Scope
Volume 13 Number 4 December 2023

Relationship between Plant Diversity and Soil Moisture for the Seasonal Health Evaluation of Riparian zone in the Central Region of Narmada

Ankita Singh[1*], Pratiksha Singh[2], Vipin Vyas[3]

[1]Department of Environmental Sciences & Limnology, Barkatullah University, Bhopal, M.P. India
[2]Department of Zoology & Applied Aquaculture, Barkatullah University, Bhopal, M.P. India
[3]Department of Biosciences, Barkatullah University, Bhopal, M.P. India
Corresponding author: **Ankita Singh**

Abstract
The distribution and primary production of plant communities are all strongly correlated with the availability of soil water. Due to anthropogenic activities, the vegetation cover near the water bodies (i.e., riparian zone) is affected. So, to improve the vegetational health of riparian zones it is necessary to evaluate the relationship between the vegetation and soil components. In this research paper, we have outlined findings from the study conducted in riparian forests of the Narmada basin to under stand the vegetational condition and soil moisture (SM), i.e., affected the variety and composition of herbs in the central Narmada region. The Shannon-Wiener diversity index (SWDI), Simpson diversity index (SDI), Margalef's index (MARI), and Menhinic's index (MERI) of species richness of the herbs were assessed in the three seasons (i.e., pre-monsoon season, post-monsoon season, and post-winter season) which showed significant positive relationships with SM. Pre-monsoon season showed a low species diversity of 1.046 to 1.807 (SWDI)and 0.001-0.473 (SDI) and high i.e., 1.238 to 1.867 (SWDI) and 0.001-0.481(SDI) in post-monsoon season, indicating poor to intermediate health of the stretch. Like how species richness is higher in the post-monsoon season, it was discovered to be 0.01-1.46 (MARI) and lowest in the post-winter season i.e., 0.001-1.369 which also indicates poor to moderate health of the river stretch. The index of the link between soil moisture and biodiversity (Root-mean-square deviation, or RSMD), which measures soil moisture at 0–12 cm depth, shows that only this association increased with the change of season. In the pre-monsoon season, the SDI's linear relationship with soil moisture was stronger than that of other indices, despite MARI and MERI exhibiting stronger linear correlations with soil moisture (SM)in the post-monsoon and post-winter seasons, respectively.
Keywords: Riparian vegetation, diversity index, richness index, soil moisture

1. Introduction

In the water cycle as well as other nutrient cycles, the riparian zone plays a significant role. The riparian zone's vegetation filters the water as it passes, improving the quality of the water downstream (Blinn *et al.*, 2001). Riparian zones have become the focus of many conservation programs, and their protection or rehabilitation has the potential to have a significant influence on all the communities that thrive on the water and nutrients of riparian zones. The types of riparian soils and plants, as well as the interconnectivity between the river and riparian zone along surface-subsurface exchange channels, all affectriparian buffering (Lind *et al.*, 2019).The interaction of soil, water, and vegetation components in riparian ecosystems defines their ecological relevance (Pandey *et al.*, 2022). High levels of species diversity and richness can be found in riparian zones, which also have the potential to serve as a local heaven for species, acting as sources of the population to promote the recolonization of disturbed ecosystems (Graziano *et al.*, 2022).

The study of biodiversity in the riparian zone will be applicable in determining the state of the vegetation in that area that has directly or indirectlysustained huge trees. Because of how badly the earth has been harmed by anthropogenic activity and climate change, biodiversity is currently a key topic in scientific inquiry. Finding the "correct" technique to assess biodiversity can be challenging because the term has been defined in a variety of ways in the scientific literature (H. G. Washington, 1984; K. J. Gaston, 2000). Since it gives insight into the biological and ecological integrity of an aquatic ecosystem through the community structurethe use of diversity indices is a useful technique for assessing the diversity conditions (Strien *et al.*, 2012; Nadeau *et al.*, 2015).These indices are also employed as a gauge for the level of pollution in aquatic environments. Numerous metrics are employed in scientific literature to quantify changes in biodiversity, but those based on phytoplankton and riparian vegetation communities are particularly useful for assessing the well-being of water bodies (Yadav *et al.*, 2015). Improving our knowledge of ecology requires an understanding of the forces that affect biodiversity. According to reports, soil moisture availability and rainfall gradients are strongly correlated with the distribution, diversity, and primary production of plant communities (Tockner *et al.*, 1999; Fu *et al.,* 2016). The availability of soil water is the most crucial element in system dynamics,following the non-equilibrium ecology theory.The availability of soil moisture may be one of the key elements (Xu *et al.*, 2022; Chan *et al.*, 2018) determining the habitat associations of tropical trees, shrubs, and herbs, along with the influence of tropical deciduous forests on plant variety and distribution in the moist and wet tropics. In many terrestrial environments, the fundamental barrier to plant communities is the availability of water (Herris J., 2019; An Y. *et al.*, 2019).According to Deng *et al.* (2016), vegetation has a significant impact on the water cycle, soil erosion, runoff, and the interactions between vegetation and soil water are essential to ecological processes in tropical areas. As a result, soil water is recognized as a key driver of the productivity and sustainability of terrestrial ecosystems (Peter *et al.*, 2012; Young *et al.,* 2010; Zhang *et al.*, 2016). Community structure and large-scale species distributions can be significantly shaped by regional climate (precipitation and temperature) and soil moisture (Valencia *et al.*, 2018).Only a small number of species are suited to severely dry circumstances, therefore the availability of soil moisture may have an impact on species richness and distributions (Wu *et al.*, 2016 and Peng *et al.,* 2018). In dry and semi-arid regions, vegetation plays a crucial role in controlling hydrological processes (Wu*et al.*, 2014; Sinoga *etal.,* 2011). Therefore,theassociation between soil moisture and plant community is important. And based on prior research, we think that increasing soil moisture will result in greater plant biodiversity since it will allow more water to reach plants, which will reduce competition.

Numerous studies have been conducted on the interactions between plant diversity, productivity, and soil moisture in temperate forest stands, agroecosystems, and grassland communities. In this study, we sought to learn more about the connection between soil moisture and plant diversity in a riparian area of Central Narmada. We explored the possibility that there might be some correlations between the soil moisture content and various plant biodiversity metrics, including species richness, Shannon-Wiener and Simpson's species diversity, and structural richness and diversity.

2. Material and Methods

2.1. Study Area

The research region is situated in the Indian districts of Narmadapuram (Hoshangabad) and the Harda basins of Narmada (Figure 1) which isthe greatest west-flowing river in peninsular India. At an elevation of roughly 1057 m, the stream emerges from the Maikala hills close to Amarkantak in the Anuppur region of Madhya Pradesh. The river's entire length is 1,312 km, of which the first 1079 km flows through Madhya Pradesh and serves as a shared border between Gujarat, Maharashtra, and Madhya Pradesh.

The Tropical of Cancer, which goes through the state and is dominated by CSA(Climate-smart-agriculture), has a significant impact on Madhya Pradesh's climate. Like other regions of India, it has three distinct seasons with varying lengths: summer, monsoon, and winter. The monsoon is either intense or a drought scenario is in effect, and the summers and winters are both exceedingly hot and chilly. The temperature varies from 29.4°C to 42°C from March to June.MP is hotter in its eastern than in its western regions. In July, when the sun moves toward the Northern Hemisphere, the state endures extreme heat. The winds from the Bay of Bengal sweep across the entire state during the monsoon season, which lasts from June to October. As we move west, the rainfall's intensity lessens. The average rainfall is 20 to 25 cm, with a maximum of approximately 152.4 cm, andthe state was affected by both drought and flooding. The winter season begins in November and lasts through February. Most of the northern region experiences a maximum temperature in January that ranges between 15 and 18 °C. The weather is dry and comfortable with a clear sky in this season.

The 188.06 km stretch of the Narmada River in the Narmadapuram (Hoshangabad) and Harda districts, situated between 22°34'38.98"N and 77°8'57.98E and 22°55'13.185"N and 78°20'50.748E, was the subject of the study. It belongs to the category of tropical deciduous forest andplant biodiversity is thought to be highest on Earth in tropical forest habitats.

2.2. Design of survey sampling

Sandiya (N1), Bankhedhi Rewa (N2), Mudiya Khedha (N3), Bandrabhan (N4), Dongarwada (N5), Anwalighat (N6), and Chhipaner (N7) are the seven sampling sites used for the study and are depicted in Figure 2. Sampling is carried out along the riparian zone, where there are the greatest interactions between riparian plants and the aquatic ecosystem. Aquatic vegetation, annual grass, perennial grass, herbs, and shrubs were counted and identified in each plot during the monsoon, winter, and summer seasons of 2021–2022, respectively. Seven 25 × 25 m plots were positioned 100 meters away from the creek. Each plot's herb population was counted and identified. Soil samples were taken from 0-12 cm depth and weighed in the field to obtain wet weight values, and then dried at 105 °C for 24 h to get the dried weight.

2.3. Data analysis

With the aid of an excel spreadsheet and the Biodiversity Calculator (http://www.alyoung.com/labs/biodiversity calculator.html), the data in Table 1 are used to calculate species diversity indices like the Shannon-Weiner index and the Simpson index, as well as species richness indices like the Margalef index and the Menhinick index. Species richness is the number of species in a community and species diversity includes a measure of the number of species in a community and a measure of the abundance of each species (Moeslund *et al.,* 2013; Wang *et al.*, 2019). Riparian health was divided into three groups (poor, moderate, and good) based on the biodiversity indices score after the richness and biodiversity indices calculation.
Gravimetric and volumetric methods are used to determine the water content in the soil, respectively. The mass of water per mass of soil is known as the gravimetric water content. Because the amount of soil water is directly assessed by measuring the mass, it is the most used method for determining the water content of the soil (Lu *et al.,* 2017).The soil moisture (SM %) was calculated as:

$$SM = (SW_{wet} - SW_{dried}) / SW_{dried} \times 100$$

where SW_{wet} is the wet weight of the soil sample, and SW_{dried} is the dried weight of the soil sample.

ANOVA was used to evaluate the variations in the communal characteristics of restored meadows. At a P-0.05 level, multiple comparisons were performed using the LSD test. To determine the relationships between soil moisture, community characteristics, and plant diversity, linear regressions were carried out (SWDI, SDI, MERI, and MARI). At the P 0.05 level, the linear regression coefficient of determination (R) was deemed significant. Using SPSS Version 16.0, all the statistical analyses were carried out.

3. Result

We collected the three seasonal data, which were analyzed in the context of riparian vegetation comprising different plants such as annual grasses, aquatic plants, perennial grasses, and shrubs. These plants were collected during the period of the entire study, and soil samples were also collected to find the relation between them, which are included in factors that may affect the health of the river either directly or indirectly (Rourke *et al.,* 2018). Diversity and richness indices were used, i.e., SWDI, SDI, and MERI, MARI, to find out the health of the Narmada River(Mollina *et al.*, 2022).

3.1. Analysis of Plant diversity indices in different seasons

The Narmada River sampling sites were fixed between the N1 and N7, which had a total length of 188.06 km. All the chosen sites had significant anthropogenic disturbances, including the footprint of cattle, agriculture practices, human presence, and built-up areas in some cases. The research sites N4 and N2 recorded the highest number of herb species during the post-monsoon season, followed by N5, N4, and N3 during the post-winter season, while N4 recorded the lowest number of herb species during the post-winter season. Site N6consistently had the lowest number(0) of species. According to Vannote *et al.,* (1980), the physical, chemical, and biological processes in the stream channel primarily were determined by, how riparian vegetation was distributed, making it a vital indicator of the health of the riparian zone. Appendix 1 list shows the total number of plant species, shrubs, aquatic plants, perennial grasses, and annual grasses presented in plots.

Figure 3 depicts the calculated species diversity and species richness which shows that SDI varied from 0.202 to 0.461 in the post-monsoon season, 0.292 to 0.473 in the post-winter season, and 0.20 to 0.402 in the pre-monsoon season for the study sites (N1, N2, N3, N4, N5, N7), indicating moderate health with the exception for site N6 (has 0.00 value) which has no herbs present due to the complete development of the riparian area, indicating poor diversity. SDI is higher where more species are found. Like this, the SWDI values were found at each site between 0.89 and 1.398 in post-winter, 1.046 to 1.807 in pre-monsoon, and 1.238 to 1.867 in post-monsoon seasons, showingpoor riparian health at all sampling sites. MARI was frequently used to compare only the aspect of diversity(species richness) among the sites.MARI demonstrates the sensitivity to a sample size that helps in the comparison of the richness among sites (Anunciaço *et al.,* 2022).It ranged from 0.673 to 1.1626 during the post-monsoon season, 0.294 to 1.369 during the post-winter season, and 0.530 to 1.464 during the pre-monsoon season for sites N1, N2, N3, N4, N5, and N7, whereas 0 for site N6, indicating poor species richness across all the studied sites.Like MARI, MERI provides information on species richness and ranged from 0.200 to 0.408 in the post-monsoon season, 0.100-0.246 in the post-winter season, and 0.236 to 0.462 in the pre-monsoon season for the study sites. The presence of herbs indicates moderate health, which translates to moderate riparian health for study sites (N1, N2, N3, N4, N5, N7) and poor riparian health for site N6.Overall riparian health category exists from moderate to poor, where no site indicates good health. Site N6 has no vegetation on the surface (Table 2).

This moderate diversity is attributed to environmental degradation whichaccountsfor anthropogenic pressures and other biotic factors (O. Ravera, 2001). The MARI and SWDI were found higher inthe post-monsoon seasonthan thepost-winter season(winter) due to significant improvement in the Physico-chemical quality of water.

The Narmada riparian zone has moderate to poor vegetation diversity, which reflects the impact of constructed and agricultural practices regions on the riparian strip and its vegetation structure. Invasive plants may begrown because of low vegetation diversity in riparian areas.

3.2. Effect of soil moisture on species diversity indexes and richness in different seasons

Overall species diversity in the study area remained low andthere were significant differences in species diversity and SM (Table 5). Our study finds a declining species number with decreasing SM. The mean SM at 0–12 cm depth was 0.206%–0.227%. Mean soil moisture was lower in the pre-monsoon season, and higher in the post-monsoon season, but none of these differences were significant (Table 4). Similarly, the mean of biodiversity had also no significant difference (Table 3).

3.3. Correlation between soil moisture and species diversity

The correlation coefficient between soil moisture and species diversity varied concerning the season, with the value range 0.586 to 0.841for the post-monsoon season, 0.349 to 0.782 for the post-winter season, and 0.233 to 0.802 for the pre-monsoon season. The post-monsoon season had a stronger correlation coefficient in comparison to the post-winter and pre-monsoon seasons.No significant correlation exists if $P > 0.05$, and a significant correlation exists if $P < 0.05$ (Chaturvedi *et al.*, 2018). The variations in soil water storage in the top layer (0–12 cm) are shown in Figures 4, 5, and 6, and were found to have a substantial impact on plant variety. In the post-monsoon season, MARI, MERI,and SWDI demonstrated a strong and significant connection ($P < 0.05$) with soil water storage in the top layer, whereas SDI did not reflect significance ($P > 0.05$) (Figure 4).

In the post-winter season, MERI and SWDI were found to be significantly and positively correlated with the top 0–12cm layer of soil water storage as well($P<0.05$) in Figure5, whereas the only SDI, is significantly correlated ($P<0.05$) with soil water,remains three indices were not correlated with the SM inthe pre-monsoon season that reflects in Figure6.

4. Discussion

A larger area of vegetation can both boost the soil's ability to absorb water and protect it from erosion caused by rain but lack of vegetation cover in riparian zonescauses soil erosion during precipitation. The vegetation cover in our study areas is in poor to intermediate condition, according to our findings.

The stretch of the study sitesis not in its natural state because of anthropogenic activity, which results in less vegetation increased soil erosion, and a loss of diversity. In contrast to our findings, Wu *et al.,* (2014) discovered a strong relationship between species diversity and soil moisture at 0–10 cm depth in a semi-arid steppe (the southwest Loess Plateau; roughly 250 mm annual precipitation).The richness or diversity of species is a crucial aspect of communities and is crucial for controlling the composition and operation of an ecosystem (Howard and Lee, 2003).

Giladi *et al.,* (2011) found that species richness was primarily influenced by the precipitation gradient, and Fry *et al.,* (2014) found that decreased rainfall lowers species richness ingrasslands. Xi *et al.,* (2015) found that the amount of precipitation during the growing season plays a valuable role in shaping the structure of the grassland community. Precipitation alters soil water content due to infiltration, which in turn affects plant diversification.According to our findings, plant diversity is greater in the post-monsoon season than in other seasons of the year. This indicates that the soil has absorbed the required amount of water after precipitation or during the monsoon season, directly promoting the growth of riparian vegetation. The pre-monsoon season had the least significant correlation, which supports the research, and the least diversity, which is caused by inadequate sunlight and pollution that is at a low altitude in our atmosphere during this time of year.

5. Conclusion

The diversity and richness indices for the Narmada River study stretch during the monsoon, winter, and summer of 2021–2022 were evaluated based on the riparian vegetation. According to the SDI and SWDI, the Narmada River is in moderate to poor health. Also revealing the river's moderate to poor health were the richness indexes MARI and MERI. The pre-monsoon season has less pollution than the post-winter season, according to diversity and richness indices, which are determined to be slightly higher from winter to summer.The abundance of vegetation has a favorable impact on the moisture content of the surface soil, and soil moisture can affect the species diversity and productivity of plant communities. The soil moisture in the 0–12 cm layer had a significant impact on the variety of species in the current study. In grassland and forest ecosystems, plant variety and production are significantly influenced by soil moisture. According to the study, soil moisture conditions have a significant impact on the diversity of plants in the riparian zone which is indirectly influenced by climate change. Climate change causes variations in soil moisture, which alters riparian ecosystems' structure and functionality.These modifications can encourage the establishment of a few species and lead to the eradication of others. A lot of established species may be wiped out if environmental conditions change drastically, and newcomers may take their place as a result. Therefore, if we are talking about the seasonal health of the Narmada riparian zone, the increase in pollution and anthropogenic activities needs to be addressed by adopting the necessary corrective measures to maintain the water quality of the stretch.According to the study, the stretch of land has moderate ecological health, which implies that although it is not recommended to drink the water, it may be utilized for bathing, irrigation, aquaculture, and other life-sustaining activities. It is advised to replace the riparian vegetation with species that have a rapid vegetative development to lessen bank erosion and create favorablehabitats for migrating birds and aquatic animals and flora which play an additional step in biodiversity conservation goals.

Statements and Declarations

Author contributions: All authors contributed to the study's conception and design. Ankita Singh conducted the data analysis with the support of Pratiksha Singh. Ankita Singh, Pratiksha Singh, and Vipin Vyas jointly contributed to the result interpretation and discussion. Ankita Singh led the writing of the manuscript with the contribution of all co-authors. All authors read and approved the final manuscript.

Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Acknowledgment: We would like to thank the anonymous reviewers of this manuscript for their feedback, which helped us to improve the paper in multiple ways.

Conflicts of Interest: The authors declare no conflict of interest.

Reference

1. An, Y., Gao, Y., Liu, X. H., & Tong, S. Z. (2019). Interactions of soil moisture and plant community properties in meadows restored from abandoned farmlands on the Sanjiang Plain, China. *Community Ecology*, 20(1), 20-27.
2. Anunciação, P. R., Sugai, L. S. M., Martello, F., de Carvalho, L. M. T., & Ribeiro, M. C. (2022). Estimating the diversity of tropical anurans in fragmented landscapes with acoustic monitoring: lessons from a sampling sufficiency perspective. *Biodiversity and Conservation*, *31*(12), 3055-3074.
3. Blinn, C. R., & Kilgore, M. A. (2001). Riparian management practices: a summary of state guidelines. *Journal of Forestry*, *99*(8), 11-17.
4. Chaturvedi, R. K., & Raghubanshi, A. S. (2018). Effect of soil moisture on composition and diversity of trees in tropical dry forest. *MOJ Ecology and Environmental Sciences*, *3*, 0059.
5. Chen, J., Chen, L., Song, N. P., Li, Y. F., Su, Y., & Yang, D. D. (2018). Soil infiltration characteristics of different soil types in desert steppe. *J. Soil Water Conserv*, *32*, 20-25.
6. Fry, E. L., Manning, P., & Power, S. A. (2014). Ecosystem functions are resistant to extreme changes to rainfall regimes in a mesotrophic grassland. *Plant and soil*, *381*(1), 351-365.
7. Fu, B. J., & Yu, D. (2016). Trade-off analyses and synthetic integrated method of multiple ecosystem services. *Resources Science*, *38*(1), 1-9.
8. Giladi, I., Ziv, Y., May, F., & Jeltsch, F. (2011). Scale-dependent determinants of plant species richness in a semi-arid fragmented agro-ecosystem. *Journal of vegetation Science*, *22*(6), 983-996.

9. Graziano, M. P., Deguire, A. K., & Surasinghe, T. D. (2022). Riparian buffers as a critical landscape feature: Insights for riverscape conservation and policy renovations. *Diversity*, *14*(3), 172.
10. Harris, J. (2019). The Effects of Changes in Soil Moisture on the Biodiversity of Herbaceous Plants.
11. Howard, L. F., & Lee, T. D. (2003). Temporal patterns of vascular plant diversity in southeastern New Hampshire forests. *Forest Ecology and Management*, *185*(1-2), 5-20.
12. Klanderud, K., Vandvik, V., & Goldberg, D. (2015). The importance of biotic vs. abiotic drivers of local plant community composition along regional bioclimatic gradients. *PloS one*, *10*(6), e0130205.
13. Lind, L., Hasselquist, E. M., & Laudon, H. (2019). Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. *Journal of environmental management*, *249*, 109391.
14. Lü, T., Zhao, X. N., Gao, X. D., & Pan, Y. H. (2017). Soil water use strategy of dominant species in typical natural and planted shrubs in loess hilly region. *Chin. J. Plant Ecol*, *41*, 175-185.
15. Moeslund, J. E., Arge, L., Bøcher, P. K., Dalgaard, T., Ejrnæs, R., Odgaard, M. V., & Svenning, J. C. (2013). Topographically controlled soil moisture drives plant diversity patterns within grasslands. *Biodiversity and conservation*, *22*(10), 2151-2166.
16. Molina, J. A., Martín-Sanz, J. P., Valverde-Asenjo, I., Sánchez-Jiménez, A., & Quintana, J. R. (2022). Mediterranean grassland succession as an indicator of changes in ecosystem biodiversity and functionality. *Biodiversity and Conservation*, 1-24.
17. Nadeau, M. B., & Sullivan, T. P. (2015). Relationships between plant biodiversity and soil fertility in a mature tropical forest, Costa Rica. *International Journal of Forestry Research*, *2015.*
18. O'Rourke, H., Lughadha, E. N., & Bacon, K. L. (2022). Can the extinction risk of Irish vascular plants be predicted using leaf traits?. *Biodiversity and Conservation*, 1-23.
19. Pandey, S., Kumari, T., Verma, P., Singh, R., & Raghubanshi, A. S. (2022). Impact of anthropogenic stresses on riparian ecosystem and their management perspectives. In *Ecological Significance of River Ecosystems* (pp. 299-324). Elsevier.
20. Peng, Y., Fan, M., Song, J., Cui, T., & Li, R. (2018). Assessment of plant species diversity based on hyperspectral indices at a fine scale. *Scientific Reports, 8(1)*, 1-11.
21. Peters, D. P., Yao, J., Sala, O. E., & Anderson, J. P. (2012). Directional climate change and potential reversal of desertification in arid and semiarid ecosystems. *Global Change Biology*, *18*(1), 151-163.
22. Ravera, O. (2001). A comparison between diversity, similarity and biotic indices applied to the macroinvertebrate community of a small stream: the Ravella river (Como Province, Northern Italy). *Aquatic Ecology*, *35*(2), 97-107.
23. Ruiz-Sinoga, J. D., Galeote, M. G., Murillo, J. M., & Marín, R. G. (2011). Vegetation strategies for soil water consumption along a pluviometric gradient in southern Spain. *Catena*, *84*(1-2), 12-20.
24. Tockner, K., & Ward, J. V. (1999). Biodiversity along riparian corridors. *Large rivers*, *11*(3), 293-310.
25. Valencia, E., Gross, N., Quero, J. L., Carmona, C. P., Ochoa, V., Gozalo, B., ... & Maestre, F. T. (2018). Cascading effects from plants to soil microorganisms explain how plant species richness and simulated climate change affect soil multifunctionality. *Global Change Biology*, *24*(12), 5642-5654.
26. Van Strien, A. J., Soldaat, L. L., & Gregory, R. D. (2012). Desirable mathematical properties of indicators for biodiversity change. *Ecological indicators*, *14*(1), 202-208.
27. Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The river continuum concept. *Canadian journal of fisheries and aquatic sciences*, *37*(1), 130-137.

28. Vásquez-Méndez, R., Ventura-Ramos, E., Oleschko, K., Hernández-Sandoval, L., Parrot, J. F., & Nearing, M. A. (2010). Soil erosion and runoff in different vegetation patches from semiarid Central Mexico. *Catena*, *80*(3), 162-169.
29. Wang, L., Wang, X., Chen, L., Song, N. P., & Yang, X. G. (2021). Trade-off between soil moisture and species diversity in semi-arid steppes in the Loess Plateau of China. *Science of The Total Environment*, *750*, 141646.
30. Wang, R., & Gamon, J. A. (2019). Remote sensing of terrestrial plant biodiversity. *Remote Sensing of Environment*, *231*, 111218.
31. Wu, G. L., Ren, G. H., Wang, D., Shi, Z. H., & Warrington, D. (2013). Above-and below-ground response to soil water change in an alpine wetland ecosystem on the Qinghai-Tibetan Plateau, China. *Journal of Hydrology*, *476*, 120-127.
32. Wu, G. L., Yang, Z., Cui, Z., Liu, Y., Fang, N. F., & Shi, Z. H. (2016). Mixed artificial grasslands with more roots improved mine soil infiltration capacity. *Journal of Hydrology*, 535, 54-60.
33. Wu, G. L., Zhang, Z. N., Wang, D., Shi, Z. H., & Zhu, Y. J. (2014). Interactions of soil water content heterogeneity and species diversity patterns in semi-arid steppes on the Loess Plateau of China. *Journal of Hydrology*, *519*, 1362-1367.
34. Xi, N., Carrère, P., & Bloor, J. M. (2015). Plant community responses to precipitation and spatial pattern of nitrogen supply in an experimental grassland ecosystem. *Oecologia*, *178*(2), 329-338.
35. Xu, Y., Dong, K., Jiang, M., Liu, Y., He, L., Wang, J., ... & Gao, Y. (2022). Soil moisture and species richness interactively affect multiple ecosystem functions in a microcosm experiment of simulated shrub encroached grasslands. *Science of The Total Environment*, *803*, 149950.
36. Yadav, N. S., Sharma, M. P., & Kumar, A. (2015). Assessment of Ecological health of Chambal River using plant species diversity. *J. Mater. Environ. Sci, 6(9*), 2624-2630.
37. Young, S. L., Kyser, G. B., Barney, J. N., Claassen, V. P., & DiTomaso, J. M. (2010). Spatio-Temporal Relationship between Water Depletion and Root Distribution Patterns of Centaurea Solstitialis and Two Native Perennials. *Restoration Ecology*, *18*, 323-333.
38. Zhang, R., Liu, T., Zhang, J. L., & Sun, Q. M. (2016). Spatial and environmental determinants of plant species diversity in a temperate desert. *Journal of Plant Ecology*, *9*(2), 124-131.

Table 1: Details of species richness indices and species diversity indices

Items	Species Richness Indices		Species Diversity Indices	
Name of Index	Margalef's richness index (MARI)	Menhinick's richness index (MERI)	Simpson's diversity index (SDI)	Shannon – Weiner diversity indices (SWDI)
Equations	$MARI = \frac{(S-1)}{\ln(N)}$	$D_{mn} = \frac{S}{\sqrt{N}}$	$SDI = \frac{N(N-1)}{\sum n(n-1)}$	$H = -\sum_1^s[(p_i)\ln(p_i)]$
Range of Indexes	$0 - \infty$	$0 - 1$	$0 - 1$	$0 - 5$
Riparian health	< 2.05: Poor 2.05 – 5: Moderate 5 - ∞: Good	0: Poor 0 - 0.5: Moderate > 0.5: Good	0: Poor 0 – 0.5: Moderate > 0.5: Good	< 2: Poor 2 – 3: Moderate > 3: Good
Where, S = the number of species in a sample, N = the number of individuals in a community, n= the number of individuals in a sample from a population, n_i = the number of individuals in a species i of a sample from a population, p_i is the proportion of i^{th} species in the total sample.				

Table 2: Categorization of plant diversity indices score

Seasons	Site ID	Site Name	Species Richness		Species Diversity	
			Margalef's Richness index	Menhinick Richness index	Simpson's Diversity index	Shanon-Weiner Diversity index
Post-monsoon season	N1	Sandiya	Poor	Moderate	Moderate	Poor
	N2	Bankhedhi Rewa	Poor	Moderate	Moderate	Poor
	N3	Mudiya Khedha	Poor	Moderate	Moderate	Poor
	N4	Bandrabhan	Poor	Moderate	Moderate	Poor
	N5	Dongarwada	Poor	Moderate	Moderate	Poor
	N6	Anwalighat	Poor	Poor	Poor	Poor
	N7	Chippaner	Poor	Moderate	Moderate	Poor
Post-winter season	N1	Sandiya	Poor	Moderate	Moderate	Poor
	N2	Bankhedhi Rewa	Poor	Moderate	Moderate	Poor
	N3	Mudiya Khedha	Poor	Moderate	Moderate	Poor
	N4	Bandrabhan	Poor	Moderate	Moderate	Poor
	N5	Dongarwada	Poor	Moderate	Moderate	Poor
	N6	Anwalighat	Poor	Poor	Poor	Poor
	N7	Chippaner	Poor	Moderate	Moderate	Poor

Pre-monsoon season	N1	Sandiya	Poor	Moderate	Moderate	Poor
	N2	Bankhedhi Rewa	Poor	Moderate	Moderate	Poor
	N3	Mudiya Khedha	Poor	Moderate	Moderate	Poor
	N4	Bandrabhan	Poor	Moderate	Moderate	Poor
	N5	Dongarwada	Poor	Moderate	Moderate	Poor
	N6	Anwalighat	Poor	Poor	Poor	Poor
	N7	Chippaner	Poor	Moderate	Moderate	Poor

Table 3: Biodiversity indices for different seasons

Seasons	*Biodiversity Index*	*Mean*	*SD*	*SE*	*Minimum*	*Maximum*
Pre-Monsoon season	MARI	0.903	0.563	0.212	0.001	1.626
	MERI	0.236	0.132	0.050	0.001	0.4075
	SDI	0.306	0.156	0.059	0.001	0.4619
	SWDI	1.254	0.608	0.230	0.001	1.803
Post-Winter season	MARI	0.612	0.429	0.162	0.001	1.369
	MERI	0.152	0.083	0.031	0.001	0.247
	SDI	0.332	0.161	0.061	0.001	0.473
	SWDI	0.961	0.470	0.177	0.001	1.398
Post-Monsoon season	MARI	0.973	0.532	0.201	0.001	1.464
	MERI	0.302	0.150	0.056	0.001	0.462
	SDI	0.240	0.129	0.048	0.001	0.425
	SWDI	1.395	0.675	0.255	0.001	1.897

Table 4: Soil Moisture in different seasons

Seasons	*Soil Depth*	*Mean*	*SD*	*SE*
Pre-Monsoon season	0-20 cm	0.206	0.164	0.062
Post-Winter Season	0-20 cm	0.207	0.153	0.058
Post-Monsoon season	0-20 cm	0.227	0.194	0.073

Table 5: Correlation between biodiversity indices and soil moisture.

Seasons	*Diversity Indices*	*Coefficient Correlation with Soil Moisture*	*P-value*
Post-Monsoon season	MARI	0.841	0.017*
	MERI	0.753	0.050*
	SDI	0.586	0.166
	SWDI	0.652	0.021*
Post-Winter season	MARI	0.620	0.137
	MERI	0.782	0.037*
	SDI	0.349	0.442
	SWDI	0.756	0.049*
Pre-Monsoon season	MARI	0.278	0.545
	MERI	0.233	0.614
	SDI	0.802	0.029*
	SWDI	0.276	0.548

*Significant at 0.05 level.

Appendix 1 List of identified species in the study area

S.N.	**Common name**	**Botanical name**	**Family**
1	Bristly starbur	*Acanthospermum hispidum*	Asteraceae
2	Indian Copperleaf	*Acalypha indica*	Euphorbiaceae
3	Sweet Flag	*Acorus calamus*	Acoraceae
4	Smooth joyweed	*Alteranthera paronychioides*	Amaranthaceae
5	Khaki weed	*Alternanthera pungens*	Amaranthaceae
6	Slender amaranth	*Amaranthus viridis*	Amaranthaceae
7	Mexican prickly poppy	*Arge mone mexicana*	Papavoraceae
8	Indian Pennywort	*Bacopa monnieri*	Scrophulariaceae
9	Para cress flower	*Blainvillea acmella*	Asteraceae
10	Malay blumea	*Blumea lacera*	Asteraceae
11	Common Hog Weed	*Boerhavia diffusa*	Nyctaginaceae
12	Indian Bluegrass	*Bothriochloa pertusa*	Poaceae
13	Buffalo Grass	*Brachiaria mutica*	Poaceae
14	Sicklepod	*Cassia tora*	Fabaceae
15	Safed Musli	*Chlorophytum tuberosum*	Asparagaceae

16	Dyer's Litmus	*Chrozophora tinctoria*	Euphorbiaceae
17	Spear Thistle	*Cirsium vulgare*	Asteraceae
18	Jew's Mallow	*Corchorus olitorius*	Tiliaceae
19	Bermuda grass	*Cynadon dactylon*	Poaceae
20	Umbrella Sedge	*Cyperus scariosus*	Cyperaceae
21	Crowfoot grass	*Dactyloctenium aegyptium*	Poaceae
22	Sacred datura	*Datura metal*	Solanaceae
23	Marvel Grass	*Dichanthium annulatum*	Poaceae
24	False daisy	*Eclipta alba*	Asteraceae
25	None	*Euphorbia microphylla Heyne*	Euphorbiaceae
26	Asthma herb	*Euphorbia thymifolia*	Euphorbiaceae
27	Eight Day Grass	*Fimbristylis dichotoma*	Cyperaceae
28	Bitter cumin	*Glinus oppositifolius*	Molluginaceae
29	Madras carpet	*Grangea maderaspatana*	Asteraceae
30	Lawn marshpennywort	*Hydrocotyle sibthorpioides*	Apiaceae
31	Pignut	*Hyptis suavedens*	Lamiaceae
32	Water lettuce	*Ipomoea aquatica*	Covolvulaceae
34	Musk Root	*Nardostachys jatamansi*	Caprifoliaceae
35	Congress grass	*Parthenium hysterophorus*	Asteraceae
36	Gulf Leaf Flower	*Phyllanthus fraternus*	Phyllanthaceae
37	Sunberry	*Physalis minima*	Solanaceae
38	Water Pepper	*Polygonum hydropiper*	Polygonaceae
39	Small knotweed	*Polygonum plebeium*	Polygonaceae
40	Purslane	*Portulaca oleracea*	Portulaceae
41	Spreading Cinquefoil	*Potentilla supina*	Rosaceae
42	Wild sugarcane	*Saccharum spontaneum*	Poaceae
43	Broadleaf arrowhead	*Sagittoria latifolia*	Alismataceae
44	Morning mellow	*Sida acuta*	Malvaceae
45	Coatbuttons	*Tridax procumbens*	Asteraceae
46	Elephant Grass	*Typha domingensis*	Typhaceae

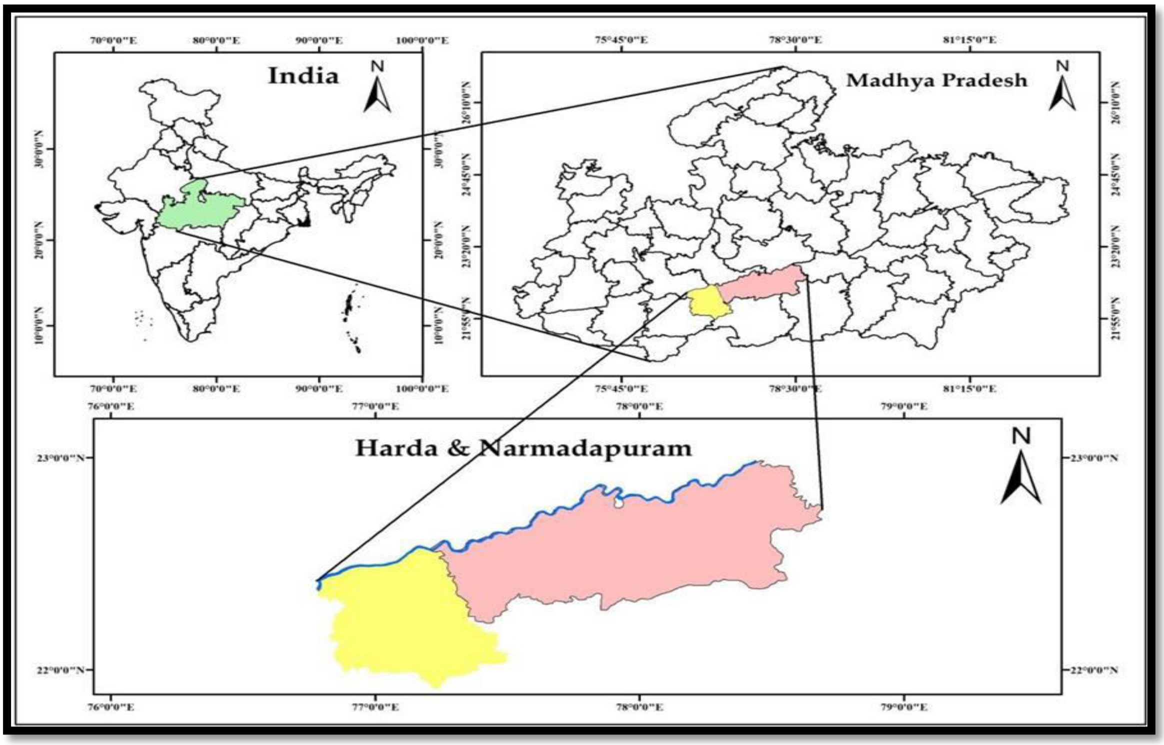


Figure 1: Location map of the study area.

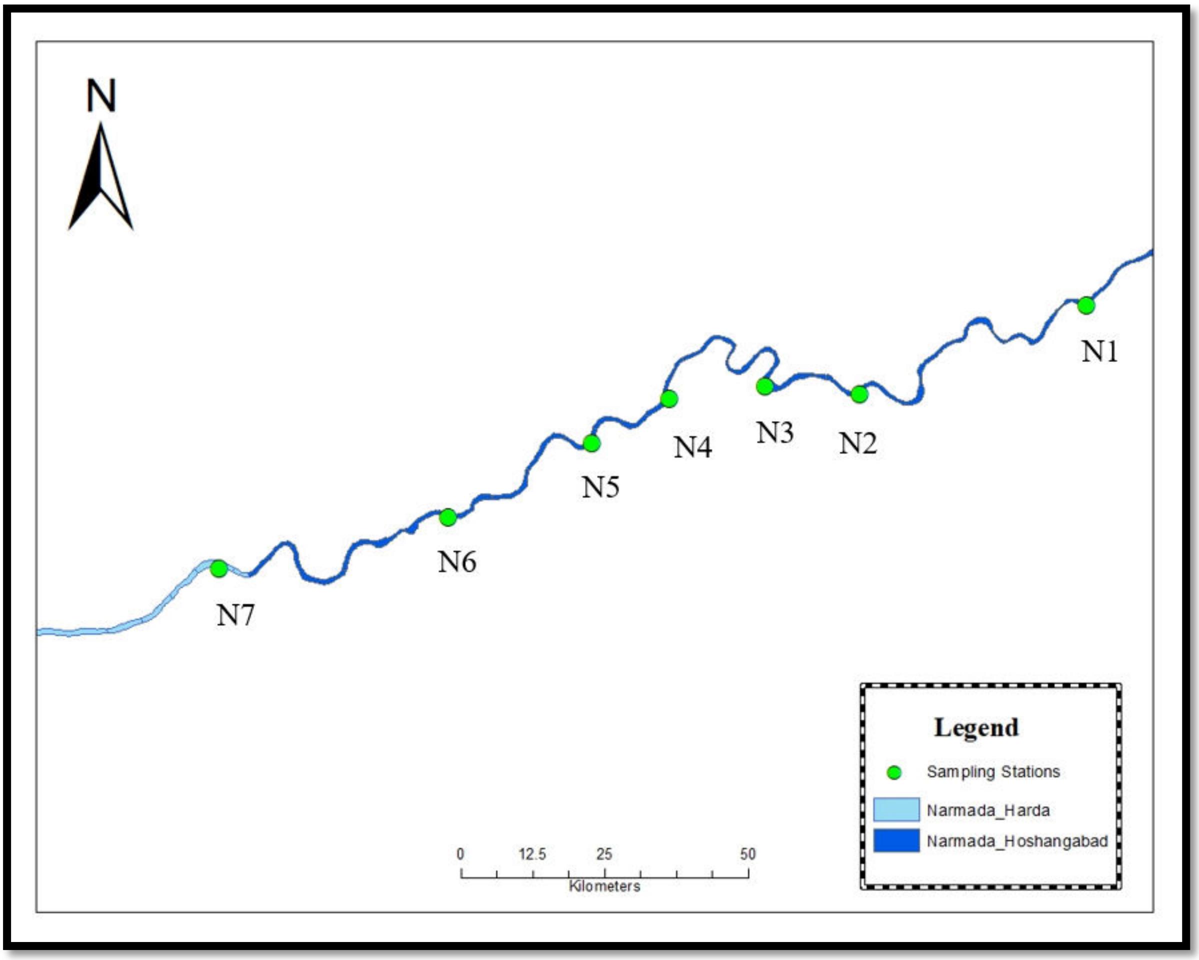
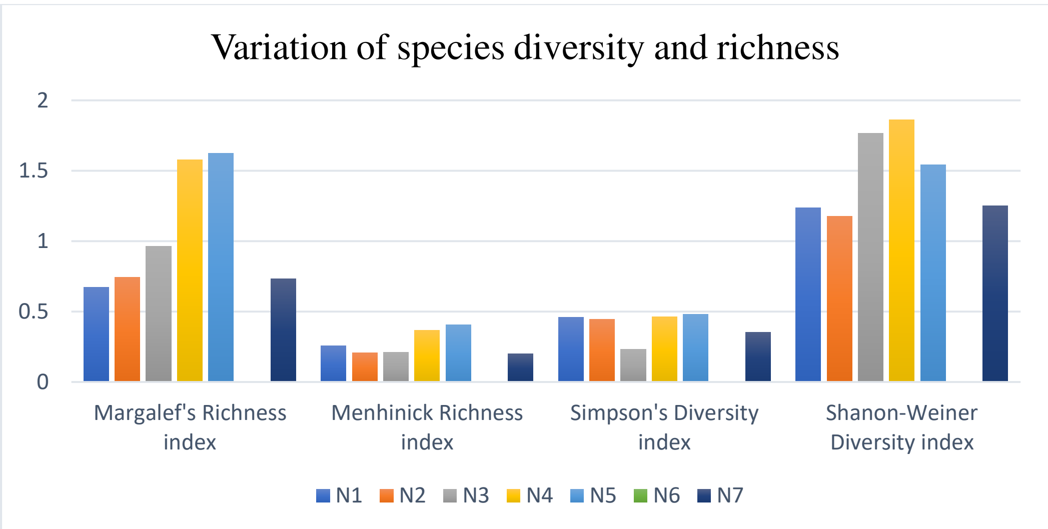
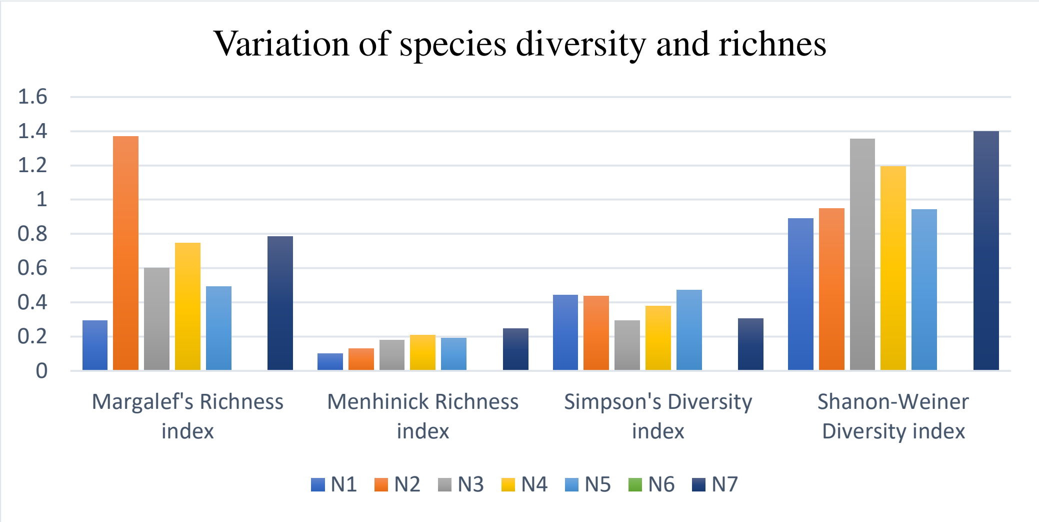


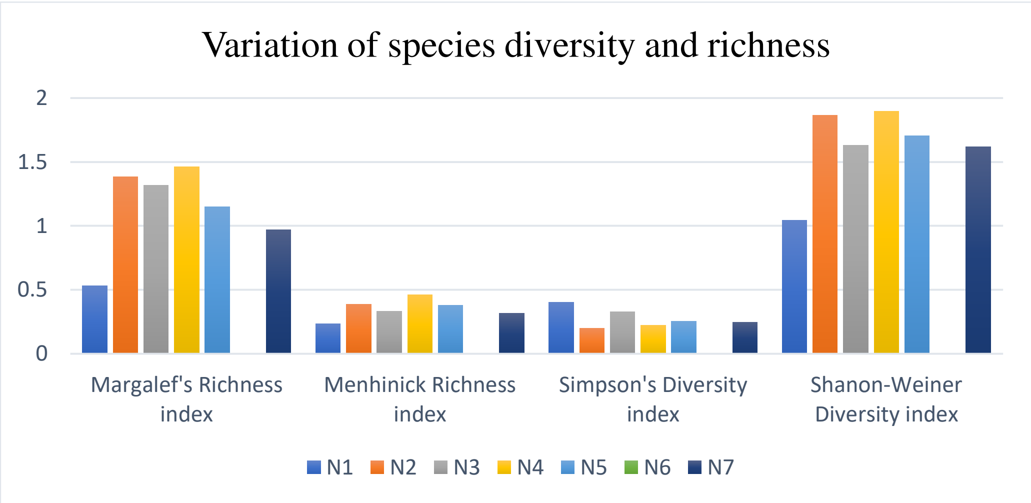
Figure 2: Study stretch of the Narmada River with study sites



(a)



(b)



(c)

Figure 3: Showing the Plant diversity and richness in different season- (a) Diversity in Post winter season (February), (b) Diversity in the Pre-monsoon season (May), and (c) Diversity in the Post-monsoon season (October)

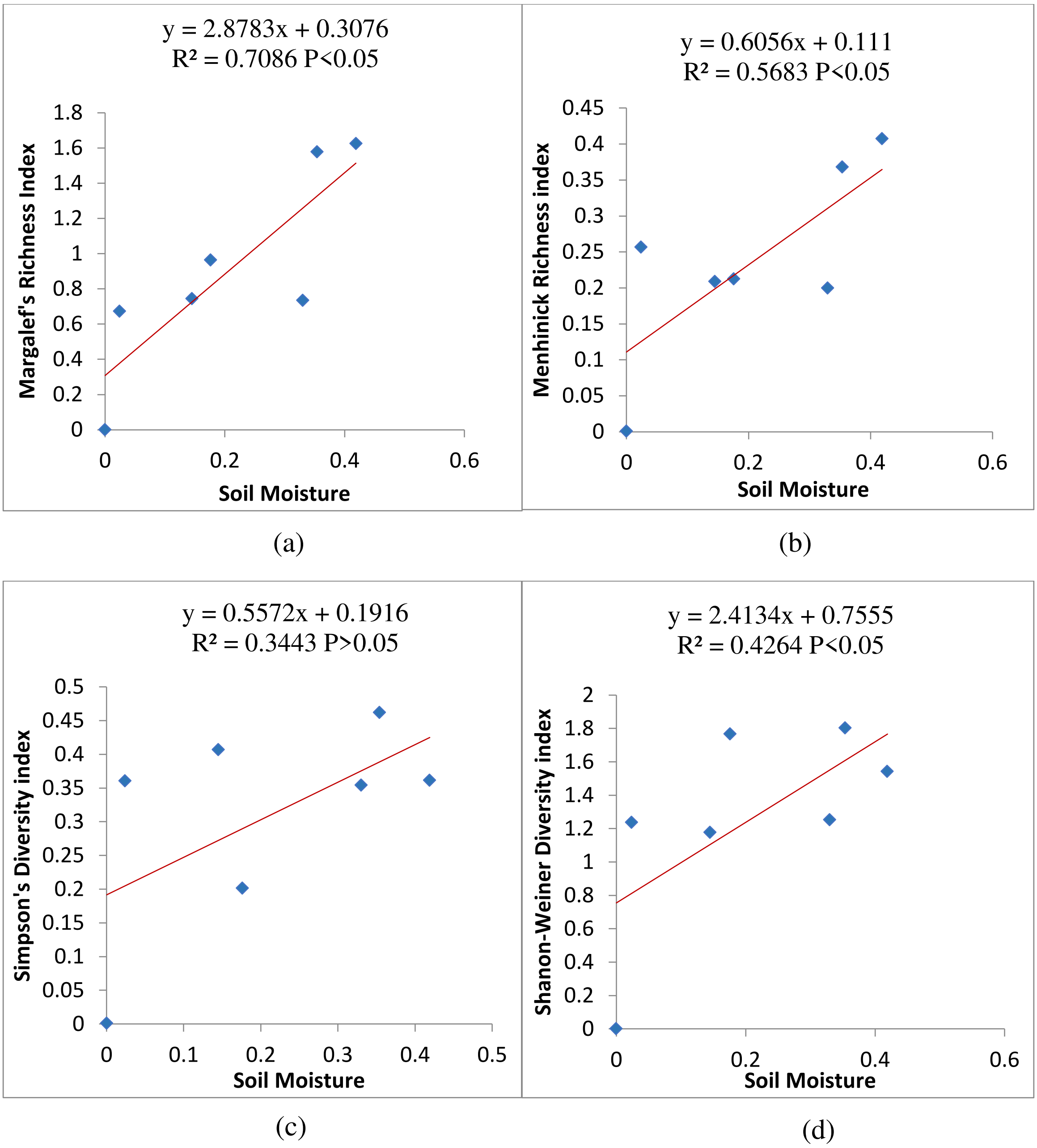


Figure 4: Effect of soil moisture content on (a)Margalef richness index,(b)Menhinick richness index, (c)Simpson's Diversity index, and (d)Shannon-Wiener Diversity index in post-monsoon season (October)

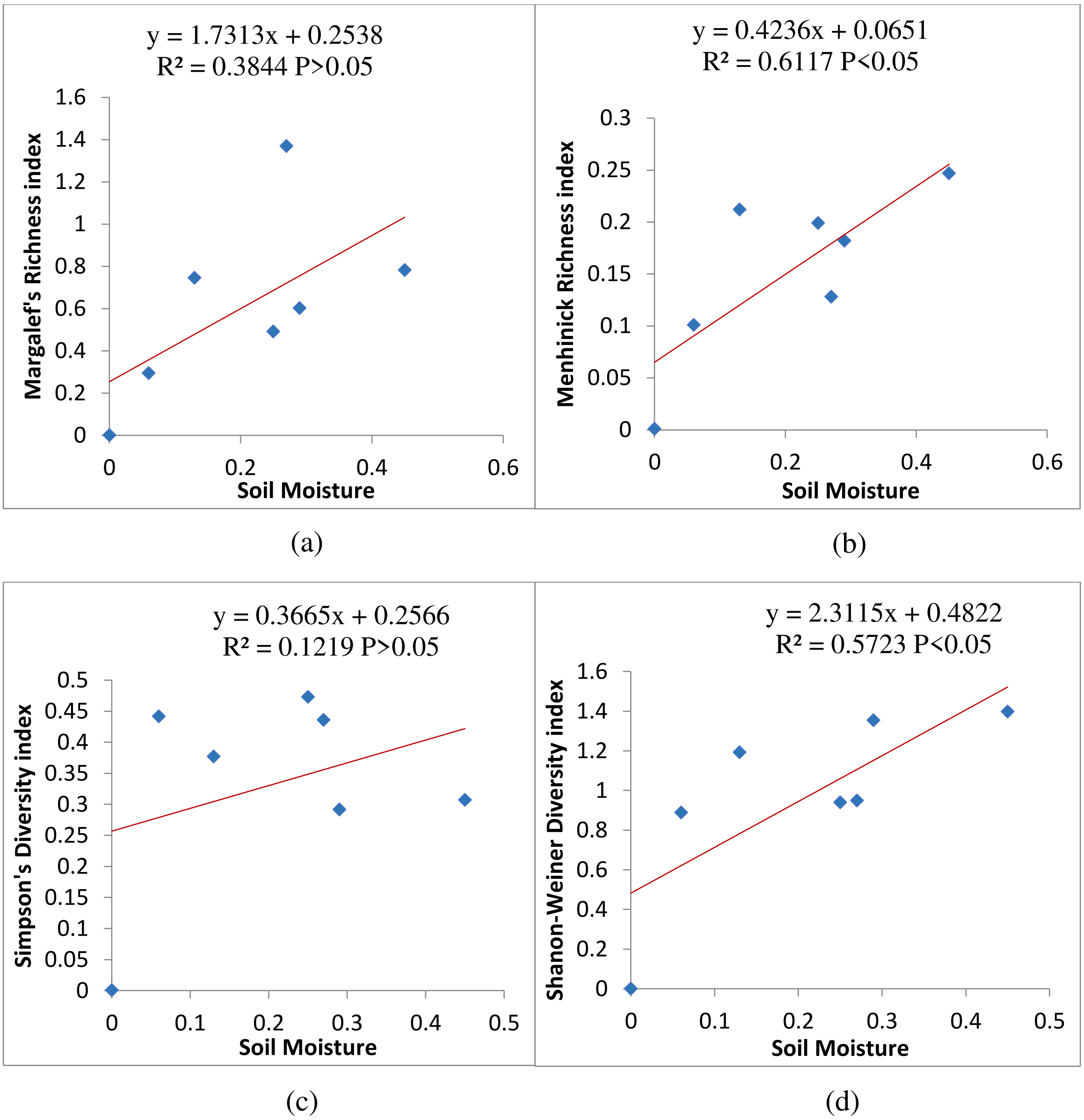


Figure 5: Effect of soil moisture content on (a)Margalef richness index,(b)Menhinick richness index, (c)Simpson's Diversity index, and (d)Shannon-Wiener Diversity index in the post-winter season (February)

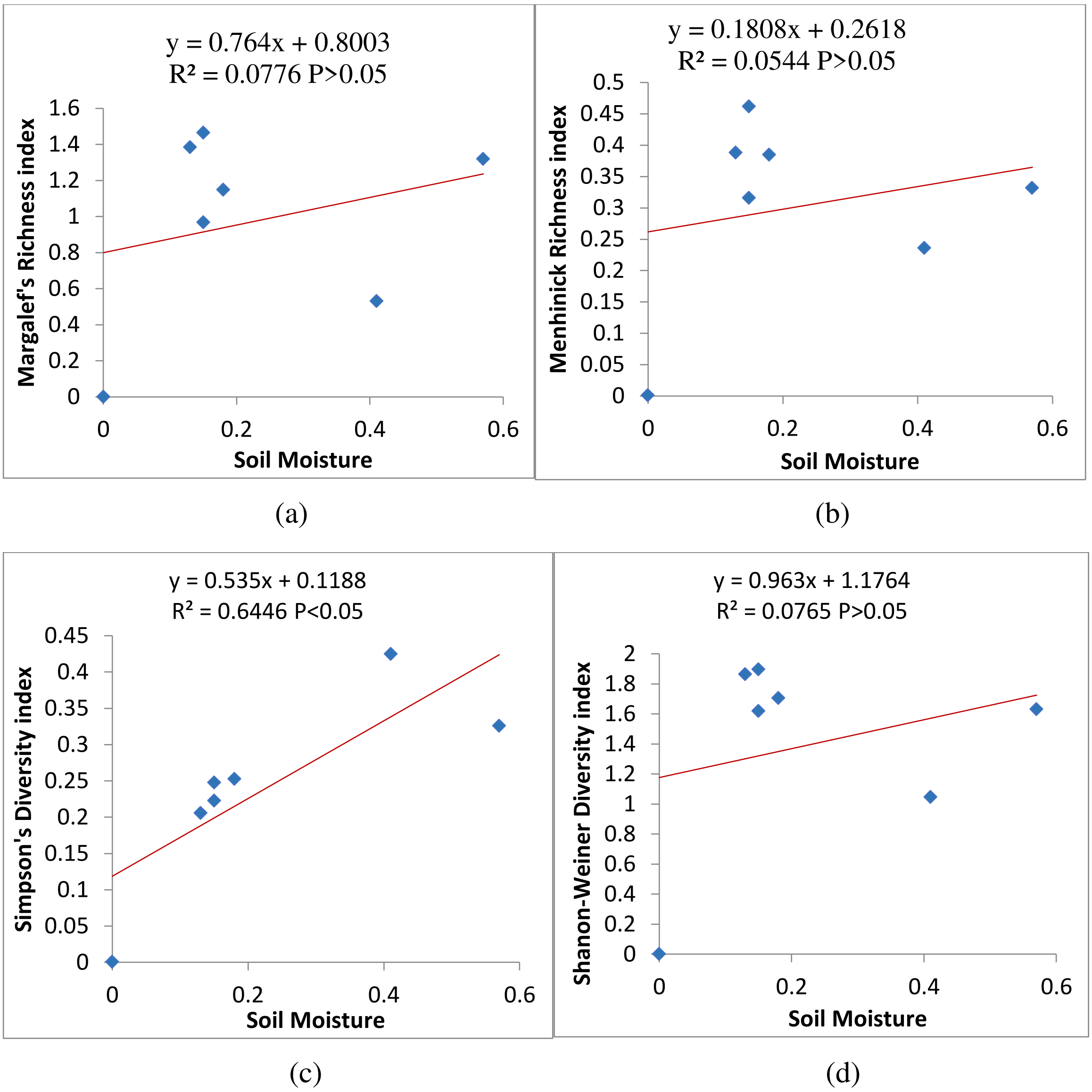


Figure 6: Effect of soil moisture content on (a)Margalef richness index,(b)Menhinick richness index, (c)Simpson's Diversity index, and (d)Shannon-Wiener Diversity index in Summer or Pre-monsoon season (May)