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PEARSON CORRELATION OF PHYSICO-CHEMICAL PARAMETERS AND MACRO-INVERTEBRATES IN JUKHALA VALLEY, BILASPUR DISTRICT, HIMACHAL PRADESH, INDIA

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ABSTRACT:

Himachal Pradesh is predominantly a hilly state nestled in the western Himalayas. Out of total 55,673sq.km geographic area of the state, the forest comprises 37,033sq.km, which is 4.80% of total forests in the country. The primary goals of this research are to assess the impact of climatic and edaphic parameters on the abundance of soil macroinvertebrates. Three sampling stations were selected at Jukhala valley in Bilaspur District during the study period (2019-2021). Three stations, namely(i) Cultivation field(stationI) (ii)MixedForest(stationII) (iii)orchard(stationIII) have been selected for the present studies. In this research, a grand total of 74 soil specimens were gathered from three distinct stations, with three samples procured from each station. These specimens underwent analysis for their physicochemical attributes employing standard laboratory methodologies. Throughout the study duration (2019-2021), there was a consistent positive correlation detected among earthworm density and organic carbon, moisture, as well as rainfall across all monitoring stations. Conversely, there was a negative correlation noted between earthworm density and phosphorus levels at all stations. Temperature, moisture, and rainfall showed a positive correlation with earthworm biomass, but moisture showed a highly significant correlation at station II. Ant density exhibited a positive association with temperature and a negative relationship with moisture at all the stations. At station II, termite density exhibited a notably strong positive correlation with nitrogen and phosphorus, whereas temperature indicated a negative correlation. Across all three stations, centipede density displayed negative correlations with nitrogen, rainfall, and organic carbon. Coleopteran density exhibited negative correlations with nitrogen, potassium, organic carbon, and moisture, and showed positive correlations with pH at all three stations, but organic carbon showed a highly negative correlation at station I. Overall, this research paper enhances our understanding of soil ecosystem dynamics and the vital role of soil macroinvertebrates in maintaining soil health and fertility, providing a foundation for further studies on soil biodiversity and ecosystem management in mountainous regions.

Key Words: Macroinvertebrates, Orchard, Cultivation field, Mixed Forest, Earthworm, Coleopteran.

1. INTRODUCTION

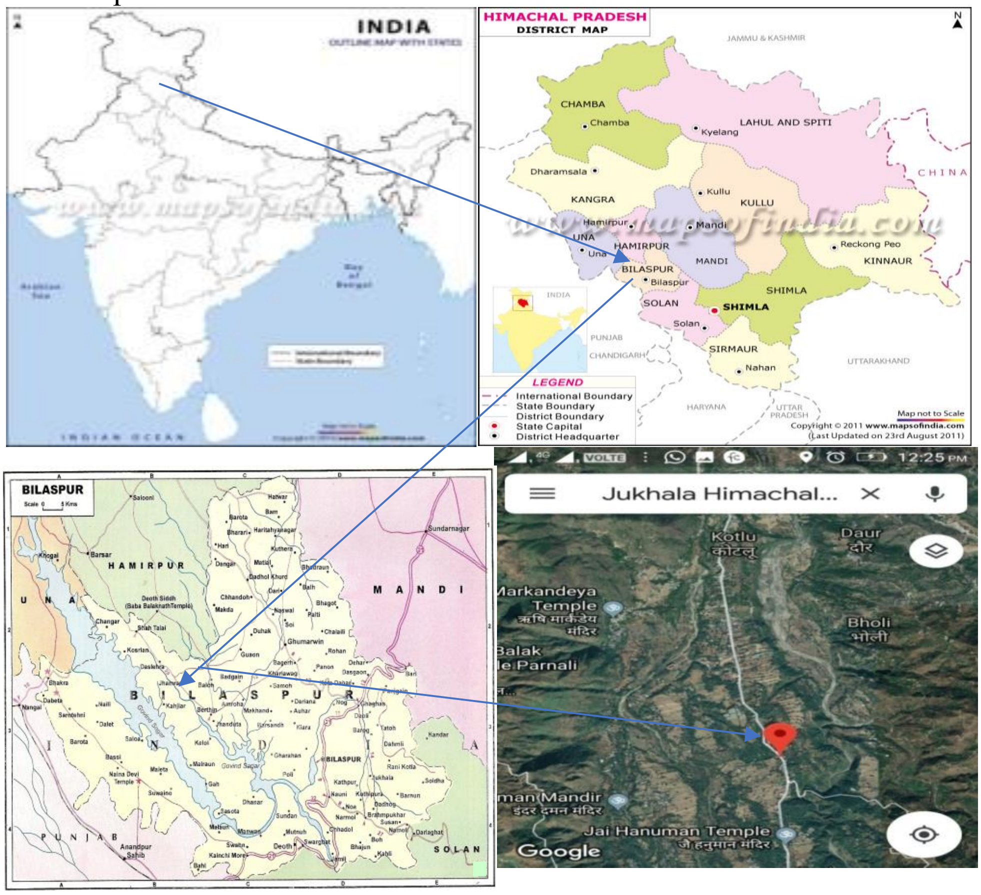
India is a diverse country harbouring a very high diversity of macro invertebrates, mostly concentrated in Eastern Himalayas and Western Ghats both of them are well recognized for its biophysical diversity and socio-cultural heritage. The Indian Himalayan Region, spanning from 27°50' to 37°06'N and 72°30' to 97°25'E, constitutes the predominant portion of the Himalayan Biodiversity Hotsp
ot. It encompasses ten states of India in their entirety: Himachal Pradesh, Sikkim, Jammu and Kashmir, Uttarakhand, Meghalaya, Arunachal Pradesh, Mizoram, Nagaland, Tripura and Manipur, Additionally, it moderately includes two states, namely the hilly districts of Assam and West Bengal. The Shivalik landscape, which aligns parallel to the Lesser Himalayas, stands as the youngest mountain range in the Himalayas, characterized by its delicate terrain, subtropical climate, diverse geography, and fertile alluvial soils, it forms a crucial component of the region's ecological makeup. The Shivalik hills, part of India's landscape, are recognized as one of the nation's eight severely degraded agro-ecosystems. The burgeoning population has spurred widespread deforestation for agricultural expansion, logging, industrial growth, infrastructure projects, and urban development.[1] Projections suggest that by 2100, the Indian Himalayas are enveloped in dense forest cover could diminish to a mere 10% of its current extent. The existence of nearly 25% of the endemic species in the area is at risk due to this situation. This includes 366 exclusive vascular plant species and 35 different vertebrate species.[2,3] Himalaya has also been identified as one of the global biodiversity hotspots experiencing significant biodiversity loss, necessitating urgent conservation efforts.
The deforestation and subsequent agricultural practices have led to a decline in soil quality, impacting its sensitivity to degradation and erosion .[4] Agricultural activities, including fertilizer application, can directly affect soil microbiota and fauna, as well as indirectly impact animal-associated microbiota.[5-7] Conservation tillage methods have been shown to influence soil biodiversity, particularly affecting soil microorganisms, fauna, and the microorganisms associated with them .[8] Alterations in land cover also impact biogeochemical processes and soil properties.[9] During rainy seasons, heavy rainfall can lead to soil degradation by reducing the fertile soil layer .[10,11] Various studies have highlighted the significant impact of soil factors such as temperature, pH, nitrogen, phosphorus, and potassium on soil fauna abundance. Environmental variables like air, soil moisture and the soil chemical properties are vital in shaping the composition of soil fauna, distribution, and density. The present study elucidates a detailed analysis of the interactions between soil physicochemical parameters and soil macroinvertebrate populations across various land use types in the Jukhala valley, Bilaspur District, Himachal Pradesh. The findings reveal significant correlations between soil characteristics and the abundance of different soil macroinvertebrates, highlighting the complexity and specificity of these relationships.

2. MATERIALS AND METHODS:

Sampling site

The research was conducted within the Bilaspur district of Himachal Pradesh, located between latitudes 31°12'30" N and 31°35'45" N, and longitudes 76°23'45" E and 76°55'40" E, in the outer regions of the Himalayas. Spanning approximately ninety kilometres, the river Satluj courses through Bilaspur. Covering an area of 1167 square kilometres, its elevation varies from 290 meters to 1980 meters. Sampling of macroinvertebrates was carried out in the Jukhala valley, which is about 21 km from Bilaspur District. It covers an area of approximately 1,264

Hectares. Three sites namely (Cultivated field) (ii) orchard (iii) Mixed scrub forest have been selected for the present studies.



Methodology

Design of experiment

Table-1: Allocation of sampling sites during each sampling period (2019-2021).

Research Location (Systems)	Plots	The number of monoliths found in each plot	Land area of each plot	Monolith dimensions : 25 x 25 x 30 cm	Soil sample	Macroinvertebrates samples
Orchard	3	5	5 m^2	15	3	15
Mixed scrub forest	3	5	5 m^2	15	3	15
Cultivation field	3	5	5 m^2	15	3	15
Total	9	15		45	9	45

Soil analysis:

A 500 g composite soil sample will be gathered from each sampling plot for laboratory analysis of various soil parameters. Samples from different land use types will undergo preparation, aside from eliminating pebbles, it entails sifting through a sieve with a 0.5 mm mesh. Sampling will occur across various seasons over two years (from July 2019 to July 2021), with soil samples stored in well-labelled airtight plastic containers for subsequent analysis.

Analysis of Physicochemical Parameters

At each sampling time, soil samples will be collected, the soil samples are enclosed within plastic bags and conveyed to the zoology laboratory. Analysis of soil texture will include determining clay (%), sand (%), and silt (%) using the hydrometer method described by Bouyoucos.[12] Soil temperature will be measured during sampling using a standard soil thermometer and moisture content will be determined gravimetrically. Soil pH will be measured with a digital pH meter, The analysis of organic carbon will follow the Walkey and Black method,[13] nitrogen content will be determined using the Kjeldahl method and available phosphorus will be assessed through Oleson's and Bray's method.[14] Potassium levels will be measured utilizing a flame photometer .[15] Statistical analyses will be conducted using the IBM SPSS Statistics 20.[14,15]

Identification of Macroinvertebrate Samples

Various groups of macroinvertebrates will be identified using the keys outlined in the following references: Earthworms will be identified to the species level using Julka.[16]Arthropods, including ants, termites, centipedes, and coleopterans, will be identified up to the morpho-species level based on the works of Imms, Mani and Dindal .[17-19]

Statistical Analysis

Different formulas have been employed in statistical analysis.

1. Relative density (%) = $\frac{\text{Number of individuals of species A}}{\text{Total number of individuals of all the species}} \text{ X } 100$

2. Relative biomass (%) = $\frac{\text{Biomass of species A}}{\text{Total biomass of all the species}} \text{ X } 100$

3. Moisture content %= (I-F) ÷ I×100

Where

I= Initial weight of sample

F= Final weight of sample

Correlation analysis

The correlation between macroinvertebrate species and physico-chemical parameters was analysed using Pearson's correlation coefficient (r) with the assistance of IBM SPSS Statistics 20 software.

Table 2: Karl Pearson coefficient of correlation between physico-chemical parameter and macroinvertebrates at station –I

	Rainfall	Temperature	Moisture	Ph	Organic carbon	Nitrogen	Phosphorus	Potassium
ED	.482*	.234	.197	-.162	.127	.143	-.220	.013
EB	.311	.328	.393	-.033	.144	-.023	-.107	.343
AD	-.061	.131	-.222	.430*	-.389	-.219	.025	-.359
TD	-.165	-.319	-.169	-.099	.384	.221	.279	.283

CD	.059	.004	.169	-.050	-.096	-.120	-.006	.145
COD	.022	.380	-.066	.218	-.506**	-.075	.009	-.381

*The correlation is statistically significant at the 0.05 level (two-tailed).
**The correlation is statistically significant at the 0.01 level (two-tailed).

ED-Earthworm Density, EB-Earthworm Biomass, AD-Ant Density, TD-Termite Density, CD-Centipede Density, COD-Coleoptera Density.

Table 3: Karl Pearson coefficient of correlation between physico-chemical parameter and macroinvertebrates at station -II.

	Rainfall	Temperature	Moisture	Ph	Organic carbon	Nitrogen	Phosphorus	Potassium
ED	.291	.220	.482*	.073	.210	-.078	-.085	.201
EB	.305	.292	.441*	.044	.188	.001	-.721**	-.420*
AD	.048	.356	-.043	-.038	.092	.326	-.023	-.163
TD	-.213	-.496*	-.469*	.098	.187	.398*	.372	.210
CD	-.080	.281	.055	.102	-.246	-.203	.320	-.043
COD	-.186	-.069	-.286	.193	-.212	-.199	.274	-.210

*The correlation demonstrates significance at the 0.05 level (two-tailed).
**Significance is observed in the correlation at the 0.01 level (two-tailed).

ED-Earthworm Density, EB-Earthworm Biomass, AD-Ant Density, TD-Termite Density, CD-Centipede Density, COD-Coleoptera Density

Table 4: Karl Pearson coefficient of correlation between physico-chemical parameter and macroinvertebrates at station -III

	Rainfall	Temperature	Moisture	Ph	Organic carbon	Nitrogen	Phosphorus	Potassium
ED	.183	.078	.105	.163	.310	.221	-.237	.161
EB	.329	.374	.561**	.465*	-.106	-.173	-.366	-.097
AD	-.053	.049	-.246	.042	.107	.268	.237	.135
TD	-.155	-.238	-.051	.050	.307	.361	.499*	-.078
CD	-.154	-.038	.219	-.520**	-.315	-.072	-.038	.380
COD	-.087	-.096	-.164	.051	-.294	-.232	-.071	-.281

*The correlation exhibits significance at the 0.05 level (twotailed).
**Significance is evident in the correlation at the 0.01 level (two- tailed).
ED-Earthworm Density-Earthworm Biomass, AD-Ant Density-Termite Density, CD-Centipede Density, COD-Coleoptera Density

The scatter diagrams shown below depict the relationship between two variables, i.e., physico-chemical parameters and macroinvertebrates, at all three stations.

Figure 1: Scatter plot between Physico-chemical parameter and earthworm density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

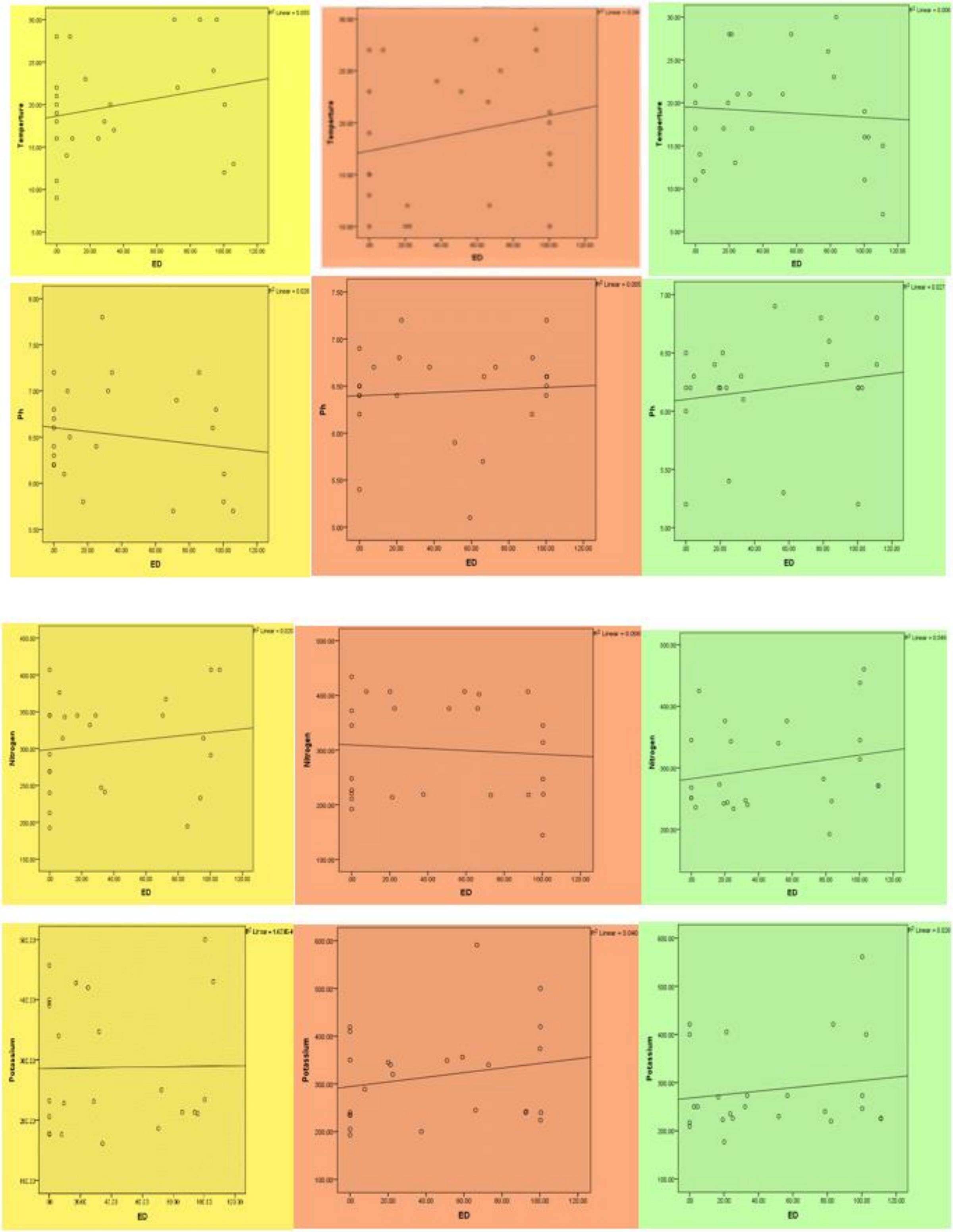
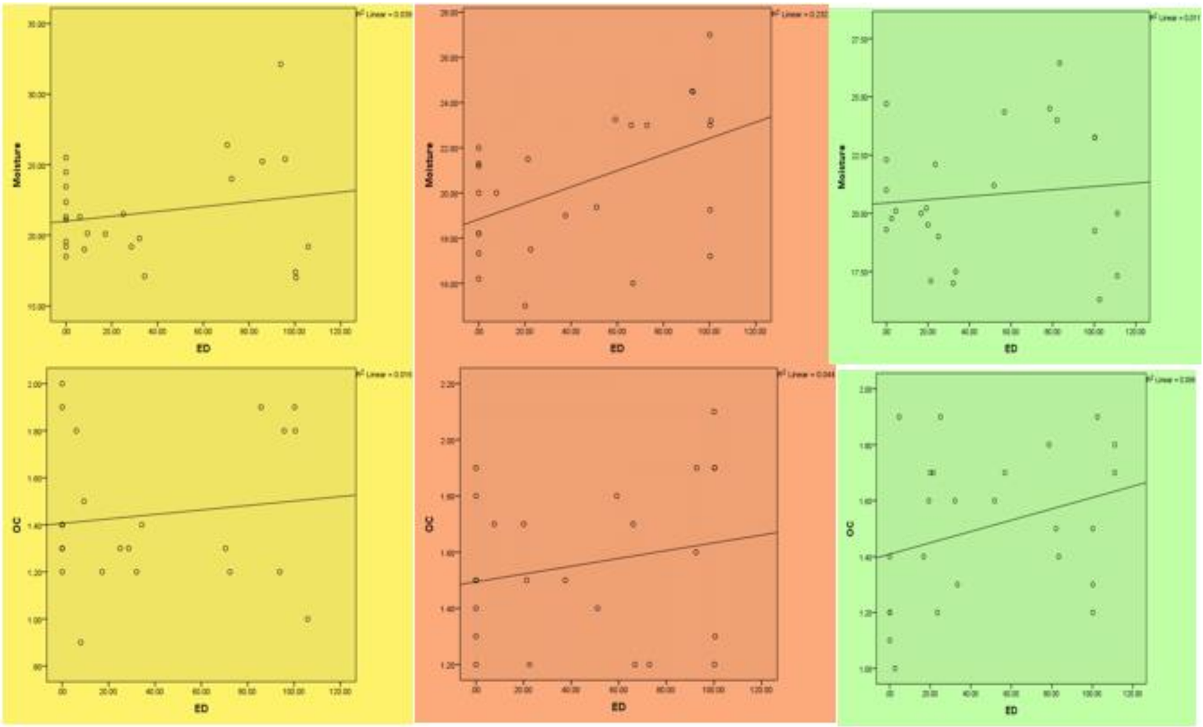


Figure 2: Scatter plot between Physico-chemical parameter and earthworm density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.



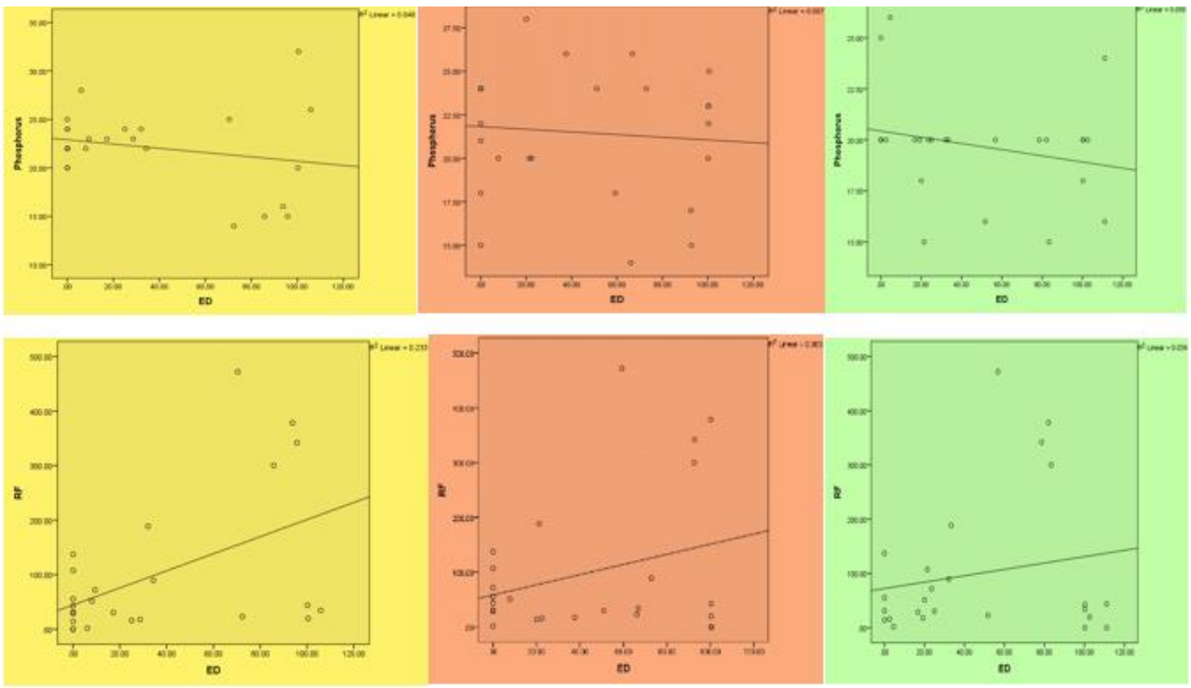


Figure 3: Scatter plot between Physico-chemical parameter and earthworm biomass at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

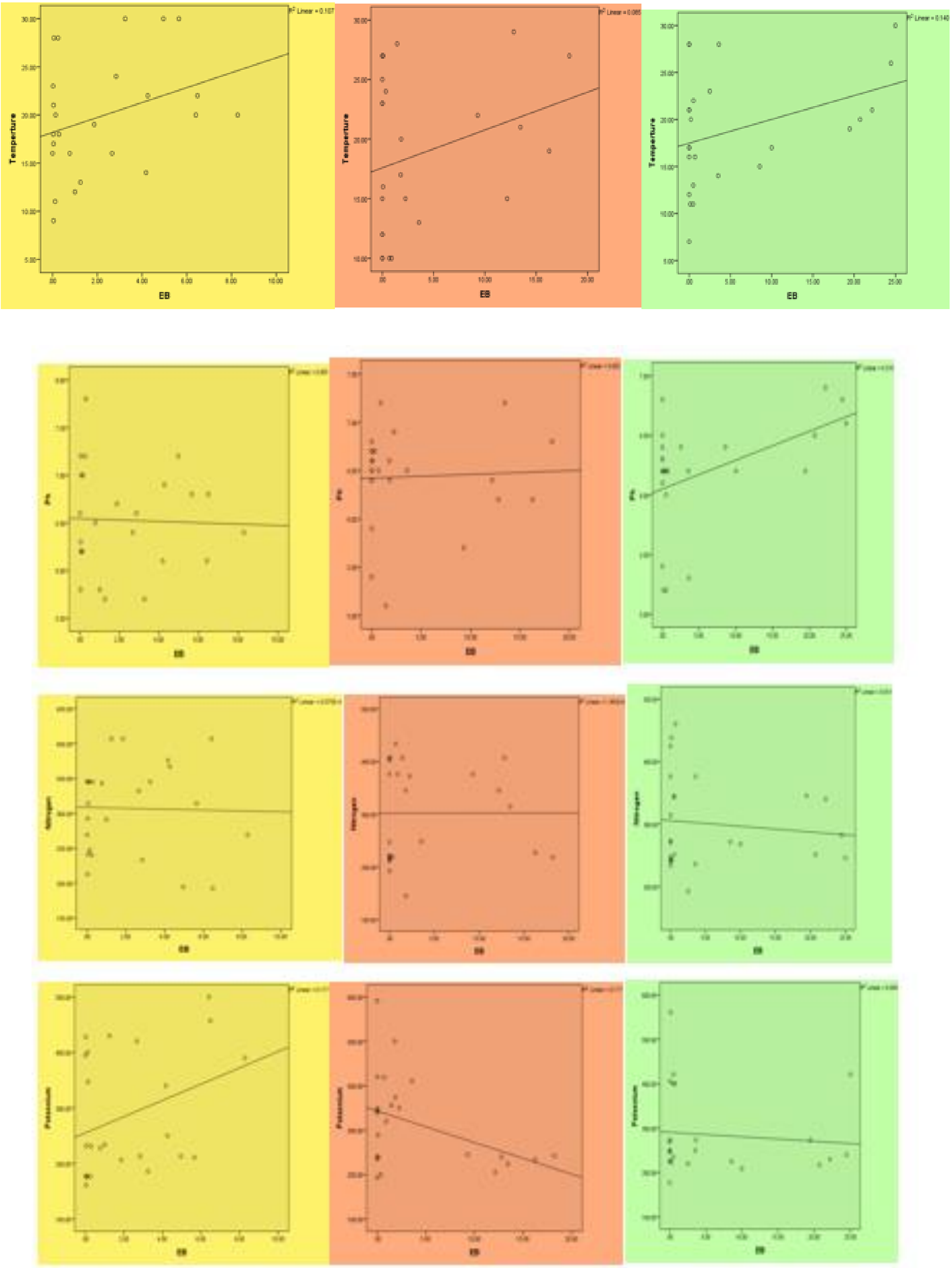
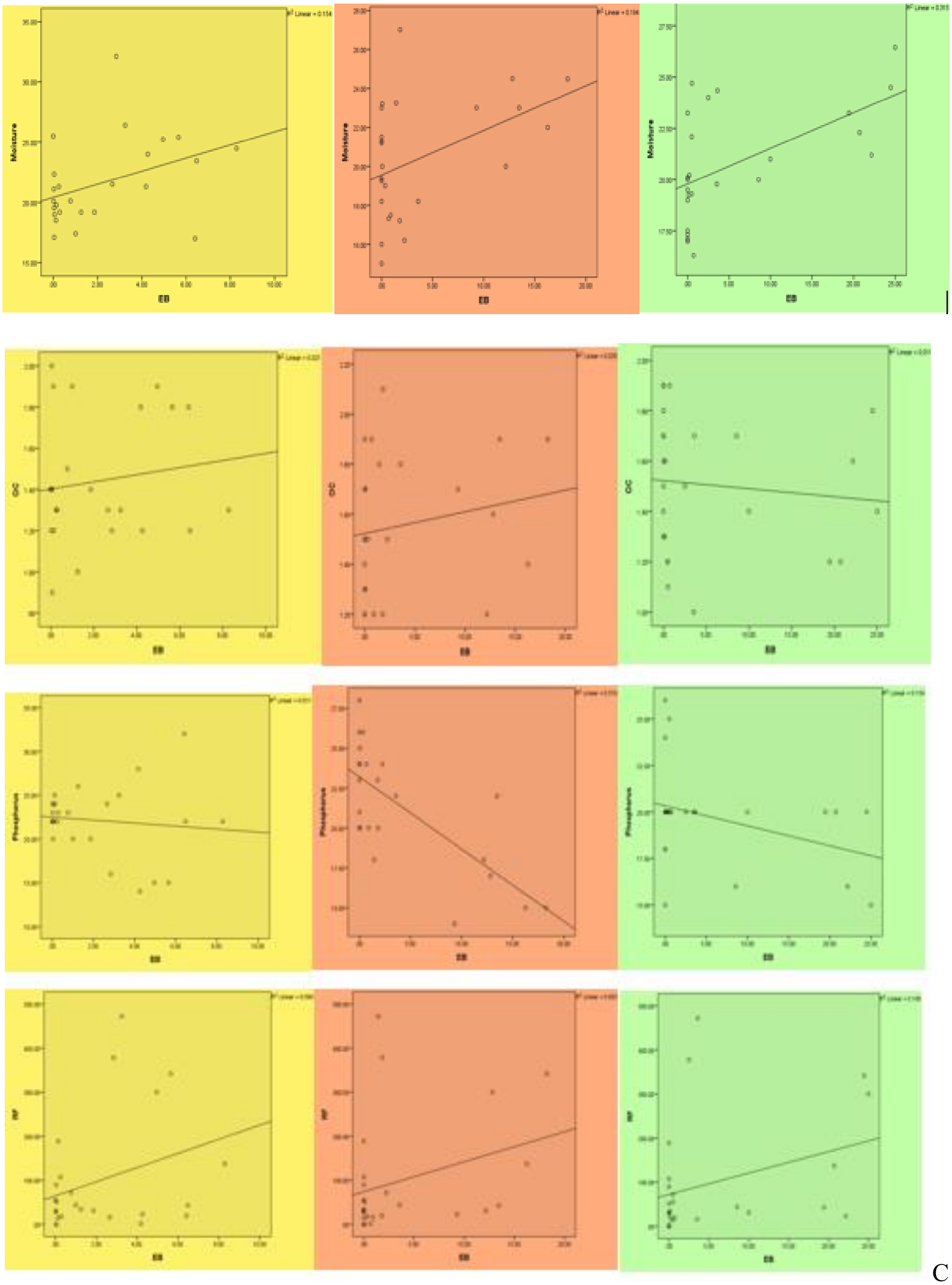


Figure 4: Scatter plot between Physico-chemical parameter and earthworm biomass at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.



C

Figure 5: Scatter plot between Physico-chemical parameter and ant density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

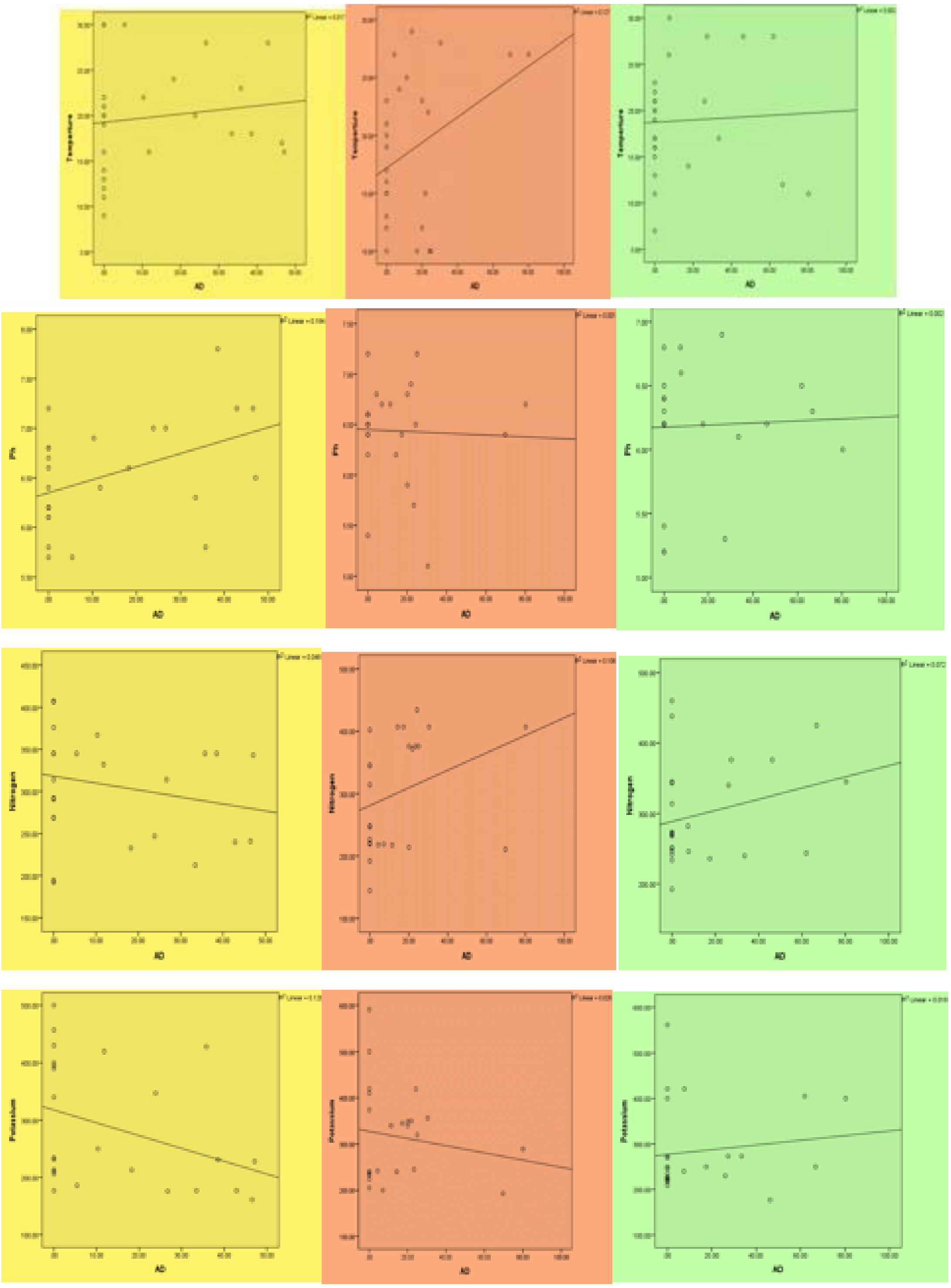


Figure 6: Scatter plot between Physico-chemical parameter and ant density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

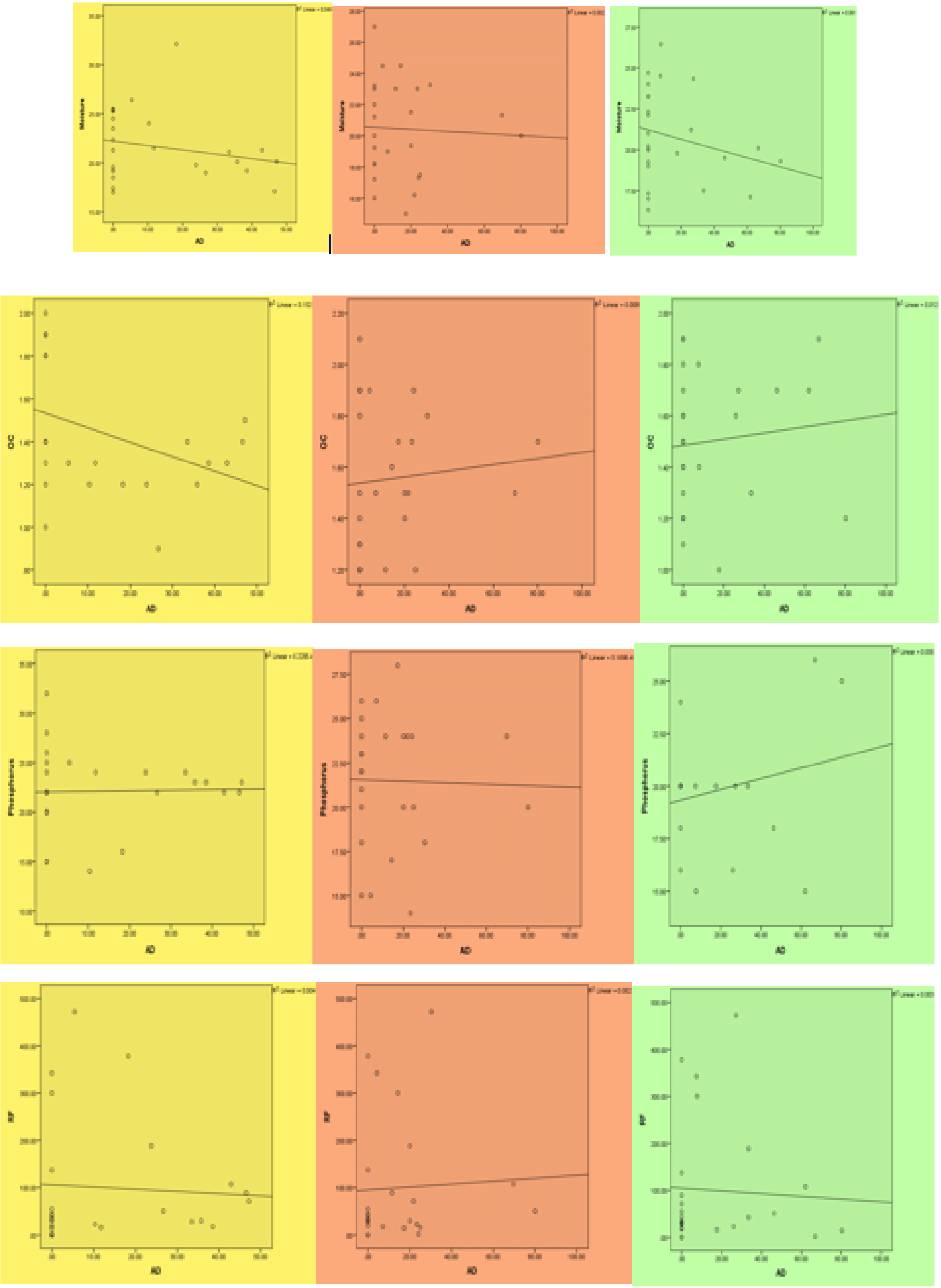


Figure 7: Scatter plot between Physico-chemical parameter and termite density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

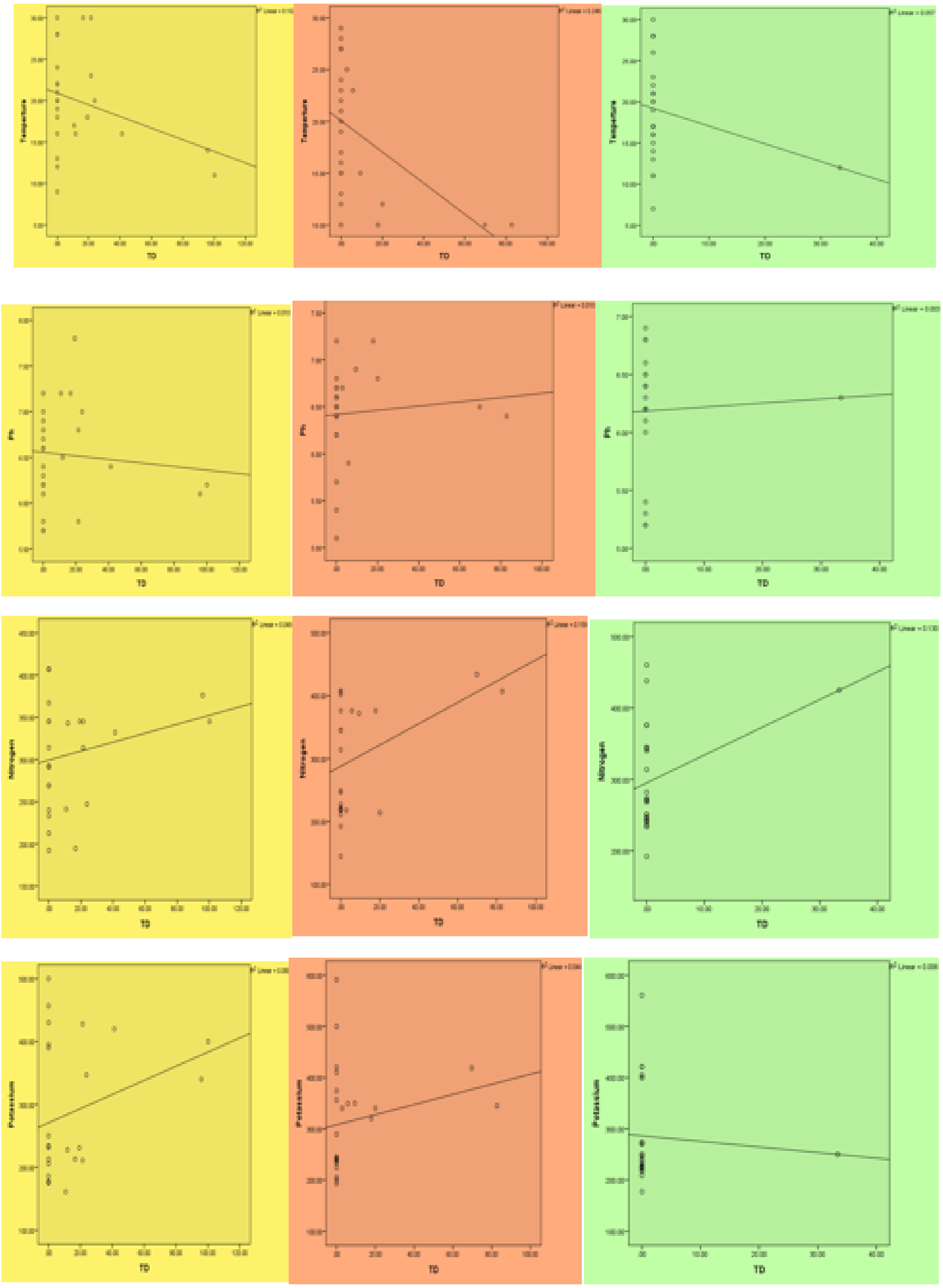


Figure 8: Scatter plot between Physico-chemical parameter and termite density at station -I (yellow colour), station-II (brick red colour) and station-II (light green colour) during 2019-21.

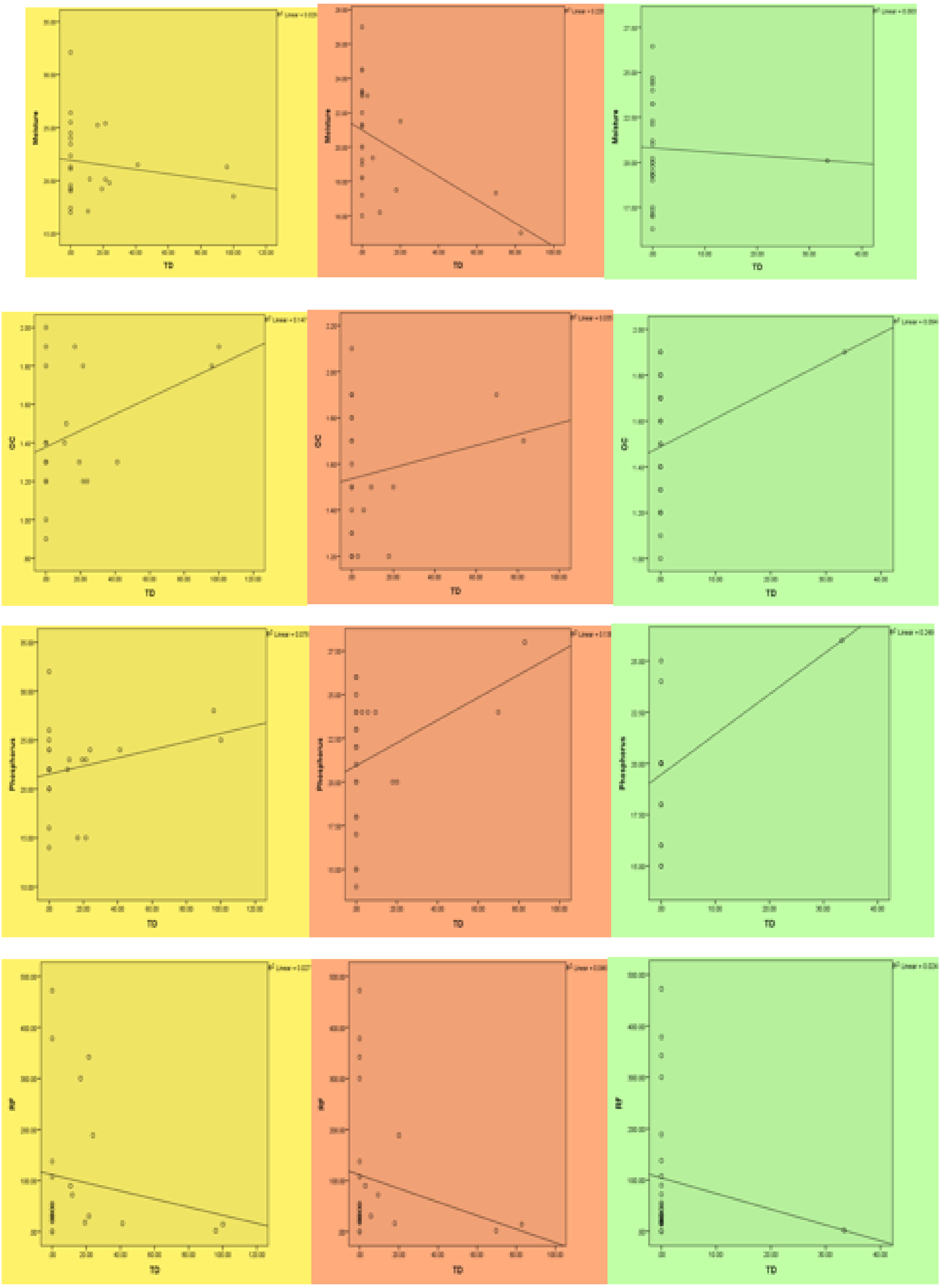


Figure 9: Scatter plot between Physico-chemical parameter and centipede density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

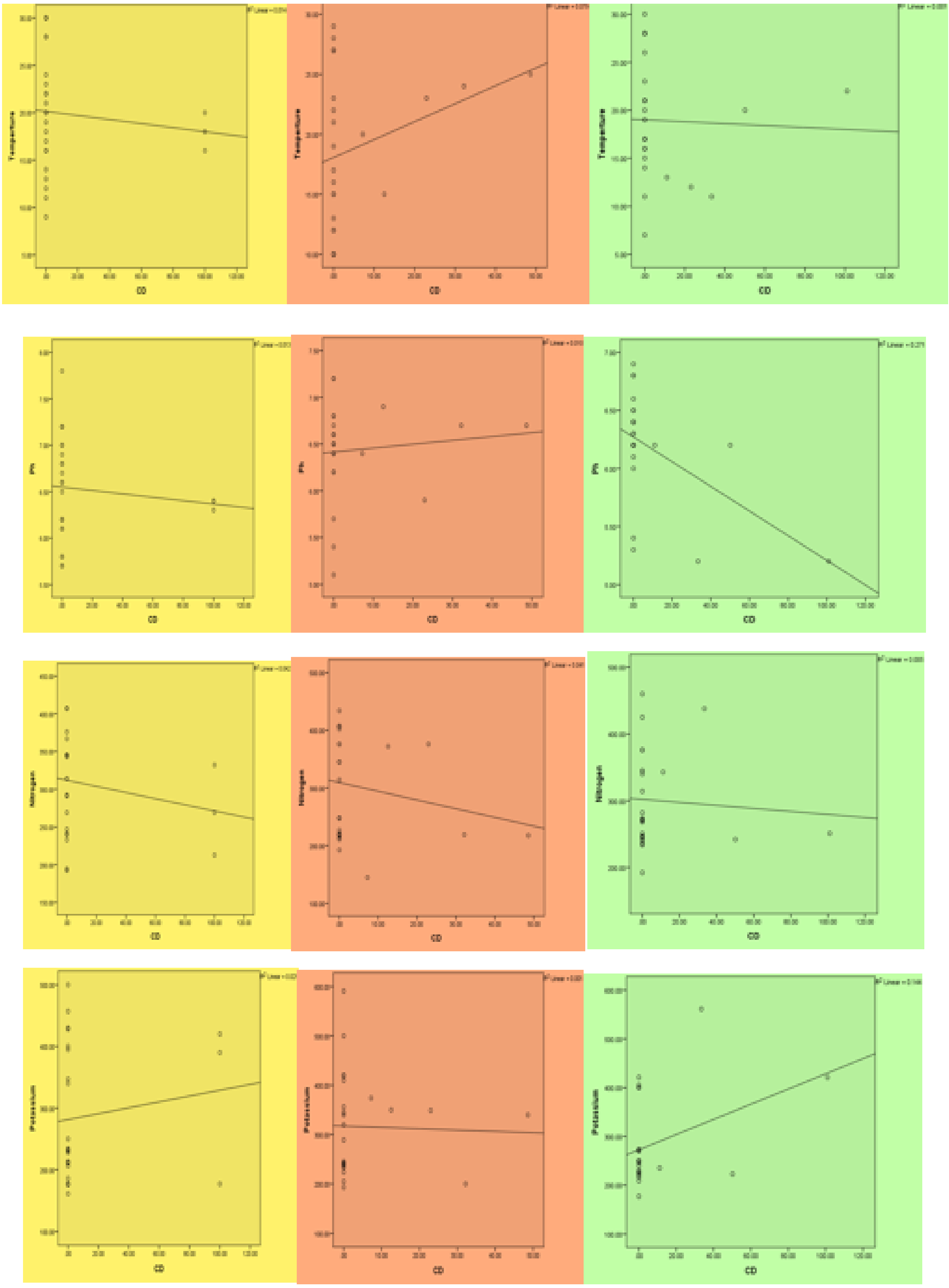


Figure 10: Scatter plot between Physico-chemical parameter and centipede density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

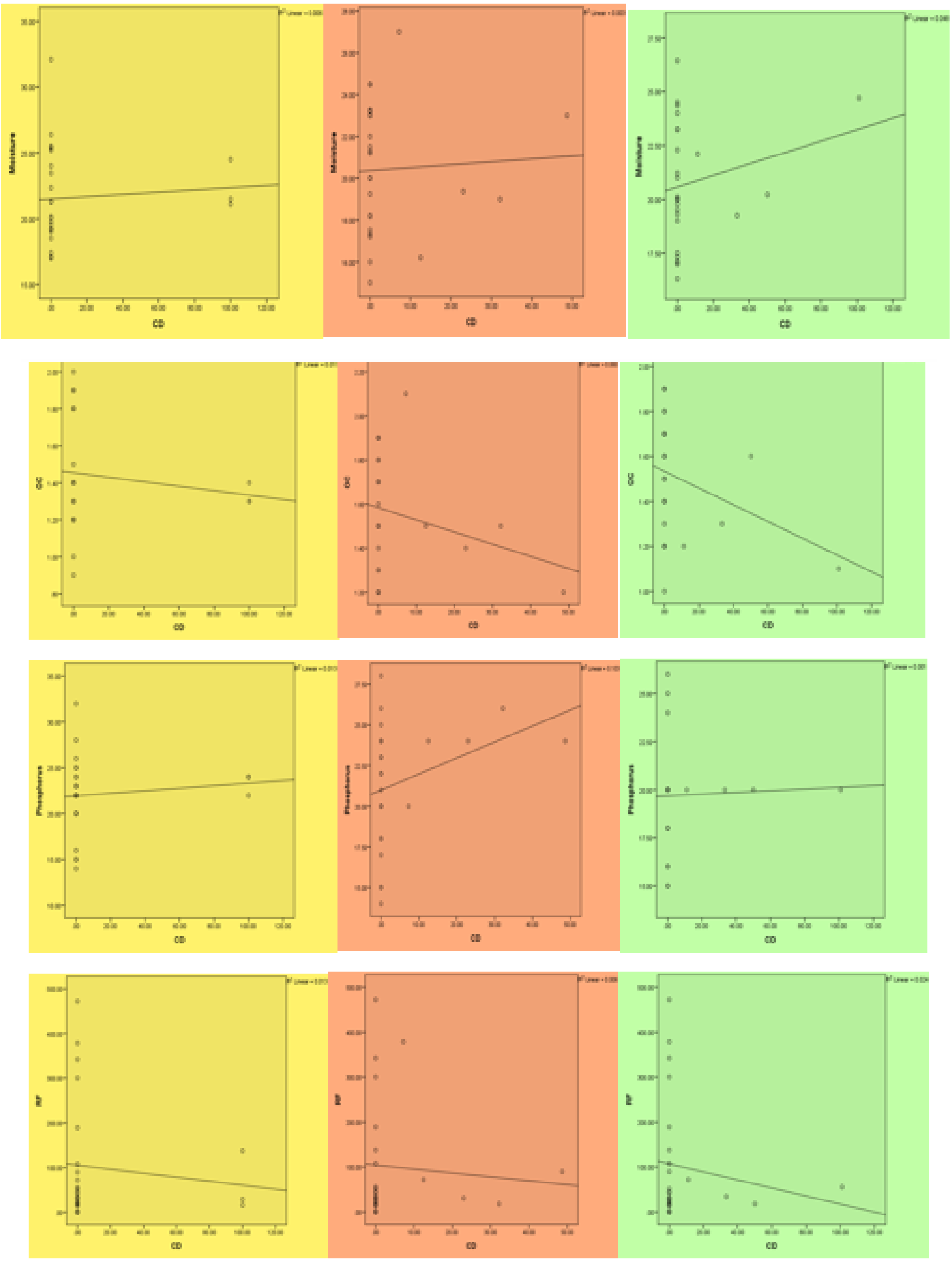


Figure11: Scatter plot between Physico-chemical parameter and coleoptera density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.

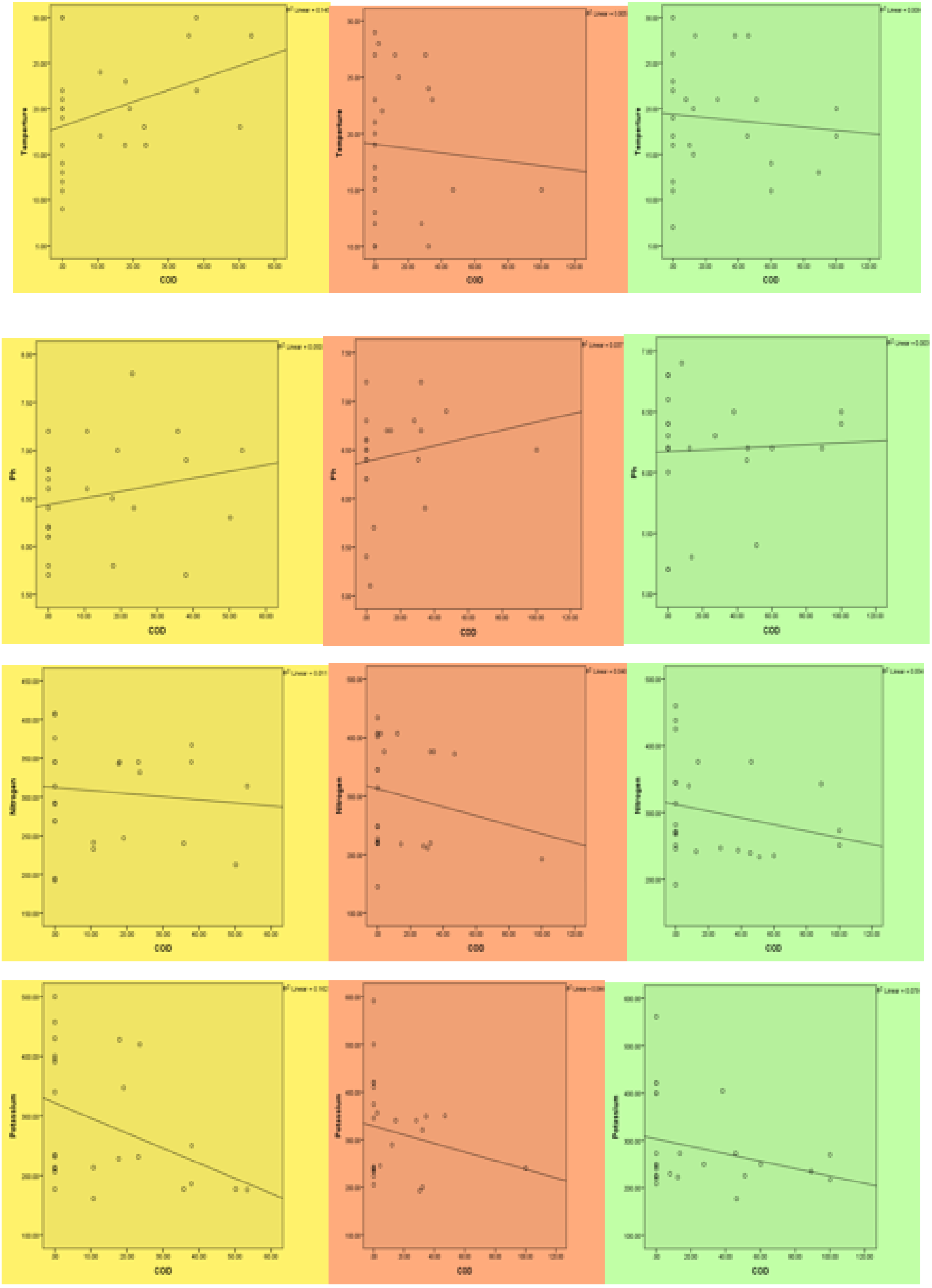
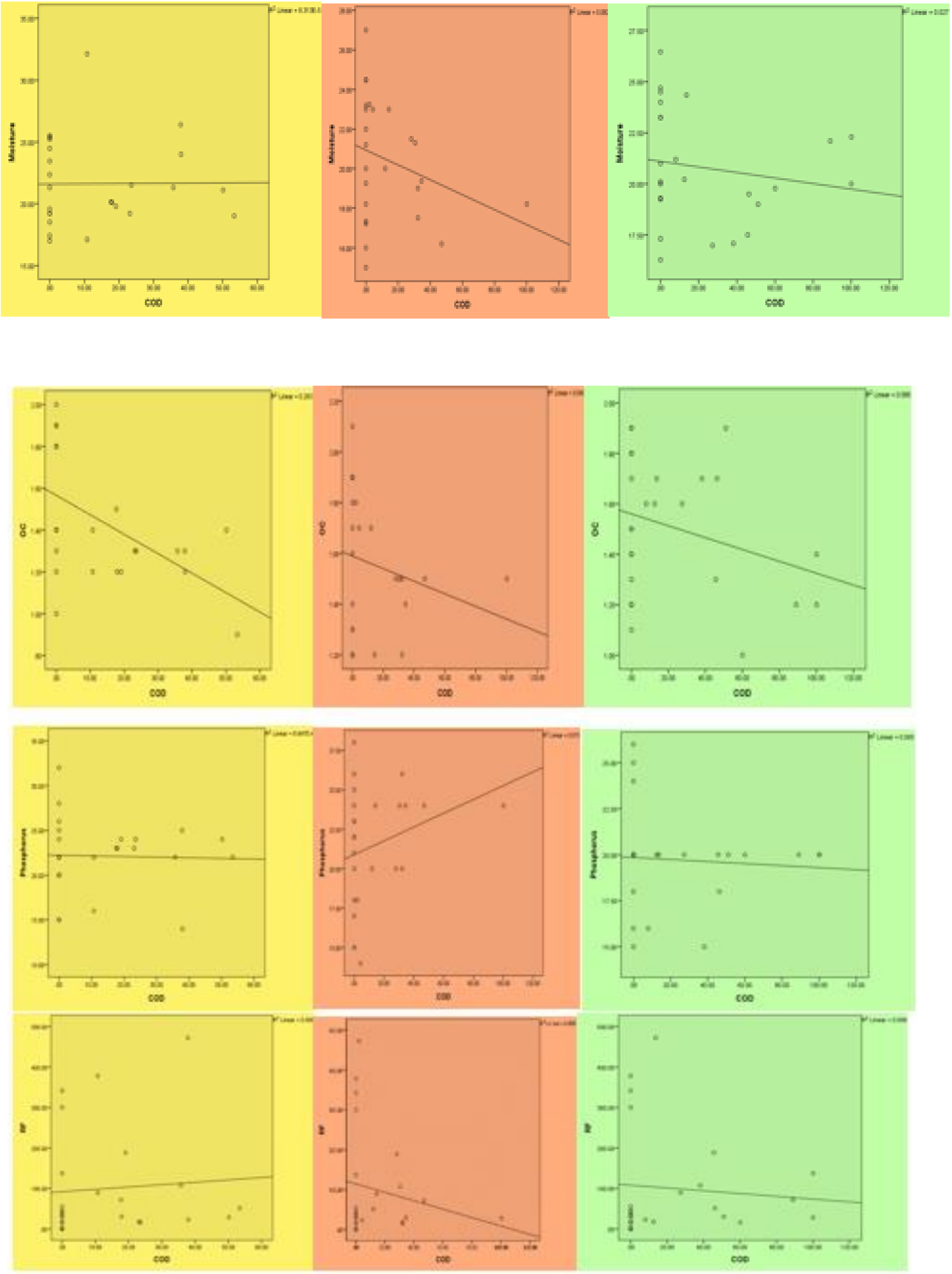


Figure12: Scatter plot between Physico-chemical parameter and coleoptera density at station -I (yellow colour), station -II (brick red colour) and station -II (light green colour) during 2019-21.


Moisture
COD
OC
Phosphorus

3. DISCUSSION

Pearson correlation coefficient results should interpret the correlation values in the context of the study's objectives and the ecological or environmental relevance of these findings.

At Station I, several significant correlations were observed between physico-chemical parameters and macroinvertebrate densities. Notable findings include:

1. Earthworm Density (ED): There is a significant positive correlation with Rainfall ($r = 0.482$, $p < 0.05$). This suggests that increased rainfall is associated with higher earthworm density, possibly due to increased soil moisture which benefits earthworm activity and survival.
2. Ant Density (AD): A significant positive correlation with pH ($r = 0.430$, $p < 0.05$) was found. This indicates that higher soil pH levels are favourable for ant populations. Alkaline conditions might enhance habitat suitability or food availability for ants.
3. Coleoptera Density (COD): A strong negative correlation with Organic Carbon ($r = -0.506$, $p < 0.01$) suggests that higher organic carbon levels are associated with lower Coleoptera density. This could be due to specific ecological requirements of Coleoptera or competition with other organisms favoured by high organic carbon.

At Station II, significant correlations include:

1. Earthworm Density (ED): There is a significant positive correlation with Moisture ($r = 0.482$, $p < 0.05$). Similar to Station I, this implies that higher moisture content is beneficial for earthworm density.
2. Earthworm Biomass (EB): Significant correlations were observed with Moisture ($r = 0.441$, $p < 0.05$), Phosphorus ($r = -0.721$, $p < 0.01$), and Potassium ($r = -0.420$, $p < 0.05$). While moisture positively affects biomass, high levels of Phosphorus and Potassium are negatively associated with earthworm biomass, indicating potential nutrient imbalances or toxicities affecting earthworm health.

1. Earthworm Biomass (EB): Positive correlations with Moisture ($r = 0.561$, $p < 0.01$) and pH ($r = 0.465$, $p < 0.05$) indicate that moist and slightly alkaline conditions favour higher earthworm biomass, consistent with observations from the other stations.
2. Termite Density (TD): Positive correlation with Phosphorus ($r = 0.499$, $p < 0.05$) suggests that higher phosphorus levels in soil benefit termite populations.
3. Termite Density (TD): There are significant negative correlations with Temperature ($r = -0.496$, $p < 0.05$) and Moisture ($r = -0.469$, $p < 0.05$), and a positive correlation with Nitrogen ($r = 0.398$, $p < 0.05$). This suggests that cooler and drier conditions, along with higher nitrogen levels, are conducive to termite populations.

At Station III, key significant correlations include:

1. Centipede Density (CD): A significant negative correlation with pH ($r = -0.520$, $p < 0.01$) implies that centipedes prefer more acidic conditions. This inverse relationship might be linked to the ecological niches centipedes occupy.

Across all stations, the significant correlations between physico-chemical parameters and macroinvertebrate densities indicate strong environmental dependencies. Rainfall and moisture consistently show positive relationships with earthworm densities and biomass, highlighting the importance of these parameters in supporting earthworm populations. Negative correlations between some nutrients (e.g., Phosphorus, Potassium) and macroinvertebrates like earthworms and Coleoptera suggest that excessive nutrient levels might be detrimental, potentially due to toxicity or competitive disadvantages. The positive correlation between pH and certain macroinvertebrates (e.g., ants, earthworms) at different stations points to the complexity of soil chemistry and its differential impacts on various organisms.

Our study corroborate with previous finding such as Pokhrel suggested that soil factors such as T, pH, N, P and K play a significant role in influencing soil fauna abundance.[20] The soil fauna's composition, distribution, and density are significantly influenced by local environmental factors such as soil moisture, air quality, water content, and the chemical and physical properties of the soil.[21] High levels of nitrogen and acidic soil can negatively impact both plants and soil fauna.[22] Sanaei found that soil fauna thrive abundantly under dense canopy areas.[23] Additionally, Cade-Menun observed a correlation between soil nutrient availability, particularly potassium and soil fauna abundance.[24] Masebo discovered significant relationships between soil macrofauna attributes and soil properties such as total nitrogen, phosphorus, pH and organic carbon.[25]

Temperature and soil moisture significantly influence earthworm populations.[26,27] Seasonal variations also impact earthworm abundance, with higher populations observed during wet seasons in the Himalayan region .[28,29] Phillips highlighted the influence of increasing air temperature on earthworm communities globally.[30] High temperatures can directly inhibit earthworm activity and reproduction while indirectly affecting soil moisture levels.[26] Conversely, Kalu observed a direct relationship between the density of earthworm and the moisture content of the soil. [31]Soil water content can mitigate the impacts of heat waves .[32] Certain researcher have documented that there is positive relationship between the biomass and density of earthworm with soil temperature.[33,34]

Regarding soil properties, earthworm populations exhibit preferences and tolerances to pH levels .[35-36] Organic carbon content positively influences earthworm diversity .[37-38] Multiple research findings suggest a direct relationship between the density of earthworms and the presence of soil organic carbon.[39-40] Additionally, soil organic carbon and nitrogen positively correlate with earthworm biomass and density .[41-42] Nevertheless, several studies have reported inconsistent findings regarding the connection between organic carbon levels and the abundance of earthworms .[43,44]

Nitrogen availability significantly influences earthworm abundance and distribution.[45,46] Available phosphorus and potassium levels also impact earthworm populations, although findings regarding their correlation vary.[35,47] Additionally, ant populations are influenced by temperature, soil organic matter, nitrogen, phosphorus, and potassium.[48,49] Termites are also affected by various abiotic factors such as temperature, humidity, and rainfall, with their diversity and distribution significantly influenced by these factors.[50-53]

Centipedes' distribution and abundance are affected by factors such as rainfall, soil parameters, and climatic conditions .[54]Additionally, soil moisture, temperature, and organic matter content influence the abundance and diversity of centipedes.[55,56] White grub beetles are impacted by temperature, moisture, pH and nutrient levels in the soil .[57.58] Changes in land use, such as cultivation, can affect soil fauna populations due to alterations in habitat and disturbance levels .[59.60] Finally, ant communities exhibit higher richness and abundance in undisturbed habitats .[61] These findings highlight the need for balanced soil environments to sustain diverse and healthy macroinvertebrate communities, which are crucial for ecosystem functioning. Future studies could explore the causative factors behind these correlations and examine the interplay between multiple parameters in influencing macroinvertebrate populations. The observed Pearson correlation results with ecological interpretations, highlighting significant patterns and potential reasons behind these relationships.

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2. REFERENCES

1. Singh JS. Forests of Himalaya with particular reference to man and forest interactions in Central Himalaya. Proceedings Indian National Science Academy. 1997; 63(3):151-173.
2. Mittermeier RA, Gil RP, Hoffman M, Pilgrim J, Brooks T, Mittermeier CG, et al. Hotspots revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. CEMEX, Conservation International; Agrupacio´n Sierra Madre, Monterrey; Washington DC. 2004; 392 p.
3. Pandit MK, Sodhi NS, Koh LP, Bhaskar A, Brook BW. Unreported yet massive deforestation driving loss of endemic biodiversity in Indian Himalaya. Biodiversity and Conservation. 2007; 16(1):153-163.
4. Abad, P., Tan, M., Baluyot, M., Villa, A., Talapian, G., Reyes, M., Suarez, R., Sur, A., Aldemita, V., Padilla, C., & Laurino, M. Cultural beliefs on disease causation in the Philippines: challenge and implications in genetic counselling. Journal of Community Genetics. 2014; 5(4), 399–407. http://doi.org/10.1007/s12687-014-0193-1'
5. Ding, J., Zhu, D., Chen, Q. L., Zheng, F., Wang, H. T., & Zhu, Y. G. Effects of long-term fertilization on the associated microbiota of soil collembolan. Soil Biology and Biochemistry. 2019; 130, 141-149.
6. Zheng, H., Wang, R., Zhang, Q., Zhao, J., Li, F., Luo, X., & Xing, B. Pyroligneous acid mitigated inseminations of antibiotic resistance genes in soil. Environment International. 2020; 145, 106158.
7. Bi, Q. F., Jin, B. J., Zhu, D., Jiang, Y. G., Zheng, B. X., O'Connor, P., ... & Zhu, Y. G. How can fertilization regimes and durations shape earthworm gut microbiota in a long-term field experiment? Ecotoxicology and Environmental Safety. 2021; 224, 112643.
8. Liu, S., Hao, C., Xie, Z., Wu, Y., Liang, A., Chang, L., ... & Chen, T. W. Conservation tillage impacts on soil biodiversity: Additional insights from the Collembola-associated bacteria. Agriculture, Ecosystems & Environment. 2024; 362, 108827.
9. Bodner, G., Loiskandl, W., Buchan, G., & Kaul, H. P. Natural and management-induced dynamics of hydraulic conductivity along a cover-cropped field slope. Geoderma. 2008; 146(1-2), 317-325.
10. Kaushik, U., Raj, D., Rani, P., & Bhardwaj, K. K. Effect of cultivation on organic carbon pools and nutrient availability in soil under different land use system: A review. International Journal of Current Microbiology and Applied Sciences. 2018; *7*(08), 1578-1591.
11. Vashisht, B. B., Maharjan, B., Sharma, S., & Kaur, S. Soil quality and its potential indicators under different land use systems in the Shivaliks of; Indian Punjab. Sustainability.2020; 12(8), 3490.
12. Bouyoucos GJ. Hydrometer method improved for making particle size analyses of soils. Agronomy Journal. 1962; 54(5):464-465.
13. Walkley A, Black IA. Determination of Organic carbon in Soil. Soil Science 1934; 37:29-31.
14. Jackson ML. Soil chemical analysis. Asia Publishing House, Bombay. 1962.
15. Stanford S, English L. Use of flame photometer in rapid soil test of K and Caribian Journal of Agronomy. 1949; 41:446-447.
16. Julka, J.M. The fauna of India and adjacent countries: Megadrile Oligochaeta (Earthworms). Haplotaxida: Lumbricina: Megascolecoidea: Octochaetidae. Zoological Survey of India, Calcutta. 1988; 400 pp+XIV.

17. Imms, A.D., O.W. Richards and R.G. Davies (1957). Imm's General Textbook of entomology. Springer publications. 1957; p-1354.
18. M. S. Mani. Introduction to High Altitude Entomology, Insect life above the timber-line in the North-West Hymalaya.1962; xix+302pp., 80 text-figures, 11 plates. Methuen & Co Ltd, London, 42s net.
19. Dindal, D. L. Soil biology guide. John Wiley & Sons.1991.
20. Pokhrel, S. Effects of microhabitat characteristics on abundance of macroinvertebrate soil fauna in Ranibari community forest, Kathmandu, Nepal.2023; Doctoral dissertation, Department of Zoology.
21. Zagatto, M. R. G., Pereira, A. P. de A., Souza, A. J. de, Pereira, R. F., Baldesin, L. F., Pereira, C. M., Lopes, R. V., & Cardoso, E. J. B. N. Interactions between mesofauna, microbiological and chemical soil attributes in pure and intercropped Eucalyptus grandis and Acacia mangium plantations. Forest Ecology and Management.2019; 433:240–247. https://doi.org/10.1016/j.foreco.2018.11.008.
22. Yu, K., Wang, L., Duan, Y., Zhang, M., Dong, Y., Jia, W., & Hu, F. Soil pore characteristics, morphology, and soil hydraulic conductivity following land subsidence caused by extraction of deep confined groundwater in Xi'an, China: Quantitative analysis based on X-ray micro-computed tomography.2021; Soil and Tillage Research 211. https://doi.org/10.1016/j.still.2021.105018.
23. Sanaei, A., Yuan, Z., Ali, A., Loreau, M., Mori, A. S., Reich, P. B., Jucker, T., Lin, F., Ye, J., Fang, S., Hao, Z., & Wang, X. Tree species diversity enhances 30 plant-soil interactions in a temperate forest in northeast China. Forest Ecology and Management. 2021;491(January). https://doi.org/10.1016/j.foreco.2021.119160.
24. Cade-Menun, B. J., Elkin, K. R., Liu, C. W., Bryant, R. B., Kleinman, P. J. A., & 27 Moore, P. A. Characterizing the phosphorus forms extracted from soil by the Mehlich III soil test. Geochemical Transactions.2018; 19(1):1–17. https://doi.org/10.1186/s12932-018-0052-9
25. Masebo, N., Birhane, E., Takele, S., Belay, Z., Lucena, J. J., Perez-Sanz, A., & Anjulo, A. The diversity and abundance of soil macrofauna under different agroforestry practices in the drylands of southern Ethiopia. Agroforestry Systems.2023; 1-19.
26. Singh, J., Schädler, M., Demetrio, W., Brown, G. G., & Eisenhauer, N. Climate change effects on earthworms-a review. Soil organisms. 2019; *91*(3), 114.
27. Briones, M. J. I., Panzacchi, P., Davies, C. A., & Ineson, P. Contrasting responses of macro-and meso-fauna to biochar additions in a bioenergy cropping system. Soil Biology and Biochemistry. 2020;145, 107803.
28. Julka JM, Paliwal R. Seasonal changes in the population of earthworms (Oligochaeta) in an orchard. Journal of the Bombay natural History Society 1990; 87(2):323-326.
29. Sinha, B., Bhadauria, T., Ramakrishnan, P. S., Saxena, K. G., & Maikhuri, R. K. Impact of landscape modification on earthworm diversity and abundance in the Hariyali sacred landscape, Garhwal Himalaya. Pedobiologia. 2003; 47(4), 357-370.
30. Phillips, H. R., Guerra, C. A., Bartz, M. L., Briones, M. J., Brown, G., Crowther, T. W., ... & Eisenhauer, N. Global distribution of earthworm diversity. Science. 2019; 366(6464), 480-485.
31. Kalu S, Koirala M, Khadaka UR. Earthworm population in relation to different land use and soil characteristics. Journal of Ecology and the Natural Environment 2015; 7(5):124-131.
32. Dong, X., Qu, L., Dong, G., Legesse, T.G., Akram, M.A., Tong, Q., Jiang, S., Yan, Y., Xin, X., Deng, J., Shao, C. Mowing mitigated the sensitivity of ecosystem carbon fluxes responses to heat waves in a Eurasian meadow steppe. Sci. Total. Environ. 2022; 853, 158610.

33. Chaudhuri PS, Nath S. Community structure of earthworms under rubber plantations and mixed forests in Tripura, India. Journal of Environmental Biology 2011; 32(5):537-541.
34. Najar, I. A., & Khan, A. B. Factors affecting distribution of earthworms in Kashmir Valley: a multivariate statistical approach. In Proceedings of the Zoological Society.2014; Vol. 67, No. 2, pp. 126-135. India: Springer India.
35. Chauhan RP. Role of Earthworms in soil fertility and factors affecting their population dynamics: A review. International Journal of Research 2014; 1(6):642-649.
36. Paliwal R, Julka JM. Survey of Earthworms of Western Himalaya with Special Reference to Search for Vermicomposting Species. Proceedings of the International Workshop on Vermitechnology in Human Welfare, Departments of Zoology and Biochemistry, Kongu Nadu Arts and Science College, Coimbatore, Tamil Nadu, India 4th- 7th, June 2007, Eds. C. A. Edwards, R. Jeyaraaj and Indira A. Jayraaj 2007; p. 38-51.
37. Tiunov AV and Scheu S. Carbon availability controls the growth of detritivores (Lumbricidae) and their effect on nitrogen mineralization. Oecologia. 2004; 83-90.
38. Ayuke FO, Pulleman MM, Vanlauwe B, de Goede RGM, Six J, Csuzdi C et al. Agricultural management affects earthworm and termite diversity across humid to semiarid tropical zones. Agriculture, Ecosystems and Environment. 2011; 140:148-154.
39. Tian G, Olimah JA, Adeoye GO, Kang BT. Regeneration of earthworm population in a degenerated soil by natural and planted fallows under humid tropical conditions. Soil Science Society of American Journal 2000; 64:222- 228.
40. Brown GG, Feller C, Blanchart E, Deleporte P, Chernyanskii SS. With Darwin, earthworms turn intelligent and become human friends: The 7th international symposium on earthworm ecology Cardiff Wales . Pedobiologia 2003; 47:924-933. 2.
41. Blanchart, E., Albrecht, A., Alegre, J., Duboisset, A., Gilot, C., Pashanasi, B., …, Brussaard, L. Effects of earthworms on soil structure and physical properties. In P. Lavelle, L. Brussaard, & P. Hendrix (Eds.), Earthworm Management in Tropical Agroecosystems. 1999; (pp. 149–171). Oxon: CAB International.
42. Shipitalo, M. J., & Le Bayon, R. C. Quantifying the effects of earthworms on soil aggregation and porosity. In C. A. Edwards (Ed.), Earthworm ecology. 2004; pp. 183–200. Boca Raton: CRC Press.
43. McLean MA, Parkinson D. Changes in structure, organic matter and microbial activity in pine forest soil following the introduction of Dendrobaena octaedra (Oligochaeta, Lumbricidae). Soil Biol Biochem. 1997a; 29:537–540.
44. Sharma RK, Bhardwaj P. Earthworm diversity in the trans-gangetic habitats of Haryana India. Research Journal of Agriculture and Forestry Sciences 2014; 2(2):1-7.Rossi J and Blanchart E. Seasonal and land-use induced variations of soil macrofauna composition in the Western Ghats, southern India. Soil Biology and Biochemistry. 2005; 37:1093-1104.
45. Shipitalo, M. J., & Le Bayon, R. C. Quantifying the effects of earthworms on soil aggregation and porosity. In C. A. Edwards (Ed.), Earthworm ecology. 2004; pp. 183–200. Boca Raton: CRC Press.
46. Saha, S., Sarkar, M. and Raychaudhuri.D. Assessing Diversity and Abundance of Soil Microarthropods in Three Discrete Plots of Ramakrishna Mission Vivekananda Ashrama, Narendrapur, South 24 Parganas, West Bengal, India. WNOFNS.2020; 31., 58-69.
47. Sharma RK, Bhardwaj P. Earthworm diversity in the trans-gangetic habitats of Haryana India. Research Journal of Agriculture and Forestry Sciences 2014; 2(2):1-7.
48. Parthasarathi, Jayanthi L, Basha SA. Population dynamics of earthworms in Cauvery delta areas in relation to soil properties. Indian Streams Research Journal 2013; 3:1-8.
49. 48. Parr, C. L., & Bishop, T. R. The response of ants to climate change. In Global Change Biology. 2022; Vol. 28, Issue 10, pp. 3188–3205. John Wiley and Sons Inc. https://doi.org/10.1111/gcb.16140

50. Saha, S., Sarkar, M. and Raychaudhuri.D. Assessing Diversity and Abundance of Soil Microarthropods in Three Discrete Plots of Ramakrishna Mission Vivekananda Ashrama, Narendrapur, South 24 Parganas, West Bengal, India. WNOFNS.2020; 31., 58-69.
51. Jouquet, P., Bottinelli, N., Shanbhag, R. R., Bourguignon, T., Traoré, S., & Abbasi, S. A. Termites: the neglected soil engineers of tropical soils. Soil Science. 2016; 181(3/4), 157-165.
52. Davies, A. B., Eggleton, P., van Rensburg, B. J., & Parr, C. L. Seasonal activity patterns of African savanna termites vary across a rainfall gradient. Insectes Sociaux. 2015; 62, 157-165.
53. Bignell, D.E. Termites as Soil Engineers and Soil Processors. In H. König, and A.Varma (editors), Intestinal Microorganisms of Termites and Other Invertebrates:183–212. Heidelberg: Springer Berlin.2006; xxiv+461 p
54. Oberst, S., M. Lenz, J.C.S. Lai, and T.A. Evans. Termites manipulate moisture content of wood to maximize foraging resources. Biology Letter. 2019; 15: 20190365.
55. Joshi, J., & Dahanukar, N. Ecology, diversity and distribution of centipedes (Scolopendromorpha: Chilo-poda) in the Northern Western Ghats, India. 2023; Julka.
56. Shakir, M. M. and Ahmed, S. Seasonal abundance of soil arthropods in relation to meteorological and edaphic factors in the agroecosystems of Faisalabad, Punjab, Pakistan. Int. J. Biometeorol. 2015; 59(5): 605-16, doi 10.1007/ s00484-014-0874-9.
57. Jabin, M., Mohr, D., Kappes, H. and Topp, W. Influence of deadwood on density of soil macro-arthropods in a managed oak-beech forest. Forest Ecol. Manag. 2004; 194, 61–69.
58. Liu, C.L., Rong, L.R., Chen, J.X., Zhang, Z.L. Study on forecast of Alissonotum impressicolle Arrow. Forecast of Disease and Pest. 1990; 1:27-31.
59. Logan, D.P. Effect of soil moisture on oviposition by childers canegrub, Antitrogus parvulus Britton (Coleoptera: Scarabaeidae). Australian Journal of Entomology. 2007; 36:175-178.
60. Zicsi A. Über die Auswirkung der Nachfrucht und Bodenbearbeitung auf die Aktivität der Regenwürmer. Pedobiologia 1969; 9:141-145.
61. Lee KE. Earthworms their Ecology and Relationships with Soils and Land Use. Academic press, 1985; 389 p.
62. Savitha S, Barve N, Davindar P. Response of ants to disturbance gradients in and around Bangalore, India. Tropical Ecology, 2008; 49(2):235-243.