The Journal of the Oceanological Society of Korea
Vol. 25, No. 4, pp. 182-188, December 1990

A Study of Sedimentary Environment in the Estuary of Nakdong River:

Sedimentation Processes and Heavy Metal Distributions

YOU DAE LEE* AND CHANG-WON KIM**
*Department of Marine Science, Pusan National University, Pusan, 609-735, Korea
**Department of Environ, Eng., Pusan National University, Pusan, 609-735, Korea

洛東江 河口域 堆積環境硏究：堆積作用 및 重金屬 分布

李裕大*·金昌元**
*釜山大 海洋科學科, **釜山大 環境工學科

The sedimentation processes and heavy metal distributions at the Nakdong estuary were investigated during October 1987 and September 1988.

The depositional sedimentary envionement of the studied area was estuarine environments and was divided into three provinces depending on its textural parameters such as barrier, tidal falt, and water passes. The relationship between the textural parameters showed that the barrier was under strong wave action, that the tidal flat was under relatively weak wind-driven currents, and that the water passes were under strong and continuous tidal currents. Each environment was resulted from different transport mechanism. The sand barrier sediments were transported by all three populations including suspension, saltation, and bed load. And water pass-deposited sediments were by the bad load with some suspension population.

In water mass over the studied area, the concentrations of heavy metals including Cu, Cd, Cr^{+6}, Pb and Zn were recorded to be 27.8, 6.7, 20.4, 16.3, and 37.3 ppb in their highest concentrations, respectively. And those in sediments were 20.0, 1.65, 25.4, 15.4, and 132.9 ppm, respectively. The total uptake factors of Cu, Cd, Cr^{+6} Pb, and Zn by V. Muller (*Corbicula fluminea*) were 1600, 310, 310, 490 and 7900, respectively.

낙동강 하구역에서의 중금속 분포와 퇴적작용에 대한 연구를 1987년 10월부터 1988년 9월에 걸쳐 수행하였다.

연구지역의 퇴적환경은 하구환경이며 입도분석 특성에 따라 모래섬, 수로 및 조간대 지역으로 분류된다. 모래섬의 퇴적물은 뜬짐, 튐짐, 굴르기 상태로 운반되었으며, 조간대는 주로 뜬짐과 튐짐으로 이동되었다. 수로의 퇴적물은 거의 굴르기와 약간의 뜬짐 상태로 운반되었다. 모래섬은 강한 파도의 영향을 받으며 그 후방에 놓인 조간대는 약한 조류의 영향을 받는다.

수중에서 Cu, Cd, Cr^{6+}, Pb, Zn의 농도는 각각 최고의 27.9, 6.7, 20.4, 16.3, 37.3 ppb를 기록하였으며, 퇴적물에서는 20.0, 1.65, 25.4, 15.4, 132.9 ppm을 나타내었다. 이들 중금속의 재첩(V. Muller)에 의한 총섭취인자는 각각 1600, 310, 310, 490, 7900g 이었다.

INTRODUCTION

The Nakdong estuary contains unique geomorphological and oceanographical conditions. There are several sand barriers and both the edges of sand barriers are water passes. The water depth of this area is usually less than 6 meters. It is deeper at both water passes and becomes shallower progressively to the center of the tidal flat, which is not affected by the direct wave action and the sand barrier.

The semi-diurnal tide penetrates into the tidal flat, the Nakdong estuary through tidal inlets, the water passes, and tidal creek. The flow velocities in the tidal inlets and in the water passes to the estuary may go up to 0.75 m/s during flood and 1.25 m/s during ebb period in the winter. In the summer, the maximum ebb velocities increase, whereas the flood velocities decrease to some extent due to the increased river discharges. The current velocities on the tidal flat are lower than those in the water passes.

The analysis of textural parameters to delineate transport mechanisms and depositional environments of sands are widely employed for studying modern sedimentary provinces. Recently significant advances have been made in the comprehension interactions between sediment transport and environmental energy.

Also the water quality has been damaged severely in this area. Several industrial sites are located around the estuary and wastewater has not been treated properly. The heavy metals are not easy to control during wastewater treatment. And since they are not biodegraded, they are usually accumulated in the sediment and biomass and their effect be magnified through trophic level accumulation.

This paper includes the textural parameters and their mutual relationships as well as the heavy metal distributions in the Nakdong estuary.

MATERIALS AND METHODS

1. Sample collection and analysis for textural parameters

During the 1987 and 1988, the samples from 15 sites have been obtained, and the sampling area is shown in the <Fig. l>. The analysis for grain size was done using a rot-tap sieve shaker with 6 step U.S. standard sieve series. a top-load balance (Libor ED2000) was adopted to weight each sand samples. For the size analysis the data were analyzed by the equations of Folk and Ward (1957).

2. Sample collection and analysis for heavy metals

Various heavy metal samples of water meas, sediments, and biomass (V. Muller; *Corbicula fluminea*) were collected four times (1987. 10. 26, 1988. 3. 22, 1988. 7. 5, and 1988. 10. 9) at the Nakdong estuary and the locations are shown in the Fig. 1. The water samples were obtained using Van Dorn samplers. The sediment samples were collected up to 4 cm depth of the river bottom with grab samplers.

The samples were analyzed for Copper (Cu), Cadmium (Cd), Chromium (C^{+6}), Lead (Pb), and Zinc (Zn) using an atomic absorption/flame emission spectrophotometer (Shimadzu Model No. AA-670/670G) according to the Standard methods (APHA-AWWA-WPCF, 1985) and their wave lengths were 324.8 nm, 228.8 nm, 357.9 nm, 283.3 nm, and 213.9 nm respectively. Pretreatment of sediments was carried out according to the soil digestion method from the Pollution Standard Methods (Environmental Office, 1985).

RESULTS AND DISCUSSIONS

1. Testural parameters and environmental recognition

Graphic Mean: The mean grain size of the sample on this studied area was separated into three groups such as coarse, medium, and find sands. Most of the samples were fine sands (1.90-2.30 ϕ). The coarse sands (0.13-0.33 ϕ) were distributed on the water passes. A belt of medium sands (1.01-2.13 ϕ) were located at the edge of the barrier, water passes, and some places at the outer part of the sand barrier. Most of the sand

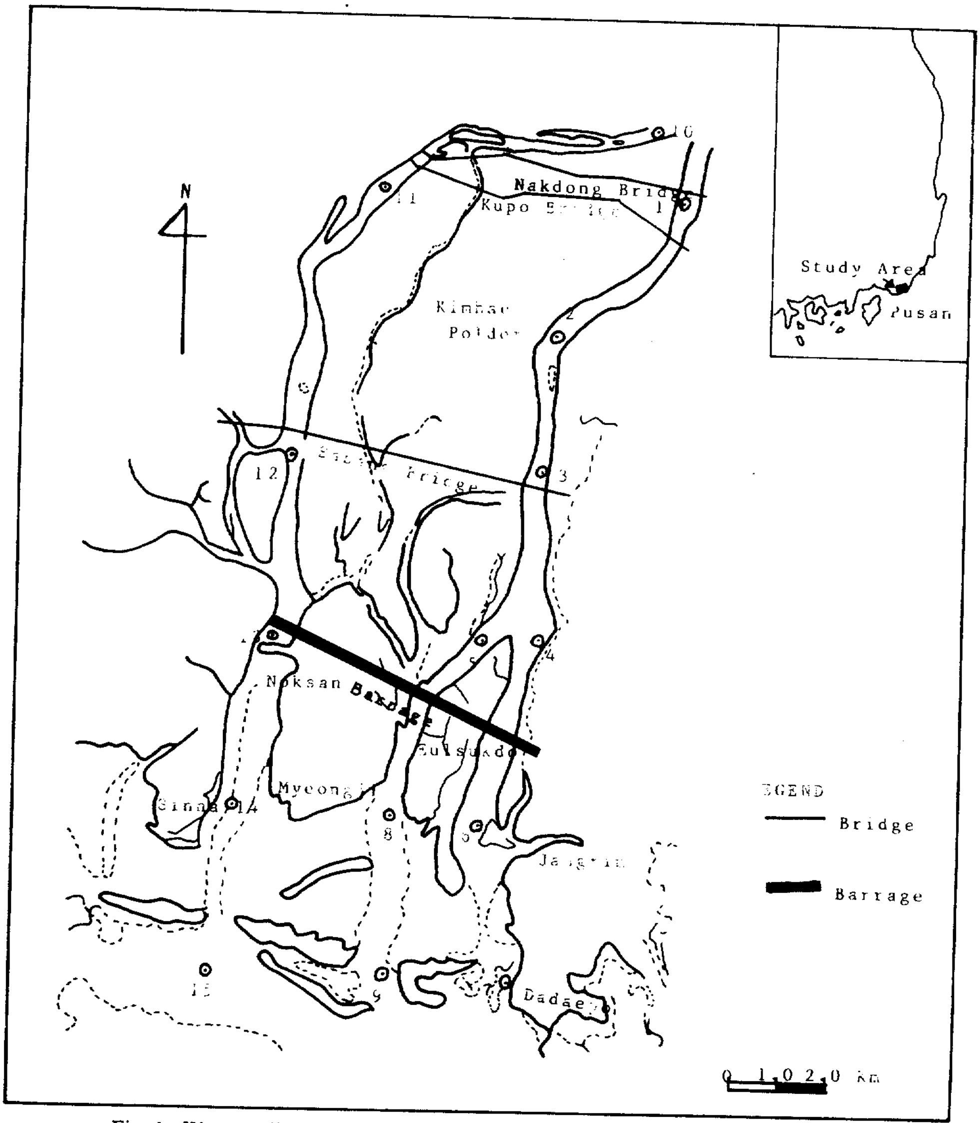

Fig. 1. Water sediments and biomass of sampling sites in the Nakdong estuary.

barrier and the tidal flat were covered with fine sands. A decrease in grain size was seen toward the center of the tidal flat.

Inclusive Graphic Sorting: The sands of this studied area were consisted of well sorted ($\delta G < 0.50\ \phi$) to poorly sorted (1.00-2.00 ϕ). The barrier sands were mainly well sorted (0.26-0.67 ϕ). The fine sands on the tidal flat showed gradational change from the edges to the center, moderately-sorted (0.71-1.00 ϕ), to well-sorted. And the most of the sands on the northern part of the tidal flat, close to land revealed moderately-sorted. The coarse sands of both water passes showed poorly-sorted (1.35-1.12 ϕ).

Inclusive Graphic Skewness: There was significant variation in skewness values on the studied area. The skewness values vary between -0.13 and 0.45. Most of the sands were nearly symmetrical to fine skewed and average value is 0.07.

Table 1. Regional comparison of heavy metal concentrations in water mass at the Nakdong estuary.

Region	Range (average) of heavy metal concentration $\mu g/l$				
	Cu	Cd	Cr^{+6}	Pb	Zn
Nakdong barrage upper zone	18.6-27.9 (23.3)	1.5-6.7 (4.1)	12.4-19.8 (15.9)	1.0-16.3 (8.65)	16.3-30.8 (23.7)
Nakdong barrage lower zone	3.2- 8.1 (5.7)	0.1-2.2 (1.2)	9.8-20.4 (15.1)	0.1- 4.6 (2.35)	7.3-36.3 (21.8)
West Nakdong river	1.9- 7.8 (4.9)	1.3-4.6 (3.0)	2.0- 5.6 (4.1)	3.9-14.1 (9.00)	15.4-37.3 (26.4)
West Nakdong river lower zone	5.1- 9.9 (7.5)	0.3-1.7 (1.0)	3.9- 5.3 (4.6)	0.1- 0.2 (0.15)	5.1- 6.2 (5.7)

2. Regional distributions of metals in water mass

The region covered by this study may be devided into four zones such as the upper zone of the Nakdong barrage (sampling points No. 1 to No. 5 in the Fig. 1), the lower zone of Nakdong barrage (sampling points No. 6 to No. 9), the West Nakdong (Jookrim) river (sampling points No. 10 to No. 13), and the lower zone of the West Nakdong river (sampling points No. 14 to No. 15). The heavy metal concentrations in water mass were compared each other based on this zoning and the results are shown in the Table 1.

In overall, the concentrations of Cu, Cd, Cr^{+6}, Pb and Zn were measured up to 27.9 ppb, 20.4, 16.3 ppb and 37.3 ppb in their averaged values. These values were slightly lower than those reported by ISWACO (1986, 1987). At the upper zone of Nakdong barrage the concentrations of all heavy metals showed highest or near highest values among the four zones. At the lower zone of Nakdong barrage Cr^{+6} and Zn were relatively high. The Pb and Zn were recorded to be highest at the West Nakdong river. All heavy metals were lowest levels at the lower zone of the Wes Nakdong river. These results may be due to relative loading from the point sources located near each zone.

The heavy metal point sources to each zone are identified as followings. For the upper zone of the Nakdong barrage, the heavy metals are discharged from the industrial sites located at Taegue and Yangsan as well as several mines through the Nakdong river basin. Also a significant amount of heavy metals are discharged directly from the Sasang industrial site. For the lower zone of barrage, the Jangrim industrial site is a primary source. The Kimhae-Andong industrial site is a major point source to the West Nakdong river. For the lower zone of the West Nakdong river, there is no significant point source except input from the upper West Nakdong river through the Naksan sluice gate.

3. Distributions of heavy metals in sediments and biomass

The heavy metal concentrations in the sediments at the Nakdong estuary were analyzed and results were summarized in the Table 2. In overall, the concentration ranges of Cu, Cd, Cr^{+6}, Pb and Zn in the sediments were 2.3-20.0 ppm, 0.08-1.65 ppm, ND-25.4 ppm, 0.1-15.4 ppm, 26.6-132.9 ppm, respectively. Other study conducted at the same region during similar period (Park, 1987) reported slightly higher values. The natural heavy metal concentration in the earth's crust including Cu, Cd, Cr, Pb and Zn were reported to be 45 ppm, 0.2 ppm, 200 ppm, 15 ppm and 65 ppm, respectively (Schroeder, 1965). The concentrations of Cu, Cr^{+6}, and Pb in the sediments at the Nakdong estuary were relatively similar to these natural values.

Table 2. Regional comparison of heavy metal concentrations in sediments at the Nakdong estuary.

Region	Range of heavy metal concentration, ppm				
	Cu	Cd	Cr^{+6}	Pb	Zn
Nakdong barrage upper zone	12.8-20.0	0.08-0.23	3.8-25.4	1.3-15.4	59.8-132.9
Nakdong barrage lower zone	5.7-13.8	1.16-1.65	4.0-12.5	3.4-11.7	28.7- 96.8
West Nakdong river	8.5-10.3	0.12-1.39	3.0- 7.7	8.8-12.3	64.1-125.9
West Nakdong river lower zone	2.3-16.2	0.22-0.23	ND	0.1-0.3	29.6- 62.6

Table 3. Heavy metal concentrations in biomass (*Corbicula fluminea:* V. Muller) at the Nakdong estuary.

Sampling Site	Concentration of heavy metals, μg/g dry wt (ppm)				
	Cu	Cd	Cr^{+6}	Pb	Zn
Sasang	9.87-52.50	0.60-1.81	1.81- 6.89	0.16-16.22	96.62-345.44
Barrage east	9.16-39.80	0.03-1.24	1.79-17.50	0.11-16.02	100.08-270.75
Jangrim	4.93-16.32	0.04-0.72	0.46- 7.56	0.10- 7.56	86.84-192.40
Naksan	9.95-14.41	0.04-0.13	0.93- 2.36	0.18- 3.04	98.07-132.77

Table 4. Concentration ratios of heavy metals in sediments and biomass against to heavy metals in water mass.

Region	Ratio to heavy metal concentration at water mass (Avg. ±St.dev.)*				
	Cu	Cd	Cr^{+6}	Pb	Zn
Sediments	1300±610	900±1500	890±620	1200±1000	3900±1500
Biomass	1600±430	310± 340	810±120	490± 310	7900±3700

*Ratio=(conc. at sediments or biomass)/(conc. at water mass)

The regional distributions of heavy metal were examined by comparing relative concentraton of those between four zones. It seemed that heavy metal concentrations in sediments were also affected by their point sources just like those in water mass.

Corbicula fluminea (V. Muller) was selected as a typical biomass at the Nakdong estuary and the sample was collected twice at four places shown in the Fig. 1, including Sasang, Barrage east, Jangrim and Noksan. The concentration ranges of Cu, Cd, Cr^{+6}, Pb and Zn in the biomass were 4.39-52.50 ppm, 0.03-1.81 ppm, 0.46-17.50 ppm, 0.10-16.22 ppm, 86.84-345.44 ppm in dry weight biomass basis, respectively, which are shown in the Table 3. These results were similar or slightly lower than Kim and Kim's report (1987). The heavy metal concentrations in biomass were affected by the point sources also.

The heavy metal concentrations in sediments an biomass were compared to those in water mass by calculating concentration ratios based on water mass. The results in their averages and standard deviations are exhibited in the Table 4.

In the sediments the average concentration ratios ranged between 890 and 3900 and those were ranged between 3100 and 7900 in the biomass. The concentration ratio in biomass may be called as a total uptake factor. These results were well compared to Brooks and Runsky's findings (1965), which showned to heavy metal concentration from the ocean into scallops was concentrated in the order of three to six. Decending order of heavy metal concentration in biomass was Zn, Cu, Pb, Cd and Cr^{+6}, which was identical to those in sediments. This finding indicated that heavy metal concentrations in biomass may be correlated with those in sediments.

4. Overall loss rate of heavy metal in Nakdong barrage reservoir

It was estimated that the leangth of Nakdong barrage reservoir was 4 km fom the barrage and the volume of this reservoir was 17,500,000 m^3 when the water depth was SMSL + 1.0 m (Pusan Environmental Office Branch, 1988). The flow of Nakdong river was estimated to be 100 m^3/sec and the input concentrations of Cu, Cd, Cr^{+6}, Pb and Zn were estimated to be 24.2 ppb, 4.95 ppb, 15.8 ppb, 10.6 ppb and 20.2 ppb, respectively. The wastewater flow from the Sasang industrial site was 1.0 m^3/sec and the heavy metal concentrations estimated to be five times higher than the river concentrations. the heavy metal concentrations in the reservoir estimated to be 18.6, 2.39, 12.5, 3.2 and 16.3 ppb of Cu, Cd, Cr^{+6}, Pb and Zn respectively. The reservoir was assumed to be mixed completely. A mathematical model (O'Connor and Mueller, 1981) was applied to this system and the overall loss rates were calculated. The steady state model is a followings, which can be used to calculated total heavy metal concentrations in water column (C_{tl}).

$$C_{tl} = \frac{W_{tl}/Q}{1 + K_t t_o} = \frac{W_{tl}}{Q + K_{tv}}$$

C_{tl} = total concentration of heavy metal in water column, $\mu g/l$

W_{tl} = total heavy metal input loading in water column, g/day

V = reservoir volume, m^3

Q = output flow from reservoir, m^3/day

t_o = hydraulic retention time, day

K_t = overall loss rate of heavy metal, day^{-1}

Desending order of overall loss rate of heavy metals was Pb, Cd, Cu, Cr^{+6}, and Zn and their values were 1.22 μg/day, 0.58 μg/day, 0.18 μg/-day, 0.16 μg/day and 0.14 μg/day, respectively. These overall loss rates are not absolute, but will give some idea to estimate behavior of heavy metals in the reservoir.

CONCLUSIONS

1. The sediments on the studied area were mainly fine sands, and that were coarse sands on the water passes. The transport mechanisms were thought as following. On the water passes the tidal current was main factor in transporting sediments and the river which was flowing over the sea water was another one to transport fine sediments to the shore. On the tidal flat the weak tidal currents and the wind-driven currents were important. On the sand barrier the wind-driven currents, especially rip current and long shore current, were main factor.
2. The transport modes were thought as three populations, including the bed-load populations with some suspension on the water passes, mainly the saltation with some suspension and bed-load on the tidal flat and the mainly saltation with some rolling and suspension on the sand barrier.
3. The heavy metal concentration in the water mass, sediments, and biomass at the Nakdong estuary seemed to be affected by the wastewater point sources. Therefore the highest concentration of Cu, Cd, Cr^{+6} were observed at the upper zone of the Nakdong barrage. In other three zones, the concentrations of those were relatively similar. The concentrations of Pb and Zn were the lowest values at the lower zone of the West Nakdong river.
4. The highest averaged concentration of Cu, Cd, Cr^{+6}, Pb, and Zn at the entire Nakdong estuary area were 27.9, 6.7, 20.4, 16.3, 37.3 ppb in the water body, 20.0, 1.65, 25.4, 15.4, 132.9 ppm in the sediments and 52.5, 1.81,

17.5, 16.2, 345.4 ppm in the biomass, respectively.

5. The highest total uptake factors by the V. Muller (*Cŏrbicular fluminea*) for Cu, Cd, Cr^{+6}, Pb and Zn were 1600, 310, 490 and 7900, respectively. The overall loss rate of heavy metals including Cu, Cd, Cr^{+6}, Pb and Zn in the Nakdong barrage reservoir were 1.22, 0.58, 0.18 and 0.16 μg/day, respectiely, based on a simple mathematical model.

ACKNOWLEDGEMENT

This paper was supported by the Korea Research Foundation, 1987-1988, (한국학술진흥재단). The office of Nakdong barrage management, Korea Water Resources Corporation is acknowledged for its help during field sampling.

REFERENCES

APHA-AWWA-WFCF, Standard Methods, 16th ed., American Public Health Association, 1985.

Environmental Office. The Environmental Pollution Standards Methods. Tong-Hwa technical Publication, 1987.

Folk R.H. and Ward, W.C., Brazos Rivers Bar; A Study in the Significance of grain size parameter. *J. Sediment. Peterol.*, **27**, 3-26, 1957.

Friedman, G.M., Dynamic Processesand Statistical Parameters for size frequency distribution of beach and river sands. *J. Sediment. Peterol.*, **37**, 327-359, 1967.

ISWACO (Industrial Sites and Water Resources Development Corporation), Study on Ecological System of Nakdong Estuary (2nd phase). Institute of Natural Science Research, Seoul National University, 1986.

ISWACO (Industrial Sites and Water Resources Development Corporation), Study on Ecological System of Nakdong Estuary (3nd phase). Institute of Natural Science Research, Seoul National University, 1987.

Kim, D.K. and J.Y. Kim, Study on the shellfish pollution in the Nakdong estury. Journal of Environmental Research. Institute of Environmental Problems Research, Pusan National University, Vol. 5, 1-21, 1987.

O'Conner, D.J. and J.A. and J.A. Mueller. Modeling of toxic substances in natural water systems. Class-note for 26th Summer Institute in Water Pollution Contral, Manhattan College, N.Y., 1981.

Park, C.K., Water quality management plan following completion of Nakdong estuary barrage. Society for Conservation of Nakdong River. Vol. 6, 14-23.

Passega, R. Grain size representation by C-M patterns as a geological tool, *J. Sediment. Peterol.*, **34**, 830-847, 1987, 1964.

Pusan Environmental Office Branch, Study on Environmental Capacity of Nakdong Barrage Reservoir. Institute of Environmental Probloms Research, Pusan National University, 1988.

Sohroedor, H.A., A.P. Nason and I.H. Tipton, "Essential trace metals in man; Cobalt", *J. Chronic Dis.*, **20**, 869-890, 1965.

Visher, G.S., 1969. Grain size distribution and depositional processes. *J. Sediment. Peterol.*, **39**, 1074-1106, 1969.

Received March 23, 1990
Accepted October 27, 1990