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Physical and chemical properties of recently deposited sediments in the reservoir of the Borçka Dam in Artvin, Turkey

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Abstract: Large dams produce important changes in flow regime and sediment deposition and distribution in rivers. When inundation starts with the building of dams, water surface area increases, flow rate decreases, and sediment carried by the river is deposited in the reservoir. However, there is a lack of research on the physical and chemical properties of recently deposited sediment in reservoirs of large dams. We aimed to fill this gap in the literature by providing valuable data on the initial formation of sediment deposition areas in reservoirs. Therefore, the aim of this study conducted within the Borçka Dam reservoir was to estimate some physical and chemical properties of deposited sediment, including grain size distribution, penetration resistance, water-stable aggregate, moisture content, organic matter content, and pH at two depths (0–10 cm and 10–20 cm). Another objective was to analyze the distribution of these properties across the sampling site. For this purpose, one of the aforementioned sediment deposition areas, approximately 3.6 ha, was designated as the study site; the study site was further divided into intersecting transects of 10 × 50 m. The penetration resistance values were determined in the field and 182 sediment samples were taken at 91 intersection points of transects, both from the surface (0–10 cm) and subsurface (10–20 cm) layers for laboratory analysis. Data gathered were evaluated using descriptive statistics and ANOVA, while geostatistical analyses were used for calculating spatial variability in the data. Results indicated that the most common texture classes were loam in the surface layer and silty loam in the subsurface layer. Moreover, the penetration resistance values, sand content, and water-stable aggregate values in the surface layer were significantly ($P < 0.01$) higher than in the subsurface layer, and moisture content, clay and silt content, pH, and organic matter were significantly ($P < 0.01$) higher in the subsurface layer than in the surface layer. Geostatistical analyses showed that all properties were described by the isotropic variogram and the ranges were lower in the subsurface layer than in the surface layer. This study revealed that the analyzed physical and chemical properties of the recently deposited sediments showed significant differences between the layers.

Key words: Dam reservoir, geostatistics, recently deposited sediment, sediment properties

1. Introduction

Sediment is described as solid particles generated by the disintegration process of organic and inorganic materials (Bortone, 2006). These particles, found in various shapes and sizes, can be transported by water, wind, glaciers, and other natural causes (Montgomery et al., 2000). Sediment deposited in deltas and reservoirs are generally fine-grained (sand, silt, and clay) (Kamarudin et al., 2009; Tigrek and Aras, 2011). The sedimentation process depends on the flow regime and flow rate of the river (Kamarudin et al., 2009).

Natural rivers are considered balanced with respect to sediment and water inflow and outflow. However, when rivers are controlled, especially by the construction of large dams, this balance can be dramatically changed (Morris and Fan, 1998). The alteration of the natural flow regime leads to changes to the hydrological, geomorphological, and ecological conditions both upstream and downstream (Galay, 1983; Graf, 2006; Magilligan et al., 2013; Csiki and Rhoads, 2014; Li et al., 2014). Dam construction in rivers decreases velocity, causing a sedimentation increase upstream of the dam. This reduces the storage capacity of reservoirs, thus negatively influencing other benefits of large dams, such as water supply, power production, and flood control (Morris and Fan, 1998). Sedimentation can change geomorphological conditions upstream of reservoir areas. For example, sediments deposited along riverbanks due to reduced flow will narrow the cross-section of a river before it reaches the reservoir, while the accumulated sediments can change the terrain of the bottom of the reservoir (Ryan, 1991; Csiki and Rhoads, 2014). Changes in the amount and composition of sediment, carrying

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nutrients, industrial chemicals, and metals, can have an impact on the ecology of the aquatic ecosystem, increasing mortality and decreasing reproductive success (Ryan, 1991; Wood and Armitage, 1997; Rabeni et al., 2005).

When analyzing properties of sediments, physical properties (such as particle size distribution and mineral components) and chemical properties (such as organic matter content, pH, contaminants, and chemicals absorbed by sediments) are taken into account (He et al., 2008; Dinakaran and Krishnayya, 2011). Previous studies reported significant levels of variation in particle size distribution related to precipitation, human activities (Xu, 2000), source material, and physiographic factors (Walling and Moorehead, 1989) in the basin. In studies investigating grain size distribution, it was determined that silt and clay deposition is higher upstream compared to the abundant sand content that is recorded downstream (Bravard et al., 2014; Csiki and Roads, 2014; Yang et al., 2014). Penetration resistance can vary by the vertical compaction of reservoir sediments over time as a result of self-weight and the amount of sediments accumulated over the years (Morris and Fan, 1998). However, researchers have also found that the penetration resistance can also change horizontally depending on the particle size distribution (Lafuerza et al., 2005; Shen et al., 2013). Sediment moisture content on the surface is usually classified as saturated, intermediate, or dry (Namikas et al., 2010). In very dry sediments, small-scale variability of moisture content tends to be the lowest; it increases gradually with the amount of moisture, but it starts to drop and reaches the lowest values in very wet sediments (Edwards, 2013). Previous studies reported spatial variability with respect to both organic matter (Szczuciński et al., 2013; Yuan et al., 2014) and pH (Diab et al., 2014; Yuan et al., 2014) for sediments along the deposition areas.

Due to the heterogeneity (Morris and Fan, 1998) and high level of variability of sediment properties even at small scales (Steiger and Gurnell, 2003; Dinakaran and Krishnayya, 2011), classic statistical methods are not suitable for analyzing the spatial distribution of sediment fractions because spatial components of distribution percentages are not considered in such analyses (Méar et al., 2006). Instead, geostatistical analyses have been widely used in recent studies to determine sediment properties (Méar et al., 2006; Cabezas et al., 2010; de Groot et al., 2011; Jerosch, 2013). These analyses are used to determine in which direction sediment is transported based on the distribution of particle sizes (Méar et al., 2006) and to develop easy-to-update digital maps showing sediment particle size distribution.

Since its completion in 2006, large amounts of sediment have accumulated in the reservoir of the Borçka Dam, resulting in small islets and elevated river banks that could provide a means to understand the scale of sediment transported by the Çoruh River. As the Çoruh River flows through valleys with different topographical and geological characteristics, materials carried by the river may also vary. This variation, in turn, shapes the physical properties of sediments in the areas of accumulation. After the Deriner Dam started to retain water in December 2012, approximately 40 km upriver of the Borçka Dam, the amount of water reaching the Borçka Dam fell significantly and the water level dropped in the reservoir. Until the Deriner Dam started to generate power in June 2013 and release water to inundate the Borçka Dam to its full capacity, sediment deposition areas appeared because of the reduction in inflow, creating a unique opportunity for this study.

The objectives of this study were to determine the differences in particle size distribution, penetration resistance, water-stable aggregate, moisture content, pH, and organic matter content between the surface and the subsurface layer in the reservoir of Borçka Dam; to determine spatial variation in these properties; and to develop distribution pattern maps of these properties. The data gathered from this research, the first study on the recently deposited sediments in the Çoruh River Valley due to several large dams, can be considered a pioneer addition of information on the recently deposited sediments accumulated in dam reservoirs.

2. Material and methods

The study was conducted in the reservoir of the Borçka Dam, located at 37T 724858 E, 4581071 N, built on the Çoruh River in the province of Artvin with an annual mean rainfall rate of 698.7 mm. The Çoruh River originates in Turkey and empties into the Black Sea by way of Georgia. It is 431 km long and 411 km of the river flows within Turkey.

The Çoruh River watershed (CRW) has one of the highest levels of soil erosion among watersheds in Turkey, with approximately 5.8×10^6 m^3 of transported sediment (Sucu and Dinç, 2008). An average slope of over 30% (Zengin et al., 2009; Akıncı et al., 2013; Yavuz Özalp et al., 2013) and degraded forest or barren lands covering the majority of the entire watershed (Pekal and Tilki, 2010) are the two main factors for the high erosion rate (Zengin et al., 2009; Akıncı et al., 2013) and the increased sediment yield for the Çoruh River.

Since the Borçka Dam, with a height of 86 m, began to collect and store water in 2006, a reservoir area of about 10.84 km^2 has developed (Figure 1) with a high rate of sedimentation. The main sources of this sedimentation are not only water erosion from the CRW but also some excavation materials discharged into the river during construction of the Deriner Dam and associated road construction about 40 km upstream of Borçka Dam.

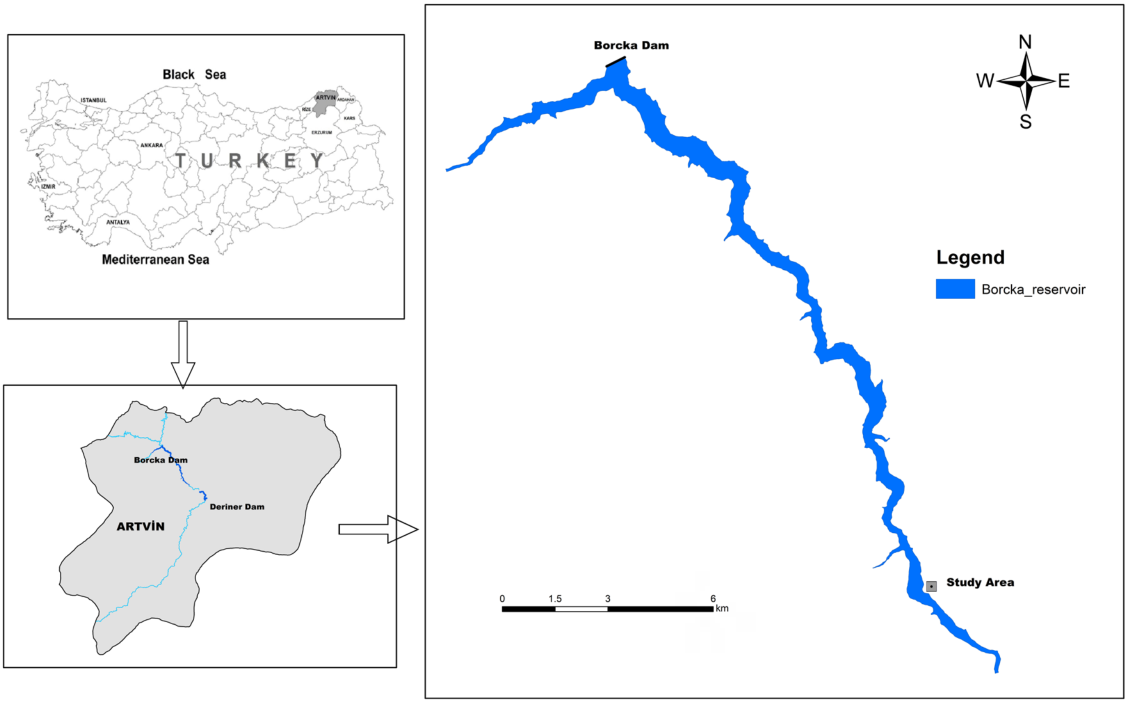


Figure 1. Location of the study area within the Borçka Dam reservoir.

One of the aforementioned sediment deposition areas, 3.6 ha in size (300 × 120 m), was designated as the study site (Figure 2). The study site was divided into 50 × 10 m grids, generating 91 sampling points. At 91 points where these grids overlapped, coordinates were obtained according to the Universal Transverse Mercator system, penetration resistance values were measured, and 182 samples were collected both from the surface (0–10 cm) and subsurface (10–20 cm) sediment layers in order to determine sediment properties in May 2013 (Figure 3). When deciding the depth of surface and subsurface layers, changes for penetration resistances measured during the initial field work were considered. In these measurements, there was no variation at the 0–10 cm depth, while initial penetration resistance values gradually dropped after 10 cm, leading us to use 0–10 cm and 10–20 cm as the surface and subsurface layers, respectively.

Figure 2. Scenes of the recently deposited sediments in the study area.

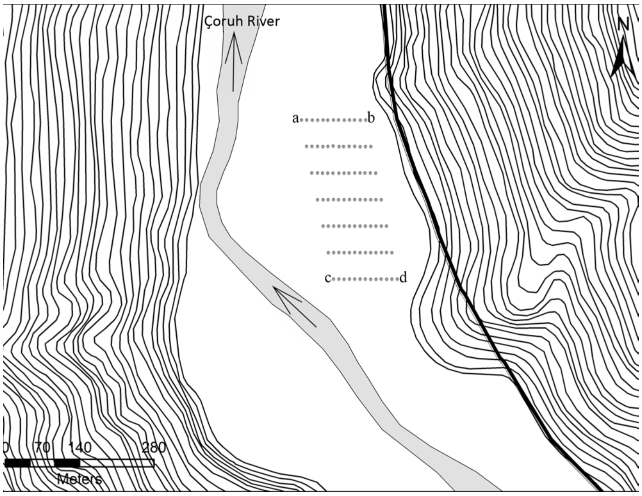


Figure 3. Sampling design and the UTM coordinates of the study area (a: 37T 734006E, 4566577N; b: 37T 734106E, 4566577N; c: 37T 734046E, 4566277N; d: 37T 734146E, 4566277N).

A digital penetrometer that could measure at every centimeter of depth was used to measure penetration resistance. The digital penetrometer developed by Eijkelkamp Company measures the penetration resistance (MPa) of the soil and saves the measurements digitally to be processed in a computer (Tillmann, 2013). Penetration resistance measurements were taken every 1 cm in the field and then average values of them were calculated for 0–10 cm and 10–20 cm. Moisture contents of the samples were determined according to weight (Smith, 2000). Soil pH was measured in a 1:2.5 soil:water suspension (Conklin, 2005). Organic matter content was determined by the wet combustion method (Sparks et al., 1996). Particle size distribution was determined by the hydrometer method (Gee et al., 1986). The amount of soil aggregates resistant to water was determined using the Yoder wet-sieving method (Dane et al., 2002).

Mean, standard deviation, minimum, maximum, and coefficient of variation (CV) were determined for all properties measured. Data were statistically analyzed by one-way analysis of variance (ANOVA) to determine the effects of layers on sediment properties. The least significant difference (LSD) test was used to identify statistically significant differences at 0.05 probabilities among the mean values of sediment properties within sediment layers. Both the ANOVA and LSD tests were carried out with JMP 5.0 software.

Geostatistical analysis was used to determine the spatial variability of sediment properties (Oliver and Webster, 2014). Experimental semivariograms, defined as a function of the distance between sampling pairs for the given separate distance *h*, were calculated with following equation (Journel and Huijbregts, 1978; Oliver and Webster, 2014):

$$\gamma(h) = \frac{1}{2}N(h)\ \sum_{i=1}^{N}[Z(x_i) - Z(x_i + h)]^2,$$

where $\gamma(h)$ refers to semivariance, $N(h)$ to the number of paired comparisons at lag h, $Z(x_i)$ to the measurement value of the property at point i, and $Z(x_i + h)$ to the measurement value of the property at point $(i + h)$. A semivariogram that serves as a function of distance and presents the semivariance between spatially separated points of data in graphics properly defines spatial relations of sediment properties (Warrick et al., 1986; Buchter et al., 1991). Variograms have three main parameters: the nugget variance (C_0), the spatially correlated variance (C), and the range (a). The nugget variance (C_0) represents the uncorrelated variation at the sampling scale; it is the variation that remains unresolved including any measurement error (Oliver and Webster, 2014). For the appropriate isotropic model, meaning that the spatial correlation structure is the same in all directions, for the soil properties under analysis in this study, out of four different isotropic semivariogram models used (exponential, spherical, linear, and Gaussian), the one with the highest R^2 value and the total least squares was considered to be the best-fitting model. An estimate was made for every 10 m via the ordinary kriging method using the designated semivariogram models. The number of adjacent points used in these estimations was determined according to the semivariogram's range of variance. GS+ (version 9.0) was used to carry out geostatistical analyses and to develop maps.

3. Results

3.1. Descriptive statistics

The descriptive statistic results, including minimum, maximum, mean, standard deviation, and CV of the sediment properties are presented in Table 1. The CV

Table 1. Statistical parameters of determined sediment properties.

Sediment properties	Layers	Min	Max	Average	Standard deviation	Coefficient of variation
Clay content (%)	Surface	6.54	59.16	27.34	13.37	48.90
	Subsurface	8.97	74.42	42.91	13.35	31.11
Silt content (%)	Surface	0.72	54.99	37.27	12.30	33.00
	Subsurface	0.00	59.61	45.41	12.24	26.95
Sand content (%)	Surface	0.68	92.19	35.39	23.00	64.98
	Subsurface	0.01	91.03	11.68	20.78	177.89
Penetration resistance (MPa)	Surface	0.45	1.07	0.75	0.122	16.27
	Subsurface	0.34	1.37	0.54	0.145	26.85
Moisture (%)	Surface	7.02	51.45	31.37	10.51	33.50
	Subsurface	13.94	63.28	47.00	8.41	17.89
pH	Surface	7.44	8.24	7.68	0.16	2.08
	Subsurface	7.42	8.14	7.75	0.15	1.94
Organic matter content (%)	Surface	0.07	3.12	0.92	0.41	44.57
	Subsurface	0.06	1.62	1.20	0.29	24.17
Water-stable aggregate (%)	Surface	0	59.61	19.21	14.27	74.28
	Subsurface	0	33.51	15.74	8.30	52.73

value is the most important parameter with respect to defining changes of an investigated property (Zhou et al., 2010). When analyzing the CV values in this study, it was determined that sand content and water-stable aggregate showed high variability (>50%) in both layers (Table 1).

3.2.Analysis of variance

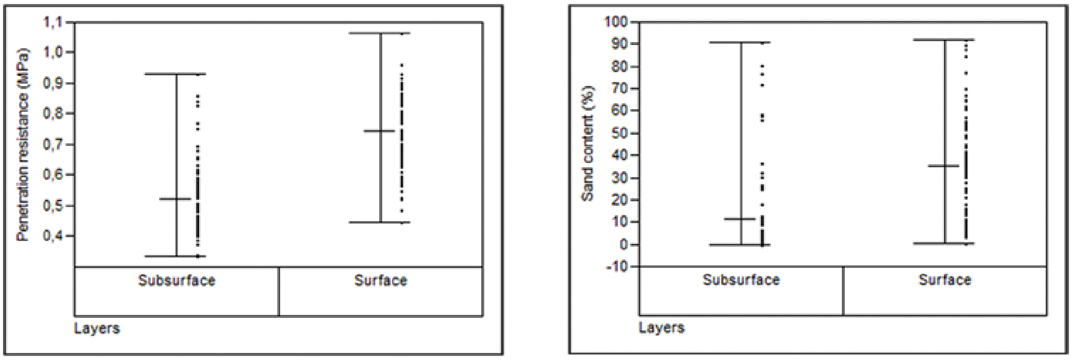
The analyses suggested that significantly higher values existed for penetration resistance (F: 152.71; $P < 0.01$, Figure 4a), sand content (F: 57.23; $P < 0.01$, Figure 4b), and water-stable aggregate (F: 4.57; $P < 0.05$, Figure 4c) in the surface layer than in the subsurface layer. Moisture content (F: 130.53; $P < 0.01$, Figure 4d), clay content (F: 68.32; $P < 0.01$, Figure 4e), silt content (F: 20.56; $P < 0.01$, Figure 4f), pH (F: 10.16; $P < 0.01$, Figure 4g), and organic matter content (F: 48.55; $P < 0.01$, Figure 4h) are statistically higher in the subsurface layer.

3.3. Geostatistical analysis

Geostatistical analysis determined that all the sediment properties changed depending on distance (isotropic). An exponential model was the best at describing the spatial dependence of surface clay content, surface and subsurface sand content, and penetration resistance values (Table 2). Subsurface clay content, surface and subsurface moisture content, water-stable aggregate, and organic matter content values were best described by a spherical model. Furthermore, while subsurface silt content and surface and subsurface pH values were best described by a Gaussian model, surface silt content was best described by a linear model (Table 2).

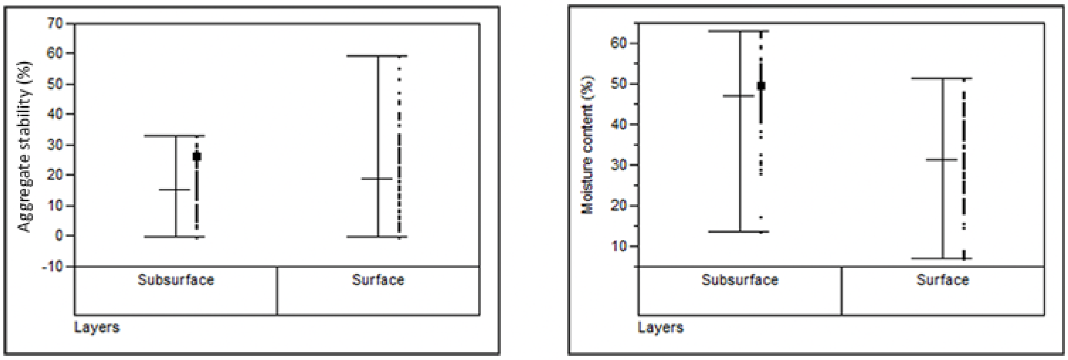
The ranges considered as indicators for spatial distribution were calculated for all the investigated sediment properties both in the surface and subsurface layers and these values are shown in Table 2. For all the properties analyzed, except for pH and silt content, the ranges of values in the subsurface layer were observed to be lower than those in the surface layer. The lowest range was observed for penetration resistance in the subsurface layer (30.3 m). On the other hand, the highest range was observed for clay content (215.10 m) in the surface layer.

Block kriging was used to estimate values for all the sediment properties in unsampled areas inside the study site. In order to easily compare the properties between surface and subsurface, the same class intervals were used for both layers. The results are displayed as contour maps showing clay content ranging between 9.0% and 74.0% (Figure 5), silt content ranging between 20.0% and 60.0% (Figure 6), sand content values ranging between 0.0% and 100.0% (Figure 7), penetration resistance ranging between 0.40 MPa and 1.00 MPa (Figure 8), moisture content ranging between 14.0% and 64.0% (Figure 9), water-stable



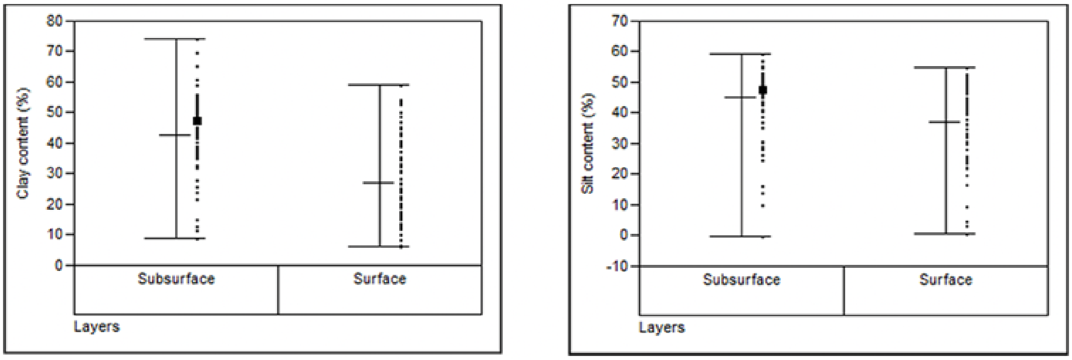
a LSD: 0.039

b. LSD: 6.45



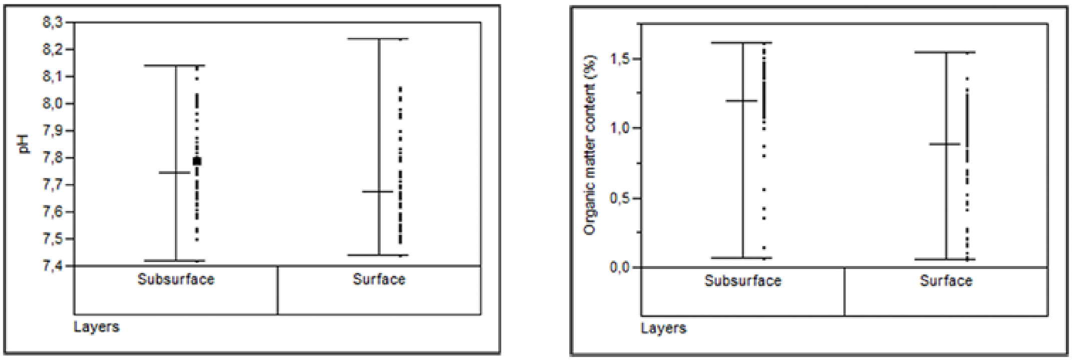
c. LSD: 3.41

d. LSD: 2.799



e. LSD: 3.928

f. LSD: 3.61



g. LSD 0.044

h. LSD: 0.105

Figure 4. The differences between the sediment properties of the surface and subsurface layers. LSD: Least significant difference; lines indicate the maximum, minimum, and mean values for each property.

Table 2. Parameters of auto-fitted variograms of sediment properties (C_0: nugget variance, $C_0 + C$: structural variance, A: range).

Sediment properties	Layers	Semivariogram model	C_0	$C_0 + C$	A	R^2
Clay content	Surface	Exponential	55.30	179.20	215.10	0.79
	Subsurface	Spherical	0.10	167.40	35.80	0.70
Silt content	Surface	Linear	19.71	105.19	113.34	0.87
	Subsurface	Gaussian	13.90	68.80	184.98	0.95
Sand content	Surface	Exponential	131.00	455.80	208.50	0.75
	Subsurface	Exponential	0.10	205.70	43.80	0.76
Penetration resistance	Surface	Exponential	0.00	0.02	39.90	0.73
	Subsurface	Exponential	0.00	0.01	30.30	0.62
Moisture content	Surface	Spherical	36.20	87.92	113.50	0.90
	Subsurface	Spherical	0.10	65.92	28.10	0.65
Water-stable aggregate	Surface	Spherical	42.20	238.90	103.80	0.96
	Subsurface	Spherical	12.50	68.97	37.50	0.79
pH	Surface	Gaussian	0.00	0.02	90.07	0.91
	Subsurface	Gaussian	0.00	0.02	93.87	0.95
Organic matter	Surface	Spherical	0.08	0.16	64.00	0.64
	Subsurface	Spherical	0.00	0.06	46.30	1.00

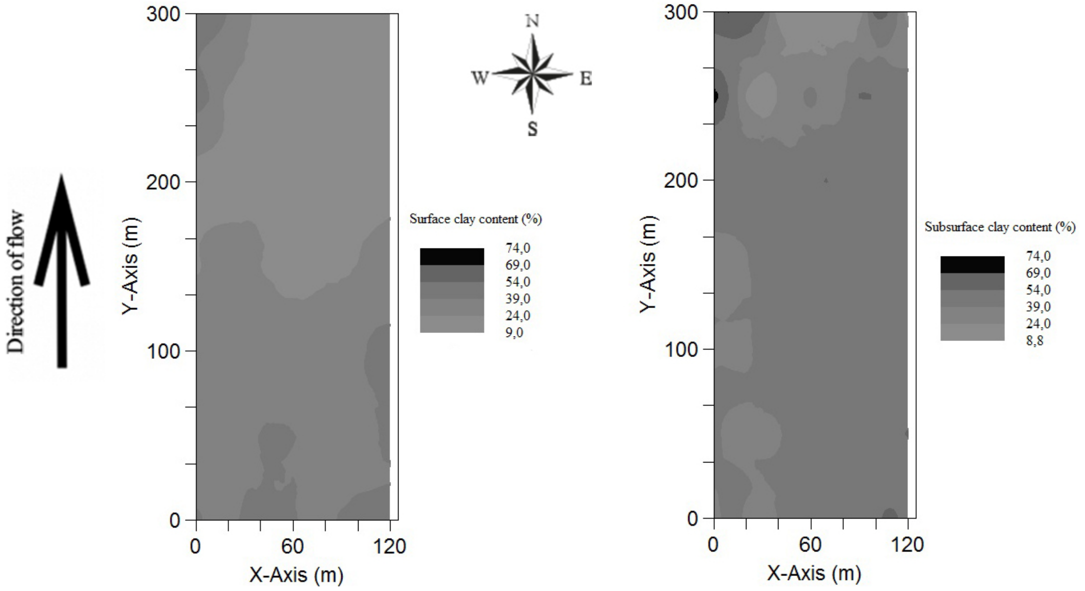


Figure 5. The map of clay content distribution for surface and subsurface layers in the study area.

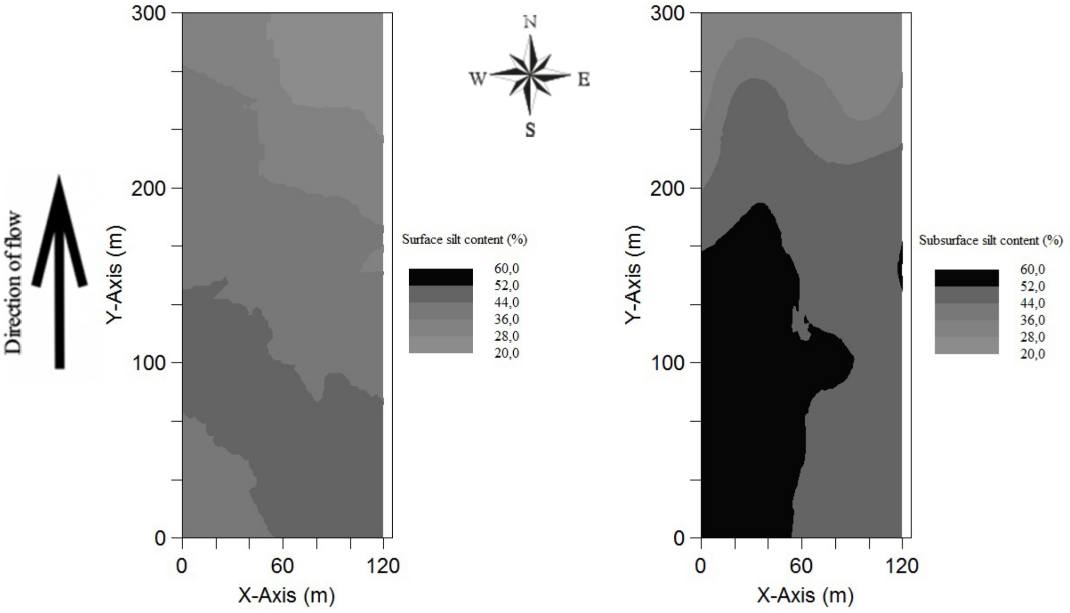


Figure 6. The map of silt content distribution for surface and subsurface layers in the study area.

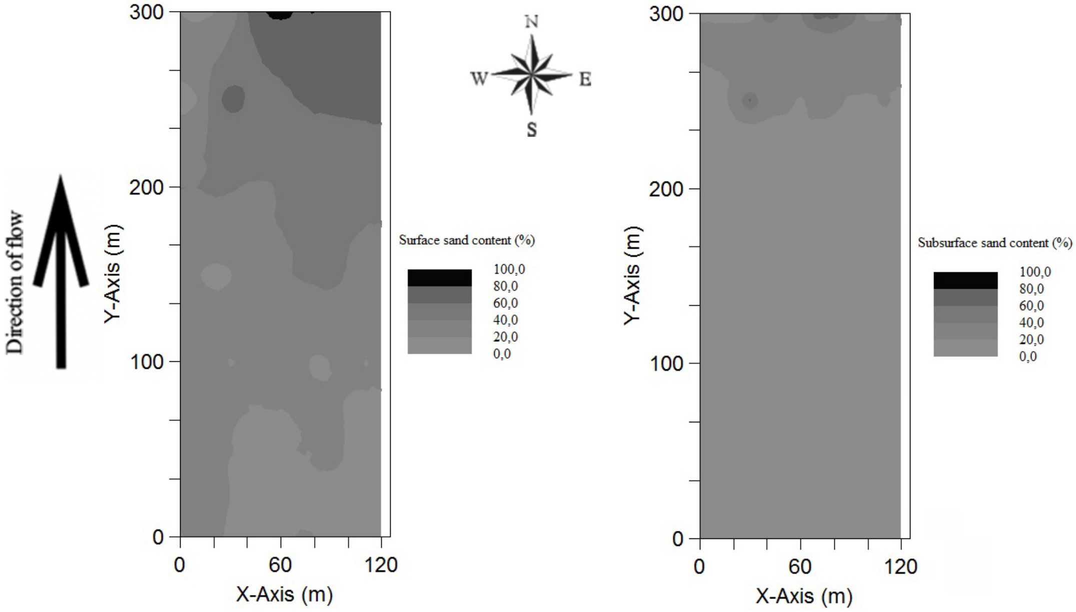


Figure 7. The map of sand content distribution for surface and subsurface layers in the study area.

aggregate values ranging between 0.0% and 50.0% (Figure 10), pH values ranging between 7.40 and 8.25 (Figure 11), and organic matter content ranging between 0.13% and 1.53% (Figure 12).

According to the distribution maps, the largest areas covered by clay and silt content were the class intervals of 9.0%–24.0% and 36.0%–44.0%, respectively, in the surface layer, and 39.0%–54.04% and 44.0%–52.0%, respectively, in the subsurface layer (Figures 5 and 6). Similar to the results of the variance analysis, these values suggest higher clay and silt content in the subsurface layer than in the surface layer. It was the opposite in terms of sand content, as the largest area covered was the class interval of 20.0%–40.0% in the surface layer, while it was 0.0%–20.0% in the subsurface layer (Figure 7). Comparable to the variance analysis, the sand content was higher in the surface layer than in subsurface layer.

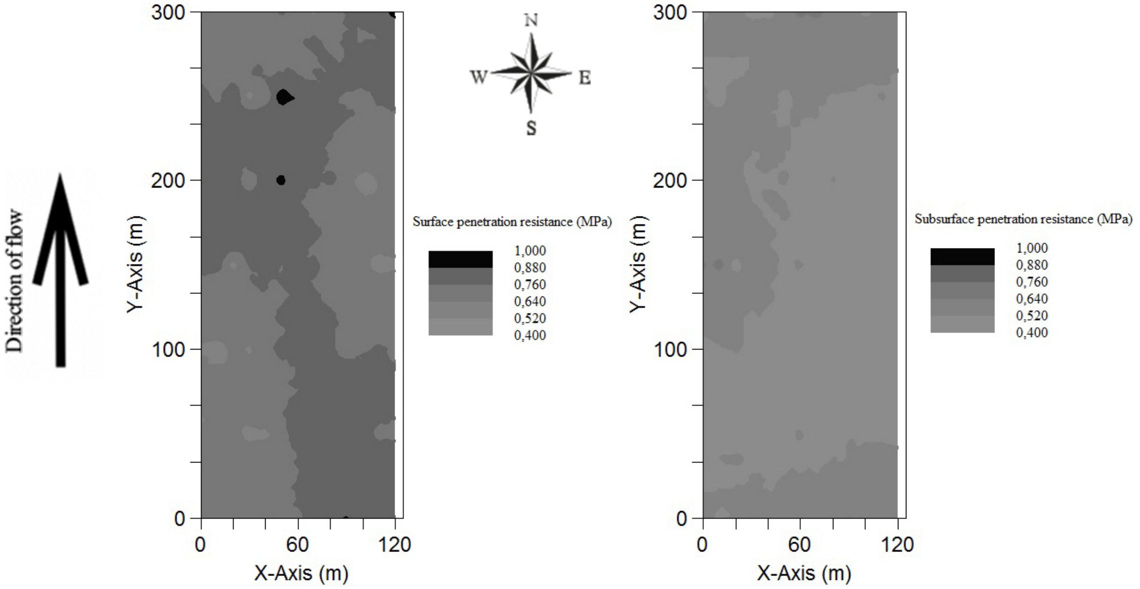


Figure 8. The map of penetration resistance distribution for surface and subsurface layers in the study area.

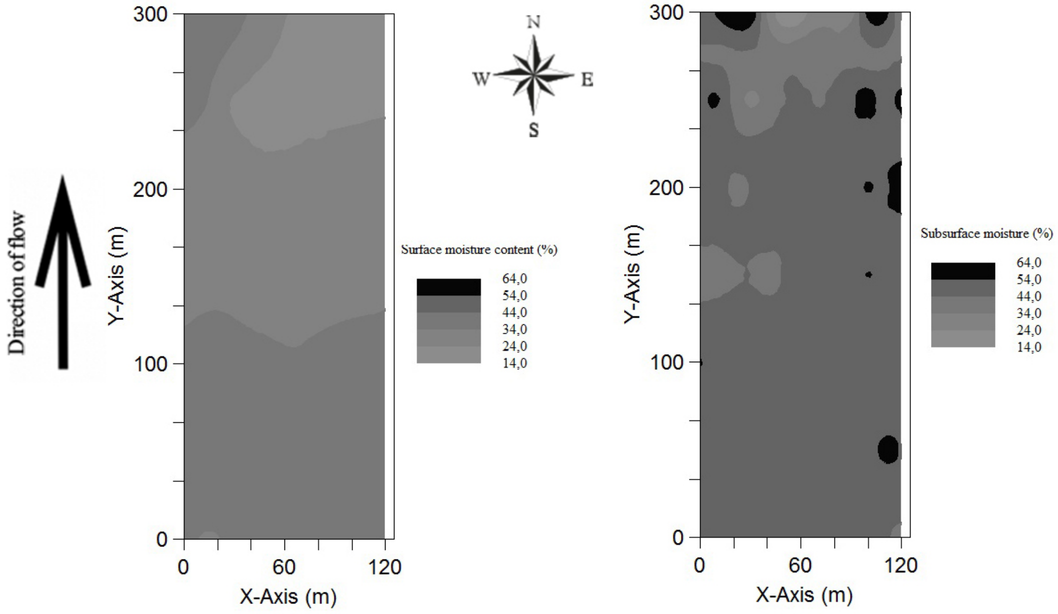


Figure 9. The map of moisture content distribution for surface and subsurface layers in the study area.

The distribution map showed that the most dominant class interval of the penetration resistance was 0.76–0.88 MPa for the surface, while it was 0.40–0.52 MPa for the subsurface layer (Figure 8). In other words, the intensity of compaction was higher in the surface layer than it was in the subsurface layer, which is indeed parallel with the ANOVA results.

According to the distribution maps, the largest areas covered by moisture content were the class interval of 34.0%–44.0% in the surface layer and 44.0%–54.0% in the subsurface layer (Figure 9). These results, similar to the ANOVA results, show higher moisture content in the subsurface layer than in the surface layer.

The dominant class intervals for water-stable aggregate were 20.0%–30.0% in the surface layer and 10.0%–20.0% in the subsurface layer (Figure 10). These results are similar to the results from ANOVA, showing a higher rate of water-stable aggregates in the surface layer than in the subsurface layer.

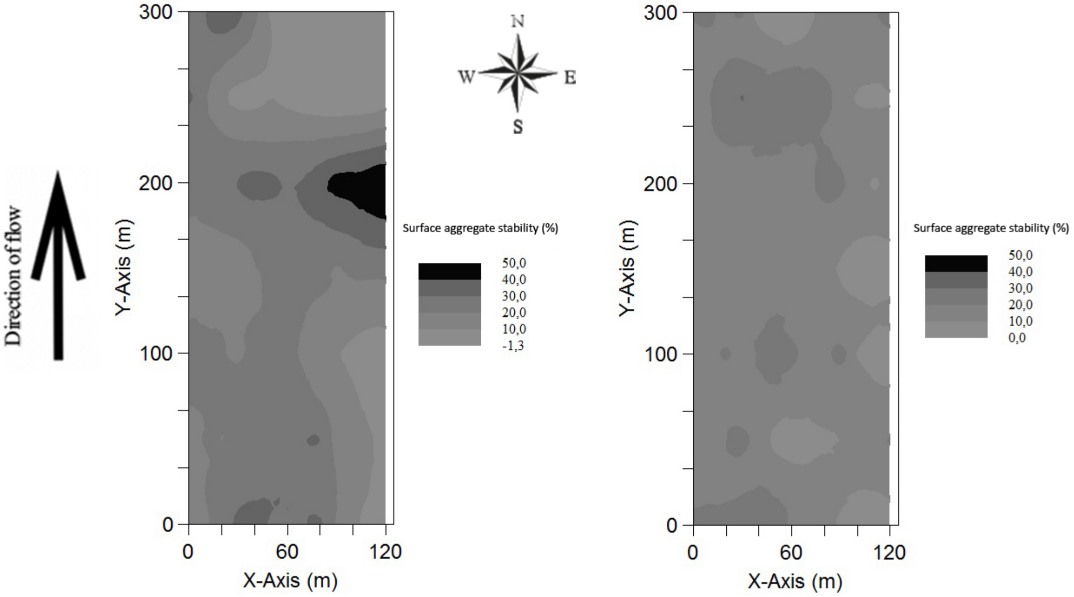


Figure 10. The map of water-stable aggregate distribution for surface and subsurface layers in the study area.

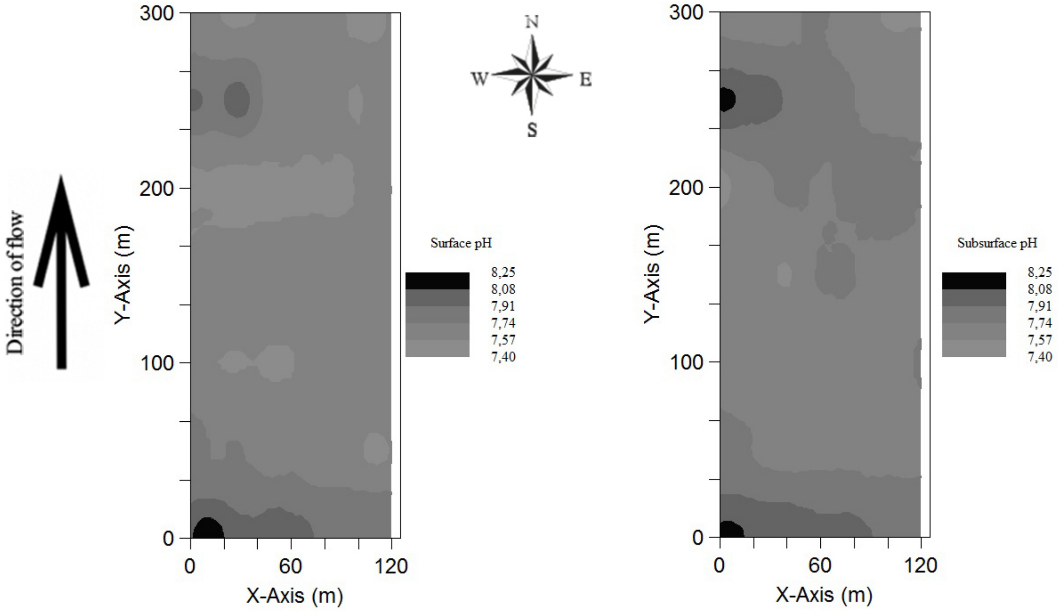


Figure 11. The map of pH distribution for surface and subsurface layers in the study area.

Along with the measurement of soil reaction at the study site, the most predominant pH value ranges were found to be 7.57–7.74 in the surface and subsurface layers, and the ranges are comparable to each other (Figure 11).

In terms of organic matter content, the most predominant class intervals were 0.97%–1.25% in the surface layer and 1.25%–1.53% in the subsurface layer (Figure 12). These results are comparable to the ANOVA results, with higher organic matter content in the subsurface layer than in the surface layer.

4. Discussion

Most of the existing studies on sediment properties have focused on sediments being deposited in dam reservoirs and/or deltas for at least several decades. The sediment deposition areas in this study, on the other hand, have been deposited for just several years, distinguishing this research from previous works. The reservoir of the Borçka Dam has been filled by sediments transported by the Çoruh River since the dam's construction in 2006. This sedimentation process is much clearer and visible at the upper section

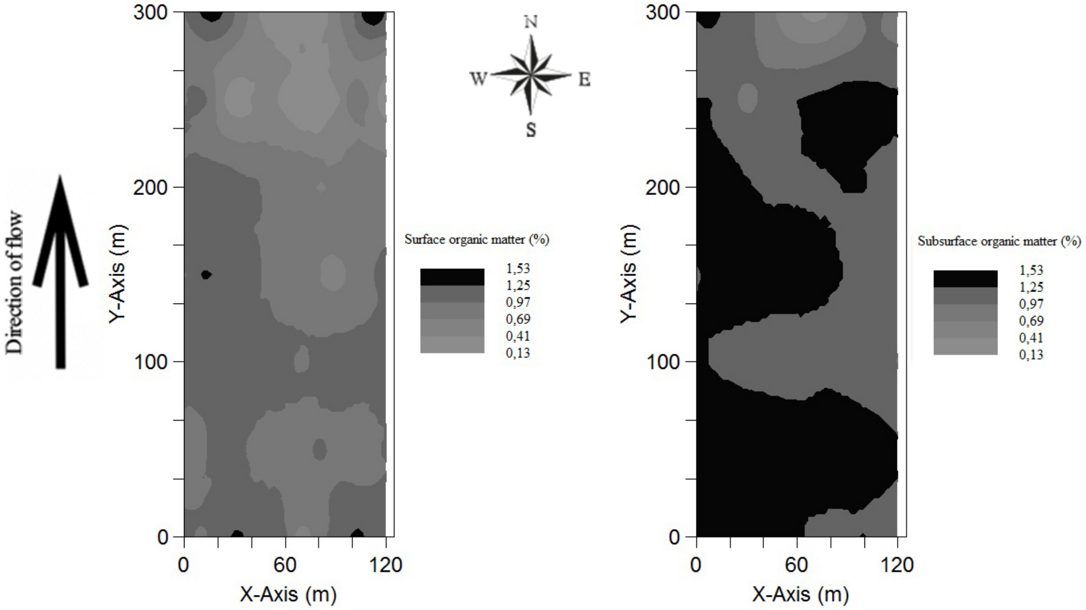


Figure 12. The map of organic matter content distribution for surface and subsurface layers in the study area.

of the reservoir and creates sediment deposition areas, especially when the level of water flow decreases. This, in turn, provides an opportunity to sample and study selected properties of recently deposited sediments.

When the particle size distribution was evaluated in terms of mean values, it was found that the deposited material mainly consisted of silt and clay fractions, with less sand fractions. Moreover, while the texture of the surface layer was predominantly loam (Figure 13a), the subsurface layer was predominantly silty clay (Figure 13b). Other studies have observed that suspended materials, primarily silt and clay, are trapped and deposited in the reservoirs due to slower flow regime and decreased sediment-carrying capacity and thus form sediment deposits with high silt and clay fractions (Yu et al., 2013; Bravard et al., 2014; Yang et al., 2014).

Values of penetration resistance in both layers were lower than those that can impede plant root growth (<2 MPa) (Taylor et al., 1966). Morris and Fan (1998) reported that sediments consisting of mostly silt and clay tend to show a loose matrix with a large volume of small water-field voids during their initial settlement. Later on, with the weight of the overlaying sediment, this causes vertical compression of the layers. However, the sediment deposition areas in our study have been recently deposited and not enough time has passed for these sediments to be compacted.

The values of moisture content determined according to weight were at field capacity (>30%) (Rowell, 1994) in the surface layer and in the subsurface layer. The higher moisture content found in this study may be associated with the closeness of the study site to the river, supplying constant water horizontally as well as vertically due to the high water table. Moreover, the other reason for the higher moisture content may be related to the seasonal climate factors of the sampling period (May 2013), as the mean

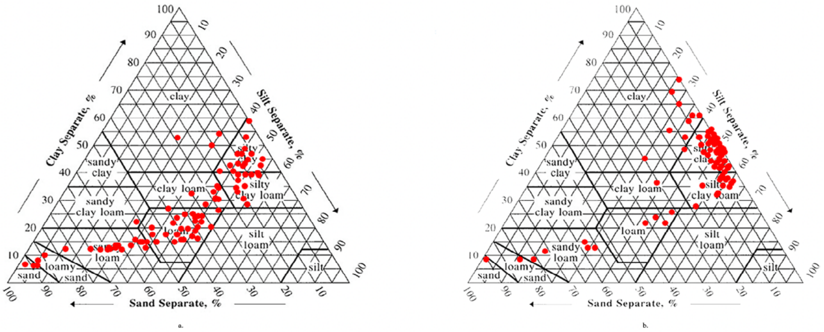


Figure 13. Particle size distribution on the surface (a) and subsurface layers (b).

temperature and precipitation was at 15 °C and 51.7 mm, respectively, limiting evaporation rate in the research area.

In terms of pH, the mean values of the sediment in the surface and subsurface layers were 7.68 and 7.75, respectively, which fell within the range of slightly alkaline (7.4–7.8) (Soil Survey Division Staff, 1993). In general, studies show that the pH of sediments is closely related to source material from various types of land use (Franz et al., 2013; Cao et al., 2011). While some studies reported low pH values (<7) in sediments that originated from agriculture and forestry sites (Romero-Diaz, 2012; Zhao et al., 2014), others found neutral or slightly alkaline pH values (≥7) in material washed down from urban and/or construction sites (Franz et al., 2013). Similarly, one of the reasons for the neutral and slightly alkaline reaction of sediments in this study can be related to the construction of several large dams and the road network within the CRW, probably resulting from the use of calcareous building materials, like cement or plaster.

The average organic matter content measured was 0.92%, which is classified as very low (ranging between 0.7% and 1.0%) for the surface layer, while it was 1.20% for the subsurface layer, classified as low (ranging between 1.01% and 1.36%), in this study (Hazelton and Murphy, 2007). According to the literature, there are two main sources for organic matter found in sediments deposited in reservoirs: allochthonous (plant and soil residue coming from outside the aquatic system) and aquatic (organisms living in large water bodies) (Morris and Fan, 1998; Page, 2003; Mash et al., 2004; Röske et al., 2008). In general, climate conditions and land-use characteristics of the watershed affect the organic matter content of sediment, varying greatly from 0.5% to 20% (Page, 2003; Fronseca et al., 2011; Romero-Diaz et al., 2012; Thevenon et al., 2013; Hur et al., 2014). In this study, one of the reasons for the low organic matter content may be the sparse vegetation coverage, especially along the upper part of the CRW, providing very little organic residue for the reservoir. In addition, the other reason may be that the length of time that the Borçka Dam reservoir has been inundated (7 years) may be considered a very short period for abundant aquatic organisms that could act as a source for organic matter accumulation.

In terms of water-stable aggregate, the mean values of the sediment in the surface and subsurface layers were 19.21% and 15.74%, respectively, which fell within the range of the weak category (<25%) (Dilkova et al., 2002). These low values were expected since the sediment deposited in the reservoir is the material detached and transported by rainfall and runoff (Ellison, 1947). Thus, the sediment lacks sufficient organic matter and inorganic soil constituents such as Fe and/or Al oxides and hydroxides to cause aggregation. In addition, as the sediment deposits can be considered relatively recent in the study area, it can be concluded that there has not been enough time for wetting and drying, freezing and thawing, and microbial activity, all of which play a role in aggregation.

Analysis of the descriptive statistics showed that most of the sediment properties have high CV values (>10%). One of the most important reasons for high CV values is the heterogeneity of the site. Studies report that sediment properties in reservoirs are distributed heterogeneously, especially in small areas (Nicholas and Walling, 1997; Morris and Fan, 1998; Cabezas et al., 2010), as in this study. Moreover, the CV values of all the sediment properties differed between the two layers.

The CV values for the properties of clay, silt, moisture, pH, organic matter, and water-stable aggregate were higher in the surface layer than the subsurface layer, meaning that these properties show higher variability in the surface layer. On the other hand, the CV values for the sand content and the penetration resistance were higher in the subsurface layer.

Based on the fact that the range is the maximum distance within which the properties under analysis can be correlated (Huang et al., 2001; Baucon and Felletti, 2013), the spatial variation of all the properties, except for pH and silt content, subject to study was higher in the subsurface layer. In other words, most of the properties analyzed varied at shorter distances in the subsurface layer.

The differences between layers in grain size distribution can be associated with both wind erosion and frequent water fluctuations in the reservoir. Wind is a significant factor that reshapes particle size distribution in sediment deposition areas (Zhang et al., 2011). This site is open and lacks plant cover during the period between high and low flow into the reservoir and it is exposed to wind erosion, which carries smaller clay and silt particles away and leaves larger sand particles on the surface. In line with these findings, other studies have reported that, proportionally, coarse particles dominate in the surface layers in sediment deposition areas and fine particles become more abundant in proportion as the depth increases (Lecce and Pawlowsky, 2004; Trannun et al., 2006). The differences between layers in grain size distribution can also be correlated to the water fluctuations in the study area, caused by runoff input from the tributaries and the occasional release of water from the Deriner Dam construction upstream. Even though such water fluctuations can still act as a factor in carrying materials (Powell et al., 2001; Lu et al., 2010), their carrying capacity was slowed due to slow water regime, which, in turn, can carry most of the silt and clay particles while the majority of the sand was left in the study area.

Penetration resistance values were higher in the surface sediment layer with higher sand content, while they were lower in the subsurface layer with higher clay and silt content. Study of the impacts of grain size distribution in sediment on penetration resistance indicates a decrease in void ratio and pore size, and an increase in penetration resistance depending on the rise in sand content (Buchanan et al., 2010).

It is not surprising to find lower moisture content in the surface layer than in the subsurface layer, due to a higher evaporation rate and the sand content of the surface layer in this study. However, we found higher moisture content in the subsurface layer mostly due to abundant clay and silt content. These outcomes indicate that the map of moisture content distribution was similar to that of clay content distribution in the surface and subsurface layers and that the values of clay content and moisture content were directly proportionate. It is well known that clay minerals adsorb water molecules of a dipole nature due to their negative surfaces and that there is a linear relationship between the water retention capacities of the soil and clay minerals (Balogh et al., 2011). Similarly, Asaeda and Rashid (2012) found a positive correlation between the ratio of grain size smaller than 1 mm and moisture content. In addition, some researchers have theorized that the water table is responsible for the high moisture content in subsurface layers of sediment (Cavazza et al., 2007; Meingast et al., 2014), but we do not have any data regarding the water table level in the study area.

The higher levels of water-stable aggregates in the surface layer are thought to be mostly driven by the wetting and drying process because, as mentioned above, the sediment deposition areas are young enough that the other factors (e.g., freezing and thawing, organic matter, and microbial activity) have not had sufficient time to play a role in the aggregation process in this study. Wetting and drying processes are reported to play an important role in the formation of aggregates and restitution of degenerate structure (Pires et al., 2007; Bravo-Garza et al., 2009). This analysis suggests that the surface layer is affected more by these processes, which are thought to influence the aggregate formation and the rise in the amount of water-stable aggregates.

The reason for the organic matter content being higher in the subsurface than the surface layer may be related to the grain size distribution of the sediment in the study area. There is a negative correlation between grain size distribution and organic matter content (Li et al., 2014). In addition, it is reported that grain size distribution is effective in the organic matter's mineralization process and that the presence of fine particulate materials with a high surface area and smaller pores protects organic matter from rapid decomposition (Waterson, 2005). Higher clay content in the subsurface layer of the study site leads to higher organic matter content, as it prevents mineralization due to a lack of aeration. The other explanation for the lower organic matter content in the surface layer may be wind erosion carrying organic residues from the surface of the study area before the mineralization process starts.

In conclusion, this study aimed to determine the changes in some physical and chemical properties and their spatial variability in recently deposited sediments. It was revealed that the selected properties showed differences between surface and subsurface layers. These findings may indicate that once the sediments were deposited in the reservoir, factors including water flow, wind erosion, precipitation, and evaporation might have played major roles in causing these differences among the analyzed soil properties between two layers. Moreover, this study demonstrated that most of the properties show variability at shorter distances in the subsurface layer. In addition, the properties analyzed in the recently deposited sediments of this study showed variation from the relatively older sediments. It can also be said that, at least in the near future, plant growth is limited in these recently deposited sediments due to inappropriate soil conditions and frequent inundation occurring in the reservoir.

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