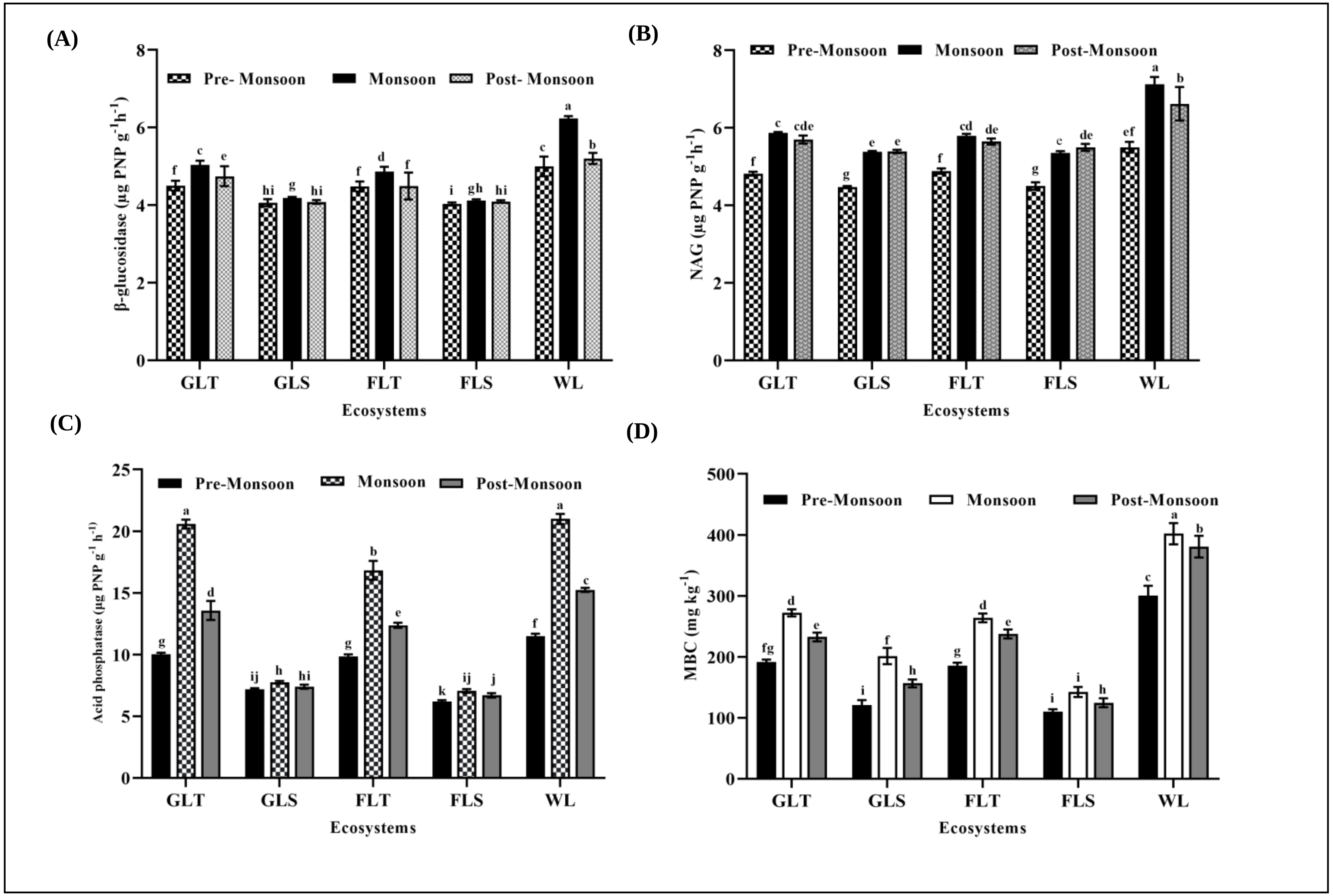


Figure 4.3. (A) β-D glucosidase activity (B) NAG activity (C) Acid phosphatase activity (D) MBC of the studied ecosystems across the seasons. Data shown are mean ± S.D. (n = 5).GL denotes grassland ecosystem; FL denotes forestland ecosystem and WL denotes wetland ecosystem. T and S denotes topsoil and subsoil, respectively. Bars sharing the same letter, for each parameter, don't differ significantly according to the Duncan's multiple range test ($p \leq 0.05$).

pre-monsoon, monsoon, and post-monsoon season respectively. The top 10 abundant phylum are shown in Figure 4.5 and Table 4.1. *Proteobacteria* (21.2–29.2%), *Acidobacteria* (9.8-22.9%), *Actinobacteria* (5.1-20.7%), *Chloroflexi* (6.6–16.7%) were the dominant phyla accounting for 62.6–67.2% of the total sequences. Other phyla with relative abundances over 1% include mostly *Latescibacteria*, *Planctomycetes*, *Gemmatimonadetes*, *Verrucomicrobia*, *Bacteroidetes*. The relative abundance of *Proteobacteria* was found to be similar in all three ecosystems. *Acidobacteria* were found in greater abundance in grassland and forestland ecosystems than in wetland ecosystems. Similarly, the relative abundance of *Actinobacteria* in grassland and forestland ecosystems was found to be greater than in wetland ecosystems. In contrast, the relative abundance of *Chloroflexi* was highest in the wetland ecosystem compared to the other two ecosystems.

Seasonal variation was noted with regard to the relative abundance of bacteria in all the three ecosystems. Relative abundance of *Proteobacteria* was found to be similar across the seasons. However, the relative abundance of *Acidobacteria* was found to be higher during the post-monsoon season compared to pre-monsoon and monsoon seasons. However, no such significant trend was noted for the relative abundance of *Chloroflexi* and *Actinobacteria* across the ecosystems and seasons. Irrespective of the seasons, similar trend was also observed for the phyla with relative abundances greater than 1%.

4.3.2. Bacterial diversity across the ecosystems of KNP in different seasons

The Shannon and Chao1 metrics were used to analyse the microbial diversity across the ecosystems of KNP in different seasons. The chao1 metric calculates species richness, whereas the Shannon metric calculates detected OTU abundances while accounting for both richness and evenness. The rarefaction curve for Chao1and Shannon metrics is provided in Figures 4.6 and 4.7. The alpha-diversity varied with ecosystem and season. The rarefaction: The Chao1 curve revealed the presence of greater number of species in the forestland ecosystem during the pre-monsoon season and lesser number of species were noted in the grassland ecosystem. Contrastingly, during the monsoon season, the grassland ecosystem recorded higher number of species, while lower number of species were found in the wetland ecosystem. Likewise, during the post-monsoon season, a similar number of species were recorded in the grassland and forestland ecosystem, but fewer species were observed in the wetland ecosystem.

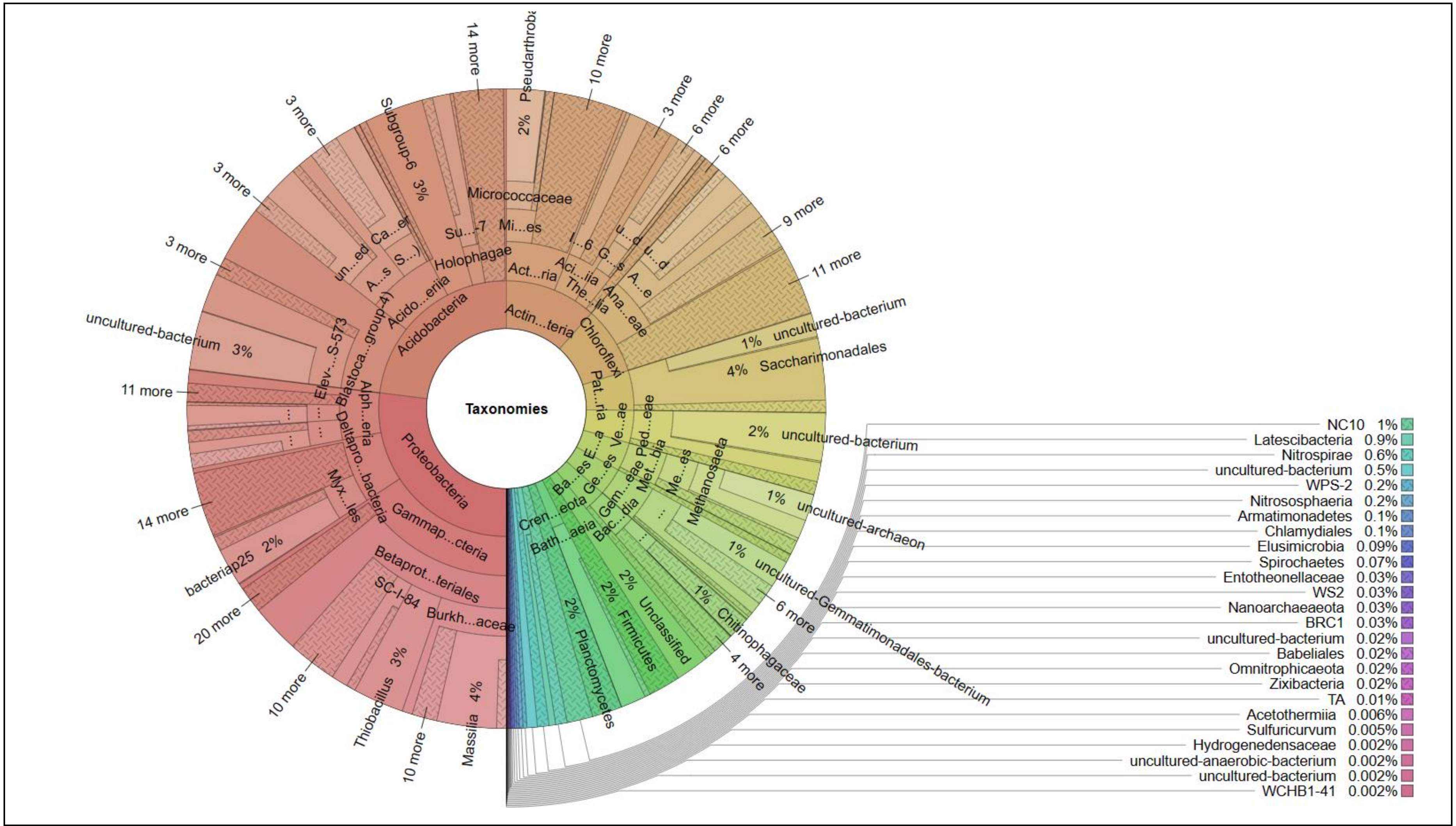


Figure 4.4. (A) KRONA plot showing the relative abundance of bacteria across the studied ecosystems during pre-monsoon season.

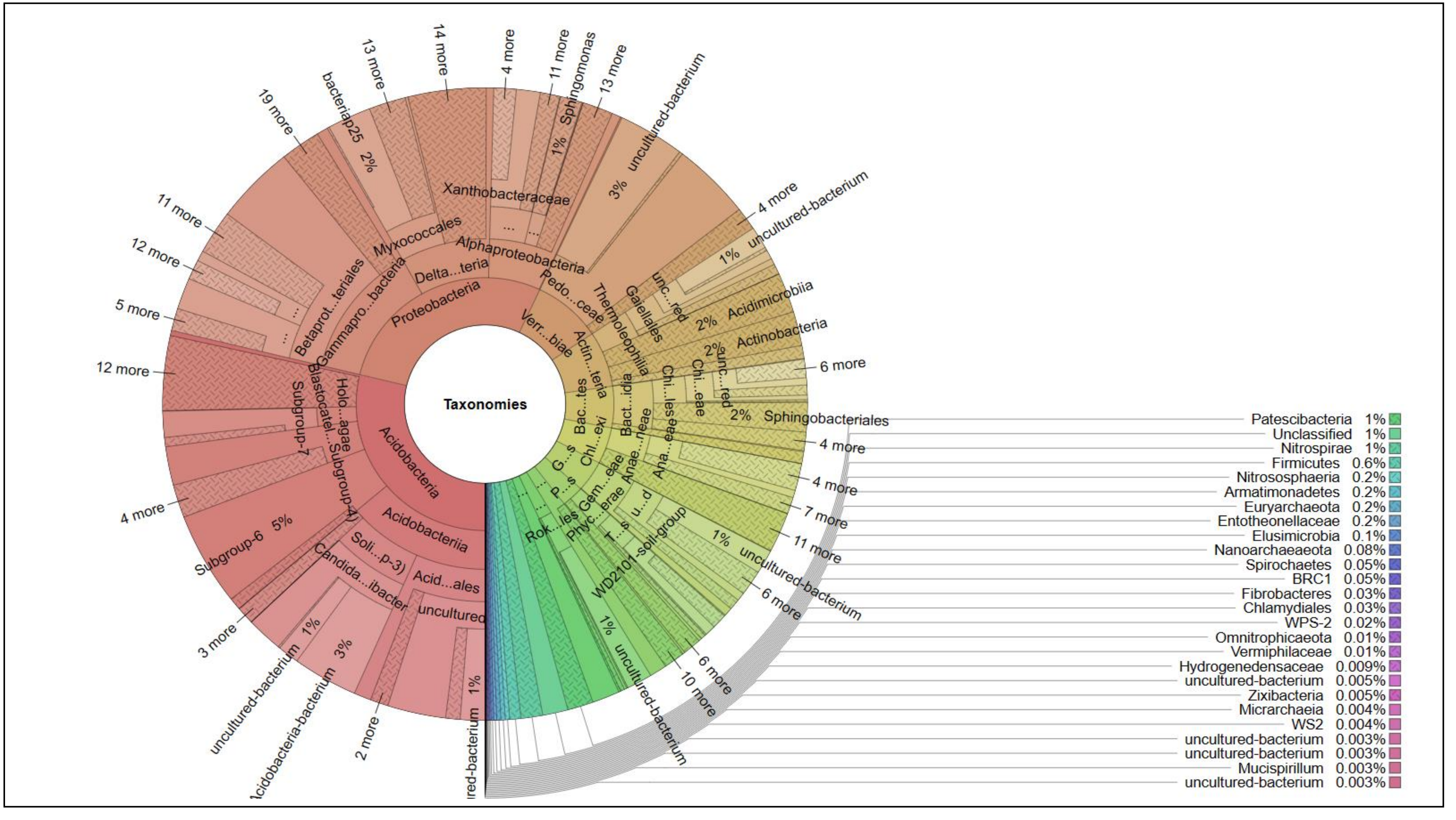


Figure 4.4. (B) KRONA plot showing the relative abundance of bacteria across the studied ecosystems during monsoon season.

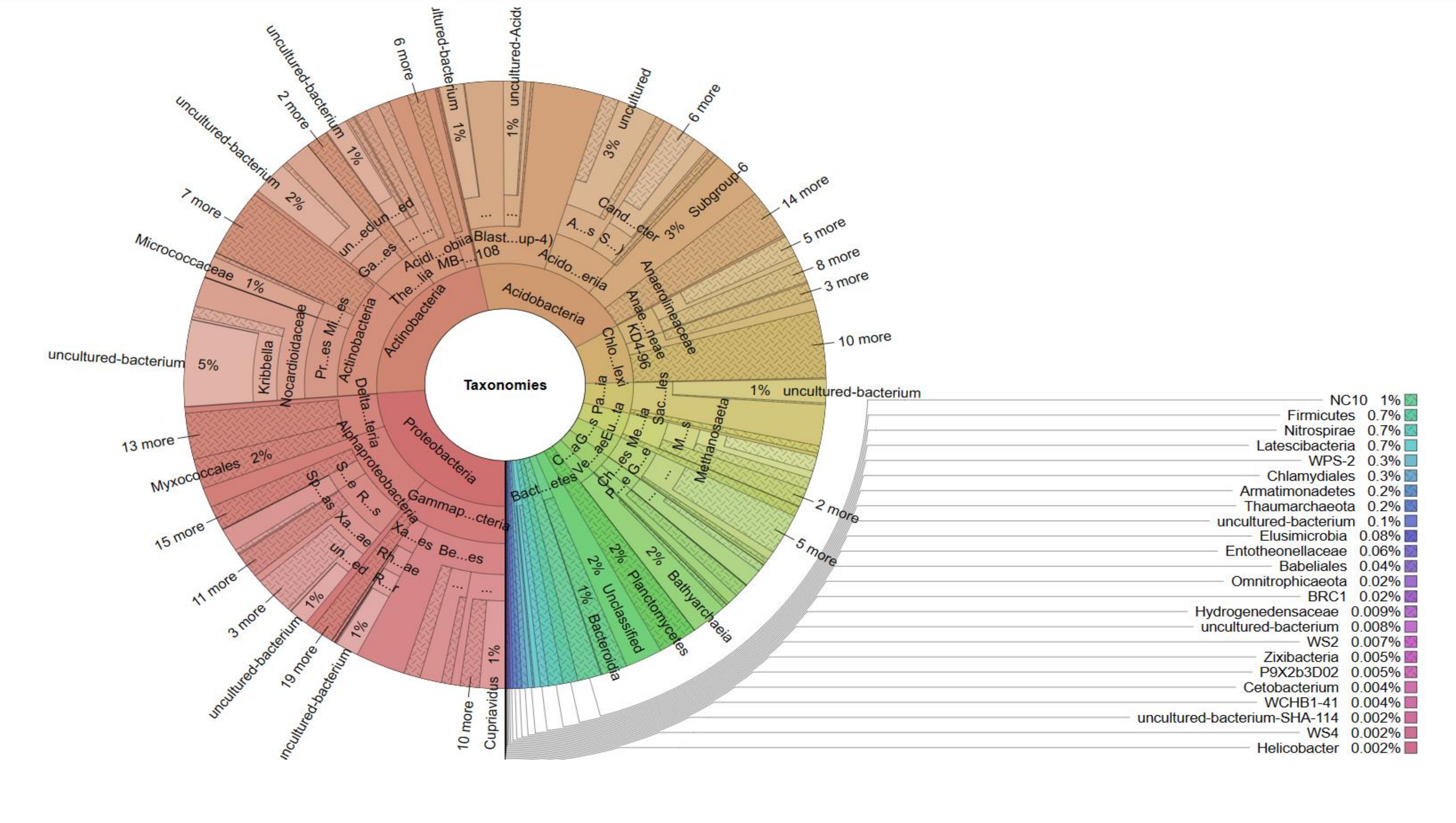


Figure 4.4. (C) KRONA plot showing the relative abundance of bacteria across the studied ecosystems during post-monsoon season.

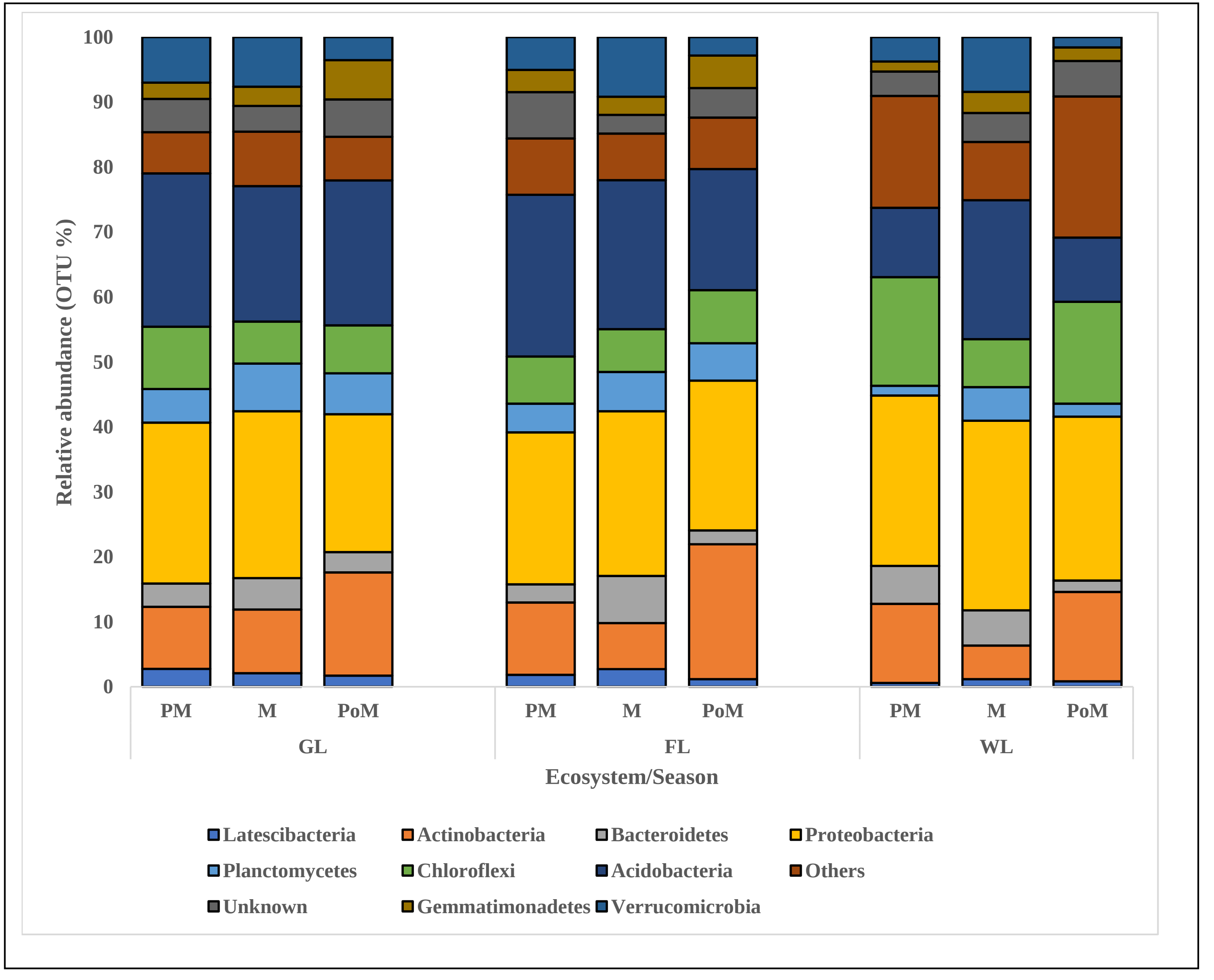


Figure 4.5. Relative abundance of top 10 abundant phylum of bacteria in the studied ecosystems across the seasons.

Table 4.1. Relative abundance of the top ten phylum of bacteria across the ecosystems of KNP in different seasons

Ecosystem	Season/ Phylum	Latescibacteria	Actinobacteria	Bacteroidetes	Proteobacteria	Planctomycetes	Chloroflexi	Acidobacteria	Others	Unknown	Gemmatimonadetes	Verrucomicrobia
GL	PM	2.760	9.534	3.584	24.767	5.161	9.606	23.620	6.344	5.125	2.473	7.025
	M	2.067	9.815	4.837	25.672	7.367	6.443	20.875	8.350	3.974	2.951	7.648
	PoM	1.703	15.911	3.119	21.206	6.291	7.392	22.333	6.710	5.740	6.055	3.539
FL	PM	1.855	11.127	2.796	23.374	4.416	7.271	24.875	8.684	7.124	3.415	5.063
	M	2.718	7.071	7.263	25.373	6.013	6.590	22.968	7.143	2.886	2.790	9.187
	PoM	1.176	20.773	2.117	23.047	5.775	8.153	18.657	7.917	4.547	5.017	2.822
WL	PM	0.567	12.183	5.841	26.235	1.502	16.722	10.681	17.222	3.738	1.535	3.772
	M	1.181	5.137	5.456	29.164	5.201	7.371	21.378	8.966	4.467	3.255	8.424
	PoM	0.849	13.743	1.738	25.263	1.981	15.683	9.863	21.746	5.457	2.102	1.576

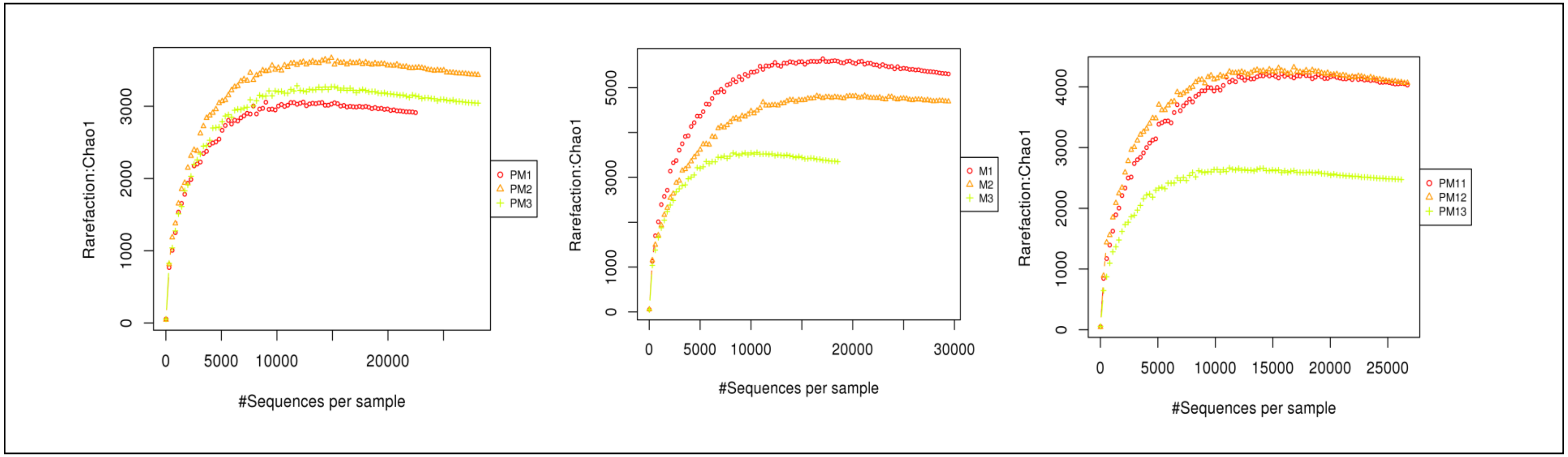


Figure 4.6. Chao1 curve of the three ecosystems of KNP during different seasons. PM1 denotes grassland, PM2 denotes forestland and PM3 denotes wetland ecosystem during pre-monsoon season. M1 denotes grassland, M2 denotes forestland and M3 denotes wetland ecosystem during monsoon season. PM11 denotes grassland, PM12 denotes forestland and PM13 denotes wetland ecosystem during post-monsoon season.

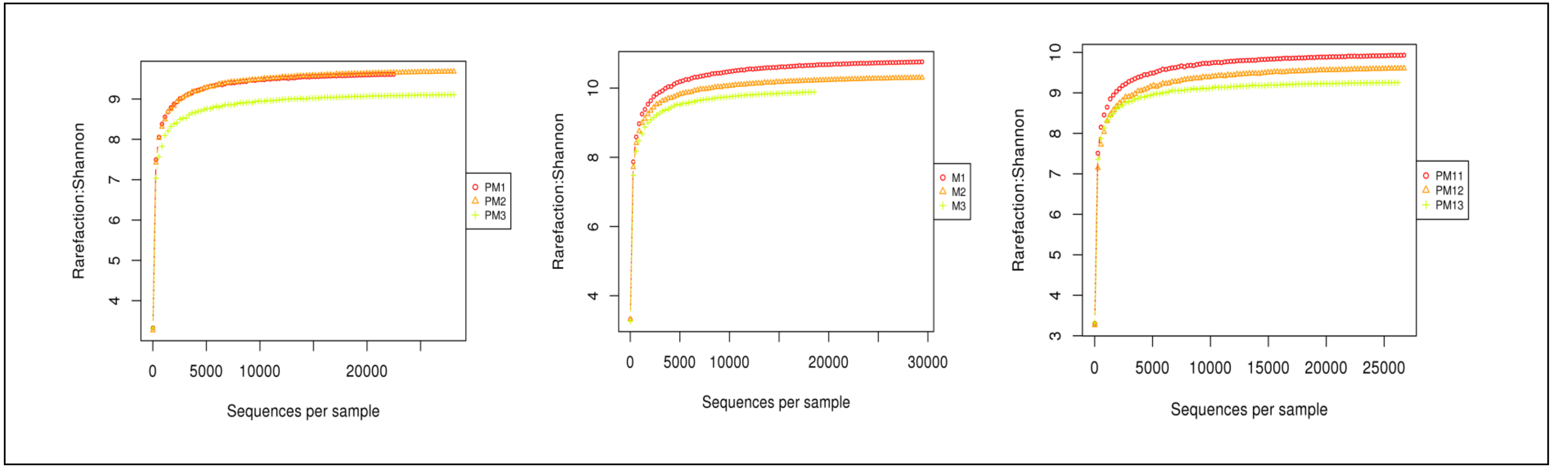


Figure 4.7. Shannon curve of the three ecosystems of KNP during different seasons. PM1 denotes grassland, PM2 denotes forestland and PM3 denotes wetland ecosystem during pre-monsoon season. M1 denotes grassland, M2 denotes forestland and M3 denotes wetland ecosystem during monsoon season. PM11 denotes grassland, PM12 denotes forestland and PM13 denotes wetland ecosystem during post-monsoon season

Furthermore, from the rarefaction: Shannon curve, a higher diversity was observed in the forestland ecosystem regardless of season. Whereas, a lower diversity was observed in the wetland ecosystem.

4.4.Soil mineralogical parameters

4.4.1. Powdered X-ray Diffraction analysis

The XRD analysis revealed the crystalline nature of the soil. Characterization of XRD peaks as depicted in Figure 4.8 indicated the presence of quartz, montmorillonite, vermiculite, augite and dolomite as the major phases. The identified minerals with their characteristic 2Θ values are given in the Table 4.2.

4.4.2. Fourier Transform Infrared spectroscopy analysis

The FT-IR spectra of all ecosystems and the characteristic peaks along with their corresponding functional groups are presented in the Figure 4.9 and Table 4.3, respectively. The spectra showed the presence of broad peaks in the 3620-3640 cm^{-1} range due to the stretching vibration of the OH moiety of clay minerals and hydroxides, adsorbed moisture and organic matters containing polysaccharides, proteins containing alcohols, phenols, carboxylic acids, NH stretching vibrations of amines and amides. These peaks also revealed the presence of aluminosilicate minerals by indicating the presence of Al-O-H stretching vibration. The peak at 3620 cm^{-1} indicated the possibility of the hydroxyl linkage and OH- groups in octahedral layers. The spectra at 2800-2950 cm^{-1} were caused by the C-H stretching vibration of organic matter. Aside from hydroxyl groups (-OH), a sharp peak was observed at 1630-1670 cm^{-1} which are characteristic stretching vibrations of C=O groups of carboxylates, amides and OH bending vibrations of adsorbed water. The peak in the range 980-1100 cm^{-1} was caused by Si-O-Si stretching of clay minerals, CO stretching of polysaccharides, and OH bending vibration of clay minerals and oxides. The similar spectral pattern in the fingerprint region of 400-700 cm^{-1} clearly revealed the presence of an almost identical functional group, i.e., similar soil inter- layer structure in all the ecosystems. The FT-IR data unequivocally confirmed the presence of organic matter in the soil.

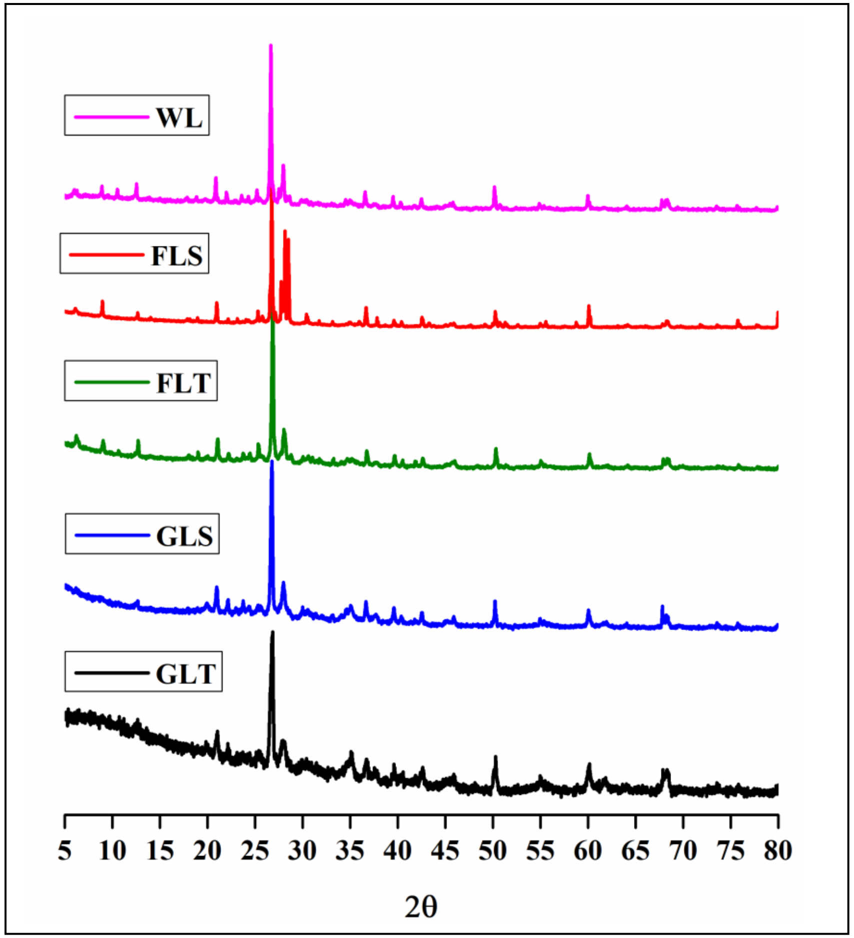


Figure 4.8. PXRD spectra of the studied ecosystems of KNP.

Table 4.2. Identified minerals of the representative ecosystems of KNP with their characteristic 2Θ values.

XRD peaks (2Θ)	Minerals
6.19, 20.01, 26.80	Montmorillonite
19.88, 26.80	Quartz
22.40, 35.08	Vermiculite
28.06, 29.90, 34.85	Augite
24,38, 37.70	Dolomite

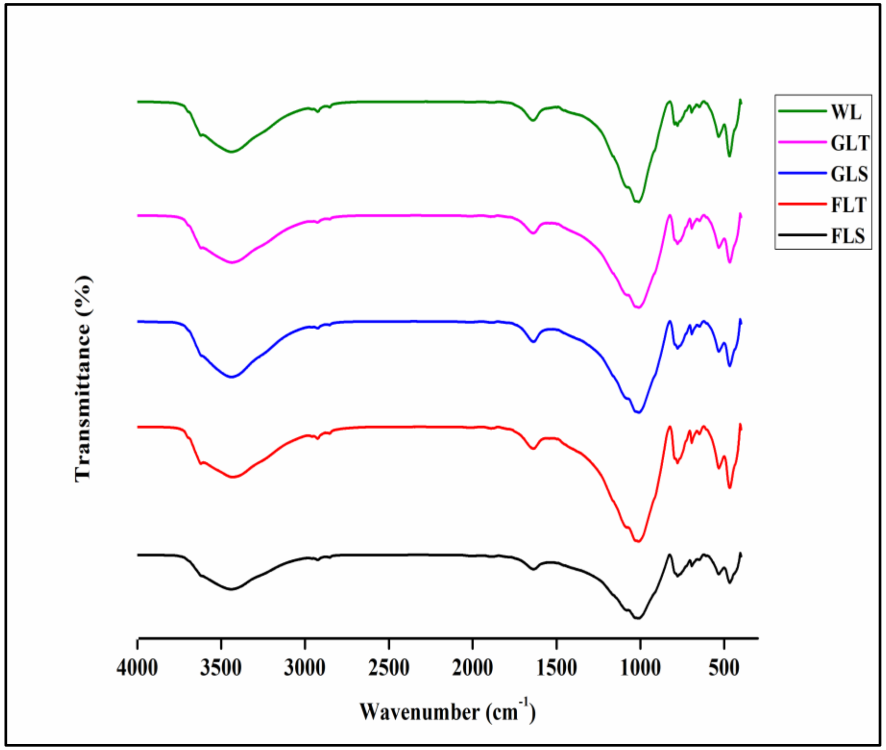


Figure 4.9. FT-IR spectra of the studied ecosystems of KNP.

Table 4.3. Characteristic FT-IR peaks along with their corresponding functional groups.

Wavelength	Functional groups
3610-3640 cm^{-1}	OH stretching, NH stretching
2800-2950 cm^{-1}	C-H stretching of organic matter
1630-1670 cm^{-1}	-OH bending, C=O stretching
980-1100 cm^{-1}	Si-O-Si stretching

4.4.3. Field emission scanning electron microscopy (FE-SEM) and Energy dispersive X-Ray (EDX) analysis

The micro morphologies of the studied soils were revealed by FE-SEM images. The presence of montmorillonite minerals in the ecosystems was represented by the irregular flakes-like shape. Furthermore, the elemental ratios of Si: Al for the soils of the ecosystem indicated by the EDX data inferred towards the presence of phyllosilicate minerals (Figures 4.10, 4.11 and 4.12).

4.4.4. Thermogravimetric analysis

The TGA spectra of the studied ecosystems of KNP is presented in Figure 4.13. The total weight loss occurred was higher in the surface soils of grassland and forestland as well as wetland soil compared to subsurface soils of forestland and grassland ecosystem. The cumulative weight loss of the soil samples at 800°C followed the order: GLT > FLT > WL > FLS > GLS (Table 4.4). The first step at 0 - 200°C signified the removal of water and some freely bound organic matter. In this step, the top soil of both the grassland and forestland ecosystem, as well as the wetland ecosystem, lost a greater percentage of its weight than the sub-surface soil of the grassland and forestland ecosystem. A similar trend was observed in the second step (200 - 600°C), where a greater percentage of weight loss occurred in the top soil of both grassland and forestland ecosystem, as well as wetland ecosystem, as compared to the sub-surface soil of grassland and forestland ecosystem. The final weight loss at 600 – 800°C is ascribed by the dehydroxylation of clay minerals. At this temperature, the top soil of both the grassland and forestland ecosystem lost the maximum weight, while the subsurface soil of the grassland ecosystem lost the least.

Furthermore, the cumulative weight loss at 800°C was found to be highest in top soil of grassland ecosystem whereas the lowest cumulative weight loss at 800°C was observed in sub surface soil of grassland ecosystem.

4.5.Cumulative carbon mineralisation

The cumulative carbon mineralisation across the ecosystems and seasons are depicted in Figure 4.14. It varied significantly among the studied ecosystems of KNP. The amount of carbon (C) mineralised during the 90-day incubation period was highest in wetland ecosystem (6.53-11.58 mg kg^{-1} soil) followed by grassland (4.05-10.21 mg kg^{-1} soil) and forestland (3.97-8.17 mg kg^{-1} soil) ecosystem. Soil C mineralisation exhibited significant

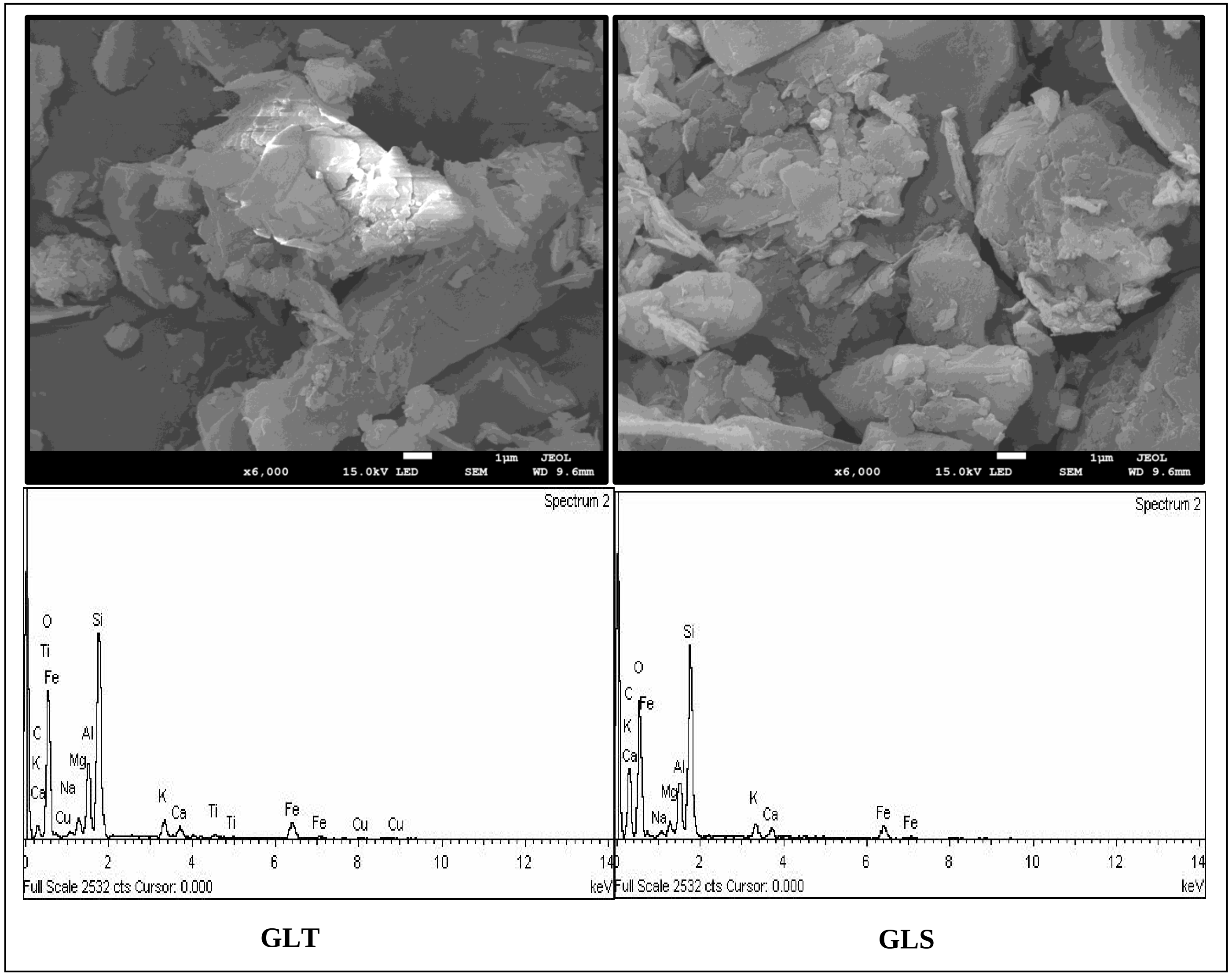
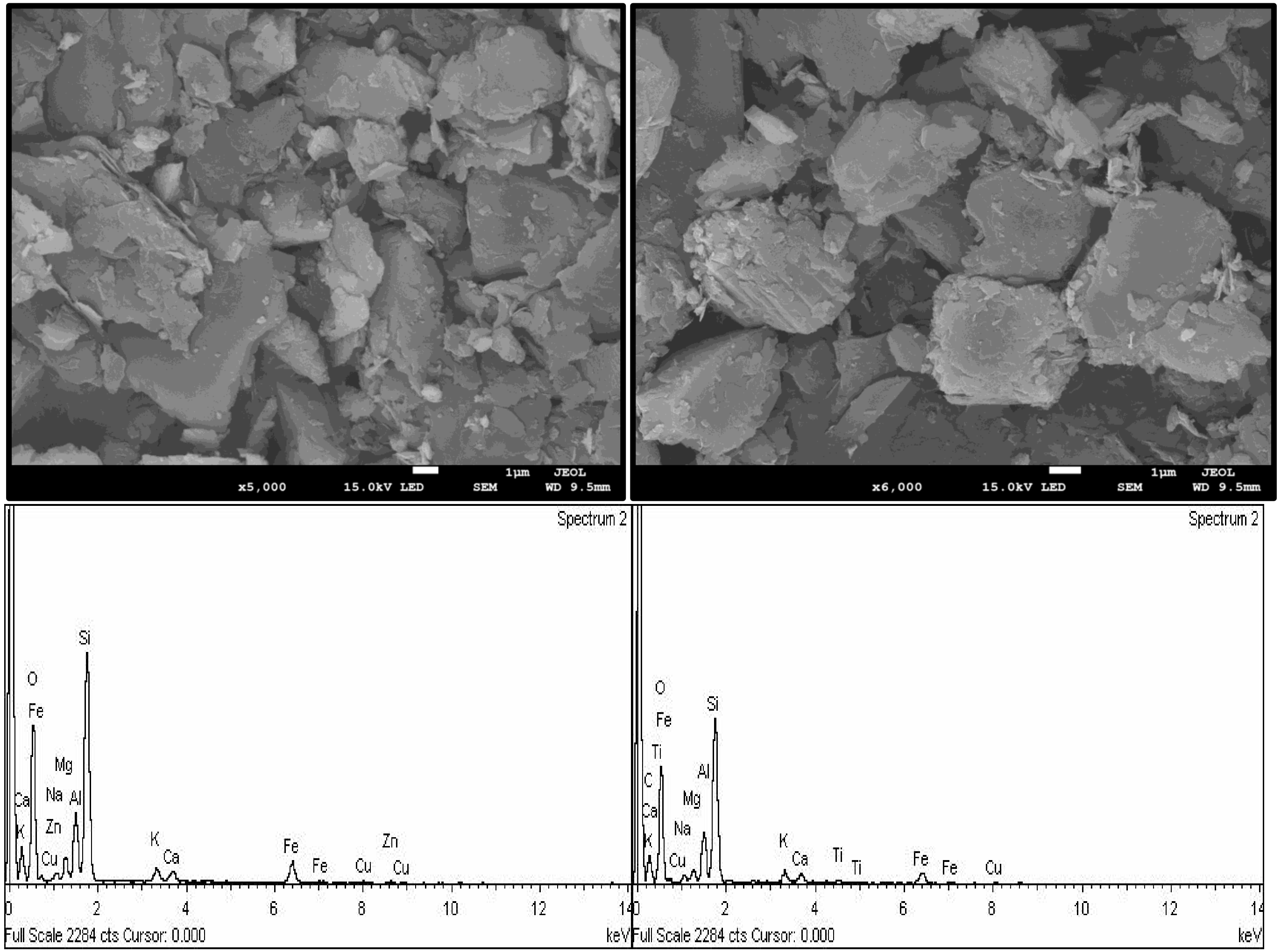
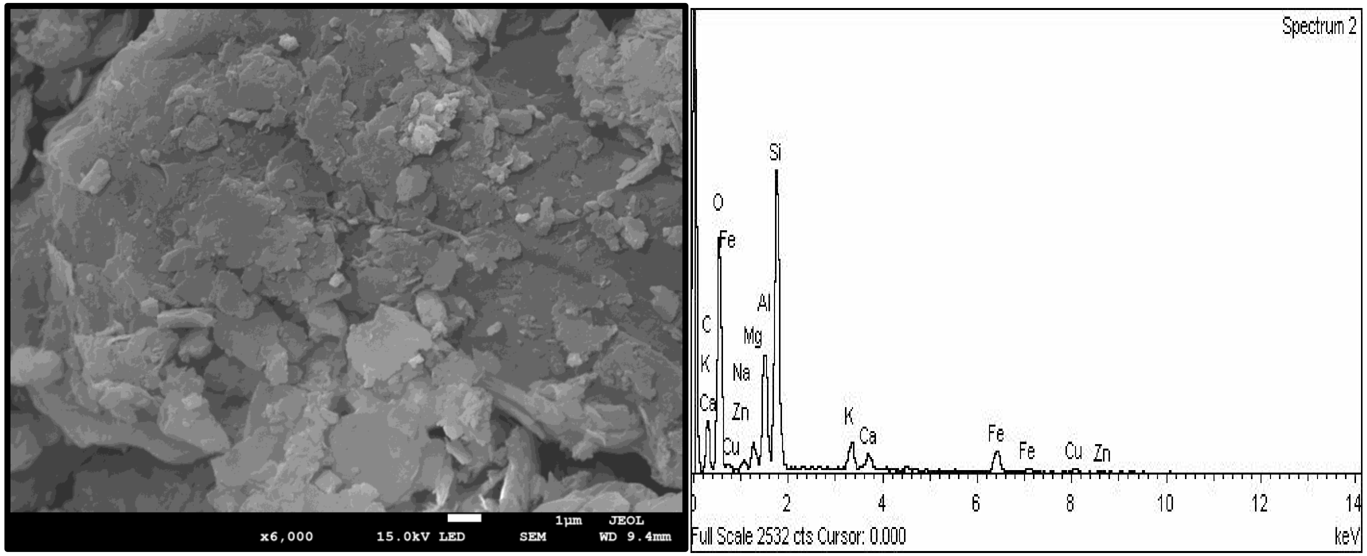


Figure 4.10. FE SEM images and EDX spectra of Grassland ecosystem (GL) of KNP. T denotes topsoil and S denotes subsoil.



FLT **FLS**

Figure 4.11. FE SEM images and EDX spectra of Forestland ecosystem (FL) of KNP. T denotes topsoil and S denotes subsoil.



WL

Figure 4.12. FE SEM images and EDX spectra of Wetland ecosystem (WL) of KNP.

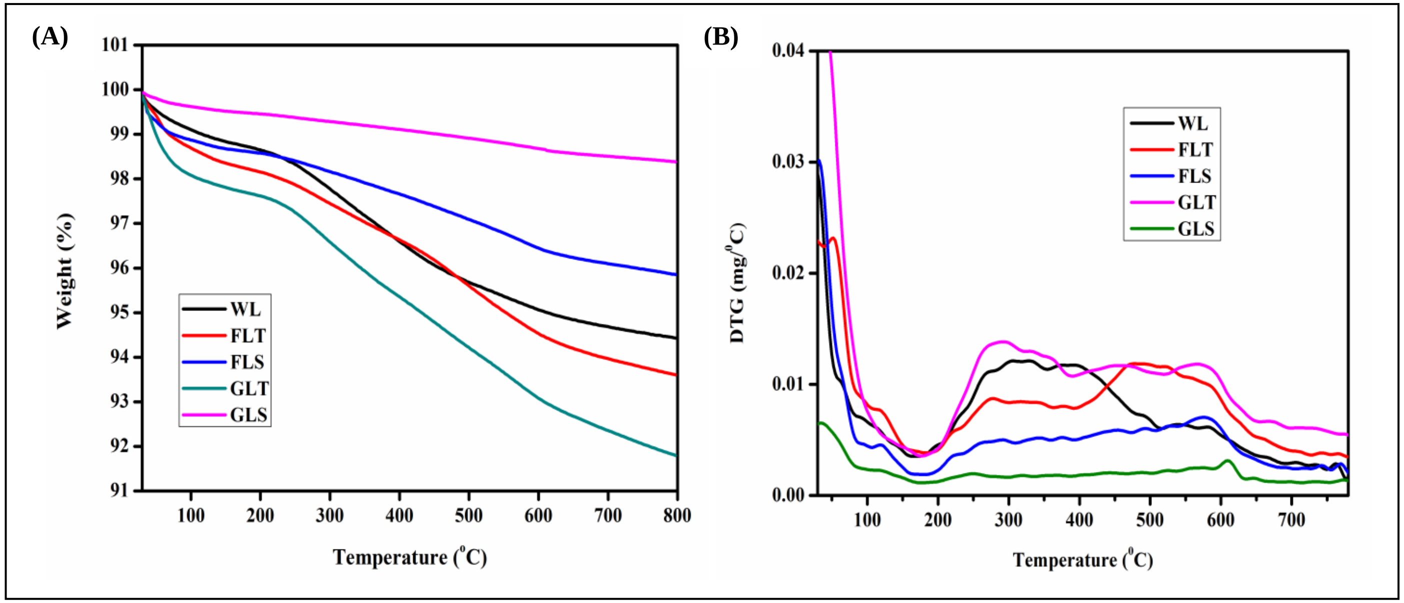


Figure 4.13. Thermogravimetric (A) and differential thermogravimetric (B) patterns of the three ecosystems of KNP. GL denotes grassland ecosystem; FL denotes forestland ecosystem and WL denotes wetland ecosystem. T and S denotes topsoil and subsoil respectively

Table 4.4. Thermogravimetric weight losses from the soils of the studied ecosystem of KNP.

Soil	% mass loss			Cumulative weight loss (%) at 800˚C
	0-200˚C	200-600˚C	600-800˚C	
GLT	2.12	4.90	0.94	7.96
GLS	0.47	0.81	0.25	1.53
FLT	1.66	3.74	0.89	6.29
FLS	1.24	2.19	0.57	4.00
WL	1.32	3.78	0.52	5.62

seasonal variation (*p≤0.05*) in all the three ecosystems of KNP. The soil C mineralisation during monsoon season was enhanced by 9.15-43.61% compared to the pre-monsoon season, which had the lowest values in all the three ecosystems.

Similarly, soil depth also exerted a significant difference *(p≤0.05)* in soil C mineralisation. Maximum soil C mineralisation was observed in topsoil of grassland ecosystem (6.39-10.22 mg kg^{-1}) and minimum value of the same was observed in subsoil of forestland ecosystem (3.97-4.37 mg kg^{-1}).

4.6.Carbon mineralisation kinetics

The CO_2 emission data was fitted using both one-pool and two-pool models of carbon mineralisation. Regardless of the seasons or ecosystems, better fitting (R^2 ranging from 0.90 to 0.99) was obtained with the one-pool model (with two fitted variables) than the two-pool model (with four fitted variables). The kinetic parameters of C mineralisation showed significant seasonal variation as depicted in Table 4.5. Monsoon recorded the highest value of kinetic parameters of C mineralisation followed by post monsoon and pre monsoon season. Among the ecosystems, wetland recorded significantly higher potentially mineralisable carbon (C_0) and maximum C mineralisation potential (C_0*k) (15.49, 0.235 respectively). This is followed by grassland ecosystem (12.59, 0.226 respectively), whereas lower value was exhibited by forestland ecosystem (4.99, 0.103 respectively).

Soil C mineralisation kinetic parameters (*p≤0.05*) varied significantly among the seasons. Regardless of ecosystem, highest values were observed during the monsoon season and pre-monsoon recorded the lowest values of the same. Potentially mineralisable carbon and maximum C mineralisation potential of soil significantly varied with soil depth. Topsoil of the grassland ecosystem recorded the greatest impact whereas the subsoil of the forestland ecosystem recorded the least.

Contrastingly, regardless of season, the rate constant (k) for carbon mineralisation is significantly higher in soils of forestland ecosystem (0.17-0.21 s^{-1}) followed by grassland ecosystem (0.10-0.23 s^{-1}). The wetland ecosystem recorded the lowest of the same (0.10-0.15 s^{-1}). The calculated rate constant (k) falls within a relatively narrow range 0.010 to 0.023 s^{-1}. Furthermore, the seasonality and soil depth brought a significant influence on the rate constant (k) for C mineralisation. Monsoon season had the highest rate constant, while pre-monsoon season had the lowest. However, in terms of soil depth, subsurface soil

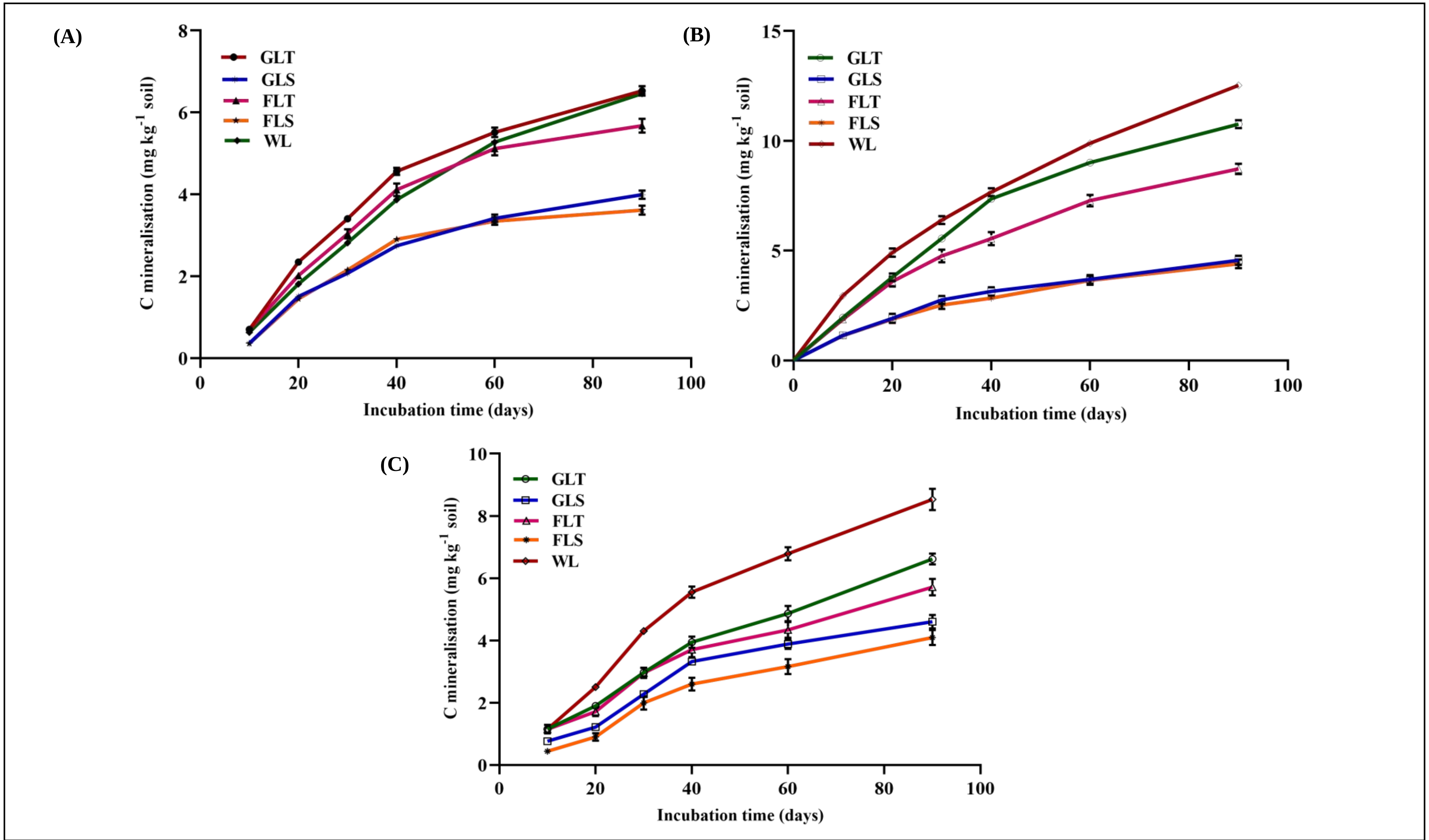


Figure 4.14. Cumulative Carbon mineralisation rates of the three ecosystems of KNP over 90 days period during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon. The vertical bars represent standard errors ($p \leq 0.05$). Data shown are mean ± S.E. (n = 5). GL denotes grassland ecosystem; FL denotes forestland ecosystem and WL denotes wetland ecosystem. T and S denotes topsoil and subsoil respectively.

Table 4.5. Carbon mineralisation kinetic parameters across the seasons and ecosystems of KNP

Ecosystem/Season	C_0	k	C_0*k	Half life	R^2
Pre-Monsoon					
GLT	9.240 ± 1.214de	0.014 ± 0.003cd	0.129 ± 0.011cd	50.332 ± 9.576bc	0.97
GLS	5.318 ± 0.635ij	0.017 ± 0.003bc	0.091 ± 0.010f	40.864 ± 6.383bcde	0.95
FLT	7.830 ± 1.231fg	0.017 ± 0.004bc	0.129 ± 0.017cd	42.915 ± 10.935bcde	0.95
FLS	4.994 ± 0.452j	0.021 ± 0.002ab	0.103 ± 0.005ef	33.850 ± 3.771de	0.92
WL	11.086 ± 0.2756c	0.010 ± 0.001d	0.114 ± 0.008de	67.430 ± 5.511a	0.98
Monsoon					
GLT	12.589± 0.6386b	0.018 ± 0.002bc	0.226 ± 0.013a	38.806 ± 4.165cde	0.99
GLS	5.274 ± 0.629ij	0.023 ± 0.005a	0.116 ± 0 .012de	31.920 ± 6.760e	0.98
FLT	9.738 ± 0.3604d	0.020 ± 0.001ab	0.195 ± 0.010b	34.730 ± 2.591de	0.99
FLS	6.264 ± 1.021hi	0.014 ± 0.004cd	0.087 ± 0.011f	51.534 ± 15.623b	0.99
WL	15.487 ± 0.8381a	0.015 ± 0.002c	0.235 ± 0.012a	45.844 ± 4.765bcd	0.99
Post-Monsoon					
GLT	11.142± 0.820c	0.010 ± 0.001d	0.115 ± 0.008de	67.339 ± 8.970a	0.99
GLS	8.073 ± 0.432ef	0.016 ± 0.001c	0.127 ± 0.007cd	43.984 ± 1.987bcde	0.91
FLT	8.704 ± 0.565def	0.016 ± 0.001c	0.136 ± 0.002c	44.230 ± 3.138bcde	0.99
FLS	6.841 ± 0.552gh	0.017 ± 0.002bc	0.117 ± 0.006de	40.698 ± 4.965bcde	0.98
WL	12.498 ± 1.174b	0.015 ± 0.003c	0.185 ± 0.017b	47.502 ± 9.159bc	0.97

C_0 denotes potentially mineralisable carbon, k denotes rate constant, C_0*k denotes maximum C mineralisation potential. Data shown are mean ± S.E. (n = 5). Mean values in the same column sharing the same letters do not differ significantly according to the Duncan's multiple range test at $p < 0.05$. GL denotes grassland ecosystem; FL denotes forestland ecosystem and WL denotes wetland ecosystem. T and S denotes topsoil and subsoil respectively.

had a higher rate constant (k) for carbon mineralisation than the surface soil of both grassland and forestland ecosystems.

4.7.Regression Analysis

The linear regression analysis between the soil physicochemical, biological parameters and carbon mineralisation are depicted in the Figures 4.15 to 4.25. Except for soil pH, linear regression analysis revealed a positive relationship between the investigated soil physico-chemical properties and carbon mineralisation. Soil moisture exhibited the maximum influence on carbon mineralisation during post-monsoon season. SOC showed the maximum influence on carbon mineralisation during pre-monsoon and monsoon season. While, the maximum influence of total N on carbon mineralisation was observed during monsoon season.

Similarly, a positive relationship was also observed between the soil biological properties and carbon mineralisation. The activities of soil β- D glucosidase and N-acetyl glucosaminidase displayed the maximum influence on carbon mineralisation during monsoon and post-monsoon season. Whereas, acid phosphatase activity showed the maximum influence on carbon mineralisation during monsoon season. The maximum influence of MBC on carbon mineralisation was observed during monsoon and post-monsoon season.

4.8.Correlation and PCA analysis

Correlation matrices revealed that the correlations between cumulative carbon mineralisation and individual soil variables were similar across seasons (Figures 4.26 and 4.27). Regardless of season, a stronger correlation of carbon mineralisation with soil physico-chemical and biological properties was found rather than soil mineralogical properties. Among the soil physico-chemical and biological properties, carbon mineralisation had stronger correlations with soil moisture, SOC, total N, MBC, β- D glucosidase, N-acetyl glucosaminidase and acid phosphatase. Among the bacterial phylum, *Proteobacteria* and *Chloroflexi* were found to have a positive correlation with cumulative carbon mineralisation whereas *Acidobacter* and *Actinobacteria* were found to have a negative correlation with cumulative carbon mineralisation across the seasons.

PCA carried out with 20 analysed soil variables (soil pH, soil Moisture, SOC, total N, MBC, β- D glucosidase, N-acetyl glucosaminidase, acid phosphatase, *Proteobacteria,*

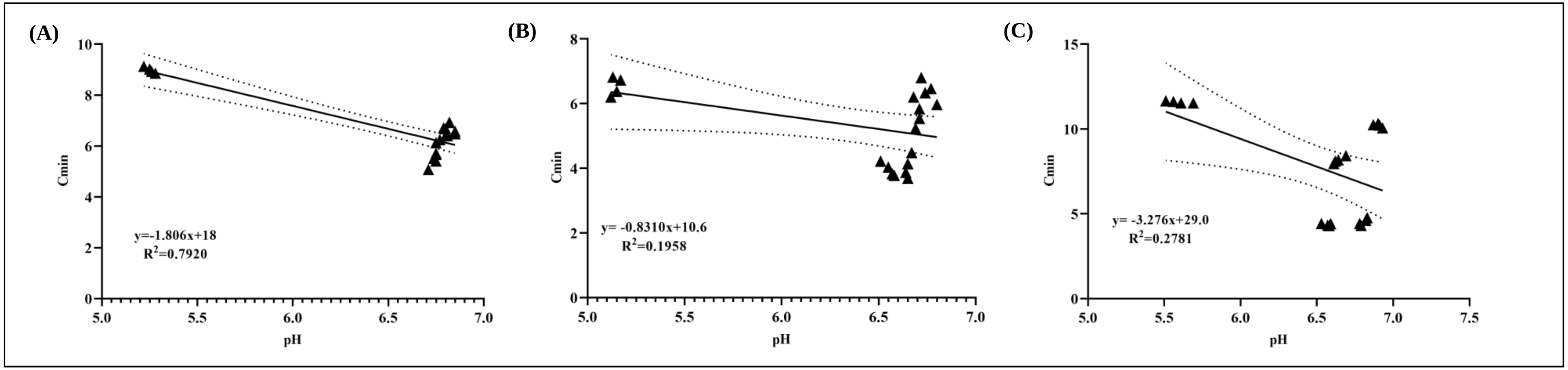


Figure 4.15. Regression analysis between soil pH and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

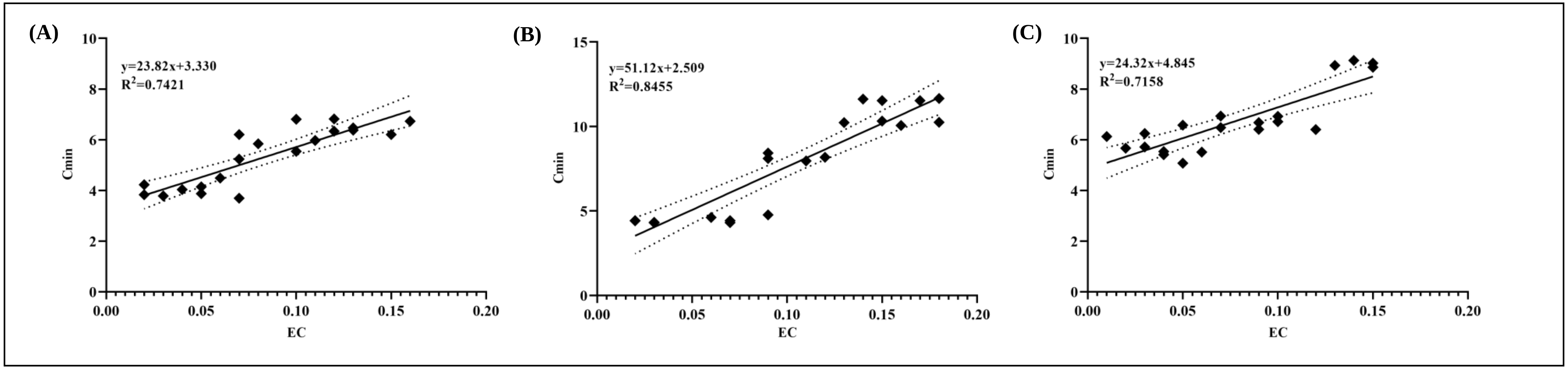


Figure 4.16. Regression analysis between soil EC and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

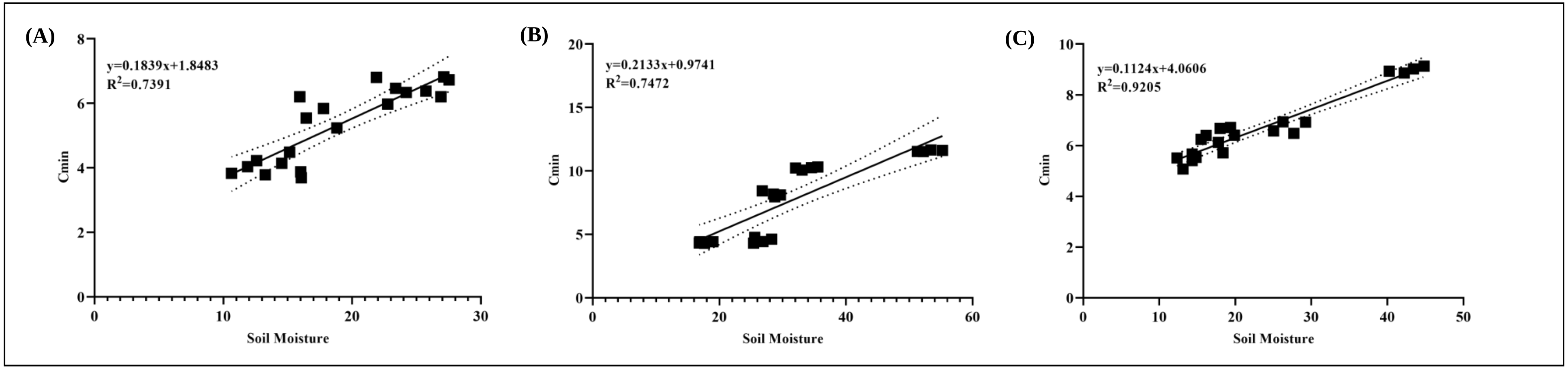


Figure 4.17. Regression analysis between soil moisture and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

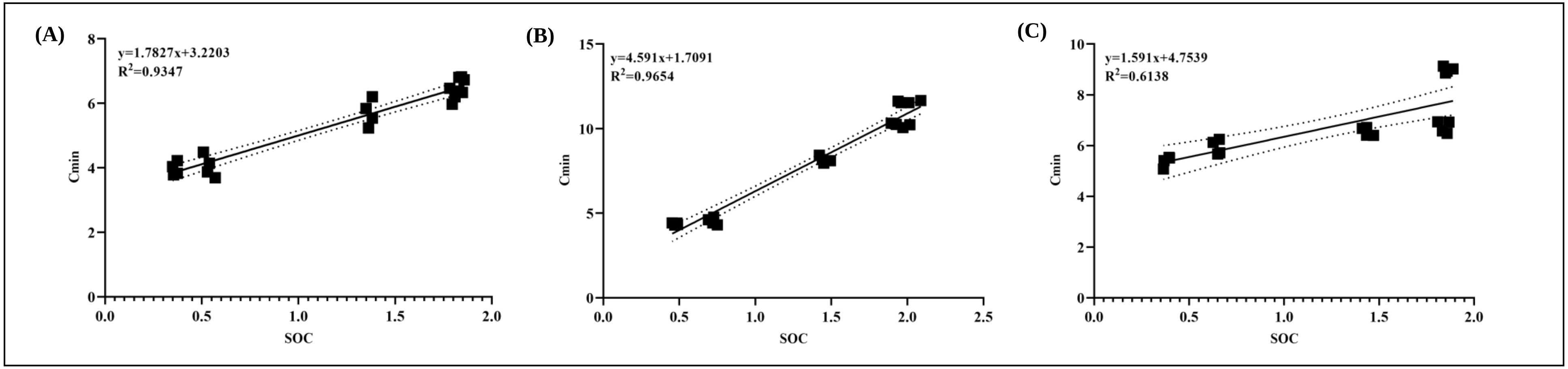


Figure 4.18. Regression analysis between soil organic carbon (SOC) and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

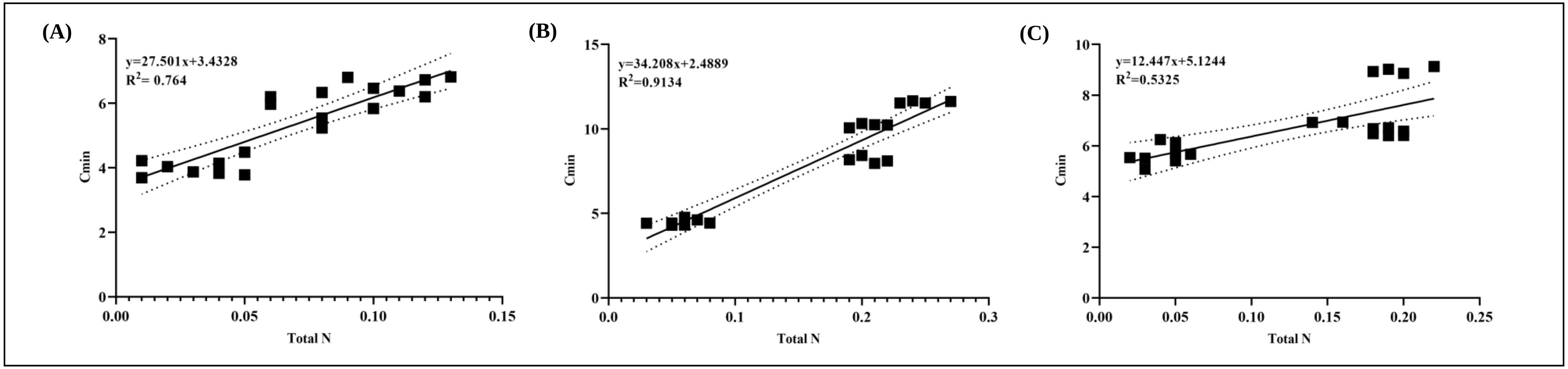


Figure 4.19. Regression analysis between total nitrogen (N) and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

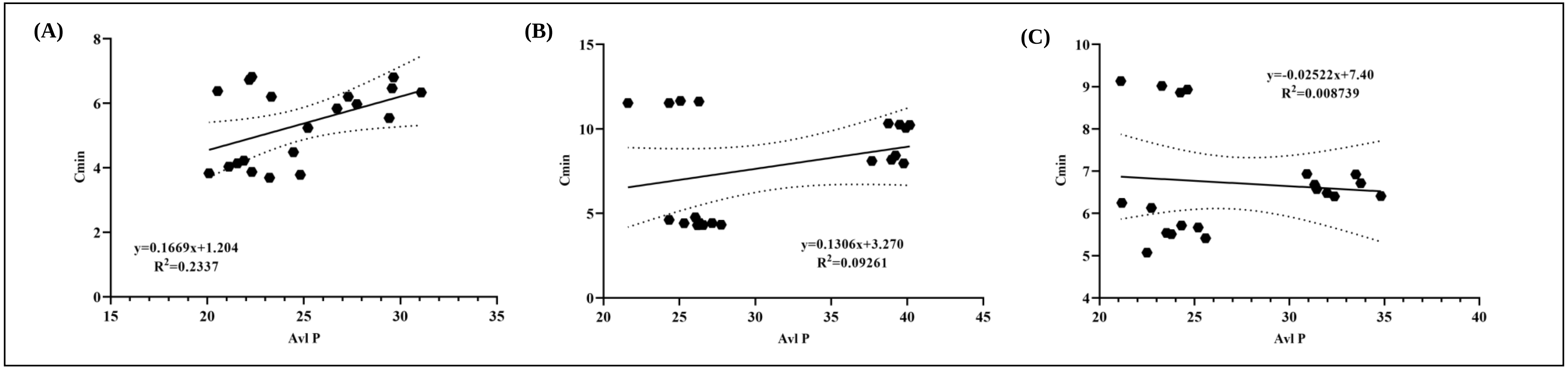


Figure 4.20. Regression analysis between soil available phosphorus (Avl P) and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

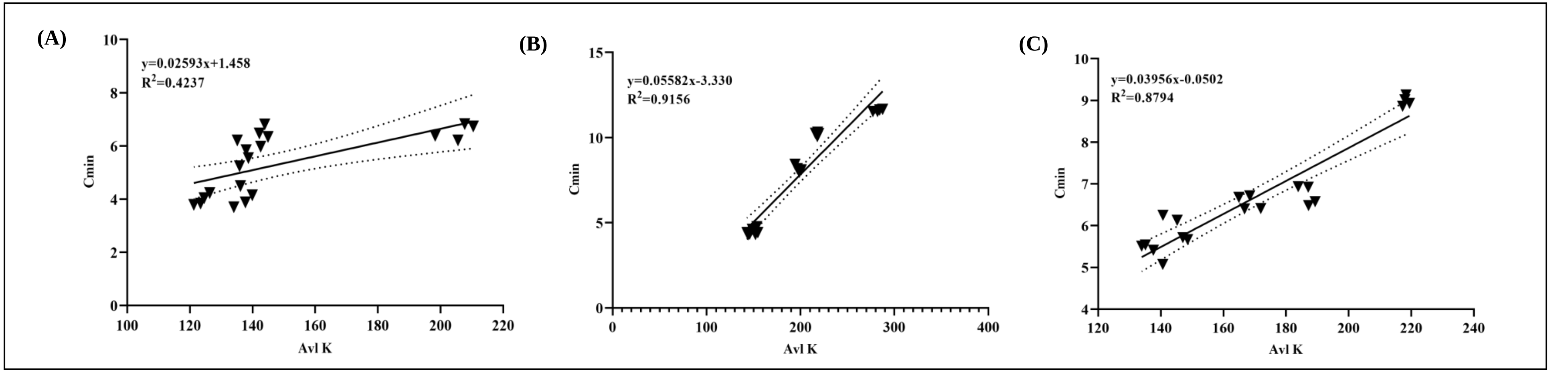


Figure 4.21. Regression analysis between soil available potassium (Avl K) and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

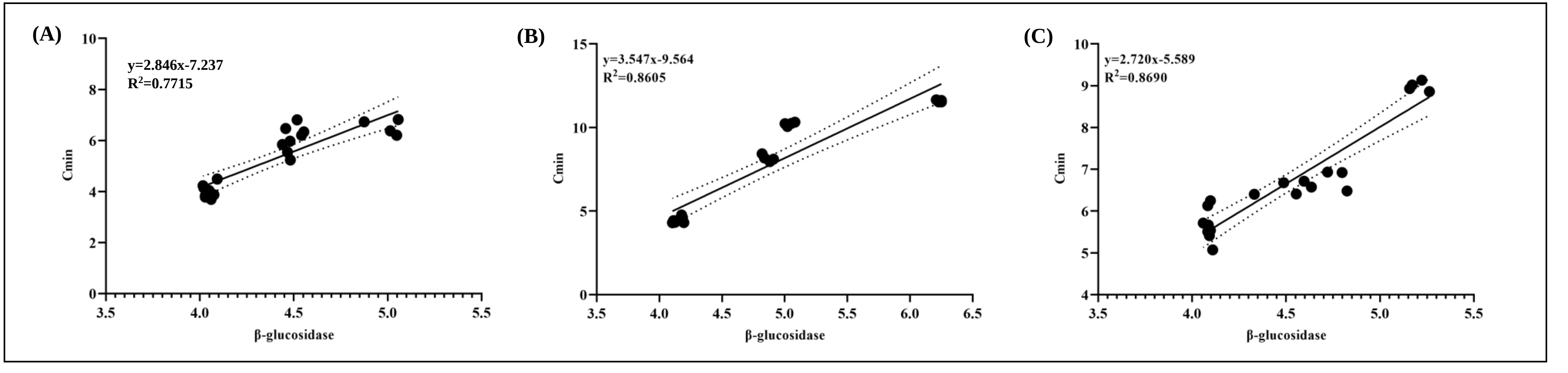


Figure 4.22. Regression analysis between β-glucosidase activity and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

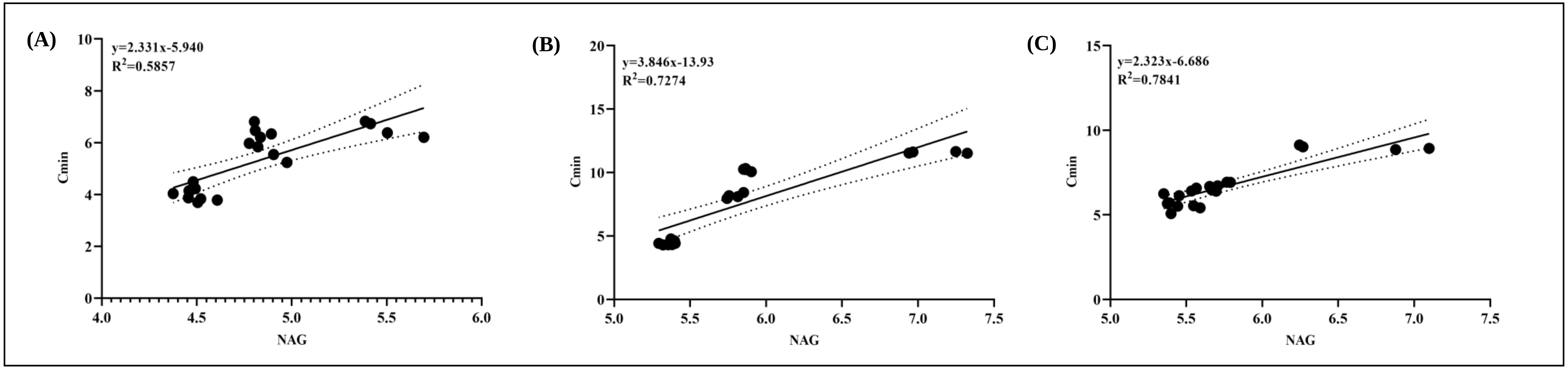


Figure 4.23. Regression analysis between N-acetyl glucosaminidase (NAG) activity and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

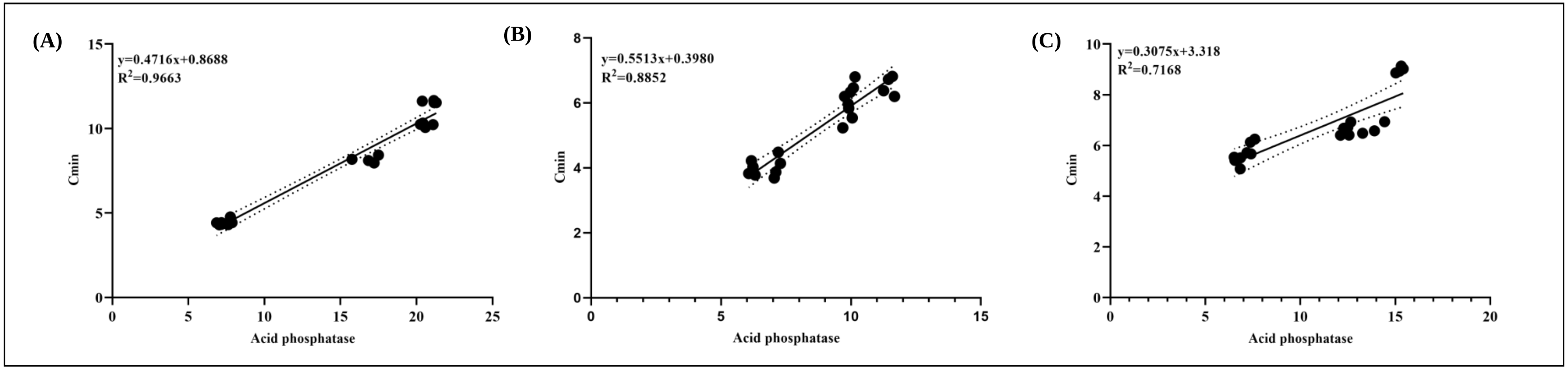


Figure 4.24. Regression analysis between Acid phosphatase activity and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

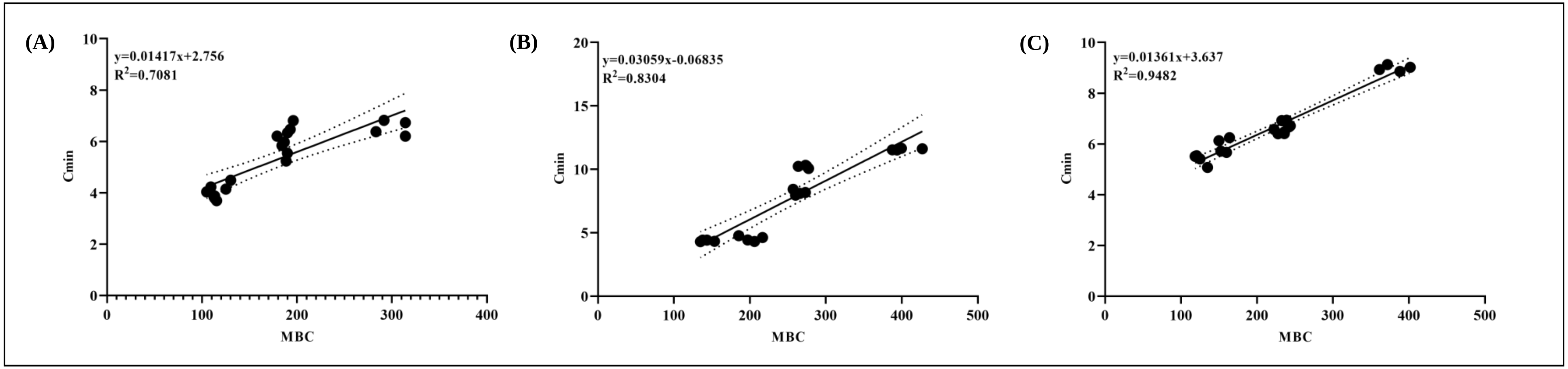


Figure 4.25. Regression analysis between Microbial biomass carbon (MBC) and Cumulative carbon mineralisation (Cmin) of the studied ecosystems during (A) Pre monsoon (B) Monsoon and (C) Post Monsoon season.

Acidobacteria, Actinobacteria, Chloroflexi, Latescibacteria, Planctomycetes, Gemmatimonadetes, Verrucomicrobia, Bacteroidetes, Unknown, others and Cumulative carbon mineralisation) among soil physico-chemical and biological properties identified two components (PC1 and PC2) that accounted for maximum variance throughout the seasons (Figure 4.28). Soil moisture, SOC, total N, MBC, *β*- D glucosidase, N-acetyl glucosaminidase, acid phosphatase, *Proteobacteria, Chloroflexi, Bacteroidetes, Actinobacteria* are the components of PC1 during pre-monsoon with 83 % variation. During monsoon season soil moisture, SOC, total N, MBC, *β*- glucosidase, N-acetyl glucosaminidase, acid phosphatase, *Proteobacteria, Chloroflexi, Gemmatimonadetes* are the components of PC1 with 72.3 % variation. Similarly, soil moisture, SOC, total N, MBC, *β*-D glucosidase, N-acetyl glucosaminidase, acid phosphatase, *Proteobacteria, Chloroflexi* are the components of PC1 during post-monsoon with 78.3 % variation. Whereas, pH, *Acidobacteria, Latescibacteria, Planctomycetes, Gemmatimonadetes, Verrucomicrobia* are the components of PC2 during pre-monsoon with 17 % variation. During monsoon season pH, *Acidobacteria, Actinobacteria, Latescibacteria, Planctomycetes, Verrucomicrobia, Bacteroidetes* are the components of PC2 with 27.7 % variation. pH, *Acidobacteria, Actinobacteria, Latescibacteria, Planctomycetes, Verrucomicrobia, Bacteroidetes, Gemmatimonadetes* are the components of PC2 during post-monsoon with 21.7 % variation.

PCA carried out with 16 analysed soil variables (soil pH, EC, soil Moisture, SOC, total N, Available P, Available K, sand, silt, clay, quartz, montmorillonite, vermiculite, augite, dolomite, Carbon mineralisation) among soil physico-chemical and mineralogical properties identified two components (PC1 and PC2) that accounted for 84.3 %, 83.5 % and 82.1% of the total variance during pre-monsoon, monsoon and post-monsoon season respectively (Figure 4.29). Soil EC, soil Moisture, SOC, total N, Available K, silt, clay, quartz, dolomite are the components of PC1 with 56.5%, 55.2%, 57.7% variation during pre-monsoon, monsoon and post-monsoon season respectively. Whereas, pH, sand, montmorillonite, vermiculite, augite are the components of PC2 with 27.8%, 28.3%, 24.4% variation during pre-monsoon, monsoon and post-monsoon season respectively.

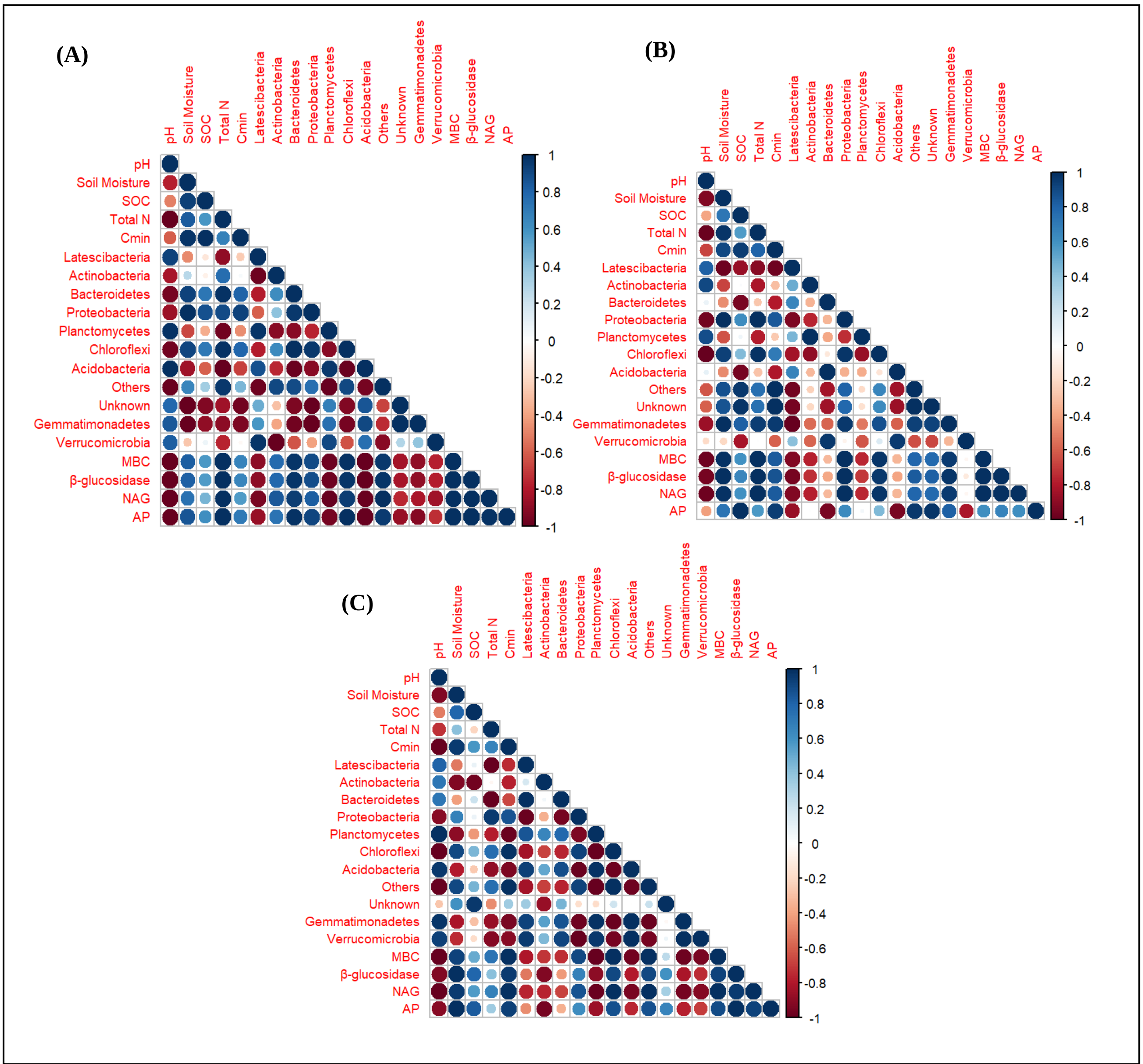


Figure 4.26. Correlation matrices in the (a) pre-monsoon (b) monsoon and (c) post monsoon season among soil physico-chemical, biological properties and cumulative C mineralisation in all the three ecosystems. Colour scheme indicates Pearson r values. Blue colour indicates positive correlation and red colour indicates negative correlation. The colour intensity depicts the strength of the relationship.

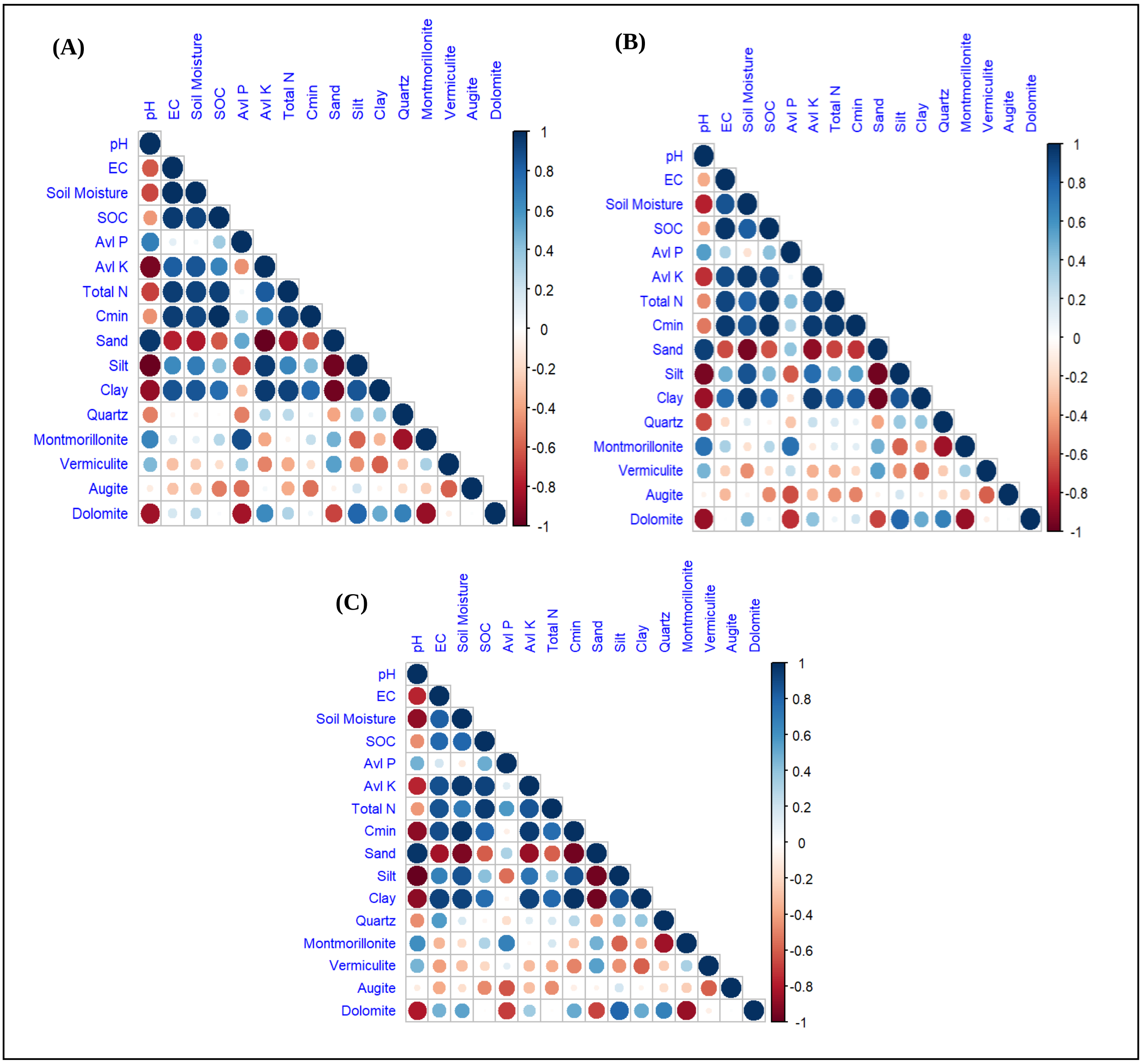


Figure 4.27. Correlation matrices in the (a) pre-monsoon (b) monsoon and (c) post monsoon season among soil physico-chemical, mineralogical properties and cumulative C mineralisation in all the three ecosystems. Colour scheme indicates Pearson r values. Blue colour indicates positive correlation and red colour indicates negative correlation. The colour intensity depicts the strength of the relationship.

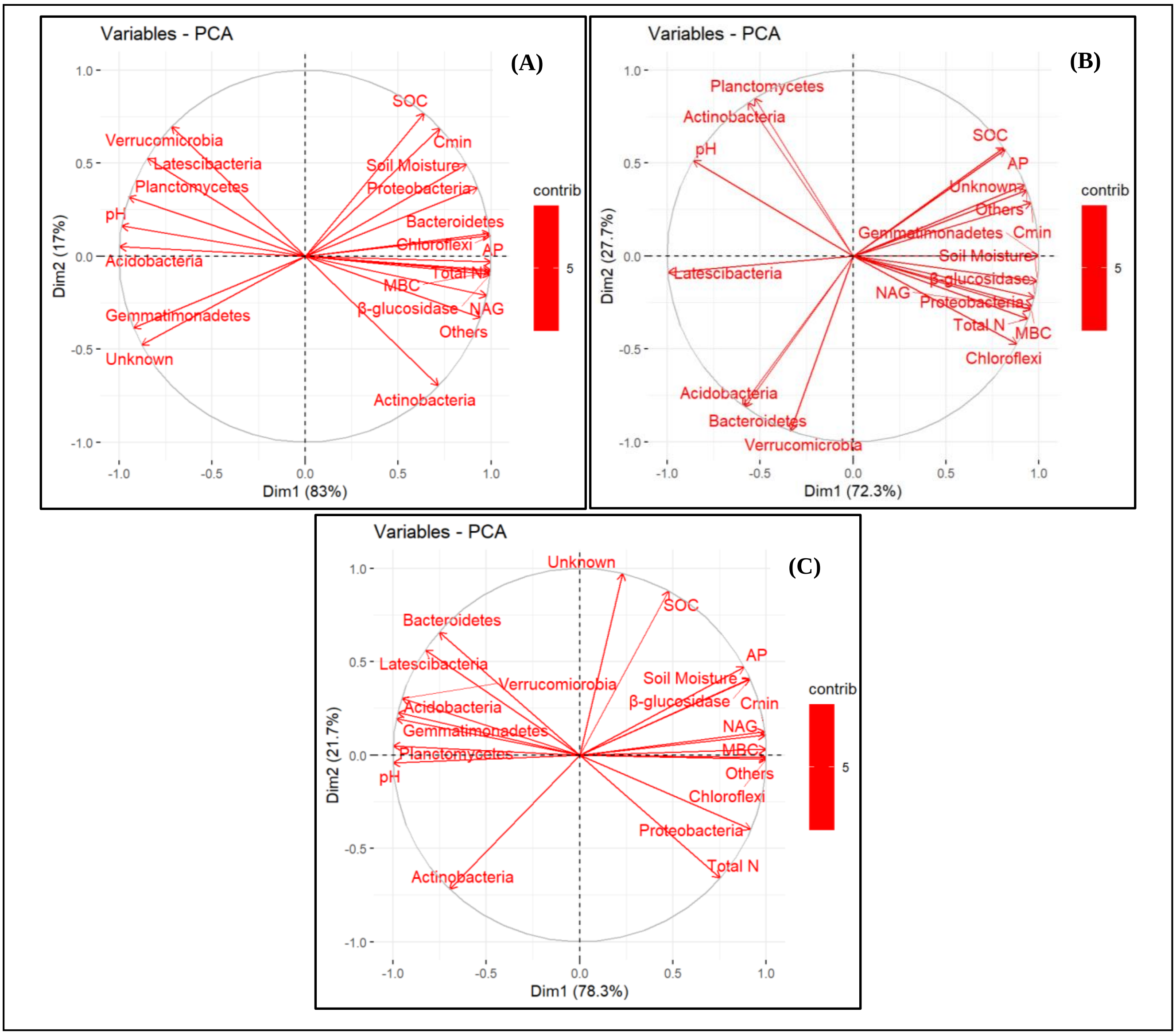


Figure 4.28. PCA analysis in the (a) pre-monsoon (b) monsoon and (c) post monsoon season among soil physico-chemical, biological properties and cumulative C mineralisation in all the three ecosystems.

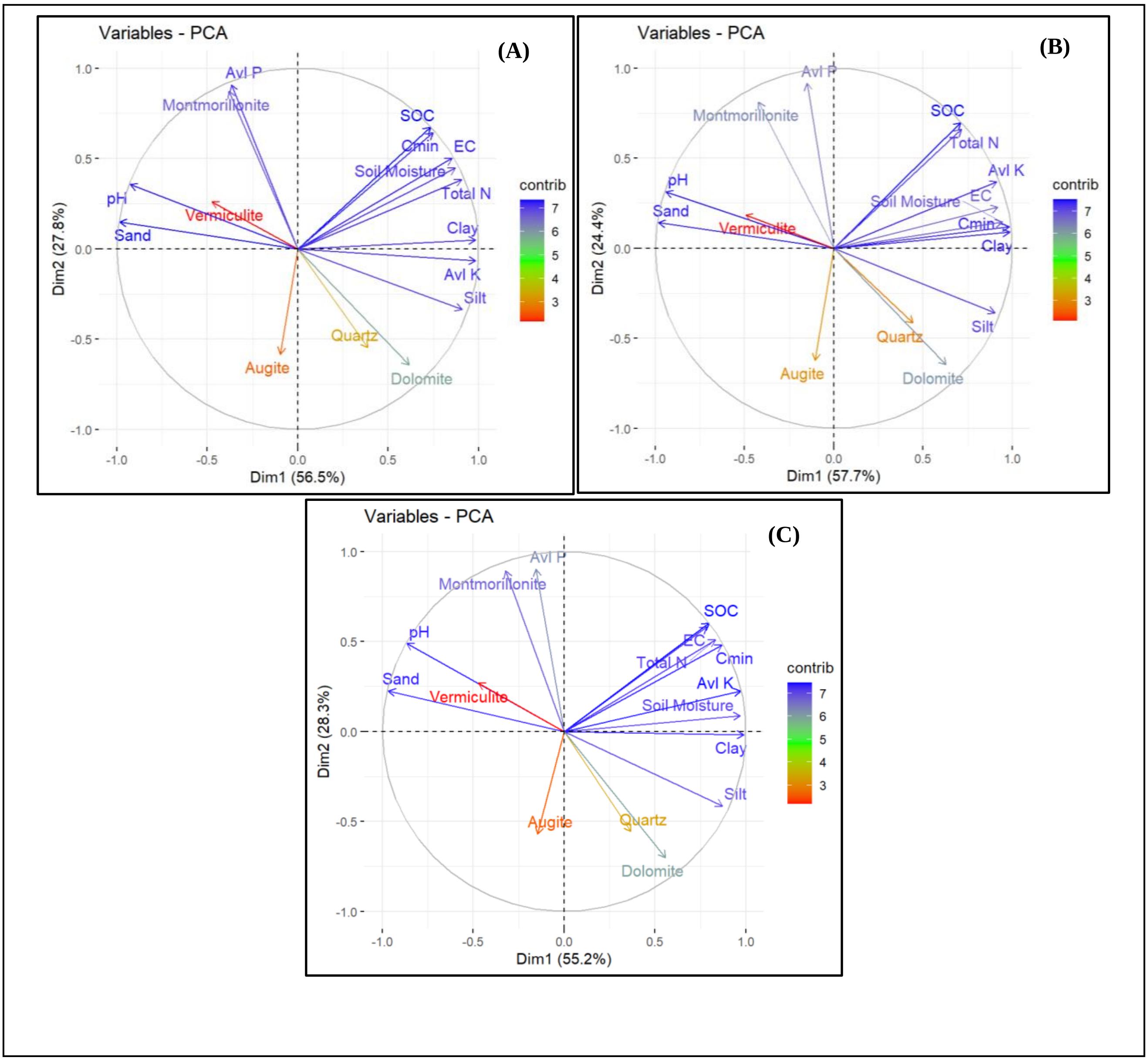


Figure 4.29. PCA analysis in the (a) pre-monsoon (b) monsoon and (c) post monsoon season among soil physico-chemical, mineralogical properties and cumulative C mineralisation in all the three ecosystems.