INTERNATIONAL CAUCASIAN FORESTRY SYMPOSIUM
24-26 OCTOBER 2013
ARTVIN TURKEY

Determining Spatial Variability of Penetration Resistance and Particle Size Distribution in Sediment Deposition

Bülent Turgut[1], Mehmet Özalp[2], Saim Yıldırımer[3]

[1]Assist. Prof., Artvin Coruh University, Artvin, Turkey;
[2]Assist. Prof., Artvin Coruh University, Artvin, Turkey;
[3]Grad. Res. Assist. Artvin Coruh University, Artvin, Turkey.
E-mail: bturgut@artvin.edu.tr

Abstract:

Erosion and sedimentation in dam reservoirs may result in both ecological and economic problems. That is why, besides its amount, it is important to know physical and chemical properties of sediment accumulated in reservoirs. Thus, it is possible to gather information regarding erosion and parameters affecting the erosion process in a watershed. Determining particle size distribution generally comes first when investigating physical properties of sediments. Despite similar texture formation, compaction degree of sediment layers increases due to repacking of particles with time. It is important to figure out compaction degree of sediment layers in accumulation sites and measuring penetration resistance is one of the techniques used mostly. This study was initiated in one of 9 sediment deposition sites determined along the Borcka Reservoir. Precipitation periods within the watershed of the reservoir and power generation cycles of the dam play an important role on the formation of these sedimentation sites. At the first stage of the study, lateral profile distribution and depth of sediment deposition were determined. Then, on sampling points, arranged by the grid system, penetration resistance was measured. In addition, disturbed sediment samples taken from the same sampling points at two depths (0-10 cm and 10-20 cm) were analyzed for moisture and particle size distribution. Geostatistical analyses were used on these values in order to produce spatial variation maps while regression was used to assess relationships between parameters investigated in this study. Results indicated that there were significant differences between layers in respect to penetration resistance values and particle size of sediments and it was found out that spatial variation of penetration resistance closely related with particle size distribution..

Key Terms: Sediment, spatial variability, geostatistics

Introduction:

Natural rivers are considered as balanced in respect to sediment and water inflow and outflow However, when rivers are controlled especially due to large dam constructions, this balance can be dramatically changed. Mainly, dam constructions on rivers decreases flow rate causing increase in sedimentation. This, in turn, will reduce storage capacity of reservoirs and may influence other benefits of large dams negatively including water supply, power production, and flood control (Morris and Fan, 2010).

Sediment deposited in reservoirs of large dams can exert various information such erosion process, land use management, and topography of watershed surrounding that dam. While sediment characteristics are examined, physical properties (e.g. particle size distribution), its mineral components and chemical properties (e.g. contaminants and chemicals) are generally taken into consideration (Xu, 2000). In addition, previous studies on this subject indicated that the particle size has a significant level of variability because mainly reason of variability is source material in the basin and physiographic factors (Walling and Mooreheas, 1989).

Spatial variability occurs when a quantity that is measured at different spatial locations exhibits values that differ across the locations (URL1). The distributions of sediment particle size are to be heterogeneous (e.g. Stanley & Swift 1976; Morrisey et al., 1992; Cabezas et al., 2010). Due to the heterogeneity in sediment deposition area, spatial variability analyses and particularly geostatistical methods use to assessment of studied sediment properties. (Morrisey et al., 1992; Cabezas et al., 2010; (Liu, He et al. 2010).

Amount of sediment deposition in to the reservoir of Borçka Dam has been dramatically reduced since Deriner Dam was completed in 2012. Due to high sedimentation rate between 2006 and 2012 and holding of river flow by Deriner Dam, small islets within the reservoir and sediment deposition areas along the edge of Borçka Dam Lake have been formed. This situation has provided the opportunity to study amount and some physical/chemical properties of sediment accumulated in the reservoir.

The objective of this study was to determine penetration resistance and spatial variability of sediment deposition areas, to reveal the degree of spatial variability and to determine the relationship between these parameters by creating pattern maps.

Material and Methods:

One of the deposition fields of the Borçka Dam reservoir area selected as the study area about 66 da. Research was divided into grids with 50m along the river and 10m perpendicular to the river (Figure 1).

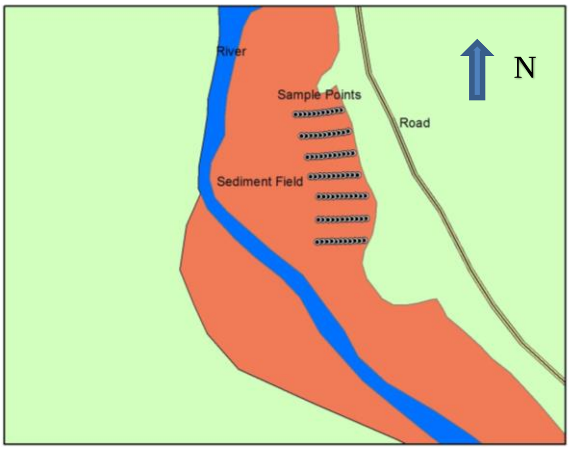

Figure 1 Study area and sampling design

Penetration resistance values, using penetrologger, were measured and surface and subsurface sediment samples were taken at each 91 intersection points. Collected sediment samples were analyzed for particle size distribution with Bouyoucus hydrometer methods (Gee and Bauder, 1986)

Descriptive statistics were applied to the data set in order to determine mean, standard deviation, min and max values, and coefficient of variation, skewness and kurtosis. ANOVA was used to detect layers effects on measured variables. The significant differences in sediment properties between different layers were determined using the least significant difference procedure for a multiple range test at the 0,05 significance level.

Spatial dependence of each sediment properties was determined semivariogram. The semivariogram (Matheron, 1965) is a basic tool for the estimation and mapping of regionalized variables. It reveals the random and structured aspects of spatial dispersion. The experimental semivariogram is defined as;

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

where N(h) is equal to the number of pairs of values in which the separation distance is equal to h, Z(x) and Z(x+h) are the values of the experimental data separated by the distance h (Isaaks and Srivastava, 1989).

Results and Discussion:

Descriptive Statistical Analysis

The data on penetration resistance, clay content, sand content and silt content are shown in Table 1. The lowest penetration resistance and sand content were observed for the sub-surface layers, furthermore the least clay content and silt content were observed for the surface layers.

Table 1 Statistical parameters of selected sediment properties along the transect.

Properties	Layers	Mean	Standard deviation	Min	Max	Skew	Kurtosis
Penetration resistance	Surface	0,747	0,12	0,45	1,07	0,055	-0,071
	Sub-surface	0,536	0,15	0,34	1,37	2,724	11,947
Clay content	Surface	27,341	13,45	6,54	59,16	0,435	-0,957
	Sub-surface	42,909	13,42	8,97	74,42	-0,912	1,067
Sand content	Surface	35,391	23,13	0,68	92,19	0,602	-0,349
	Sub-surface	11,679	20,89	0,01	91,03	2,628	6,149
Silt content	Surface	37,268	12,37	0,72	54,99	-1,266	1,239
	Sub-surface	45,412	12,31	0,00	59,61	-1,820	3,594

For surface layer, penetration resistance and sand content were significantly (p<0.01) higher than subsurface layer (Figure 2). On the other hand clay content and silt content measured sub-surface layer were significantly (p<0.01) higher than surface layer (Figure 3).

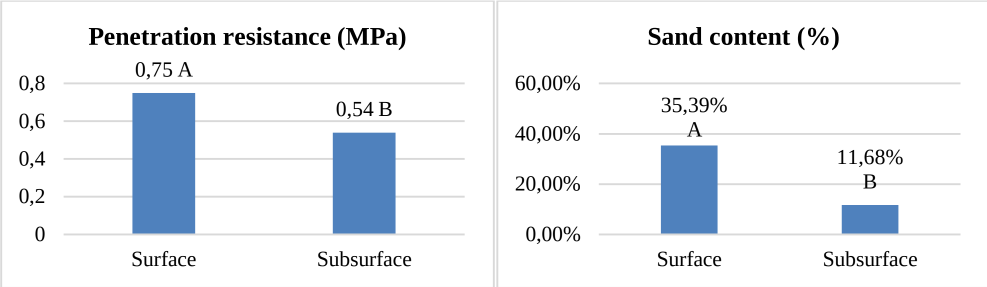

Figure 2 Penetration resistance and sand content for surface and sub-surface layers (*$LSD_{Penetration\ Resistance}$: 0,038, $LSD_{Sand\ Content}$: 5,11) *LSD: Least significant differences*

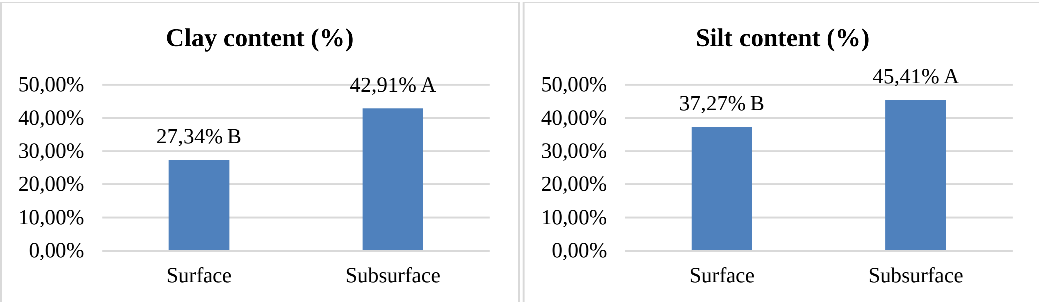

Figure 3 Clay content and silt content for surface and sub-surface layers *($LSD_{Clay\ Content}$: 3,71; $LSD_{Silt\ Content}$: 2.44) *LSD: Least significant differences*

Geostatistical Analysis

As a result of geostatistical analysis, it was found that the surface penetration resistance values changed depending on distance (isotropic). Exponential model was the best describing spatial dependence of the surface penetration resistance In addition, analysis showed that the range in subsurface layer was 13.30m, which indicates that the spatial pattern vary for each 13.30m, and the points lower than 18.80m apart from each other have similar penetration resistance (Figure 4a). The same trend is observed for penetration resistance data in subsurface layer, although the range values decreased to 10.10m (Figure 4b).

Clay content in surface layer was described by Exponential semivariogram and the range of spatial dependence exceeded 71.70m (Figure 4c). As in surface clay content, subsurface clay content was described by Exponential semivariogram but the range of spatial dependence decreased to 15.10m (Figure 4d).

As a result of geostatistical analysis, it was found that surface silt content values changed depending on distance (isotropic). Gaussian model was the best describing spatial dependence of surface silt content and the range of spatial dependence exceeded 83.60m (Figure 4e). As in surface silt content, subsurface silt content values also changed depending on distance (isotropic). Gaussian model was the best describing spatial dependence of subsurface silt content but the range of spatial dependence increased to 126.10m (Figure 4f).

Sand content in surface layer was described by Exponential semivariogram and the range of spatial dependence was up to 39.80m (Figure 4g). As in surface layer, sand content in subsurface layer was also described by Exponential semivariogram but the range of spatial dependence decreased to 14.60m (Figure 4h).

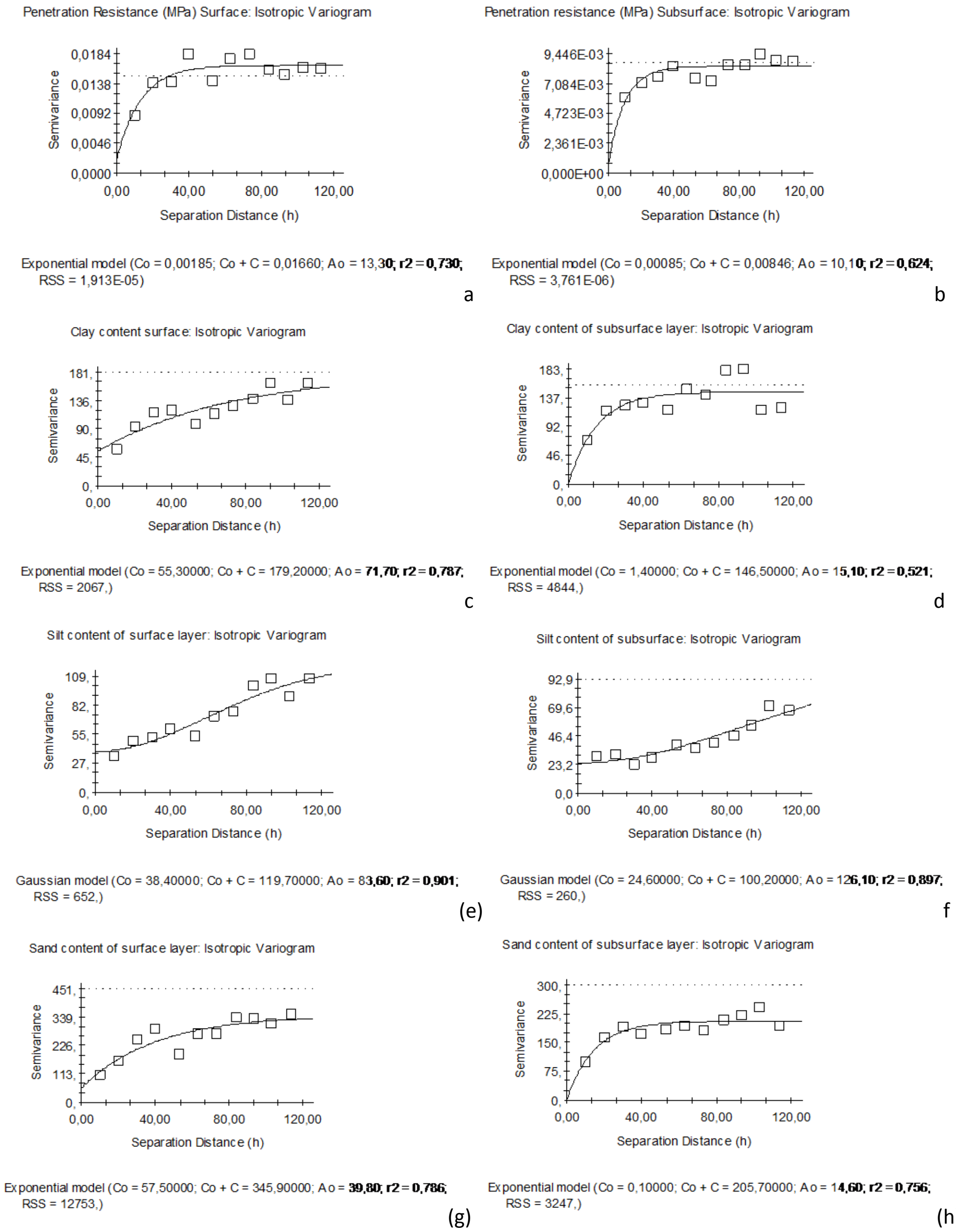

Figure 4 Semivariogram models of surface penetration resistance (a), subsurface penetration resistance (b), surface clay content (c), subsurface clay content (d), surface silt content (e), subsurface silt content (f), surface sand content (g), subsurface sand content (h).

Block Kriging was used to produce an estimation of penetration resistance at unsampled locations inside the study area. The results are displayed as contour maps showing surface penetration resistance ranging between 0.45MPa and 1.07MPa. Moreover it was also seen that the penetration resistance values ranging between 0.756MPa and 0.826MPa are distributed over a great part of total area (Figure 5a). The contour map showed that the subsurface penetration resistance values ranged between 0.34MPa and 1.37MPa while the penetration resistance values ranged between 0.458MPa-0.506MPa were distributed over a great part of total area (Figure 5b).

The contour map showed surface clay content ranging between 6.54% and 59.16%. Clay content values between 9.8% and 17.1% are distributed over a great part of total area (Figure 5c). The contour map obtained by

Kriging analyses showed subsurface clay content ranging between 8.97% and 74.42%. Clay content values between 34.6% and 47.5% are distributed over a great part of total area (Figure 5d).

The contour map showed that the surface silt content ranged between 0.72% and 54.99% and the penetration resistance values ranging between 41.00% and 49.60% were distributed over a great part of total area. Also analysis showed that the silt content indicated a decreasing tendency in parallel to the flow direction of the river. (Figure 5e). The contour map showed subsurface silt content ranging between 0% and 59.61% and the silt content values ranging between 49.20% and 57.10% were distributed over a great part of total area. Also analysis showed that the silt content indicated a decreasing tendency in parallel to the flow direction of the river (Figure 5f).

The contour map showed the surface sand content values ranging between 0.68% and 92.19%. Sand content values between 9.6% and 24.00% were distributed over a great part of total area and unlike the clay and silt content, sand content indicated an increasing tendency in parallel to the flow direction of the river (Figure 5g). The contour map showed subsurface sand content ranging between 0.01% and 91.03%. Sand content values between 0.3% and 15.2% were distributed over a great part of total area and like surface layer, the sand content indicated an increasing tendency in parallel to the flow direction of the river (Figure 5h).

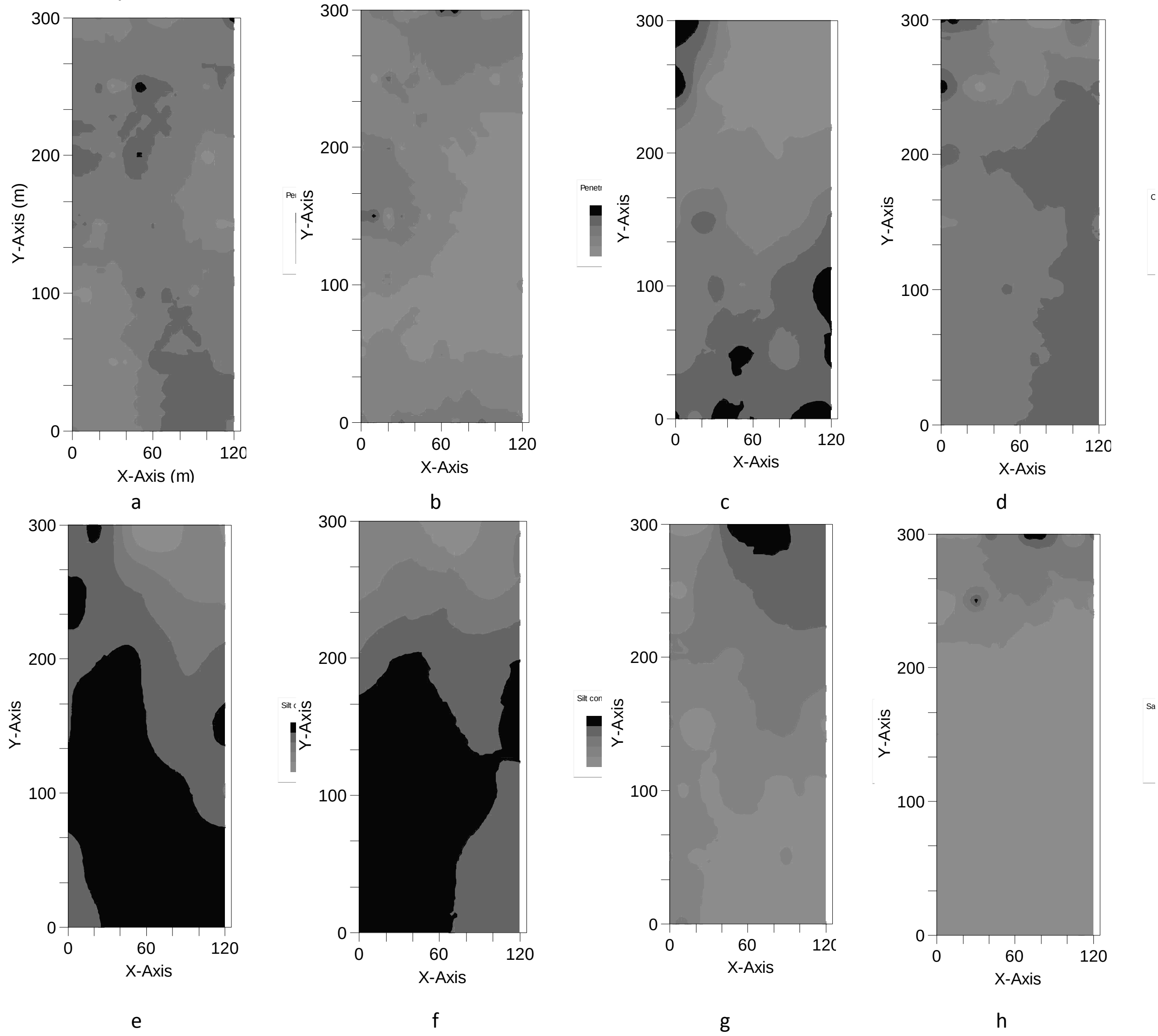

Figure 5 Spatial distributions of surface penetration resistance *(a), subsurface penetration resistance (b), surface clay content (c), subsurface clay content (d), surface silt content (e), subsurface silt content (f), surface sand content (g), subsurface sand content (h).*

Conclusion:

In this study, penetration resistance and particle size distribution of sediment deposited in Borçka Dam reservoir area were investigated. The results showed significant differences for investigated properties between surface and subsurface sediment layers. As expected, penetration resistance values, one of the indicators for compaction, were higher in the surface sediment layer than subsurface layer. One of the reason for this result can be explained by hardening of clay minerals in the sediment especially when they lose water due to direct exposure to the sun.

As for particle size distribution, analyses indicated that sand content was higher at surface layer than subsurface. Wind carrying clay and silt since their smaller size leaves sand at the surface can be one of the reasons. The other reason might be changes in flow regime and water stage of the reservoir, removing small particles (clay and silt) and depositing sand.

Spatial variability of penetration resistance and particle size distribution was also investigated in this study. As a result of the spatial variability analysis, it was found that penetration resistance and clay content values varied depending on distance while sand and silt content values varied from depending on both distance and direction. At the far north part of the study area, there was a natural barrier decreasing flow rate and causing mainly sand particles to be deposited. Therefore in the spatial variability map it is seemed that sand content was higher at this location of the study area.

References

Cabezas, A., M. Angulo-Martinez, M. Gonzales-Sanchis, J.J Jimenez, F.A. Comin, Spatial Variability in floodpain sedimentation: the use of generalized linear mixed-effects models. Hydrol. Earth Syst. Sci. Discuss., 7, 1589–1619,

Gee, G.W., and Bauder, J.W., 1986. Particle-Size Analysis. Methods of Soil Analysis.Part 1. Physical and Mineralogical Methods. 2nd Edition. Agronomy No: 9. 383-411, 1188 p, Madison, Wisconsin USA.

Isaaks, E.H., Srivastave, R.M., 1989. An introduction to applied geostatistics. Oxford University press, New York, 600pp.

Liu, H., Q. He, Z. Wang, G. J. Weltje and J. Zhang (2010). "Dynamics and spatial variability of near-bottom sediment exchange in the Yangtze Estuary, China." Estuarine, Coastal and Shelf Science **86**(3): 322-330.

Matheron, 1963. Principles of geostatistics. EconomicGeology 58, 1246-1266

Morris, G.L., J. Fan, 1997. Reservoir Sedimentation Handbook.

Morrisey, D.J., L. Howitt, A.J. Underwood, J.S. Stark, Spatial variation in soft-sediment benthos, Marine Ecology Progress Series, Vol: 81:197-204.

Stanley, D.J., Swift, D.J.P., 1976. Marine Sediment Transport and Environmental Management. John Wiley and Sons, N.Y.

URL 1, 2013. http://en.wikipedia.org/wiki/Spatial_variability

Walling D.E. and Moorehead P.W. (1989) The particle size characteristics of fluvial suspended sediment: An overview. Hydrobiologia, 176/177, pp. 125-149

Xu, J. X. (2000). Grain-size characteristics of suspended sediment in the Yellow River, China. *Catena* **38**, 243-263.