

Physicochemical Properties of River Sediments in an Agriculture Region: A Case Study of Buyeo County, South Korea

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Abstract: This study investigated the physicochemical characteristics of river sediments across Buyeo County, Chungnam Province, South Korea. Surface sediments (0–10 cm) were collected from 106 sampling sites and analyzed for pH, electrical conductivity (EC), total nitrogen (T-N), total phosphorus (T-P), exchangeable cations, and soil texture (sand, silt, and clay). Multivariate statistical analyses were employed to examine the distribution characteristics and potential sources of these components. The average pH of the sediments was 6.07 (range 4.54–8.13), and EC averaged 1.11 dS/m (range 0.17–4.86). The mean concentrations of T-P and T-N were 677 mg/kg (range 134–1,760) and 1,155 mg/kg (range 130–6,757), respectively. The coefficients of variation (CV) for T-P (51.6%) and T-N (85.2%) were relatively high, suggesting pronounced spatial heterogeneity and potential anthropogenic influence. Correlation and multivariate analyses further revealed strong associations among T-N, T-P, and EC, indicating that nutrient enrichment in the study area is likely governed by multiple sources, including diffuse agricultural runoff, domestic wastewater, and agricultural drainage. To our knowledge, this work represents the first county-scale sediment assessment of nutrient variability in Buyeo using CV, correlation, PCA, and cluster analysis. The results provide a useful baseline dataset for sediment management and non-point source pollution control in agricultural watersheds.

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Introduction

Rivers serve as dynamic interfaces between terrestrial and aquatic ecosystems, mediating the transport, transformation, and storage of sediment-bound nutrients, organic matter, and pollutants. They facilitate the downstream transport and accumulation of diverse materials generated within their basins. Among these, river sediments function as both a reservoir and a secondary source of nutrients, heavy metals, and other pollutants, playing a pivotal role in riverine biogeochemical cycling. This has been demonstrated to exert a strong influence on the long-term variation of river water quality [1]. Accordingly, evaluating the physicochemical characteristics of sediments is a core approach for assessing riverine environmental health. These characteristics demonstrate a high degree of sensitivity to land use, hydrological conditions, agricultural activities, and material inputs within the watershed, thus reflecting the spatial heterogeneity of river and soil environments [2].

In Korea's major river systems, point-source pollution has significantly declined following the nationwide implementation of the Total Maximum Daily Load (TMDL) program. However, the relative contribution of nonpoint-source pollution originating from agricultural, livestock, and urban land use has been increasing [3,4]. In particular, the land-use sector has been reported to account for a substantial proportion of total phosphorus loads from nonpoint sources, indicating that nutrient management in agriculture-dominated catchments is a key factor determining the overall performance of the TMDL program [3,4]. Furthermore, sediment texture plays a crucial role in nutrient behavior; an increase in the proportion of fine particles enhances the adsorption and accumulation of phosphorus [5,6]. It has been demonstrated by a considerable number of studies that agricultural nonpoint-source pollution is a significant source of total nitrogen (T-N) and total phosphorus (T-P), with these nutrients being able to accumulate in river sediments over an extended period of time [5,7,8].

The Geum River basin, a major river system in the Chungcheong region, is a complex watershed where diverse hydrological and topographical conditions coexist with strong anthropogenic influences, stretching from Daechong Lake in the upper reaches to the Geum River Estuary Barrage in the lower reaches. In the main channel of the Geum River, changes in sediment nutrient concentrations following the opening of weirs have been reported [7]. Recent studies in the main channel and its tributaries have examined changes in sedimentary environments associated with weir operations, differences in nutrient concentrations according to land use, and variability in the chemical composition of downstream sediments [9,10]. Furthermore, there have been studies of long-term (over 10 years) trends in water quality deterioration based on changes in electrical conductivity (EC) and nitrate-nitrogen concentrations in groundwater and river water. These studies have also included simulations of nonpoint-source pollutant loads under future climate scenarios in highland agricultural watersheds [11-13]. However, the majority of these studies have focused on in-stream concentrations, flow-load relationships, or limited river sections near specific structures. Consequently, there is a paucity of basin-wide analyses that link the spatial characteristics of river sediments—which function as storage, buffering, and delayed-release media for nutrients—to agricultural nonpoint-source pollution.

Internationally, numerous studies have simultaneously assessed the concentrations and speciation of heavy metals together with T-N, T-P, and organic matter in river and lake sediments, and have evaluated ecological risks using tools such as Sediment Quality Guidelines (SQGs) [14-16]. The aforementioned studies emphasise the pivotal role of sediments in regulating the long-term internal loading of nutrients and heavy metals within aquatic ecosystems. They underscore the necessity of comprehensively characterising sediment properties in the formulation of water quality and sediment management policies. Furthermore, recent studies have demonstrated that alterations in rainfall intensity and frequency, which are associated with climate change, have the potential to augment nonpoint-source pollutant loads in agricultural watersheds and modify the spatio-temporal distribution of Critical Source Areas (CSAs) within basins [4,13]. In this context, the characterisation of the physicochemical properties of river sediments adjacent to agricultural land is of significance not only for the comprehension of contemporary conditions, but also for the assessment of the potential for internal nutrient loading under future climate regimes.

Recent studies have further highlighted that sediment-water interactions in agricultural and urbanizing rivers can substantially control nitrogen and phosphorus dynamics and internal loading, especially under changing hydrological regimes [2].

Buyeo County, located in the middle-to-lower reaches of the Geum River, is a typical agriculture-dominated region where farmland and rivers are closely associated. Consequently, the characteristics of its river sediments are likely to directly reflect the impacts of agricultural activities and nonpoint-source pollution. In contrast to the preceding studies in the Geum River basin, which have predominantly concentrated on the quality of water and the properties of sediment in the primary channel or in sections in the vicinity of particular weirs [8,18], this study has undertaken a comprehensive investigation. This investigation has involved the simultaneous examination of the soil textures of river sediments and the key chemical properties of river sediments, including pH, EC, T-N, T-P, and exchangeable cations, at a total of 106 sites dispersed throughout the study area. Furthermore, by conducting a spatial analysis of the relationships among sediment properties according to texture class and nutrient concentrations, this study provides baseline information that can be used for sediment management, the TMDL program, and the development of non-point source pollution reduction measures in small to medium-sized river basins where agricultural

non-point source pollution is dominant [12,17-19].

The objectives of this study were to (1) evaluate key physicochemical properties (pH, EC, T-N, T-P, and exchangeable cations) of river sediments collected from 106 sites, (2) analyze variation patterns according to soil texture (sand, silt, clay) and clarify interrelationships among properties, and (3) characterize spatial distribution features to provide baseline information for sediment management and agricultural NPS pollution reduction in the Geum River basin. The study aims to support the establishment of environmental policies and watershed management plans for Buyeo County and the wider Geum River basin by achieving these objectives.

Results and Discussion

Physicochemical properties of river sediment

The physicochemical properties of river sediments in the study area are summarized in Table 1. The measured pH values ranged from 4.54 to 8.13, with a mean of 6.07. The mean EC was 1.11 dS/m (range 0.17-4.86), with relatively high values at several sampling points, likely reflecting the influence of salts derived from agricultural drainage and non-point source pollution in this typical agricultural area. The pH and EC values used in this study were obtained from our previous work reported by Son and Yun [23]. The average concentrations of T-N and T-P were 1,155 g/kg (range 130-6,757) and 677 mg/kg (range 134-1,760), respectively. The mean concentrations of exchangeable Ca^{2+} , Mg^{2+} , Na^{+} , and K^{+} were 2.47, 0.65, 0.33, and 0.25 cmol/kg, respectively. The average particle-size composition of the sediment samples was 58.5% sand, 32.6% silt, and 9.68% clay (Table 1). As shown in Fig. 1, most samples (70%) were classified as sandy loam (34%) or loamy sand (36%). Detailed physicochemical data for all sampling sites are provided in Supplementary Table S1 of the Supplementary Materials.

The coefficient of variation (CV) for each sediment parameter ranged from 12.5% to 85.2% (Table 1). The CV indicates the relative dispersion of the data and is generally low in environments influenced by natural factors, and high in environments significantly affected by human activity. Notably, the CVs for T-N, T-P and EC were elevated to 85.2%, 51.6% and 81%, respectively, suggesting the presence of spatially heterogeneous anthropogenic loading [24]. In previous sediment studies, CV values greater

Table 1. Statistical description of physicochemical properties of river sediment in the study area

	Mean	Median	Min	Max	SD	CV	Skew.	Kurto.	p (K-S test)
(N=106)									
pH (1:5)	6.07	6.14	4.54	8.13	0.76	12.5	0.07	-0.03	0.20
EC (dS/m)	1.11	0.86	0.17	4.86	0.90	81.0	1.98	4.55	0.00
T-N (g/kg)	1155	879.8	129.9	6756	984.4	85.2	2.37	9.48	0.00
T-P (mg/kg)	677.2	586.8	134.2	1760	349.1	51.6	0.99	0.78	0.00
Ex. cation (cmolc/kg)									
K	0.25	0.23	0.01	1.04	0.16	45.6	1.45	4.57	0.01
Ca	2.47	2.23	0.43	5.76	1.34	34.2	0.60	-0.55	0.01
Mg	0.65	0.58	0.10	3.03	0.48	44.5	2.15	7.12	0.00
Na	0.33	0.18	0.09	2.14	0.36	48.3	2.26	5.71	0.00
Soil texture (%)									
Sand	58.5	63.4	0.96	89.2	22.8	39.0	-0.63	-0.63	0.00
Silt	32.6	28.8	1.20	84.9	22.1	67.9	0.62	-0.64	0.01
Clay	9.68	9.82	0.85	30.6	3.51	36.2	2.07	13.2	0.00

SD, standard deviation; CV, coefficient of variation; Skew, skewness; Kurto, kurtosis; p (K-S test), p-values of Kolmogorov-Smirnov test for normality of the raw data (for values higher than 0.05 the distribution is normal). The pH and EC values used in this study were obtained from our previous work reported by Son and Yun [23].

USDA Soil Texture Triangle with FAO soil textures outlined

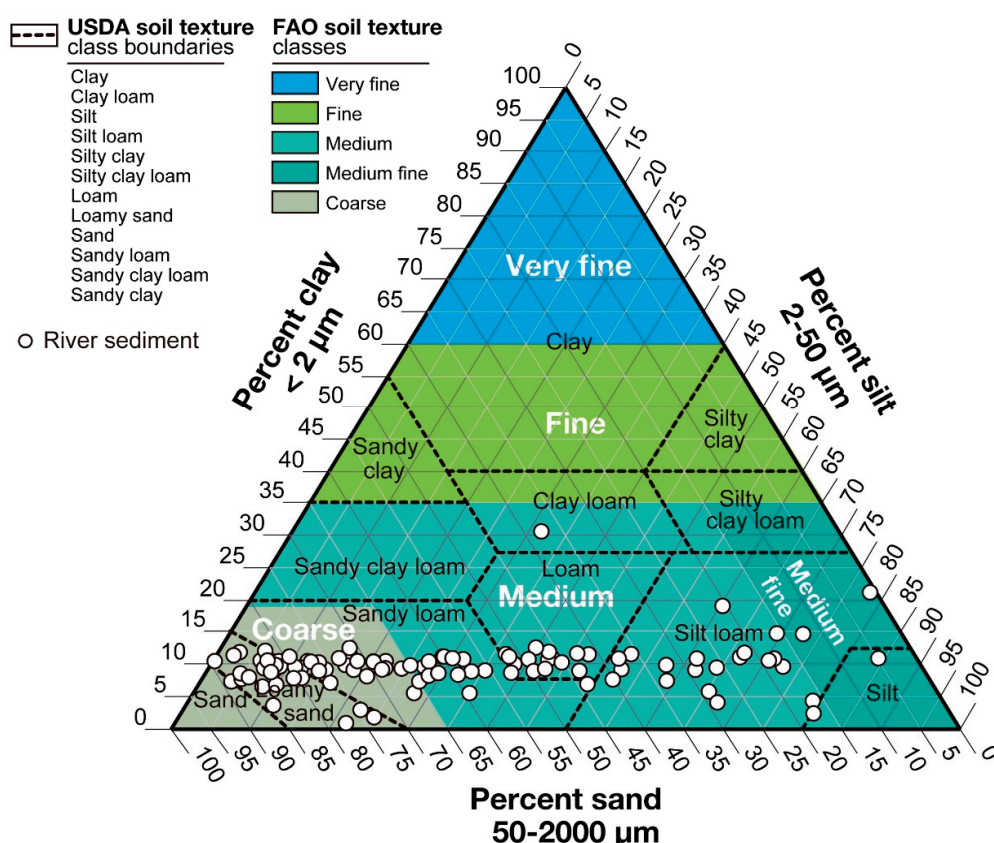


Fig. 1. Particle size distribution of river sediments in the study area.

than approximately 50% have often been interpreted as indicative of spatially heterogeneous anthropogenic inputs such as fertilizer application, livestock manure, and drainage from cultivated fields rather than purely natural background variation [24]. In general, upstream sites located in the northern and western tributary sub-basins of Buyeo County showed lower T-N and T-P concentrations, whereas midstream and downstream reaches near irrigated agricultural lands exhibited higher nutrient levels, likely reflecting the cumulative influence of agricultural runoff and drainage from surrounding farmlands.

The Kolmogorov–Smirnov test was applied to assess the normality of the statistical distribution of the data. As shown in Table 1, the results suggest that most datasets (excluding pH) for the physicochemical properties of river sediment do not follow a normal distribution. Among multivariate statistical techniques, cluster analysis and principal component analysis are non-parametric methods that do not require the data to be normally distributed. Therefore, in this study, the data sets were used for multivariate statistical analysis without transformation to ensure normality.

Correlation analysis

The results of the correlation analysis are shown in Fig. 2. The correlation coefficient between T-N and EC was $r=0.54$, indicating a relatively high positive relationship. The correlation coefficient between T-P and silt was also significantly high at $r=0.68$ ($p<0.01$). These results stem from the strong adsorption of phosphate onto fine particles (silt), showing that sediment grain-size distribution is a major driver of the spatial variability of phosphorus [2]. The robust positive correlation between T-P and silt supports the interpretation that phosphorus is predominantly retained on fine-grained sediments through sorption onto Fe- and Al-oxide surfaces and organic matter coatings, a mechanism consistently reported for river sediments in agricultural catchments [2,25,26]. This mechanism is particularly relevant in agricultural catchments, where fertilizer-derived phosphorus read-

Table S1. Physicochemical properties of 106 stream sediment samples and corresponding spatial data. The pH and EC values used in this study were obtained from our previous work reported by Son and Yun [23]

Sample	pH	dS/m	mg/kg		cmol _e /kg			Transverse mercator		Soil texture			
		EC	T-P	T-N	K	Ca	Mg	Na	Y	X	Clay(%)	Sand(%)	Silt(%)
S1	6.86	0.55	218	284	0.12	1.42	0.16	0.91	310586.3	172791.3	10.5	77.4	12.9
S2	6.22	0.72	409	824	0.15	2.59	0.34	0.91	309653.8	174831.8	9.3	66.1	25.4
S3	6.76	0.41	181	315	0.15	1.91	0.22	0.95	311043.8	173918.2	11.8	85.3	3.7
S4	7.14	0.37	243	436	0.08	2.06	0.42	0.92	311826.5	173219.3	10.4	67.5	22.8
S5	8.13	0.80	275	436	0.18	5.06	0.11	1.07	311493.0	173721.1	11.2	60.0	29.7
S6	7.23	1.10	692	1346	0.23	4.46	0.75	1.04	312629.8	174160.0	11.6	35.9	53.3
S7	5.79	0.43	212	337	0.09	1.85	0.14	0.93	314035.1	176388.8	9.5	78.7	12.6
S8	6.97	0.30	178	337	0.12	2.31	0.31	0.95	314277.6	177551.0	9.1	82.2	9.5
S9	6.66	0.31	134	229	0.11	2.06	0.12	1.15	313149.2	175440.3	11.3	86.3	3.2
S10	7.18	0.37	240	197	0.09	1.60	0.10	0.87	314236.4	175534.0	6.5	85.1	9.2
S11	6.89	0.44	247	531	0.11	3.10	0.39	1.31	315575.4	175124.2	3.6	85.2	12.0
S12	6.93	0.43	287	562	0.08	3.60	0.59	0.87	316568.4	175742.7	9.1	75.8	15.9
S13	6.60	0.52	456	1632	0.12	4.07	0.73	0.93	317215.4	175534.9	5.5	66.4	28.9
S14	5.89	1.98	343	1842	0.24	3.44	0.61	0.94	317217.7	176010.1	11.3	71.6	17.9
S15	6.44	1.03	697	1936	0.29	4.70	0.95	0.96	307044.6	189467.6	9.6	17.7	73.5
S16	5.85	2.56	599	1535	0.35	4.19	0.93	1.00	306312.8	187055.8	9.0	55.7	36.1
S17	6.33	1.03	1036	2025	0.39	5.42	1.05	1.17	305895.0	186128.8	10.9	18.2	71.7
S18	7.40	1.55	861	2009	0.15	0.64	0.23	0.21	301925.9	201528.1	11.0	46.2	43.6
S19	5.61	1.47	1074	1426	0.08	0.43	0.14	0.16	300460.7	198614.6	9.2	38.3	53.3
S20	7.25	0.68	1069	1916	0.34	5.56	1.40	0.45	301354.5	199233.6	9.5	26.2	65.2
S21	5.48	1.36	406	360	0.73	3.88	1.97	0.30	304303.6	202437.7	19.0	20.7	61.1
S22	4.93	4.25	601	1068	0.37	3.46	0.88	0.19	305430.9	201461.7	11.2	59.8	29.9
S23	5.63	2.75	824	2966	0.26	2.45	0.53	0.16	305006.4	201048.3	8.1	63.6	29.1
S24	4.86	2.79	1748	2437	0.24	2.37	0.97	0.36	302588.4	199631.7	10.7	46.9	43.3
S25	6.68	0.52	362	162	0.11	1.01	0.27	0.18	304061.2	199613.6			
S26	5.91	0.77	356	256	0.11	0.70	0.17	0.16	305314.4	199151.1	10.5	81.0	9.3
S27	6.00	0.88	698	944	0.44	2.72	0.70	0.25	294427.7	188385.2	14.7	12.7	73.5
S28	5.81	0.89	667	1080	0.31	4.57	1.29	0.31	295593.2	188574.0	11.9	46.2	42.7
S29	6.28	1.22	955	1998	0.23	2.56	0.68	0.29	296563.9	187389.1	10.8	57.6	32.5
S30	6.16	1.47	1130	2356	0.18	2.11	3.03	0.44	296441.2	195513.3	10.9	5.0	84.9
S31	6.67	1.04	1207	2371	1.04	4.95	1.34	0.28	297430.3	195507.6	11.1	22.4	67.3
S32	5.26	0.52	393	130	0.34	2.68	0.76	0.28	300479.4	192428.5	7.3	88.6	4.9
S33	6.52	0.65	375	200	0.33	5.76	0.88	0.27	301388.0	191192.3	10.5	83.3	7.0
S34	6.78	3.17	1121	3381	0.40	4.44	1.44	0.25	301541.8	190243.0	9.7	81.3	9.9
S35	5.27	1.61	423	359	0.07	1.20	0.42	0.11	297404.7	190695.8	12.6	47.5	40.8
S36	4.74	1.78	1064	1755	0.16	1.76	0.45	0.15	297988.3	188310.9	7.4	33.5	59.9
S37	7.75	0.85	573	677	0.09	3.92	0.34	0.14	298549.8	187898.2	9.6	63.1	28.1
S38	5.77	1.36	519	704	0.11	1.05	0.35	0.11	298418.0	183836.9	9.9	82.3	8.6
S39	5.95	1.43	382	1031	0.04	0.53	0.10	0.12	307472.1	196444.5	10.5	89.1	1.2
S40	6.49	0.98	587	681	0.12	1.74	0.24	0.12	307080.5	195623.2	7.7	87.1	6.0
S41	5.69	1.35	587	603	0.16	1.21	0.29	0.13	305724.3	196406.0	12.5	71.1	17.2
S42	5.84	1.43	669	935	0.26	2.27	0.60	0.24	306812.9	194403.6	14.7	15.9	70.1
S43	6.73	0.72	1092	1143	0.18	3.38	0.75	0.21	307143.8	193436.9	11.5	41.3	48.0
S44	6.85	2.15	1187	1566	0.24	4.18	0.80	0.24	307482.4	192759.7	11.6	42.7	46.4

Sample	pH	dS/m	mg/kg		cmol _c /kg			Transverse mercator		Soil texture			
		EC	T-P	T-N	K	Ca	Mg	Na	Y	X	Clay(%)	Sand(%)	Silt(%)
S45	5.35	2.43	669	680	0.13	1.53	0.25	0.14	307863.1	193158.6	9.8	72.9	18.0
S46	7.11	1.87	573	198	0.10	1.34	0.29	0.13	308700.4	195523.2	9.1	72.3	19.4
S47	6.44	1.59	1501	2819	0.27	5.08	0.95	0.29	308376.1	196502.5	10.4	62.1	28.3
S48	6.29	0.72	532	283	0.06	0.84	0.23	0.11	309722.8	196284.9	9.3	83.5	8.0
S49	6.48	0.77	641	1032	0.11	2.09	0.52	0.12	309737.8	195484.9	10.4	69.1	21.3
S50	6.73	0.74	873	1452	0.20	2.96	0.76	0.14	310341.1	194215.2	10.2	45.4	45.2
S51	5.43	1.31	532	612	0.10	1.12	0.25	0.10	311269.6	196879.2	9.5	79.4	11.8
S52	5.07	1.35	478	624	0.11	1.01	0.29	0.11	311642.1	196031.4	7.8	79.4	13.5
S53	4.85	3.20	983	1374	0.20	2.97	0.63	0.15	311989.3	194728.0	7.3	64.9	28.6
S54	5.89	0.97	587	320	0.06	0.86	0.18	0.10	311292.9	194031.3	12.0	82.0	6.8
S55	5.78	1.18	1760	1887	0.16	3.04	0.67	0.15	310760.6	193281.1	6.9	43.8	50.1
S56	6.49	1.07	914	1093	0.20	2.67	0.66	0.14	312913.8	197035.8	9.3	68.1	23.3
S57	6.43	0.99	737	619	0.16	3.11	0.57	0.19	313166.3	195986.2	10.5	19.0	71.2
S58	6.24	1.20	1597	1354	0.09	4.01	0.59	0.18	313038.7	195300.3	9.9	32.4	58.6
S59	4.83	1.02	328	479	0.06	0.77	0.16	0.11	310285.5	188560.2	6.8	83.2	10.8
S60	5.60	0.95	464	840	0.11	1.31	0.33	0.15	311925.8	187783.9	10.9	73.2	16.7
S61	5.51	1.69	546	627	0.11	1.62	0.35	0.16	312231.9	186769.3	10.2	82.3	8.3
S62	5.09	2.69	901	2544	0.23	2.23	0.53	0.15	312959.3	186311.2	8.8	57.5	34.5
S63	5.70	1.00	560	693	0.09	1.69	0.46	0.11	314112.8	185292.1	9.9	81.8	9.2
S64	6.56	0.47	287	319	0.05	0.73	0.19	0.09	314565.8	184202.6	8.5	86.9	5.4
S65	6.29	0.57	437	774	0.09	1.88	0.47	0.11	315069.2	182903.1	0.8	77.3	22.6
S66	7.18	0.60	819	755	0.10	4.52	0.64	0.16	309023.7	189907.9	10.9	37.9	52.1
S67	6.88	0.67	1119	1418	0.14	5.17	1.32	0.19	309284.4	189565.5	4.3	16.6	79.9
S68	5.77	1.20	546	1076	0.43	2.70	0.65	0.19	309236.2	187896.0	10.7	49.3	40.7
S69	6.20	0.97	560	1468	0.41	2.59	0.73	0.15	308985.6	187598.6	10.3	76.1	14.5
S70	6.34	0.62	696	1169	0.40	2.22	0.69	0.19	308293.8	184797.0	1.8	73.3	25.7
S71	6.28	0.22	464	142	0.33	1.32	0.59	0.15	308742.7	184246.7	2.9	74.5	23.4
S72	6.54	0.60	669	1503	0.46	2.99	0.49	0.18	310104.0	184309.3	8.2	63.2	29.4
S73	6.38	0.57	464	797	0.24	1.64	0.51	0.18	310695.9	183402.5	10.4	77.0	13.4
S74	5.49	0.98	1174	2473	0.48	3.27	1.08	0.23	306436.7	183881.2	7.6	40.2	53.0
S75	6.15	0.65	1187	2271	0.42	3.72	1.21	0.21	307039.3	183214.3	10.0	51.5	39.3
S76	6.02	1.98	491	611	0.32	1.57	0.27	0.82	307980.4	182888.8	7.8	80.5	12.5
S77	6.13	0.26	491	832	0.34	1.59	0.48	0.15	308603.7	182300.7	30.6	37.8	32.5
S78	5.87	0.23	314	404	0.30	0.90	0.30	0.15	305579.6	184413.4	10.3	69.1	21.3
S79	5.94	4.29	1324	2164	0.44	3.82	1.00	2.14	305776.6	183436.6	9.1	29.0	62.7
S80	4.63	2.78	846	2117	0.46	3.22	0.89	0.19	305487.1	181986.1	8.9	49.6	42.3
S81	5.50	0.34	532	468	0.01	1.16	0.38	0.16	306065.9	181164.8	7.1	76.2	17.5
S82	4.76	0.82	287	542	0.32	0.97	0.26	0.14	307057.7	181584.7	11.1	79.4	10.3
S83	5.35	0.67	396	918	0.37	1.44	0.47	0.17	307233.4	182058.7	9.8	64.7	26.3
S84	5.11	1.38	832	3505	0.43	3.33	1.01	0.19	307666.8	181445.2	2.3	17.5	81.0
S85	5.10	1.16	587	1456	0.35	1.91	0.61	0.13	308314.3	180724.5	8.4	59.4	33.0
S86	5.45	4.86	680	6757	0.37	1.61	0.69	0.14	309345.7	180274.1			
S87	6.75	0.30	669	1540	0.31	3.39	0.84	0.14	310061.8	179207.8	5.5	59.4	35.9
S88	5.60	0.82	887	1899	0.52	3.26	0.84	0.20	310901.4	178875.3	5.7	29.0	66.0
S89	5.61	0.17	505	429	0.29	1.01	0.74	0.11	311116.5	178397.0	8.1	71.1	21.6
S90	6.43	0.46	573	978	0.13	2.25	0.93	0.16	310748.6	177734.8	10.9	28.0	62.0

Sample	pH	dS/m	mg/kg		cmol _c /kg		Transverse mercator			Soil texture			
		EC	T-P	T-N	K	Ca	Mg	Na	Y	X	Clay(%)	Sand(%)	Silt(%)
S91	4.70	0.27	655	457	0.03	1.88	0.92	0.14	305862.1	190240.3	8.6	61.8	30.4
S92	4.96	0.75	1160	1211	0.39	2.69	1.19	0.13	305446.9	189514.8	11.8	21.5	67.5
S93	5.61	1.08	409	542	0.54	3.72	2.58	0.16	304679.6	188862.0	21.1	1.0	78.7
S94	6.52	0.38	1010	1413	0.34	3.22	1.79	0.20	304164.5	188456.5	4.0	28.8	68.0
S95	4.80	0.61	996	1250	0.11	1.38	0.99	0.25	303697.7	187396.6	9.0	43.8	48.1
S96	7.74	0.48	491	293	0.32	1.87	0.38	0.13	303620.0	184076.5	10.5	82.4	7.8
S97	5.55	0.50	560	639	0.32	1.06	0.32	0.11	303117.2	182883.9	8.9	76.7	15.1
S98	6.25	0.30	805	1071	0.42	2.06	0.66	0.14	302650.5	182162.7	11.6	51.8	37.5
S99	4.54	1.14	628	740	0.32	1.34	0.53	0.12	301752.4	180755.2	10.9	58.9	31.1
S100	6.06	0.46	887	1285	0.44	2.31	0.69	0.13	300989.0	179824.3	9.3	48.0	43.6
S101	6.65	0.19	396	165	0.23	0.86	0.18	0.18	300518.9	178100.1	8.8	82.9	9.2
S102	6.56	0.25	478	254	0.35	1.08	0.23	0.18	300269.0	177570.6	8.7	52.6	39.6
S103	6.39	0.28	328	195	0.22	0.75	0.19	0.15	299756.4	177036.0	7.9	86.1	6.8
S104	6.50	0.25	560	569	0.28	1.60	0.32	0.15	299611.9	176419.3	10.5	71.1	19.2
S105	5.34	0.54	573	646	0.28	1.62	0.44	0.14	299911.0	176002.2	9.1	68.7	23.0
S106	5.54	1.39	1460	4088	0.47	4.92	1.16	0.25	309520.3	188583.8	11.2	51.6	38.1

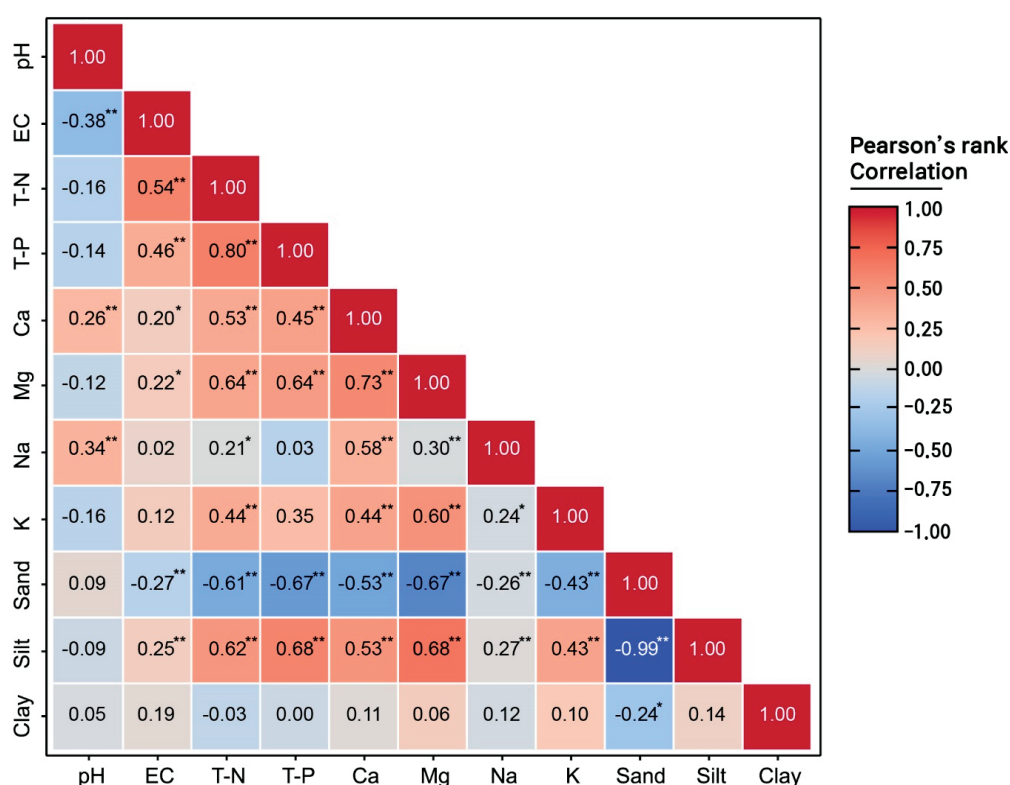


Fig. 2. Correlation matrix of physical and chemical properties of river sediments.

*Significant at $p < 0.05$, **Highly significant at $p < 0.01$.

ily binds to mobile fine sediment particles and is subsequently transported to downstream reaches. This trend was especially evident in the downstream sediments of the study area. The high correlations among EC, T-N, and T-P reflect the accumulation of nutrient salts in the sediments originating from agricultural drainage and nonpoint-source inputs from surrounding farmlands.

Principal component analysis (PCA)

The PCA results are summarised in Table 2 and Fig. 3. Three principal components (PC1, PC2 and PC3) satisfy the condition of an eigenvalue of at least 1. PC1, which comprises T-N, T-P, K, Mg and Silt, explains 39.5% of the total variance. PC1 shows T-N, T-P, K, Mg and silt appearing in particularly close proximity (Fig. 3), suggesting that these variables share a common origin. As the study area is a typical agricultural region, this implies that nutrients flowing in from non-point sources in farmland have accumulated in the sediment. Accordingly, PC1 represents an anthropogenic nutrient-enrichment component characterized by high loadings of T-N, T-P, and EC, indicating strong agricultural non-point source influence. PC2 primarily represents sediment texture and geogenic background conditions, whereas PC3 reflects localized contributions from Na and other ions, likely associated with irrigation water and river-groundwater interactions [1,11].

Cluster analysis

Figure 4 shows the results of the cluster analysis in the form of a dendrogram. Distance clustering indicates the degree of

Table 2. Total variance explained and matrix of principal components for physicochemical properties of river sediment in the study area

Component	Total variance explained								
	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)
1	4.347	39.515	39.515	4.347	39.915	39.515	4.016	36.506	36.506
2	1.647	14.975	54.490	1.647	14.975	54.490	1.640	14.906	51.412
3	1.362	12.380	66.870	1.362	12.380	66.870	1.544	14.034	65.445
4	1.032	9.386	76.256						
5	0.770	6.998	83.254						
6	0.661	6.010	89.263						
7	0.406	2.880	95.830						
8	0.317	2.880	95.830						
9	0.264	2.400	98.230						
10	0.195	1.770	100.000						
11			100.000						

Element	Component matrixes					
	Component matrixes			Rotated component matrixes		
	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
pH	-0.109	0.829	0.109	0.003	-0.548	0.658
EC	0.394	-0.421	0.485	0.103	0.919	0.084
T-N	0.763	-0.201	0.410	0.609	0.536	0.071
T-P	0.761	-0.271	0.246	0.674	0.386	-0.120
Ca	0.696	0.483	0.228	0.651	0.094	0.573
Mg	0.800	0.079	-0.203	0.819	0.085	0.030
Na	0.460	0.635	-0.438	-0.075	0.146	0.869
K	0.611	0.016	-0.234	0.607	0.144	0.004
Sand	-0.863	-0.101	0.311	-0.916	-0.011	0.011
Silt	0.867	0.090	-0.221	0.916	0.009	-0.009
Clay	0.147	0.086	-0.632	0.183	0.016	-0.011

Extraction method: principal component analysis; Rotation method: Varimax with Kaiser normalization; Significant loading factors are emphasized in bold

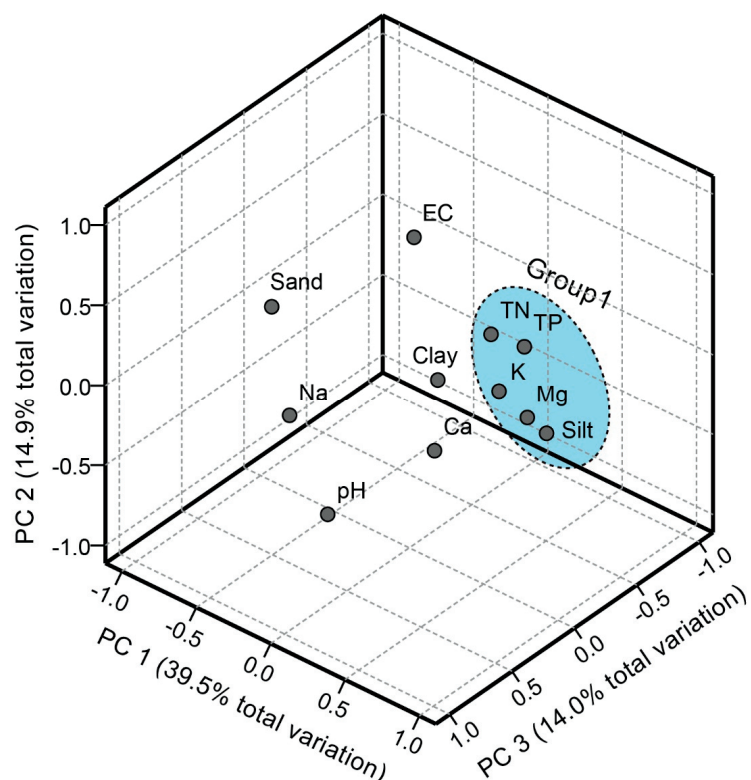


Fig. 3. Factor loadings for two principal components (PCs) after varimax rotation.

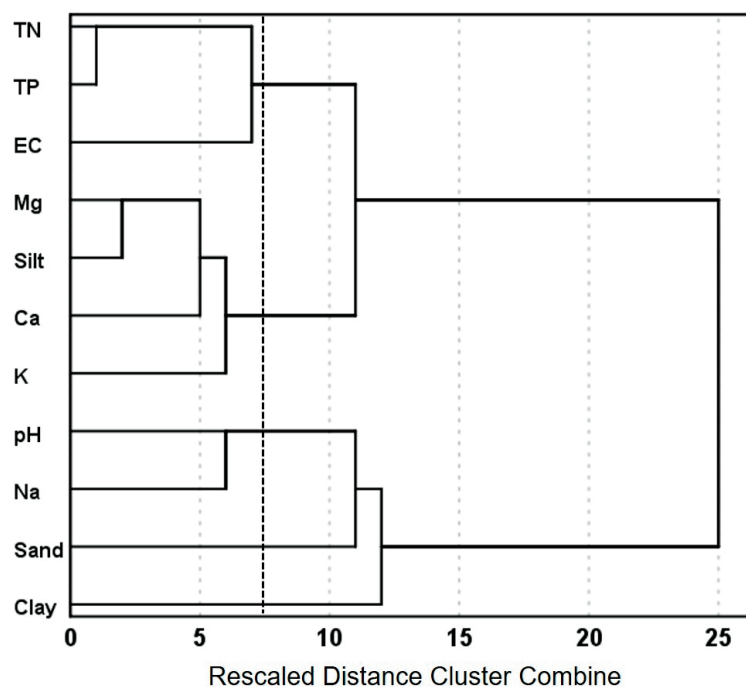


Fig. 4. Hierarchical dendrogram showing clustering of physicochemical properties according to Ward's method, using squared Euclidean distance. The dashed line in the dendrogram represents the phenon line (7-phenon).

association between components, with smaller values indicating a stronger association. Therefore, components that are classified into the same cluster in the cluster analysis can be interpreted as sharing similar characteristics. In Fig. 5, the variables group

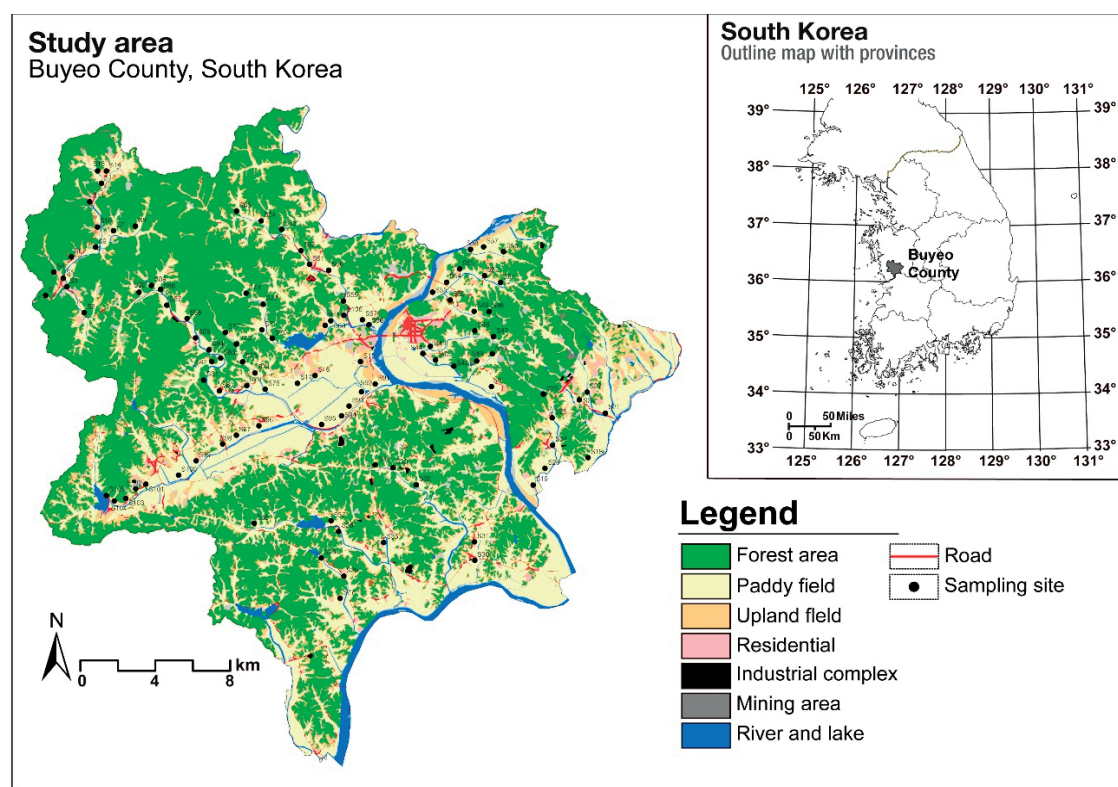


Fig. 5. Sampling points in the study area, showing the land uses.

into two distinct clusters. Cluster 1 consists of T-N, T-P, and EC, while Cluster 2 comprises Mg, Ca, K and silt. Notably, all the components in Cluster 1 (T-N, T-P and EC) exhibit a very high coefficient of variation exceeding 50%, as described in Table 1. Therefore, the variables in Cluster 1 can be considered to originate from shared anthropogenic sources. The cluster analysis results were consistent with the correlation and PCA findings, indicating that the downstream area of the study region plays a central role in the accumulation and diffusion of pollutants within the sediment layer. When the cluster membership of sampling sites was examined spatially (using TM coordinates), Cluster 1 was predominantly distributed in midstream and downstream agricultural sections, whereas Cluster 2 occurred more frequently in upstream and forested areas [27]. This spatial distinction supports the interpretation that nutrient enrichment is linked to diffuse, rainfall-driven agricultural runoff rather than geogenic processes. This spatial distinction could be used to inform the establishment of future regional management zones and prioritisation of river restoration efforts under TMDL frameworks. In this context, Cluster 1, comprising T-N, T-P, and EC, can be interpreted as a “nutrient enrichment” cluster reflecting anthropogenic inputs such as fertilizer application, manure management, and agricultural drainage. These practices collectively increase nutrient loads and enhance sediment-bound phosphorus retention, whereas Cluster 2, including Mg, Ca, K, and silt, represents a geochemical and sediment-matrix cluster associated with basic cations and fine-textured particles derived from soil erosion and parent-material weathering [4,12].

Conclusion

This study investigated the physicochemical characteristics of river sediments across Buyeo County, Chungnam Province, South Korea, focusing on spatial variability and anthropogenic influences using correlation and multivariate statistical analyses. The results obtained from 106 sampling sites showed mean values of pH 6.07 (range 4.54-8.13) and EC 1.11 dS/m (range 0.17-4.86). The average concentrations of T-P and T-N were 677 mg/kg (range 134-1,760) and 1,155 mg/kg (range 130-6,757), respectively.

The high coefficients of variation (CV) for T-P (51.6%) and T-N (85.2%) indicate pronounced spatial heterogeneity and suggest the possible influence of diffuse agricultural sources rather than uniform geogenic inputs.

Multivariate analyses further revealed strong co-variation among T-N, T-P, and EC, implying that nutrient enrichment is governed by multiple processes, including fertiliser application, agricultural runoff, and drainage pathways within the watershed. These results demonstrate that fine-textured sediments in agricultural stream networks may act as key reservoirs of nutrients, especially phosphorus and nitrogen, and should be considered in watershed-scale pollution control strategies.

Collectively, the findings provide baseline information to support evidence-based sediment management in agricultural catchments. The analytical framework applied in this study (CV, correlation analysis, PCA, and cluster analysis) can be used as a rapid screening approach to identify critical source areas under TMDL-based watershed management. Future work should incorporate GIS-based spatial interpolation and land-use data to delineate priority management zones and assess temporal variability in sediment-associated nutrient loads. In addition, periodic monitoring will be necessary to determine seasonal changes and evaluate the long-term impacts of agricultural non-point source pollution on river sediment quality.

Materials and Methods

Overview of the study area

The study area is Buyeo County, which covers an area of 624.2 km² and is located in the south-central part of South Chungnam Province. It is a typical, agriculture-centred river basin traversed by the main stream of the Geum River and numerous tributaries (Fig. 5). The land is used as follows: 318.7 km² (51.0%) for forestry, 148.8 km² (23.8%) for paddy fields and 45.8 km² (7.3%) for dry fields [20], while residential and other land uses account for 111.0 km² (18%). Buyeo County has a total population of approximately 63,580, 19,850 of whom (around 31%) are agricultural workers [21]. This is significantly higher than the national average agricultural population ratio of about 4.5%, making Buyeo County a representative rural area in which agricultural activities substantially impact the surrounding environment, including the soil and rivers. Buyeo County is located in the middle and lower reaches of the Geum River basin. The extensive plains and densely concentrated farmland along the riverbanks make it an ideal area in which to study the direct impact of agricultural activities on river sediments. For the purpose of spatial interpretation, the 106 sampling sites were also grouped into upstream, midstream, and downstream zones along the Geum River and its tributaries based on their TM coordinates and relative position to the main channel. This classification was later used to compare sediment properties with regional land use and non-point source pollution patterns [4,13]. The location of each sampling site is provided in Supplementary Table S1 of the Supplementary Materials.

Sampling procedure

River sediment samples were collected from 106 locations (S1-S106) along major rivers and tributaries in Buyeo County between May and August 2021 (Fig. 5). Sampling focused on the sedimentation zones or fluvial flats of each river to ensure representativeness, considering diverse environments such as areas of agricultural runoff, meandering sections of the river and areas downstream of bridges. Sediment samples were collected from a depth of approximately 0-10 cm below the surface using stainless steel samplers, with around 500 g of sediment collected per site. The collected samples were sealed in polyethylene containers, labelled with sample numbers (S1-S106) and coordinate information, and transported to the laboratory. Once there, the samples were air-dried, passed through a 2 mm sieve to homogenise them, and stored in sealed containers until analysis.

Soil physicochemical analysis

The physicochemical analysis of the samples was performed according to the standard analytical methods of the Rural Development Administration [22].

pH and EC: A 1:5 (v/v) suspension was prepared by adding 25 ml of distilled water to 5 g of air-dried sample, and pH and EC were measured using meters. T-N: Determined using the Kjeldahl digestion method. T-P: Determined by acid digestion with $\text{H}_2\text{SO}_4\text{--H}_2\text{O}_2$, followed by quantification using the molybdenum blue method with a UV-1800 Shimadzu spectrophotometer. Exchangeable cations: Concentrations were measured using ICP-OES (Optima 8300, PerkinElmer, USA) after extraction with a 1 N NH_4OAc solution at pH 7.0. Soil texture: The sand, silt and clay contents were calculated using the hydrometer method and the soil texture types were classified according to the USDA texture triangle.

Statistical analysis and GIS

Statistical analyses were conducted using SPSS 20.0 (IBM, USA). The statistical distribution of the data was examined using the Kolmogorov–Smirnov test for normality, setting the confidence interval at 95%. Spearman's rank correlation coefficient was used as a non-parametric measure to evaluate the relationships between pairs of data variances, with statistical significance set a priori at $p < 0.01$.

Multivariate statistical analysis, including cluster analysis (CA) and principal component analysis (PCA), was employed. In CA, the data were standardised to a Z-score (with a mean of 0 and a standard deviation of 1) and then classified using Ward's method [23]. PCA aims to explain most of the variance in the data while reducing the number of variables to a few uncorrelated components, known as principal components (PCs). The PCs were determined based on the correlation matrix. Varimax rotation with Kaiser normalization was applied, as this minimises the number of variables with high loadings on each component and facilitates interpretation of the results. Only components with eigenvalues above 1.0 were considered, in accordance with the Kaiser criteria.

GIS mapping software (ArcGIS 10.2.2, ESRI, USA) was used to create the land use map and mark the locations where samples were collected in the study area.

Data Availability: All data are available in the main text or in the Supplementary Information.

Author Contributions: Hong, Y. and Son, J.: conducted the experiments; Lee, C., Jang, J., and Moon, J.: investigation and data curation; Hong, Y.: wrote original draft, Yun, S.W.: designed, supervised, edited all drafts, and financed the research.

Notes: The authors declare no conflict of interest

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Additional Information:

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