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Seasonal Variations and Land-Use Impacts on Soil Fertility in Riparian Zone of the Dhansiri River, North East, India

W. Lemla, M.R. Singh and W. Temjen[1]

Department of Botany, Nagaland University, Lumami-798 627, India
[1]Department of Botany, Fazl Ali College, Mokokchung-798 601, India
E-mail: watilemm@gmail.com

Abstract: Riparian zones are critical for ecosystem functions such as nutrient cycling, erosion control, and flood regulation. However, these zones are increasingly impacted by human activities. This study investigates seasonal variations in soil physicochemical properties across three land-use types in the Dhansiri River Basin, Northeast India. Key soil parameters, including pH, soil temperature, soil moisture, bulk density, soil organic carbon, and nutrients (available nitrogen, available phosphorus, exchangeable potassium), were analysed across four seasons. Statistical analyses revealed significant seasonal and spatial variations in soil properties. Seasonal fluctuations were observed in pH, soil moisture, soil temperature, and nutrient levels, with urban areas showing higher nutrient concentrations due to organic waste deposition. Bulk density and soil organic carbon content varied significantly across land-use types, reflecting the influence of anthropogenic activities. Correlation analysis demonstrated strong positive associations between pH, soil moisture, and nutrient availability, highlighting the impact of seasonal changes and land-use practices on soil fertility. The findings underscore the need for sustainable land management to mitigate anthropogenic impacts and preserve riparian soil health.

Keywords: Riparian zone, Dhansiri River, Soil properties, Seasonal variation, Land use-impacts

The riparian zone denotes the broad area encircling a water body, stretching from the riverbank to the floodplains. The primary definitions of riparian zones emphasize a functional perspective, highlighting the reversible hydrological, morphological, chemical, and biological interactions present in both water and land systems (Majumdar and Avishek 2023). Besides these essential functions, riparian zones provide various ecosystem services and products that enhance human well-being, including livestock feed, genetic resources, flora and fauna for decorative purposes, fuelwood, carbon sequestration, regulation of the air quality, flood mitigation, pollination, recreation, and aesthetic value. In addition, the riparian vegetation prevents riverbanks against erosion, diminishes evaporation, and prevents soil sediments and minerals from runoff (Dufour et al., 2019). However, despite providing several ecological functions and service are most endangered ecosystems globally because of human activities and natural disturbances. Most commonly, agricultural practices, urban development, alteration in river flow, overexploitation, climate change, pollution, and biological invasions are significant hazards that compromise and degrade riparian zones (Singh et al., 2021). The riparian zones of Indian rivers exhibit diverse influences due to considerable changes in temperature, topography, soil, land use, and anthropogenic activities. Survey in 1995 by the Forest Survey of India indicated that 85% of the Ganga River basin is devoid of forest cover Roy et al. (2015). This is chiefly attributable to agriculture, pollution, dam construction, water extraction, logging, tourism, and flooding (Majumdar and Avishek 2023). Given the importance of the riparian zone, a thorough examination of the soil's physicochemical properties conducted across three distinct land use activities within the Dhansiri river basin to assess soil fertility and the impact of seasonal fluctuations on the soil.

MATERIAL AND METHODS

Experimental area: The present study was conducted in the riparian zone of the Dhansiri River Northeast India. Soil samples were taken from December 2021 to November 2022, encompassing the four seasons: winter, spring, summer, and autumn (Fig. 1). Soil samples were collected from three distinct sites within the Dhansiri River basin, each representing different land-use practices, for subsequent analysis. The sites were selected to reflect a range of land-use types in the region.

Rural Site (R-S1): Located in an agricultural area with typical farming practices, latitude 25°45'20"N and longitude 93°34′38″E with elevation 193.53 msl.

Urban Site (U-S2): Situated in an urbanised zone, affected by anthropogenic activities, including waste disposal, sand mining, and infrastructure development, latitude25°55′24″N and 93°44′58″E, with elevation 163.12 msl.

Semi-Rural Site (SR-S3): Impacted by sand mining, and brick kiln operations, latitude 26°13′07″N and 93°50′54″E with elevation 141.54 msl.

Soil analysis: Soil samples were collected from three different locations, placed in airtight bags, air-dried, and sieved to ensure a consistent particle size. Methodology used for analysis soil parameters listed in Table 1.

Statistical analysis: This was performed using SPSS version 21, including correlation analysis to explore the relationships between soil properties .Significant differences were identified at the 5% level using Duncan's Multiple Range Test (DMRT, p<0.05).

RESULTS AND DISCUSSION

The mean values of soil physico-chemical parameters from three different study sites are presented in Table 2. The p-values and F-values for the seasonal variation of soil parameters, are shown in Table 3.

pH: Soil pH peaked at SR-S3 with a mean of 7.15, whereas the lowest was at R-S1 (6.21). The lower pH at R-S1 may be due to the application of compost and manure fertilizers in the topsoil, which can acidify the soil (Temjen et al., 2022). Similar observation was recorded by Yadav et al. (2024), where at higher elevations, low pH was observed, likely due to the leaching of exchangeable bases through runoff and erosion. In all sampling sites and seasons, the soil pH ranged from slightly acidic to neutral. The highest pH was during the summer, while the lowest occurred in winter. Statistically significant differences were observed in all three stations.

Soil temperature (ST): Soil temperature is strongly influenced by seasonal changes, with summer temperatures reaching 33.92°C and winter temperatures dropping to 22.04°C. These fluctuations are further impacted by spatial and temporal variations, as well as the surrounding vegetation density. In particular, the SR-S3 exhibited higher temperatures, likely due to its lower elevation and the depletion of vegetation caused by sand mining activities. Statistical analysis revealed the ST differences at this site were significant,.

Soil moisture (SM): At all sampling points, SM was consistently lower due to the predominance of sandy soil, which exhibits high permeability and thus reduced moisture retention capacity compared to other soil types. SM content was highest during the rainy season i.e. summer (17.46%), which concurrently diminished in the winter (7.97%). The

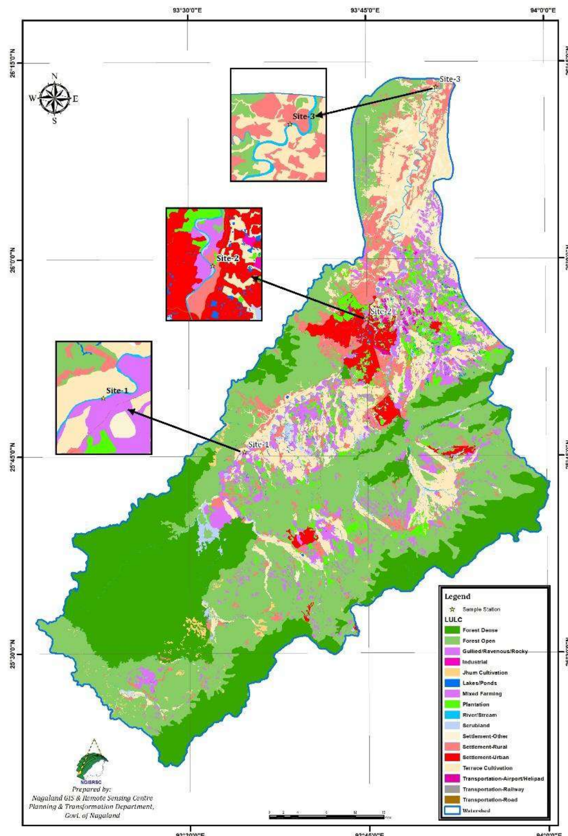

Fig. 1. Land use and land cover map of the three-sampling point of the Dhansiri river

Table 1. Methodology and instruments used to analysis the soil parameters

Parameters	Method	Reference/Instrument
pH	Glass electrode method	Glass electrode
Soil temperature (ºC)	Soil thermometer	Soil thermometer
Soil moisture (%)	Gravimetric method (weighing before and after drying)	Oven, Analytical balance
Bulk density (g cm^{-3})	Core sampler method	Core sampler, Oven, Analytical balance
Conductivity (µS cm^{-1})	Electrical conductivity meter (1:5 w/v, distilled water).	Electrical conductivity meter
Organic carbon (%)	Walkley and Black method (titration method)	Walkley and Black, 1934
Exchangeable potassium (kg ha^{-1})	Flame photometry (photometric method)	Flame photometer
Available nitrogen (kg ha^{-1})	Kjeldahl method (distillation and titration method)	Kelplus Nitrogen Estimation system
Available phosphorus (kg ha^{-1})	Bray's no. 1 extraction method	Bray's no.1, 1945; Spectrophotometry
Soil texture (%)	Pipette method for particle size distribution	Piper, 1942

Table 2. Seasonal mean values of the physicochemical properties of soil of the three sites with Duncan's multiple range test (p<0.05)

	Seasons	pH	ST (ºC)	SM (%)	BD (g cm^{-3})	EC (µS cm^{-1})	SOC (%)	K_{ex} (Kg ha^{-1})	N_{av} (Kg ha^{-1})	P_{av} (Kg ha^{-1})	Sand (%)	Silt (%)	Clay (%)
R-S1	Winter	5.7 ± 0.01^{a}	22.68 ± 0.50^{a}	8.75 ± 0.61^{a}	1.48 ± 0.03^{b}	206.44 ± 6.86^{a}	0.2 ± 0.01^{a}	187 ± 2.92^{a}	67.37 ± 5.38^{a}	7.43 ± 0.28^{a}	82.8 ± 0.33^{b}	10.26 ± 0.53^{a}	5.97 ± 0.22^{a}
	Spring	6.2 ± 0.07^{b}	26.5 ± 1.22^{b}	11.74 ± 0.34^{b}	1.43 ± 0.04^{b}	228.47 ± 2.32^{b}	0.22 ± 0.01^{a}	212.04 ± 5.60^{b}	86.27 ± 3.44^{b}	8.34 ± 0.42^{ab}	81.19 ± 0.66^{a}	11.83 ± 0.62^{bc}	6.63 ± 0.33^{ab}
	Summer	6.5 ± 0.01^{c}	32.6 ± 1.16^{d}	16.85 ± 0.49^{c}	1.34 ± 0.03^{a}	226.97 ± 0.71^{b}	0.3 ± 0.02^{b}	238.55 ± 2.72^{c}	106.84 ± 4.52^{c}	10.13 ± 0.28^{c}	82.7 ± 0.7^{a}	11.24 ± 0.48^{c}	6.61 ± 0.25^{ab}
	Autumn	6.2 ± 0.13^{b}	29.38 ± 1.43^{c}	12.68 ± 1.89^{b}	1.43 ± 0.01^{b}	218.95 ± 4.05^{b}	0.32 ± 0.03^{b}	220.27 ± 5.73^{b}	92.04 ± 3.30^{bc}	8.93 ± 0.36^{bc}	81.21 ± 0.22^{ab}	11.76 ± 0.11^{ab}	6.92 ± 0.13^{b}
Mean±S.E.		6.15±0.10	27.79±0.68	12.5±0.57	1.42±0.01	220.21±1.86	0.26±0.01	214.47±3.45	88.13±3.21	8.71±0.21	81.97±0.33	11.27±0.28	6.53±0.12
U-S2	Winter	6.1 ± 0.09^{a}	22.27 ± 0.33^{a}	7.97 ± 0.68^{a}	1.42 ± 0.01^{c}	212.89 ± 3.25^{a}	0.2 ± 0.02^{a}	174.46 ± 2.50^{a}	81.78 ± 3.98^{a}	9.39 ± 0.34^{a}	82.8 ± 0.33^{a}	10.26 ± 0.53^{a}	6.94 ± 0.28^{ab}
	Spring	6.51 ± 0.1^{b}	26.59 ± 1.23^{b}	12.18 ± 0.66^{b}	1.38 ± 0.02^{bc}	246.42 ± 2.01^{b}	0.22 ± 0.02^{a}	185.71 ± 7.56^{a}	101.6 ± 8.10^{b}	10.55 ± 0.02^{ab}	81.22 ± 0.66^{a}	11.81 ± 0.64^{b}	6.97 ± 0.54^{b}
	Summer	7.11 ± 0.09^{c}	33.68 ± 0.62^{d}	17.4 ± 1.1^{c}	1.32 ± 0.02^{a}	249.06 ± 5.34^{b}	0.39 ± 0.04^{b}	216.98 ± 5.11^{b}	141.45 ± 5.80^{c}	12.73 ± 0.23^{c}	82.72 ± 0.72^{a}	11.22 ± 0.51^{ab}	6.05 ± 0.31^{a}
	Autumn	6.57 ± 0.24^{b}	30.3 ± 2.43^{c}	13.01 ± 2.25^{b}	1.37 ± 0.02^{b}	215.56 ± 1.41^{a}	0.25 ± 0.03^{a}	204.86 ± 7.17^{b}	110.46 ± 7.99^{b}	11.57 ± 0.62^{bc}	81.25 ± 0.18^{a}	11.71 ± 0.07^{ab}	7.03 ± 0.12^{b}
Mean±S.E.		6.57±0.13	28.21±0.80	12.64±0.67	1.37±0.01	230.98±3.28	0.26±0.01	195.5±3.37	108.82±4.10	11.06±0.26	81.99±0.29	11.25±0.22	6.75±0.14
SR-S3	Winter	6.05 ± 0.14^{a}	22.04 ± 0.82^{a}	8.25 ± 0.81^{a}	1.39 ± 0.02^{b}	186.54 ± 3.50^{a}	0.21 ± 0.01^{a}	185.5 ± 9.70^{a}	84.55 ± 1.41^{a}	9.24 ± 0.31^{a}	82.2 ± 0.12^{a}	11.57 ± 0.13^{a}	6.23 ± 0.18^{ab}
	Spring	6.54 ± 0.09^{b}	27.92 ± 1.59^{b}	12.8 ± 0.50^{b}	1.36 ± 0.03^{b}	207.57 ± 3.85^{b}	0.27 ± 0.03^{b}	207.36 ± 15.79^{b}	107.59 ± 8.12^{b}	11.16 ± 0.07^{b}	80.94 ± 0.36^{a}	12.3 ± 0.18^{a}	6.75 ± 0.21^{ab}
	Summer	7.15 ± 0.13^{c}	33.92 ± 0.23^{c}	17.27 ± 0.63^{c}	1.26 ± 0.01^{a}	202.98 ± 0.63^{b}	0.32 ± 0.01^{bc}	253.77 ± 6.78^{c}	116.11 ± 5.24^{b}	12.62 ± 0.51^{c}	82.59 ± 0.68^{a}	11.57 ± 0.53^{a}	5.83 ± 0.16^{a}
	Autumn	6.79 ± 0.2^{b}	29.87 ± 1.99^{b}	13.22 ± 2.2^{b}	1.23 ± 0.03^{a}	200.57 ± 3.42^{ab}	0.35 ± 0.01^{c}	221.39 ± 8.81^{b}	106.67 ± 5.33^{b}	12.19 ± 0.28^{bc}	80.62 ± 0.63^{a}	12.09 ± 0.37^{a}	7.28 ± 0.54^{b}
Mean±S.E.		6.62±0.14	28.44±0.81	12.88±0.66	1.31±0.01	199.41±2.24	0.29±0.01	217±4.95	103.73±2.74	11.30±0.30	81.59±0.29	11.88±0.17	6.52±0.16

The mean values in column with superscript (a,b,c,d) are significantly different at 5% level by Duncan's multiple range test (p<0.05)

difference was seen at all three sites.

Bulk density (BD): The average means recorded in R-S1, U-S2, and SR-S3 were 1.42g cm^{-3}, 1.37g cm^{-3}, and 1.31g cm^{-3}, respectively. The maximum BD of 1.48g cm^{-3} was in winter at R-S1. Similar findings was reported by Takele et al. (2014). Minimum value of 1.26 g cm^{-3} was observed in summer at SR-S3. In R-S1 and U-S2 and SR-S3 statistical difference was observes at p<0.001.

Electrical conductivity (EC): The average EC in R-S1, U-S2, and SR-S3 varied from 199.41 to 230.98 µScm^{-1}. The minimum concentration of EC was in winter at SR-S3 (1876.54 µScm^{-1}) and maximum in summer at U-S2 (249.06 µScm^{-1}), which attributed to the increased concentration of salts from various chemicals, dissolved solids, trace metals, colloidal particles, and ions, hence enhancing soil conductivity (Tewari et al., 2016). The three sites demonstrate significant seasonal variation.

Soil organic carbon (SOC): Soil Organic Carbon plays a crucial role in maintaining soil health, contributing significantly to soil fertility, productivity, and overall ecosystem functionality (Ebabu et al., 2020). The SOC content was highest in U-S2 (0.39 %). Similar observation of high OC content in dumping site was observed by Agbeshie et al., (2020) and lowest in R-S1 (0.19 %), with the oxidation of organic carbon being exacerbated by practices such as shifting agriculture, overgrazing, and leaching near the riparian zones. These factors contribute to a decrease in SOC. Additionally, seasonal fluctuations in SOC were significant at p<0.001 indicating variation over time in all three sites.

Exchangeable potassium (K_{ex}): Potassium is crucial for various physiological processes in plants and is an essential element for their development. The mean K_{ex} in R-S1, U-S2, SR-S3 soil was 214.47, 195.5 and 217±4.95 kg ha^{-1}. The maximum was in S3 (253.77 kg ha^{-1}), while the minimum in U-S2 (174.46kg ha^{-1}). The diminished quantity of potassium may result from extensive garbage disposal, causing deterioration and loss of vegetation in that region. The comparable pattern was corroborated by Njue et al. (2016). Seasonally, the maximum K_{ex} was in summer and minimum in winter across all three land types. K_{ex} exhibited variation across all three sites.

Available nitrogen (N_{av}): Available nitrogen is an essential element of soil quality, significantly influencing plant growth, agricultural yield, and overall ecosystem functionality (Prasad et al., 2023). There were significant seasonal variations in the N_{av} across three distinct soil samples. During summer, the soil exhibited the maximum N_{av} level in U-S2 (141.45kg ha^{-1}), followed by SR-S3 and R-S1. Similar findings were observed by Ramya et al. (2021). The elevated N_{av} levels can be attributed to the deposition of nutrient-rich organic matter in the dumping zones, which enhances the population of nitrogen-fixing organisms, as well as to higher biological nitrogen fixation. This is in agreement with Saha et al. (2018).

Available phosphorous (P_{av}): Seasonally fluctuation was observed with the maximum P_{av} in summer (12.62-12.73 kg ha^{-1} in SR-S3 and U-S2). The concentration of P_{av} was minimum in winter (7.43kg ha^{-1}). Significant difference was observed among the seasons. Among the three sites, the P_{av} concentration was higher in U-S2 and SR-S3. The high moisture content in U-S2 and SR-S3, along with the presence of organic carbon and microbial activities in the dumping area, could be the reason for the increased availability of phosphorus and other nutrients in these sites compared to R-S1. Semy and Singh (2021) reported similar findings.

Soil texture: The textural analysis of the three study areas revealed that the soils were primarily loamy sand. The sand content ranged from 82.62 to 82.80%, silt from 10.26 to 12.30%, and clay from 5.83 to 7.28%, with variations observed across the four seasons. The significant seasonal variation in sand and silt content was in R-S1 with the highest sand percentage in winter and the lowest in spring and autumn. Silt content peaked in spring SR-S3 and autumn for SR-S3, while silt was lowest in winter at all sites. No significant seasonal variations in sand, silt, and clay concentration were observed in U-S2 and SR-S3. Meanwhile, in all three sites highest clay content occurred in autumn, with the lowest levels recorded in summer. These

Table 3. Seasonal variation of the three-study area

Parameters	R-S1		U-S2		SR-S3	
	p-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value
pH	< 0.001	25.81	< 0.001	26.45	< 0.001	32
ST	< 0.001	46.09	< 0.001	41.37	< 0.001	42.48
SM	< 0.001	28.73	< 0.001	21.70	< 0.001	22.99
BD	< 0.001	10.54	< 0.001	16.40	< 0.001	26.82
EC	< 0.001	13.63	< 0.001	32.12	0.003	5.71
SOC	< 0.001	24	< 0.001	23.00	< 0.001	19.18
K_{ex}	< 0.001	50.07	< 0.001	23.19	< 0.001	26.72
N_{av}	< 0.001	13.30	< 0.001	38.83	< 0.001	11.39
P_{av}	0.001	11.61	< 0.001	12.45	< 0.001	17.49
Sand	< 0.001	9.26	0.043	3.05	0.031	3.34
Silt	<0.001	10.21	0.038	3.15	0.319	1.22
Clay	0.58	2.77	0.034	3.27	0.12	4.25

Table 4. Correlation among the different soil parameters

	PH	ST	SM	BD	EC	SOC	K_{ex}	N_{av}	P_{av}	SAND	SILT	CLAY
pH	1											
ST	.951**	1										
SM	.981**	.954**	1									
BD	-.911**	-.871**	-.854**	1								
EC	.694*	.615*	.690*	-.468	1							
SOC	.786**	.841**	.741**	-.804**	.462	1						
K_{ex}	.911**	.969**	.896**	-.873**	.539	.849**	1					
N_{av}	.959**	.978**	.950**	-.850**	.669*	.794**	.971**	1				
P_{av}	.929**	.962**	.941**	-.828**	.650*	.845**	.895**	.932**	1			
Sand	.061	-.034	.022	-.035	-.104	.156	.065	.037	-.097	1		
Silt	.284	.366	.315	-.337	.371	.120	.314	.323	.372	-.851**	1	
Clay	-.201	-.072	-.192	.187	-.150	-.145	-.140	-.143	-.019	-.857**	.544	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

findings suggest that the soils have low porosity and poor water retention capacity, with sand being the dominant particle size at all sites. This observation is consistent with the results of Singh et al., (2016) in soils of Punjab. The reduced presence of clay and silt particles may be linked to the effects of grazing animals, which can cause the removal of finer particles through wind and water erosion (Hishe 2017).

Correlation: The Pearson correlation analysis indicate a very strong positive association between pH and SM, with a correlation coefficient of r=0.981, which is statistically significant (Table 4). This signifies that as pH rises, SM also ascends in a nearly linear manner. In addition, pH showed a positive corelation with ST, SOC, N_{av}, P_{av}, and K_{ex}, obtaining significance at $p<0.01$, indicating that fluctuations in pH values will appropriately influence the rise or a decline of specific parameters. Semy and Singh (2021) also observed a substantial negative correlation between BD and pH. ST exhibited a positive significance with SM, SOC, and NPK. Jiao et al. (2016) reported a similar observation, increase in ST elevates nutrient levels in the soil. The ST was found to have a negative correlation with BD. SM was strongly and significantly positively correlated with micronutrient concentration NPK and with EC and SOC at $p<0.05$. BD exhibits a negative connection with, NPK at $p<0.01$. The majority of the parameters did not exhibit a significant relationship with EC, with the exception of N_{av} and P_{av}, which was positively significant. Substantial positive correlation was observed between SOC and NPK. The SOC exhibited a significant positive correlation with NPK, presumably as available nutrients are integral components of organic matter. The quantity of organic matter and its mineralization by microorganisms play a critical role in the availability of nutrients in soils (Singh et al., 2012). SOC was negatively correlated with BD, which can be attributed to the high organic matter present. Similar findings were reported by Ruiz Sinoga et al. (2012). The micronutrients NPK exhibited positive correlations with each other, as well as with pH, ST, and SM. NPK showed a negative correlation with BD. Sand content was negatively correlated with both silt and clay

CONCLUSION

This study highlights the negative impact of agricultural expansion, landfills, and sand mining on the Dhansiri riparian zone. Clearing vegetation and poor land management have degraded soil quality, reducing fertility and ecosystem services. Soil properties show seasonal variation, with lower bulk density in summer and moderate to low organic carbon levels. Despite some increases in nutrients (NPK), the overall soil health has declined, reflecting the effects of population growth and development. The findings emphasize the need for sustainable land use and riparian conservation to restore soil fertility and ecosystem function.

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