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Original article

Monitoring of Moisture Content and Sediment Fineness as Predictors of Shoal Breaching in an Estuary

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Abstract

Namdae-cheon in Gangwon-do Province, Korea, is a valuable well-preserved lagoon. The estuary of Namdae-cheon Stream is closed because of the surrounding natural sand shoal. Thus, during the dry season, river water cannot easily flow to the ocean and therefore stagnates. River water congestion causes environmental deterioration of estuaries, often by eutrophication. In this study, we examined wall disintegration in the estuary area and used it to determine appropriate measures for the conservation of estuary water quality in the future. A total of 24 sites were selected, with 13 sites on the west side and 11 sites on the east side of the estuary study area. Samples were collected and analyzed for particle size and moisture content both vertically and horizontally. Sedimentary deposition rate was measured, and subsidence analysis was performed. Particle size, water content, sedimentary deposition, and subsidence analyses indicated that flow shifted to the west during the study period. In conjunction with other variables that may affect changes in flow, these parameters can be used in future research to predict shoal breaches and associated changes in water flow direction.

Keywords: Namdae-cheon, Breaching, Grain Fineness, Moisture Content, Deposition

1. Introduction

The Namdae-cheon Stream originates from Doolubong in Ganggye-myeon, Gangneung, and joins the streams from the valleys of Mt. Seorak, Mt. Jokbong, Ngokbuksan, and Huangbashan in the Taebaek mountains (Byeon *et al*., 1996). The population of Namdae-cheon is low, and the area has little industrial activity. These factors, combined with the geographic isolation of the mountain area, keep the environment relatively pristine. The average water depth is about 1 m, resulting in an extreme temperature difference between winter and summer. In addition, floods and high waves cause cyclic breaching that connects the lagoon and the sea. Breaches allow chub mackerel, flatfish, black sea bream, gizzard shad, and other species to live near the stream inlet instead of the more typical crucian carp and Asiatic ricefish. Species such as cold-water fish, aquatic fish, and Japanese reptiles are becoming more abundant. This contrasts with the dominance of salmon, particularly in domestic rivers (Kwon *et al*., 2002).

The Namdae-cheon estuary is a closed estuary because of the surrounding natural sand shoal. Because the estuary basin closed, water does not flow smoothly into the ocean and becomes stagnant. In addition, the partial penetration of seawater through the intermittent opening and closing of the shoal leads to salinity-dependent density stratification. Under these conditions, organic inflows from upstream or from the surrounding ground area can cause environmental degradation in the estuary, such as eutrophication. A long residence time in the downstream area causes stagnant

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organic matter and the accumulation of floating matter and nutrients, resulting in the deterioration of the quality of the estuary (Yoon, 1999). In 2007, Song Ji-ho discovered more than 1000 marsh clams per meter. In December 2007, a total of 180 million clam worms were observed in the lagoon, with a density of 3787 clam worms per meter (Heo, 2008). The Namdae-cheon estuary is a major travel route for anadromous fish such as salmon. Considering the high abundance of the Japanese marsh clam, appropriate conservation measures and management of the water quality of the Namdae-cheon estuary are necessary. Samples were collected from 13 sites on the west side and 11 sites on the east side of the estuary study area to assess breach tendencies(Fig. 1). Grain fineness number and moisture content were measured both vertically and horizontally to facilitate prediction of breach movement. Sedimentary deposition and subsidence rate analyses were performed using a sedimentation rate plate. Previous study was to analyze breaches that affect discharge, which in turn affects water quality, and to use this information to determine the best approaches for conservation (You *et al.*, 2003, Kim *et al.*, 2007, Jang and Cheong, 2010, Bang *et al.*, 2013).

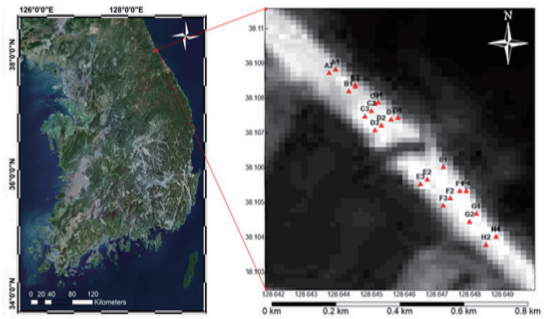

Fig. 1. Study area with the observation points around the breaching in an estuary(Left: A~D Right: E~H)

The purpose of this study is to analyze the result of several information related with grain fineness, moisture content and sediment rate for Namdae-cheon estuary sand deposit from the field survey data.

2. Methods

2.1 Grain fineness number analysis

Table 1. Classification of sediment particle size

mm	φ	Classification		Mesh # (US Standard sieve)
409.6	-12	egaclasts		
			very coarse	
204.8	-11		coarse	
1202.4	-10	boulder	medium	
512	-9		fine	
256	-8		coarse	
128	-7	cobble	fine	
64	-6		very coarse	
32	-5		coarse	
16	-4	pebble	medium	
8	-3		fine	-4(4.76mm)-
4	-2	granule		-10(2.00mm)-
2	-1		very coarse	
1	0			
0.5	1		coarse	
0.25	2	sand	medium	-40(0.42mm)-
0.125	3		fine	
0.0625	4		very fine	-200(0.074mm)-
		silt		
0.0039	8	clay		

Grain fineness number (i.e., particle diameter) is used in the study of sediments. As the size of sediment particles is highly variable, a standard reference scale is needed to distinguish particles of different sizes. Udden (1898) set the reference value at 1 mm. A particle size larger than the reference value is twice that of the adjacent size on the scale, whereas a particle size smaller than the reference value is half that of the adjacent size on the scale. A size difference of 1 mm is important for sand-sized particles, but for gravel-sized particles and larger it is less important, as it can be considered within the range of measurement error. Fine-grained soil particles are inconvenient because of the number of digits required to express their size value. Krumbein (1934) noted that it is more convenient to express the millimeter sizes of particles on a logarithmic scale to overcome this problem.

Therefore, Udden's (1898) widely used particle size standard is defined as phi (φ). Wentworth *et al*. (1992) also devised a scheme that is used as a standard classification scale. Table 1 shows the particle sizes in mm and φ and indicates the term for the particle size in each section (Lee, 2015).

In this study, the particle sizes of dried sand samples were analyzed using sieve analysis with a standard sieve. The sizes of the particles on the phi (φ) scale were determined as shown in Eq. (1).

$$\varphi = -\log2(d/d0) \tag{1}$$

where *d* represents the diameter of the particle in mm. d0 is a reference diameter, which indicates a diameter of 1 mm. Particle diameter can be determined using a sieve or by direct measurement from a thin section. The distribution of sediment particle size is analyzed using numerical values for the distribution form or shape such as the cumulative frequency curve or mean value, mode, median value, classification, skewness, and kurtosis. These statistical quantities can be calculated using the moment method by converting the particle size data into the φ standard. Graph based on data using the φ standard is more commonly used than is moment calculations, as the size of the largest or smallest particles is not certain. In this study, particle size analysis was performed as in Eq. (2) by applying the method proposed by Folk and Ward (1957). For example, $\varnothing 16$, $\varnothing 50$ and $\varnothing 84$ represent cumulative weight percent (16%, 50% and 84%) for calculating grain size.

$$\begin{aligned} \text{Mean} &= \frac{(\varnothing 16+\varnothing 50+\varnothing 84)}{3} \\ \text{Sorting} &= \frac{(\varnothing 84-\varnothing 16)}{4} + \frac{(\varnothing 95-\varnothing 5)}{6.6} \\ \text{Skewness} &= \frac{\varnothing 84+\varnothing 16-2\varnothing 50}{2(\varnothing 84-\varnothing 16)} + \frac{\varnothing 95+\varnothing 5-2\varnothing 50}{2(\varnothing 95-\varnothing 5)} \\ \text{Kurtosis} &= \frac{\varnothing 95-\varnothing 5}{2.44(\varnothing 75-\varnothing 25)} \end{aligned} \tag{2}$$

Sediments were collected at a depth of 1 m from sites A1 to F4, and sand was sampled every 20 cm to analyze the extent of the Namdae-cheon Stream area (Fig. 2).

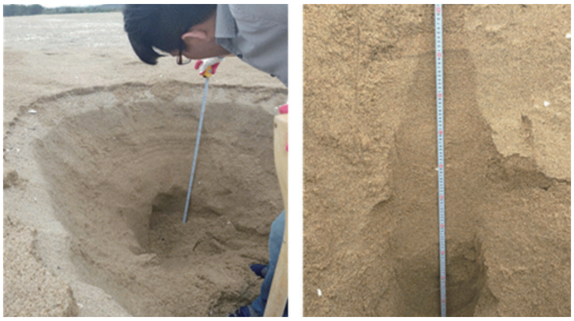

Fig. 2. Sampling up to 100 cm with every 20 cm spacing in estuary sand sediments area from the Namdae-cheon stream

Table 2 . Location of measurement point

	Point	Latitude	Longitude		Point	Latitude	Longitude
1	A1	38.10884	128.6439	14	E1	38.10601	128.6472
2	A2	38.10874	128.6437	15	E2	38.10567	128.6467
3	B1	38.10834	128.6445	16	E3	38.10554	128.6465
4	B2	38.10821	128.6443	17	F1	38.10534	128.6477
5	B3	38.10839	128.6445	18	F2	38.10513	128.6474
6	C1	38.10785	128.6451	19	F3	38.10492	128.6472
7	C2	38.10765	128.6450	20	F4	38.10535	128.6479
8	C3	38.10749	128.6448	21	G1	38.10468	128.6482
9	C4	38.10789	128.6452	22	G2	38.10446	128.648
10	D1	38.1074	128.6456	23	H2	38.10380	128.6485
11	D2	38.10723	128.6453	24	H4	38.10403	128.6488
12	D3	38.10709	128.6451				
13	D4	38.10745	128.6458				

The vertical distribution of the data was calculated by analyzing the particle size relative to the amount of sand collected The samples were classified into 0.044, 0.105, 0.25, 0.50, 1.00, 2.00, and 4.00 mm sizes using analytical sieves, and the analysis was performed using Eq. (3). In the Namdae-cheon Stream estuary, approximately 1 m deep pits were drilled at 15 points, and sand was collected at 20 cm depth intervals. The sampling locations are shown in Fig. 1 and listed in Table 2.

2.2 Moisture content analysis

We analyzed the moisture content of sediments on the east and west sides of the gravel rupture in the estuary. A uniform amount of each wet sand sample was weighed. The samples were then dried for 24 h, after which each sample was weighed again. The weights of each of the sand samples before and after drying were compared to determine the mass ratio. Fig. 3 outlines the moisture content analysis performed in this study.

Fig. 3. Process of analysis of moisture content

2.3 Sedimentary deposition rate analysis

On March 31, 2017, a sedimentation rate plate was placed on the west side of the Namdae-cheon Stream estuary to determine the amount of sedimentary deposition and/or subsidence. Data were collected after 53 days (i.e., on May 22, 2017) (Fig. 4).

Fig. 4. Sediment rate plate before and after measurement (Right: 17/3/31, Left: 17/05/22(after 53 days))

3. Results

3.1 Grain fineness number analysis

The sedimentary depositional environment in the study area was determined by analyzing data from 24 sample sites, with 13 of the sites on the west side of the estuary and 11 on east side. Five samples were collected at depths of 20, 40, 60, 80, and 100 cm at each sample site and analyzed for grain fineness number, classification skewness, and kurtosis (Fig. 5).

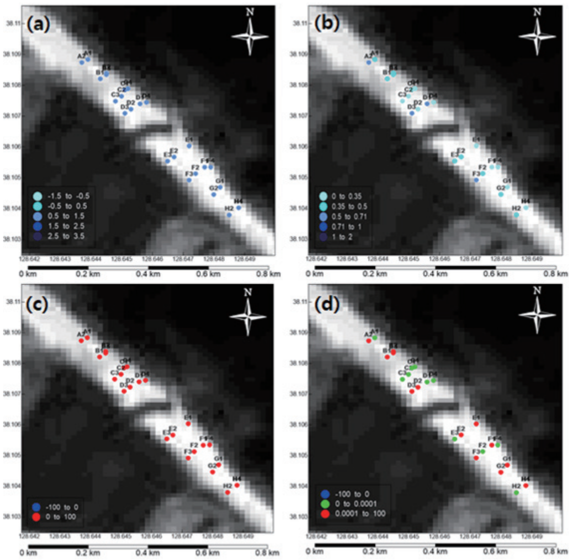

Fig. 5. An analysis of parameter (a) average of fineness number (b) classification (c) skewness (d) kurtosis

Table 3. An analysis of parameter by location

	F	C	S	K		F	C	S	k
A1	1.067	0.353	2	0	E1	0.8	0.301	0.3	0.164
A2	0.867	0.503	0.2	0.409	E2	0.667	0.382	0.4	0.327
B1	1.133	0.412	1.9	0.164	E3	0.867	0.353	1.8	0
B2	0.8	0.483	0.5	0.164	F1	0.933	0.262	1.5	0.164
B3	0.8	0.412	1.1	0.409	F2	1	0.433	0.9	0
C1	1	0.272	2.1	0	F3	1	0.503	0.6	0.327
C2	1	0.303	2	0	F4	0.933	0.323	1.7	0
C3	1	0.312	1.9	0	G1	1.133	0.312	2.3	0
C4	1.067	0.231	2.4	0	G2	1	0.419	1.167	0.273
D1	1.067	0.559	2.429	0	H2	1.133	0.373	1.5	0
D2	0.933	0.322	1.3	0.164	H4	1.133	0.342	2.2	0.082
D3	0.667	0.503	0.8	0.164					
D4	0.917	0.289	1.75	0					

F:Average of fineness number / C:Classifications / S:Skewness / K:Kurtosis

Table 3 shows the results of the particle size analysis. Fig. 5 shows the results of the particle-size parameter analysis for each sample site and depth. Four sites among sites A–H were selected, and samples were collected according to the local environmental condition of the study area. The results were analyzed by selecting the locations where valid research data were available. The average particle size at each sampling location was calculated and classified according to the Udden–Wentworth scale (Fig. 5(a)). The average particle size at each site ranged from 0.667 mm to 1.282 mm, indicating that the Namdae-cheon Stream estuary sediments consist mainly of sand. In general, within 0.35 φ is considered a very good classification, and within 0.5 φ is considered a good classification. Therefore, as most sites in the Namdae-cheon Stream area were in the range of 0.5 φ, the classification of the samples can be considered good (Fig. 5(b)). Fig. 5(c) shows the skewness of surface sediments in the study area; the blue dot indicates positive skewness. Most of the study sites showed positive skewness that is biased toward a medium grain size. The kurtosis is mostly zero or positive; therefore, the distribution is generally leptokurtic (Fig. 5(d)). Sites E1, E2, E3, and E4 on the east side of the Namdae-cheon estuary and sites D1, D2, D3, and D4 on the west side near the breach were compared. A 0.25 mm particle size was dominant among the small particles in the western sites, whereas a 1 mm particle size was dominant in the eastern sites, indicating westward movement of the breach.

Table 4 shows the average depth of each sample site. Averages were calculated from sites A–D and sites E–H around the breach. The average grain fineness number analysis indicated that the grain fineness numbers of the samples were generally similar, about 0.9–1 mm, and that the particle size did not vary with the depth. A comparison of both sides of the study area revealed that fineness numbers remained the same. Most of the sample classifications are within ~0.3–0.53 φ, and the classifications analyzed by depth are considered good classifications according to the results of the analyses. The classification of sites E–H appears to be poor compared with that of sites A–D because of transported particles. In addition, skewness analysis along the depth of the sediments shows positive leptokurtic distribution and positive kurtosis.

Table 4. An analysis of parameters by depth

	D/L.	20	40	60	80	100		D/L.	20	40	60	80	100
Average of fineness number	A	1	0.889	1	0.777	0.889	Classifications	A	0.469	0.386	0.469	0.419	0.368
	B	1.083	1	1.083	1.166	1.083		B	0.376	0.314	0.414	0.39	0.49
	C	1	0.916	1	1	1		C	0.303	0.327	0.352	0.227	0.265
	D	1	1	0.916	1	0.75		D	0.227	0.39	0.528	0.428	0.485
	Avg.	1.021	0.951	1	0.986	0.93		Avg.	0.344	0.354	0.441	0.366	0.402
	E	0.833	0.5	1.125	0.916	0.75		E	0.352	0.439	0.666	0.289	0.452
	F	0.833	1	1	1	1		F	0.465	0.39	0.465	0.227	0.352
	G	1.083	1.375	0.833	0.916	1.125		G	0.327	0.823	0.39	0.672	0.842
	H	1.333	1.222	1.222	1	1.111		H	0.401	0.469	0.495	0.252	0.285
	Avg.	1.021	1.024	1.045	0.958	0.996		Avg.	0.386	0.53	0.504	0.36	0.483
Skewness	D/L.	20	40	60	80	100	Kurtosis	D/L.	20	40	60	80	100
	A	1.333	0.666	1	0.5	2		A	0.273	0.273	0.546	0.136	0.136
	B	1.875	1.875	1.75	2.125	1.25		B	0.409	0	0	0	0.102
	C	2	1.625	1.75	2.25	1.5		C	0	0	0	0	0
	D	2.25	1.625	0.125	1.5	2.786		D	0	0	0.204	0	0.204
	Avg.	1.864	1.447	1.156	1.593	1.884		Avg.	0.17	0.068	0.187	0.034	0.11
	E	0.75	0.375	2.161	1.25	0.375		E	0.307	0.307	1.721	0.204	0.409
	F	0.125	1.125	0.625	2.25	1.75		F	0.409	0.204	0	0	0
	G	2.125	4.323	-0.125	2.036	4.78		G	0	0.923	0.307	1.333	1.692
	H	2.5	1	4.215	2.166	2.333		H	0.136	0	0	0	0
	Avg.	1.375	1.705	1.719	1.925	2.312		Avg.	0.213	0.358	0.507	0.384	0.525

3.2 Moisture content analysis

Samples collected from 24 sites on both sides of the estuary were analyzed to vertically assess the moisture content ratio. Table 5 shows average of moisture content ratio in a depth direction. Fig. 6 shows the moisture content of each site for each 20 cm subsample to illustrate the horizontal moisture content ratio trends. Fig. 6(a)–(e) shows the moisture content ratios according to depth. Fig. 6(f) shows the average moisture content ratio, which is relatively high at sites A–D (from west to east; eastward around the shoal) and relatively low in sites E–H, although the moisture content ratio varies with depth. Higher moisture content on either side of the breach indicates the influx of water, meaning that a breach is likely to occur. Therefore, the relatively high moisture content ratio indicates that a breach will likely occur on the west side.

Table 5. Average of moisture contents ratio in a depth direction

Location	Moisture ratio (%)	Location	Moisture ratio (%)	Location	Moisture ratio (%)
A1	2.8274938	D1	3.0901908	F2	3.4507062
A2	2.8135064	D2	3.5982602	F3	1.8331722
B1	3.125935	D3	2.76988	F4	3.0077596
B2	3.102753	D4	3.4537342	G1	2.937256
B3	2.91651	E1	1.679797	G2	1.8914838
C1	6.717588	E2	2.5855886	G3	1.9850312
C2	5.0897996	E3	2.3445098	G4	2.7274488
C3	2.795743	E4	2.3182034	H2	0.9946802
C4	4.7224084	F1	2.9097972	H4	1.845565

3.3 Sedimentary deposition rate analysis

A sedimentation rate plate installed on the west side of Namdae-cheon was considered settled after 53 days (from March 31 to May 22, 2017), with about 57 cm of sediment accumulation. The breach is thought to have moved westward, consistent with the results of the grain fineness number and moisture content analyses.

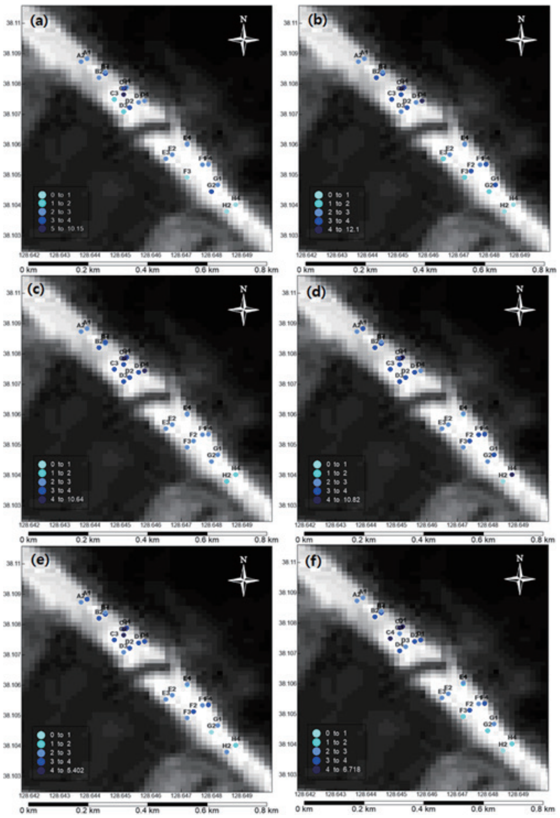

Fig. 6. Moisture contents according to depth (a) 20 cm (b) 40 cm (c) 60 cm (d) 80 cm (e) 100 cm (f) average

4. Conclusion

The purpose of this study was to assess breach tendencies in the estuary, as breaches can affect the water quality of the Namdae-cheon Stream. Grain fineness number, moisture content, sedimentary deposition, and subsidence rates were analyzed in the breach area. A total of 24 sample sites were selected from east to west around the breach, and five samples were collected from each site at 20 cm intervals up to a depth of 100 cm. Particle size in the Namdae-cheon sediment samples ranges from a minimum of 0.667 mm to a maximum of 1.282 mm, indicating primarily coarse and medium sediments with positive skewness. The particle size analyses for sites D1–D4 and E1–E4 indicate that the breach is moving westward. The high moisture content at sites A–D indicates a high breach probability compared with the low moisture content at sites E–H.

The sedimentary deposition and subsidence rate analyses after about 53 days from the date of installation indicated around 57 cm of sediment accumulation and westward movement of the breach. The results of this study suggest that analyses of grain fineness number, moisture content, sedimentary deposition and subsidence rates can be used to understand and predict the direction of movement of the Namdae-cheon estuary. However, as it is difficult to determine a trend based on the results of a single study, continuous research and data collection are required, and the theoretical diversity and accuracy of the approach taken in this study must be validated for it to be useful in additional research. A breach occurred during the field survey on March 31, 2017, whereas no breach occurred during fieldwork on May 22, 2017. Precipitation also affects breaches in the Namdae-cheon, as 18.4 mm of precipitation fell over the 7 days before March 31, 2017, compared with 0 mm over the 7 days before May 22, 2017. In addition, the effectiveness of this research approach can be substantiated by examining the relationships between the study results and satellite images.

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