Ocean Research 21(2): 117-126, 1999

Development of a Real-Time Water Quality Monitoring System using Coastal Passenger Ships and PCS Telemetry

Jae-Youll Jin, Jin Soon Park, Jongkuk Lee*, Kwang Soon Park, Dong-Young Lee, and Ki Dai Yum

Coastal and Harbor Engineering Research Center, KORDI
Ansan P.O. Box 29, Seoul 425-600, Korea

**DATAPCS Company*
B-513 SIGMA II, 18 Kumi-dong, Bundang-gu, Seongnam 463-500, Korea

Abstract: To meet increasing needs for environmentally sustainable management of coastal area, there has been compelling pressure to establish a cost-effective and long-term coastal water quality (CWQ) monitoring system. A remote CWQ monitoring system, STAMP, has been developed and is in operation along the route between Kyema harbor and Anma Island in the southwestern coastal area of Korea. STAMP uses a PCS phone as a telemetry unit to transmit acquired data for monitoring general water quality parameters, and a routinely operating coastal passenger ship or car ferry. STAMP has various merits of low-cost operations; long-term monitoring with secure instrumentation; and stable real-time telemetry of acquired data without the loss and noise. It is expected that the system will serve as a very useful tool in the CWQ managing programs of Korea taking the advantage of many coastal passenger ships in various routes including the ships departing from the coastal industrial cities. The acquired data compiled on suspended surface sediment concentrations (SSSC) will be also valuably helpful in understanding the sediment budget across the routes of the vessel.

Keywords: Real-time telemetry, PCS (Personal communication services),Passenger ship route, Coastal water quality monitoring system, General water quality parameters.

1. Introduction

Korean coastal areas have been pressured to accommodate various industrial infrafacilities such as industrial complexes, power plants and ports of medium to large dimensions in order to keep up with its economic growth. However, an integrated CWQ managing program or an efficient CWQ monitoring system has been hardly associated with the coastal development which more often than not has potential to deteriorate the CWQ. The coastal environment has been suffering from the adverse effects of coastal development of various types such as toxic land based and nutrient pollutants, red tides, oil spills, and etc. threatening public health, habitats, and the economic well-being of local communities that depend on fishing, tourism, and marine related commerce. Pollution continues to contaminate the waters, and need to monitor those pollution for appropriate management of coastal regions is greater than ever.

Generally, three methodologies, i.e., monitoring buoys, observation towers, and the measuring or the seawater sampling onboard of designated vessels, have been used for the measurements of water quality parameters. A CWQ monitoring buoy has merits in that it produces continuous data from a site as well as easy mobility when changing the monitoring site. On the other hand, it does not allow to cover a wide area. Moreover, the authorities concerned with such CWQ management system have been unwilling to adopt it due to possibility of damages or lost of instruments. Nevertheless, more intelligent profiling and data transmitting buoys have been recently commercialized including the Radio Buoy of Idronaut of Italy, the Rem-Pro of CSIP Ltd. of the UK and the SeaHorse of Brook Ocean Technology Ltd. of Canada. In spite of its stable long-term monitoring, an observation tower also has the inherent limitation of high constructional cost. The main and common limitation of both point measurements from a buoy and from an observation tower is that neither could measure the water quality parameters that require field or laboratory experiments for their analyses. Although, the tower can be equipped with the semi-autonomous facilities for the chemical analyses of the parameters, until now, the general methods for CWQ monitoring use a designated vessel for data acquisition. However, a bi-monthly or seasonal monitoring program is not expected to contribute to the effective CWQ management in Korea where illegal dumping of various toxic pollutants and other contamination are frequently occurred especially during the rough sea state.

Monitoring general water quality parameters using regularly operating vessels has advantages in cost efficiency, time-efficient long-term monitoring, and instrument security, albeit the measurements are confined to the surface layer. Thus, it can serve as a supplementary measure to cover the various demerits of the above three methodologies.

There are some examples of monitoring using the routinely operating vessels for various purposes. Harashima (1993, 1994) measured seawater temperature, salinity, pH, and nutrients using an automated system installed on a car ferry crossing the Korea Strait. Cooper *et al.* (1998) measured the partial pressure of carbon dioxide using a fully automated instrument installed on a merchant ship traveling between the UK and the Caribbean. MOMAF (1999) has developed a more elaborated system to measure various chemical and biological parameters and has successfully tested it along the 15-hour ferry route between Inchon and Cheju Island. Jin *et al.* (1999a) have tested an underwater monitoring system using a multi-parameter instrument along a relatively short route traveled by a coastal passenger ship focusing on the SSSC data acquisition.

STAMP, which means a *S*ystem *T*ransmitting the acquired data with a PCS phone *A*nd *M*onitoring using coastal *P*assenger ships, is the extension of the results obtained by Jin *et al.* (1999a). In this paper, the system configuration and preliminary results obtained along a coastal passenger ship route in Korea are described.

2. System Configuration

The total configuration of the system consists of three parts (Fig. 1); the Field-Data Acquisition System (F-DAS)

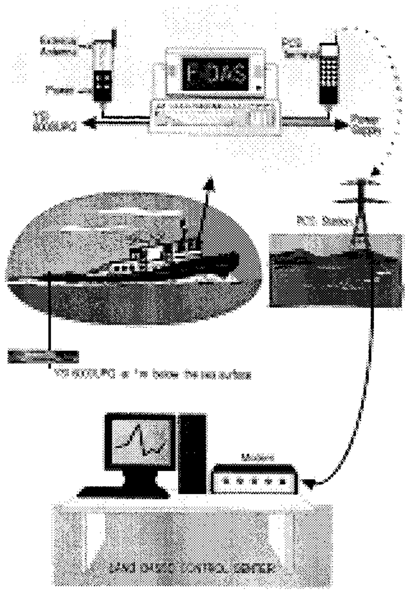


Fig. 1. Diagrammatic configuration of STAMP.

in the steering house; the *in-situ* measuring instrument; and the remote control center.

The Shipboard F-DAS

Yeo *et al.* (1997) developed a practical field data acquisition device which integrates a personal computer, GPS, and three aquatic environmental sensors. The F-DAS of STAMP is an extension of their results. A microcomputer, GPS, PCS terminal, hardware rebooter, power source, and a power booster/distributor are the components which make up the shipboard F-DAS (Fig.2). Original specifications of the microcomputer, model Libretto of the Toshiba, are 815MB hard disk, 20MB RAM memory, a parallel port, a serial port and a PCMCIA slot. The PCMCIA slot is extended into two serial ports for this F-DAS. The updating rate and velocity accuracy of the GPS, model GPS III of Garmin Corporation of the USA, are 1/sec and 0.1 knot RMS (root mean square), respectively. And its position accuracy is 1-5 m with DGPS corrections, 15 m 3D RMS, and 100 m 2D RMS. GPS III of F-DAS has not been upgraded to the DGPS correction: Hence its position accuracy ranges 15-100 m according to the satellite situation. Of three PCS companies in Korea, only LG TeleCom Ltd. provides bi-directional data transmitting service at 1.8GHz. The Libretto is rebooted everyday by the hardware rebooter for the system stability. The battery system supplies DC 12V current to the booster/distributor and the water quality measuring instrument. And it is recharged during routine ship operations: Hence the whole system is able to continue working even during the periods when the ship's engines are turned off. The booster/distributor raises the power supplies to DC 14.8V and powers to the Libretto, whereas 12V current is supplied to the GPS III. The power source for the PCS terminal is the Libretto.

In the Libretto, a program was installed for the instrumentation controls, data acquisition and bi-directional communication with the remote control center.

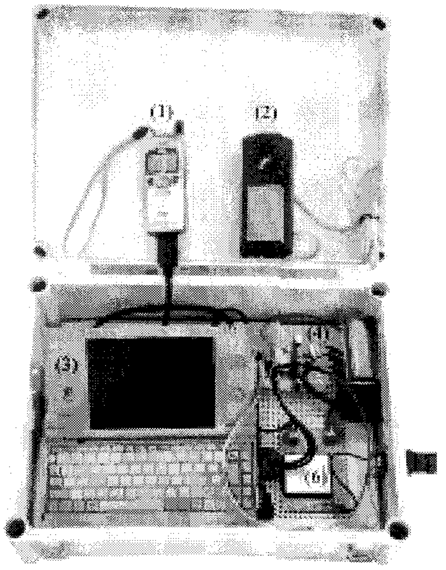


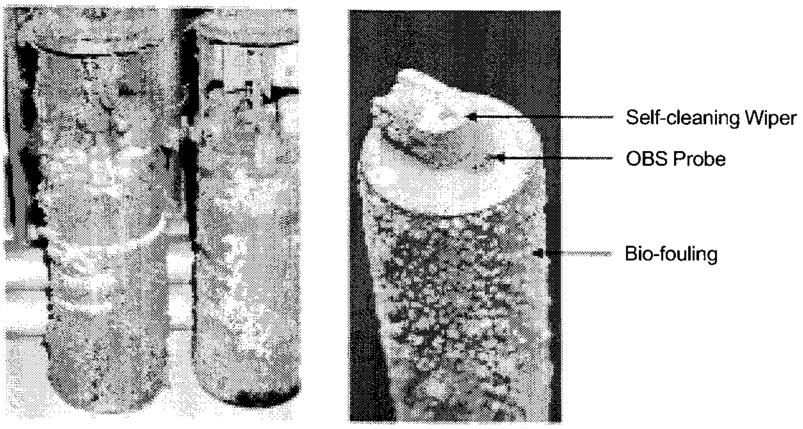
Fig. 2. Constituents of the Field-Data Acquisition System (F-DAS): (1) PCS terminal, (2) GPS, (3) notebook PC, (4) hardware rebooter, (5) DC 12V power port, and (6) power booster/distributor.

Instrumentation for Water Quality Monitoring

The multi-parameter water quality monitoring instrument for STAMP is the 6000UPG of YSI Inc. of the USA that can optionally measure seawater temperature, salinity, water depth, DO, pH, turbidity, and ammonia in direct reading, self-recording or telemetering mode.

The main reason Jin *et al.* (1999a) selected the 6000UPG for their SSSC monitoring is that it has a self-cleaning wiper to prevent the bio-fouling on the optical backscatter sensor (OBS) for the turbidity monitoring which is very important especially in an automated long-term monitoring set-up (Fig. 3).

Another critical point that should be rigorously considered in the continuous CWQ monitoring using a routinely operating ship is to determine the location of the monitoring instrument. There are two methods; by pumping the surface water into a shipboard measurement system and through *in-situ* measurement by instruments attached underside of the vessels. Shipboard measurement has an



(a) (b)

Fig. 3. (a) Bio-fouling on the current meters retrieved after one month mooring in Youngkwang (KEPCO 1992); (b) 6000UPG OBS retrieved after 39-day deployment in Lavaca Bay, USA.

advantage of the instrument security, while *in-situ* measurement is free of any potential data contamination or data artifact that can be induced in the circulation chamber of the pumped seawater. After several field and laboratory experiments, Jin *et al.* (1999a) adopted *in-situ* measurement as the more optimal monitoring method. *In-situ* measurement was also adopted for STAMP, but the guard frame was modified for the instrument security as shown in Fig. 4.

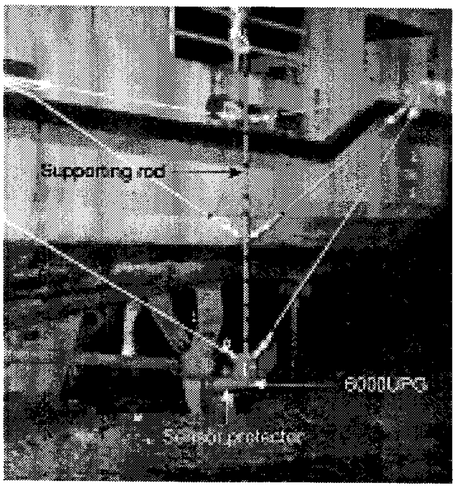


Fig. 4. Configuration of the instrument attachment to a routinely operating passenger ship.

Remote Control Center

Although a remote control system such as shown in Fig. 1 uses a wire telephone, it is also possible to use a PCS terminal without a modem. Thus, the mobility of the control center is another advantage of the system.

The Windows program, YSICALL, controls the system. After connection to the shipboard F-DAS, YSICALL provides four optional modes. The first mode is to download the acquired data from the shipboard F-DAS. The second is to upload a new program from the control center to the

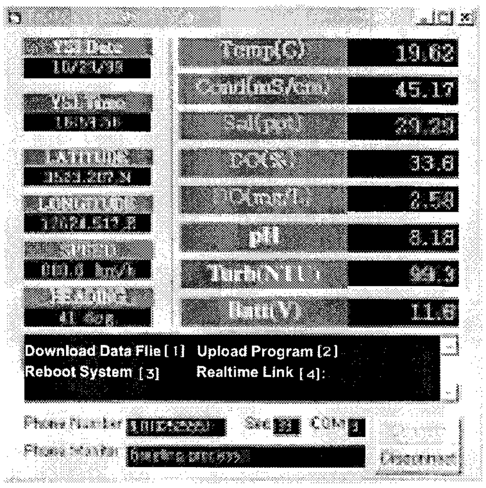


Fig. 5. F-DAS interface in real-time mode

shipboard F-DAS. The second mode enables the system operator to remotely change the sensing interval. The third mode for rebooting the Libretto is another means for checking the system. The real-time data is provided by the fourth mode. The Windows interface in the real-time mode is shown in Fig. 5.

3. Operational Monitoring along the Kyema-Anma Route

After several field tests and improvement, the system started operational monitoring along the Kyema-Anma route in the Youngkwang area (Fig. 6) on October 28, 1999. According to the extensive oceanographic survey conducted by KEPCO (1994) of the area, the mean spring and neap tidal ranges are about 5.4 m and 2.2 m, respectively. The mode directions of incoming waves in summer and winter seasons are from West (18%) and WNW (61%), respectively. Occurrence frequency of the significant wave heights beyond 0.8 m is only 2% in summer, while 31.3% in winter. Thus, the area around the route is a low macrodtidal regime (Hayes 1979) embracing strong wave actions due to the winter monsoon from Siberia.

On the north, Kyema harbor is contiguous to the Youngkwang Nuclear Power Plant (YNPP). Its cooling water intake basin and the outfall are located at about 1.3 km and 3.3 km away from the harbor, respectively.

The car ferry operating along the route of 41 km is the *Sinhae IX* which has dimensions of weight, length and width as 154 tons, 49.5 m and 8.4 m, respectively (Fig. 7). The *Sinhae IX* plies once a day via Songi Island with average cruising speed of 13 knots.

Every five minutes, STAMP saves or provides the date and time information, seawater temperature, conductivity, salinity, DO (% and ppm), pH, turbidity in nephelometric turbidity unit (NTU), battery voltage, and the location, cruising speed and direction of the *Sinhae IX*. Considering that the water quality around Youngkwang is relatively

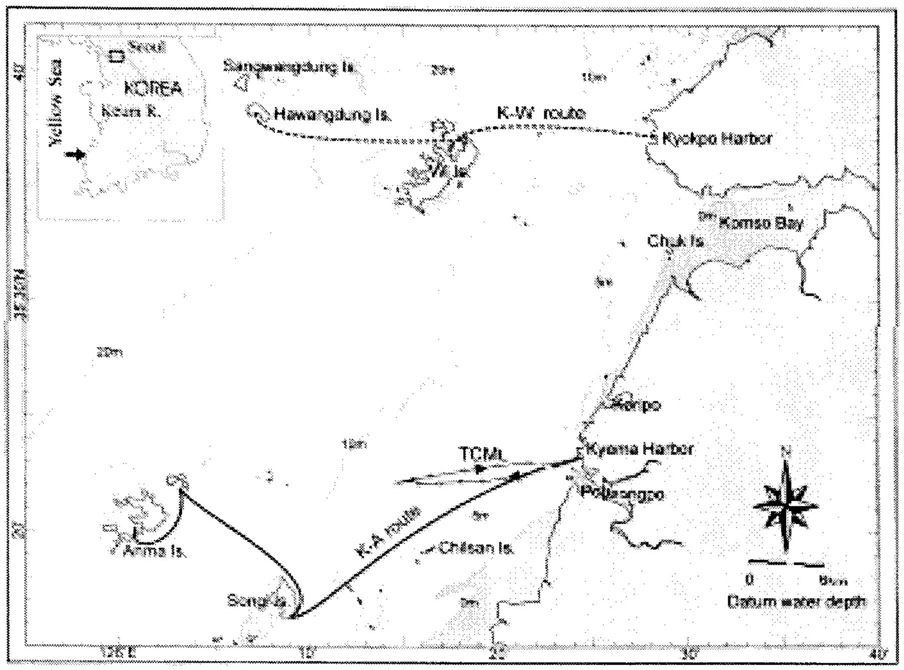


Fig. 6. Bathymetric chart around Youngkwang and passenger ship routes.

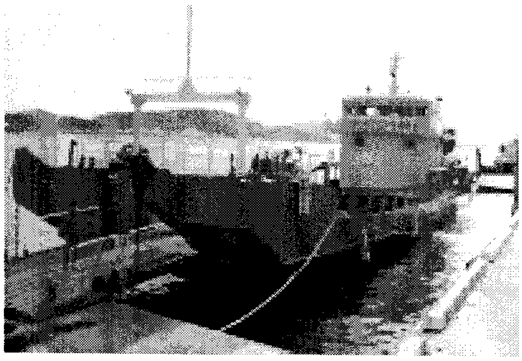


Fig. 7. The *Sinhae IX* operating along Kyema-Anma route.

good except for the thermal pollution due to the discharges from YNPP, and that the telephone charges for the real-time telemetry is a burden to the CWQ program, the data file is downloaded once everyday.

In order to remove any possibility that seawater may intrude into the OBS sensor through the wiper shaft, the self-cleaning wiper was programmed not to work when the ship cruises over 5 km/h.

4. Results and Discussion

Point Monitoring in Kyema Harbor

As described above, STAMP is able to monitor CWQ even for the several days when the *Sinhae IX* lies at anchor in the harbor due to the rough sea state of the route. An example of the harbor CWQ monitoring is shown in Fig. 8. The tidal curve is based on the prediction for Anma Island by NORI (1999).

Significant temperature variation is noticed. The temperature increased markedly from 18.2°C at 14:40 to 19.9°C at 15:30. Referring to the well-known flow patterns of the area (KEPCO 1994; KOPEC 1999), this increment may be a suspect caused by the thermal discharges from YNPP. That is, during ebb periods, the heated cooling water discharged at about 500 m south of Koripo flows southwestward, hence may not directly advect into Kyema harbor. However, thermal plume stretched on the southwest off the harbor flows to the shoreline during flood periods inducing the seawater temperature in the harbor to increase. The temperature for the former flooding, however, slightly decreased as shown in Fig. 8, which may be due to the difference in solar radiation and/or high water level. Actually, the former flooding had occurred in the night while the latter occurred during the day. And the high water levels at 05:02 and at 17:38 on October 29 were 4.8 m and 5.4 m, respectively (NORI 1999). Compiling more information by STAMP will be of help to understand the temperature and salinity fluctuations in the harbor.

There are two peaks in the turbidity measurements (Fig. 8), 418.8 NTU at 09:55 and 462.9 NTU at 13:55, respectively. Predicted tidal phase at Anma Island (NORI 1998) and that measured near Kyema harbor by Jin *et al.* (1999b) indicate that the phase at Anma is faster by about 20 minutes. Thus, the tidal curve in Fig. 8 should shift to the right in order to be adjusted to the harbor, and the low water in the harbor might occur at about 11:45 because it was 11:25 at Anma. Accordingly, the two turbidity peaks occurred at 110 minutes before and 130 minutes after the low water. Although the peaks can be interpreted in various directions for the present, some hydrodynamic surveys including water level and tidal current measurements should be associated with for more detail study.

Turbidity in the NTU should be carefully calibrated in the unit of mg/l in order to have sedimentological interpretation, and the results of Jin *et al.* (1999a) may be applied. The relation between the 6000UPG values and the real concentrations is shown in Fig. 9. The empirical formula in Fig. 9(a) was derived from the field experiment on December 14, 1997 along the test cruise monitoring line (TCML in Fig. 6) and that in Fig. 9(b) on the *Sinhae IX* for two weeks beginning March 6, 1998 along the Kyema-Anma route. Applying these relationships, the former and latter peak concentrations in Fig. 8 range 333~433 mg/l and 368~479 mg/l, respectively.

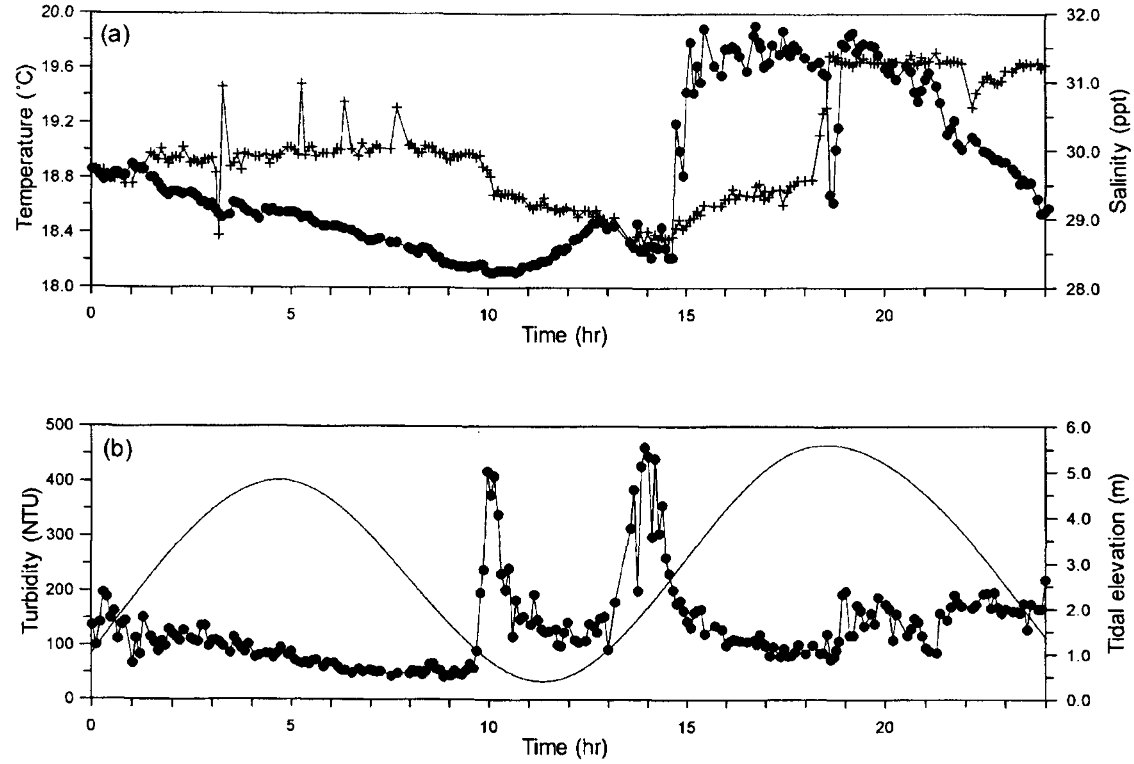


Fig. 8. An example of point monitoring in Kyema harbor on October 29, 1999 : (a) Filled circle and cross represent seawater temperature and salinity, respectively; (b) Filled circle represents turbidity.

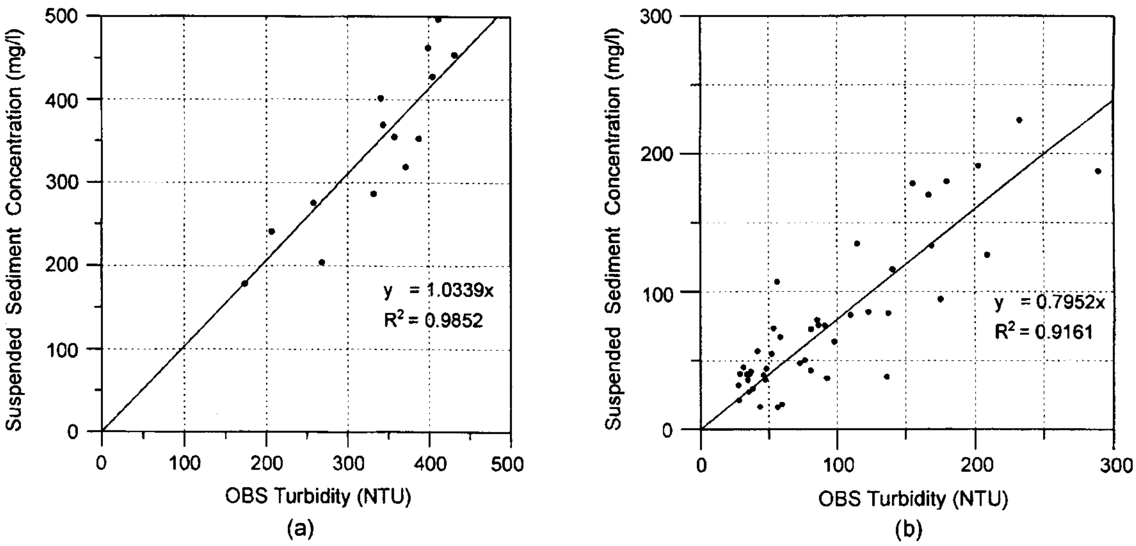


Fig. 9. *In-situ* 6000UPG calibration results (a) for a day using a chartered fishing boat and (b) for two weeks on the *Sinhae IX* (Jin *et al.* 1999a).

Cruise Monitoring along the Kyema-Anma Route

The results obtained by the ship-cruise monitoring on November 11, 1999 are shown in Figs. 10 and 11. The high and low water levels on the day and their episodic time periods are described in Table 1. From the view of the tidal curve of Anma, the *Sinhae IX* left Kyema 190 minutes after the high water level and arrived in Anma 34 minutes before the low water. Then, it left Anma 120 minutes after the low water and arrived in Kyema 110 minutes before the high water.

There is a common feature in the temperature and turbidity distributions on both cruises. That is, between Kyema and Songi Islands, 27 km apart from the harbor, the seawater temperature is concavely distributed, while the turbidity convexly. During the cruise for Anma, the maximum turbidity of 277.4 NTU occurred at 12.5 km from Kyema and at 07:40 when it was 144 minutes before the low water at Anma. The maximum turbidity during the

Table 1. Tide levels at Anma Island on November 11, 1999 (NORI 1999).

Time(h:m)	Elevation (m)
03:51	4.6
10:04	0.7
16:19	5.1
22:41	1.2

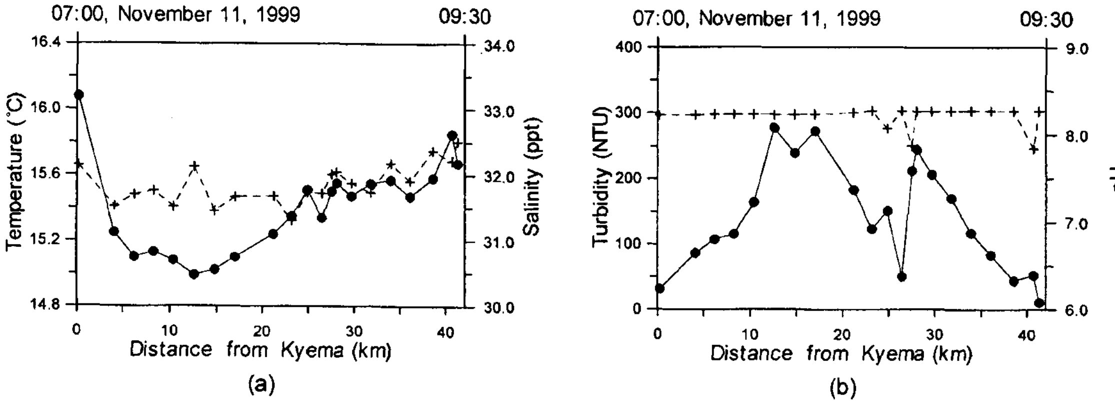


Fig.10. An example of cruise monitoring from Kyema to Anma: Filled circlerepresents (a) seawater temperature and (b) turbidity; cross represents (a) salinity and (b) pH.

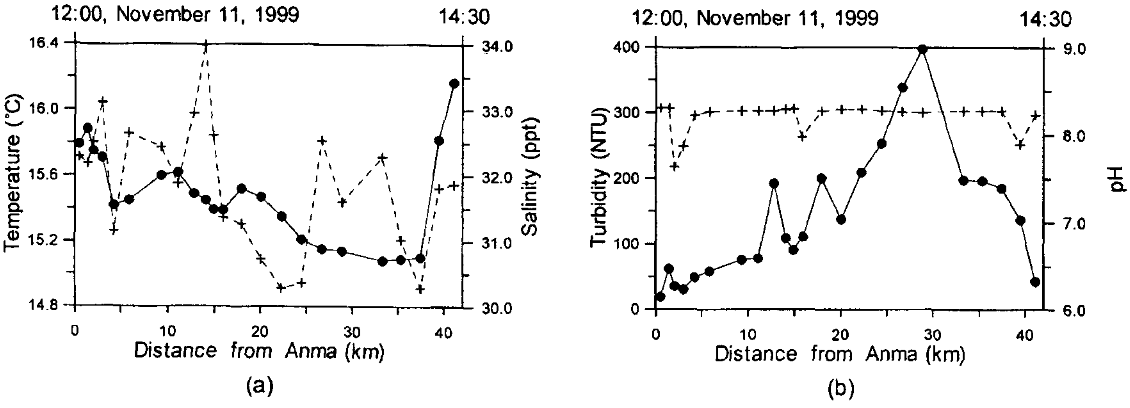


Fig.11. An example of cruise monitoring from Anma to Kyema: Filled circle represents (a) seawater temperature and (b) turbidity; cross represents (a) salinity and (b) pH.

cruise for Kyema was 398.2 NTU at the nearly same location and it occurred at 14:00 when it was 139 minute before the high water at Anma. Considering the flow conditions at nearly maximum ebbing and flooding, the flooding concentrations across the line between Kyema harbor and Songi Island is higher than the ebbing concentrations, which agrees with the results of Jin *et al.* (1997) of a point measurement for 5 days including two storm periods.

The pH measurement shows nearly constant values of about 8.3 during both cruises, although there are some minor fluctuations.

Salinity during the cruise for Anma fluctuated from 31.31 ‰ to 32.51 ‰, while a more wider range was observed of 3.71 ‰ during the cruise for Kyema. Although it may be thought that the increment in its fluctuation range was caused by northeastward flooding of higher saline open seawater and the variation of the water depth along the route, more data are necessary for a more detailed interpretation.

Further Applicability of the STAMP for the CWQ Management in Korea

STAMP is a very simple and stable systematic method which does not require additional construction of an onshore data receiving station, and the data are bi-directionally transmitted in digital format. In short, the system has advantages in cost and data quality. Although its telemetering coverage depends on the terminal distance to the PCS station, it reaches up to about 40 km along the Kyema-Anma route.

As shown in Fig. 12, there are many coastal passenger ship routes in Korea. Moreover, many routes start from relatively large cities including Inchon, Kunsan and Mokpo that have their onshore industrial complexes as potential point sources of contamination and pollution. Thus, STAMP can cost-efficiently and effectively contribute to the CWQ management along several important routes.

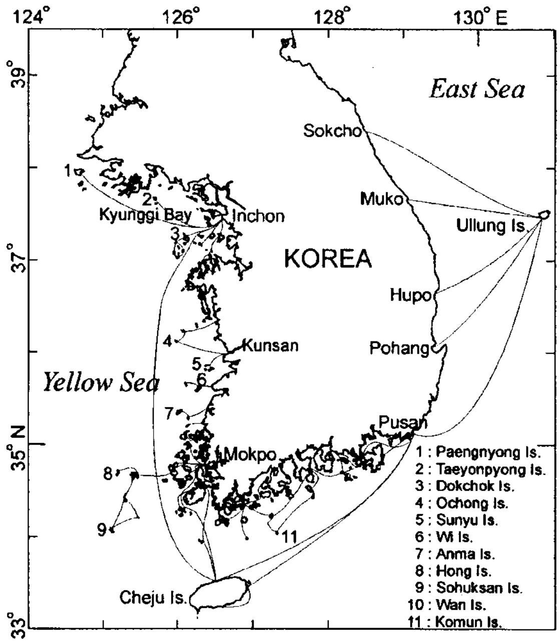


Fig.12. Major passenger ship routes in Korea.

5. Conclusions

A real-time CWQ monitoring system of STAMP is developed as a management tool for Korean coastal waters. STAMP is purposed for monitoring the general water quality parameters along coastal passenger ship routes and transmit the data using a PCS wireless phone. It is possible for the system to remotely communicate in both directions. Another advantage of the system is that with this system a point monitoring is also possible for several days without power supplies from the ship. The system can serve as a cost-effective methodology for the reliable long-term management of Korean regional coastal waters.

From the preliminary results along the route between Kyema harbor and Anma Island in the Youngkwang area, it was proved that more data accumulation would be of help in understanding the behavior of related CWQ parameters in the area.

Acknowledgement

This study was supported by the Ministry of Maritime Affairs and Fisheries of Korea under grant No. PM99043. We are grateful to Captain Il-Rae Kim and the crew of the *Sinhae IX*. Our many thanks extend to Mr. Sung Eun Kim and Mr. Won Dae Baek for their help in the field experiments. We thank Prof. W. K. Yeo, Myongji Unvi. and Dr. K. S. Park, Ocean Tech. Co. for their kind comments on the manuscript.

References

Cooper, D. J., A. J. Watson, and R. D. Ling. 1998. Variation of PCO_2 along a north Atlantic shipping route (U.K. to Caribbean): A year of automated observation. *Marine Chem.*, 60, 147-164.

Harashima, A. 1993. High temporal-spatial resolution marine biogeochemical monitoring from Japan-Korea ferry 1991 results. Monitoring report on global environment, Center for Global Environmental Research, Japan.

Harashima, A. 1994. High temporal-spatial resolution marine biogeochemical monitoring from Japan-Korea ferry 1992-1993 results. Monitoring report on global environment, Center for Global Environmental Research, Japan.

Hayes, M. O. 1979. Barrier island morphology as a function of tidal and wave regime. p.1-27. In *Barrier Island*. ed. by S. P. Leatherman. Academic Press, New York.

Jin, J.-Y., K. D. Yum, and J. S. Park. 1997. On the importance of consolidation and fluidization in numerical modelling of muds and pollutants transports. *J. Korean Soc. Coastal and Ocean Engrs.*, 9(1), 43-55.

Jin, J.-Y., D.-Y. Lee, J. S. Park, K. S. Park, and K. D. Yum. 1999a. Monitoring of suspended sediment concentration using vessels and remote sensing. In *Coastal and Estuarine Fine Sediment Transport*. ed. by W. H. McAnally and A. J. Mehta. Elsevier Science (in press).

Jin, J.-Y., K.C. Hwang, J. S. Park, K. D. Yum, and J. K. Oh. 1999b. Development of a time-selective self-triggering water sampler and its application to *in-situ* calibration of a turbidity sensor. *J. Korean Soc. Oceanogr.*, 34(4), 200-206.

Korea Electric Power Company. 1992. A study on the coastal environment around Youngkwang nuclear power plant. (in Korean).

Korea Electric Power Company. 1994. A study on the reduction of thermal discharge effects around nuclear power plants-1st interim report (Youngkwang). Rep. No. 92-802. (in Korean).

Korea Power Engineering Company. 1999. A study on the reduction of thermal discharge effects around Youngkwang nuclear power plant. (in Korean).

Ministry of Maritime Affairs and Fisheries. 1999. Marine environmental monitoring by using ship-of-opportunity. Rep. No. BSPM98001-00-1118-2. (in Korean).

National Oceanographic Research Institute. 1998. Tide tables (Coast of Korea). Ministry of Maritime Affairs and Fisheries. (in Korean).

National Oceanographic Research Institute. 1999. Tide tables (Coast of Korea). Ministry of Maritime Affairs and Fisheries. (in Korean).

Yeo, W. K., B. M. Yoon, J. Lee, and J. H. Hur. 1997. Development of a practical field data acquisition device for civil and environmental engineering application. *J. Korean Soc. Coastal and Ocean Engrs.*, 9(4), 176-181. (in Korean).

Received Sep. 22, 1999
Accepted Dec. 15, 1999