Spread Patterns of Thermal Effluent Discharged From Young-Kwang Nuclear Power Plant Using Remote Sensing Data

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Abstract: This study is focused to analyze the movement of thermal effluent dischargeed from nuclear power plant by season, ebb and flow, and before and after foundation of tide embankment using thermal infrared band image of 28 scenes observed from Landsat from 1987 to 2004, which is the early stage of operation of young-kwang nuclear power plant. In diffusion of thermal effluent discharge by seasons, spring and summer is spreading further than autumn and winter. It is considered to distribute widely mixed with thermal effluent discharge and hot water, which is distributed naturally along the seaside. It is known the fact that tidal currents control the direction of diffusion of thermal effluent discharge by the change of ebb and flow. Namely, it is distributed widely on the Southwest direction along the seaside by tidal currents when ebb and, it is moved widely on the Northeast direction along the seaside by tidal current when flood. However, in the early stage of flood current, the mainstream of thermal effluent discharge is spread on Southwest direction and, the direction is changed on Northeast way when the latter period of flood current. Similarly, in the early stage of ebb current, the mainstream of thermal effluent discharge is spread on Northeast direction and, the direction is changed on Southwest direction when the latter period of ebb current. As the result of comparing to the diffusion pattern of thermal effluent discharge before and after the foundation of seawall, discharged thermal effluent from the drain of plant by the foundation of dike is shown as curved circle pattern on Northeast to West direction from the ending portion of the seawall.

Keywords: Thermal effluent, Landsat, Nuclear power plant

1. Introduction

Korea has built and run numerous nuclear and thermoelectric power plants on the coast. Built on the coast, nuclear and thermoelectric power plants use seawater as a coolant to reuse the steam, which has already been used for generation of electric power, by condensation of water. From this process, the coolant is discharged to the sea because the temperature rises and, we call this as thermal effluent. Recently, the power plant has a tendency to large size and, it is constructed and managed as various power plants by one site. Therefore, it is required for proper ways and means to monitor and control that how much influences can be caused for the around of sea environment by discharged thermal effluent.

It is important to understand for water temperature and its movement condition correctly as long as possible in order to analyze the influence of environment by thermal effluent discharge. Even though direct attempts to measure water temperature using probe vessel to do this are conducted, the measuring time takes long in case using probe vessel. So, the movement condition of thermal effluent discharge by the current should be considered by time. Furthermore, because obtained materials are point data, it is not easy to understand exactly for the overall condition. And, there is also a weak point to spend lots of time, manpower, and cost, cause it should be observed periodically for a wide area at the same time by observation from a station. From this background, the need of remote sensing technology has been emphasized ever to collect objective data at the same time for a broad area by periodically.

Remote sensing is a technology that reflected or radiated electromagnetic waves are collected from the object of surface using loaded sensor from airline of satellite and, using the materials, the technology can get the data for the object about various conditions. Remote sensing has been started after NASA in the U.S. discharged the satellite for globe observation called ERTS-1 (later, it has been changed the name as Landsat-1). Currently, applied study in the field of environment, investigation of resources, and ocean is in the processing and, because it is obtained marvelous outcome, the applied field has a tendency to increasing gradually.

The materials from artificial satellite and Airborne Multi-spectral Scanner are used mainly as a technology of remote sensing for observation of ocean environments in domestically[1]. As a satellite data, NOAA, MODIS, Landsat TM are used in large numbers. Korea launched KOMPSAT-1 loaded with OSMI sensor to observe ocean environments in 1991. But, in order to obtain the materials connected with seawater temperature among ocean environments, satellite data, which can be obtained for the data of wavelength of thermal infrared, are used NOAA SST data mainly[2, 3]. However, even though NOAA SST materials are proper for the study of wide area of thermal effluent discharge because they can obtain spatial information of low resolution (1.1km/pixel), as this study, satellite materials of high resolution are needed to analyze the range of thermal effluent discharge from localized nuclear power plants. Therefore, wavelength of thermal infrared in high resolution and Landsat satellite materials, which have 16 days observation cycle, are used mainly. Spatial resolution of wavelength image of thermal infrared of TM sensor, which is loaded onto Landsat 5, which is used for thermal effluent discharge study, is 120m/pixel and, it is operated currently. Spatial resolution of wavelength data of thermal infrared ETM+ sensor of Landsat 7, which has been started to operate from April 1999, is reached about 60m/pixel, which has better resolution than TM sensor about 2 times. However, due to the trouble of SLC (Scan Line Corrector), which corrects the distortion of image occurred by image scanning for ETM+ sensor on May in 2003, utilizing of Landsat 7 satellite images is restricted.

In this study, sea surface temperature around nuclear power plant coastal water is measured using thermal infrared band image, which is observed from Landsat affiliated satellite from initial operation of young-kwang nuclear power plant (1987) to at present (2004) and, it is analyzed for the movement and spreading pattern of discharged thermal effluent from nuclear power plant by seasons, ebb and flow, and numbers of operating nuclear power plant unit.

2. Materials and Method

1) Study area

Fig. 1 is topographical map on the periphery of young-kwang nuclear power plant. Young-kwang nuclear power plant is located on Gaema-ri, Hongnong-eub, Youngkwang-gun, Chunranam-do. Gochang-gun, Chunrabuk-do is located on Northeast direction, which is adjacent to drain. On Southwest direction, youngkwang and Hampyung is located and, Gochang and Buahn are on Northeast direction. Around 50 km on East-South direction, Gwangju is located and, around 65 km on South direction, Mokpo is located. Focused on nuclear power plant, Gomsoman is located on North and, Hampyungman is located on South. In those areas, inter-tidal flats are distributed widely. Especially, Youngkwang (Baeksu) intertidal flat, which is located upper side of Hampyungman, is important area for the study of ocean environmental system[4].

Located area of young-kwang nuclear power plant has topographical features to connect the west sea directly because they have small numbers of coasts comparing to west-south coasts, which is the closed due to it is surrounded by large and small coasts. Because such characteristic differences and various oceanographic workings of coast, in consequence, broad muddy tidal flat on West-South coast and sandy tidal flat on coast near around nuclear power plant are formed respectively. And, on the South direction of studied area, Baeksu inter-tidal flat is located, which is one of the largest flats. In the meantime, Gomsoman is located on north direction. Inter-tidal flat is exposed zone on the air when the tide is low and, it contacts with the air directly to exchange the heat when the tide is low. After that, it exchanges the heat again with seawater.

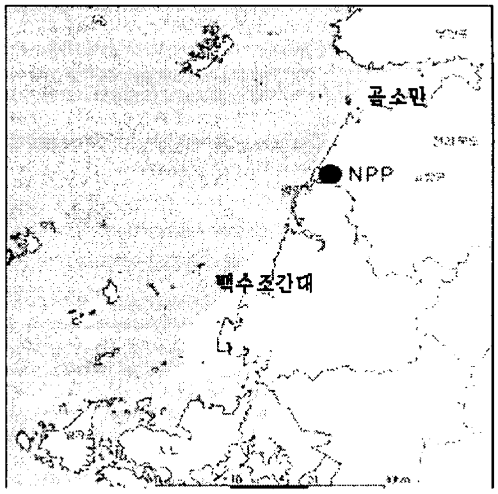


Fig. 1. Study area, Young-kwang nuclear power plant

2) The present condition of young-kwang nuclear power plant

After young-kwang nuclear power plant, which is located on West coast in Korea, was started to operate in commerce on August 1986 as a unit 1, nuclear power plants of 6 units are in operation so far [Table 1]. Intake and outlet of young-kwang nuclear power plant is composed by sea surface intake and sea surface outlet form.

Table 1. The present condition of intake and outlet at young-Kwang nuclear power plant

Unit	Location	Form	Capacity (mW)	Coolant (m^3/sec)	Outlet water Form	Intaking water form	Commercial Operating day
1	Chunnam Young-kwang-gun	PWR	950	57.5	Sea surface Outlet	Sea surface intake	'86. 08. 25
2			950	57.5			'87. 06. 10
3			1000	53.8			'95. 03. 31
4			1000	53.8			'96. 01. 01
5			1000	54.3			'02. 05. 21
6			1000	54.3			'02. 12. 23

3) Thermal infrared band image of Landsat and measure of sea surface temperature

Total 28 scenes are used among Landsat thermal infrared band images, which have been photographed 1987 to 2004(at present) in order to analyze the movement and spreading pattern of thermal effluent discharge at young-kwang nuclear power plant [Table 2]. The images, which has been used in this study, can be classified by seasons as follows; 6 scenes of spring, 5 scenes of summer, 9 scenes of autumn, and 8 scenes of winter. If it is classified by ebb and flow, 7 scenes of low tide, 6 scenes of high tide, 10 scenes of ebb tide, and 5 scenes of flood tide. It is also can be classified by the unit number of nuclear power plant as follows; 2 scenes as 1 unit is in operation, 7 scenes as 2 units are in operation, 5 scenes as 3 units are in operation, 10 scenes as 4 units are in operation, 1 scene as 5 units are in operation, and 3 scenes as 6 units are in operation.

Table 2. List of Landsat images used in this study

Satellite & sensor	Date	Season	Tide type	Operation condition
Landsat 5 TM	1987. 02. 13	WT	FT	1
Landsat 4 TM	1991. 11. 15	WT	ET	2
Landsat 5 TM	1992. 06. 02	SM	ET	2
Landsat 5 TM	1992. 11. 25	WT	LT	2
Landsat 5 TM	1993. 03. 17	SR	HT	1
Landsat 5 TM	1993. 10. 27	AT	FT	2
Landsat 5 TM	1994. 07. 26	SM	LT	2
Landsat 5 TM	1994. 09. 28	AT	ET	2
Landsat 5 TM	1995. 04. 08	SR	ET	2
Landsat 5 TM	1996. 09. 01	AT	LT	4
Landsat 5 TM	1996. 10. 19	AT	ET	3
Landsat 5 TM	1997. 01. 14	WT	ET	3
Landsat 5 TM	1997. 06. 16	SM	HT	4
Landsat 5 TM	1997. 12. 25	WT	HT	4
Landsat 5 TM	1998. 11. 10	AT	ET	3
Landsat 5 TM	1998. 11. 26	AT	ET	3
Landsat 5 TM	1999. 02. 14	WT	FT	4
Landsat 5 TM	1999. 05. 21	SR	ET	3
Landsat 5 TM	1999. 10. 20	AT	HT	4
Landsat 5 TM	1999. 11. 13	AT	LT	4
Landsat 5 TM	2000. 04. 13	SR	HT	4
Landsat 7 ETM+	2002. 02. 14	WT	LT	4
Landsat 7 ETM+	2002. 03. 18	SR	LT	4
Landsat 7 ETM+	2002. 06. 06	SM	HT	5
Landsat 5 TM	2003. 02. 01	WT	LT	4
Landsat 5 TM	2003. 07. 19	SM	ET	6
Landsat 5 TM	2003. 10. 07	AT	FT	6
Landsat 5 TM	2004. 05. 18	SR	FT	6

Season
SR: Spring
SM: Summer
AT: Autumn
WT: Winter

Tide type
LT: Low tide
HT: High tide
ET: Ebb tide
FT: Flood tide

In order to measure seawater surface temperature from Landsat thermal infrared band images, developed model method by NASA is used[5, 6, 7]. Thermal band data (band 6) from Landsat 4/5 TM and 7 ETM+ can also is converted from spectral radiance to effective at-satellite temperature. The effective at-satellite temperature of the imaged Earth surface assumes unity emissivity. A conversion formula is

$$T = \frac{K2}{\ln(\frac{K1}{L_\lambda}+1)}$$

Where:
T : Effective at-satellite temperature in K
K2 : Calibration constant 2 in K
*K1 : Calibration constant 1 in W/(m^2 *sr * μm)*
Lλ : Spectral radiance at the sensor's aperture

Table 3 gives values of K1 and K2 defined for the Landsat 4/5 TM and 7 ETM+ sensors. The following equation is used to perform a Qcal to radiance(L_λ) conversion for a L1 product:

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax}}\right) \cdot Q_{cal} + LMIN_\lambda$$

Where
*L_λ: Spectral Radiance at the sensor's aperture In W/(*m^2 * sr * μm)
Qcal: The quantized calibrated pixel value in Digital Number (DN)
Qcalmin: The minimum quantized calibrated pixel value (DN=0) corresponding to $LMIN_\lambda$
Qcalmax: The maximum quantized calibrated pixel value (DN=255) corresponding to $LMAX_\lambda$
*$LMIN_\lambda$: The spectral radiance that is scaled to Qcalmin in W/(m^2*sr* μm)*
*$LMAX_\lambda$: The spectral radiance that is scaled to Qcalmax in W/(m^2 *sr* μm)*

The LMIN/LMAX set of TM Spectral Radiance Range of band 6 is 1.2378/15.303 watts/(meter squared * sr * μm) and ETM+ is 3.2/12.65 in high gain mode.

The foregoing water temperature, which is measured by seawater surface temperature, is computed under the assumption that the emissivity of the whole earth is same. In this manner, it is needed to correct by water temperature data through actual measurement because the emissivity can be shown differently in accordance with region or target object in real world. Therefore, in this study, water temperature value from satellite images is calibrated to use water temperature value by actual measurement from intake and outlet of nuclear power plant, which is adjusted the photographing time from satellites.

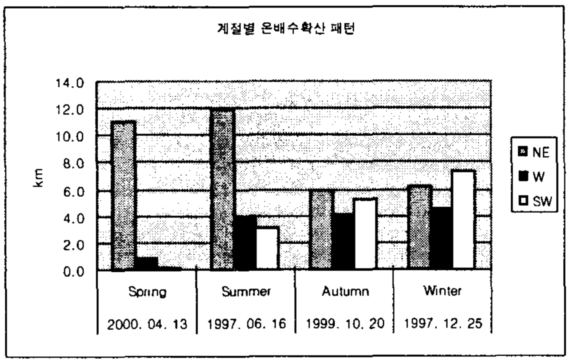
Table 3. Values of K1, K2 defined for the Landsat 4/5 TM and 7 ETM+sensors.

Landsat Thermal Band Calibration Constants		
Units	W/(m^2 * sr * μm)	Kelvin
Constant	K1	K2
Landsat 4	671.62	1284.30
Landsat 5	607.76	1260.56
Landsat 7	666.09	1282.71

3. Test results

1) Spreading pattern of thermal effluent by the change of seasons.

In autumn and winter, seawater temperature is to become lower when it is nearer to coastline. So, the boundary between thermal effluent discharge from nuclear power plant and ambient effluent can be divided into clear. However, in spring and summer, due to the characteristics of seasons that seawater temperature is higher when it is nearer to coastline, the mixed zones of thermal and ambient effluent have a difficulty to divide into clear because the boundary between them is not clear. Namely, the distinction of boundary between thermal and ambient effluent, which are appeared the coast by naturally in accordance with coastline, is not easy.In order to analyze the spreading pattern of thermal effluent by seasons, the diagram of surface seawater distribution is analyzed under the same condition of ebb and flow and the operation of nuclear power plant. In Graph 1, ebb and flow is high tide before the establishment of sea wall and, it is indicated to measure the spreading direction and distance of thermal effluent in the diagram of seawater surface distribution extracted from satellite images, which were photographed by seasons when the unit 4 of nuclear power plant was in operation. When the thermal effluent is in high tide, it is spread further on Northeast direction in spring and summer than autumn and winter. Even if such conditions, which have been distributed by naturally in accordance with coastline, happened because hot and thermal effluent are mixed and distributed widely, additional study is needed to approve it.



Graph 1. Spreading pattern of thermal effluent by seasons

2) Spreading pattern of thermal effluent in accordance with the change of tide

Because the coastal area of young-kwang nuclear power plant, which is located in West Sea, has a big difference in time-varying tide, low and high tide are appeared distinctly. Due to the reason, the spreading direction, distance, and the shape of spreading pattern of thermal effluent from nuclear power plant are appeared differently. In a tide of coastal area of young-kwnag nuclear power plant, it flows on South-West direction when an ebb tide, while it flows on North-East direction when a flood tide. In Fig. 2, the spreading pattern of mainstream of thermal effluent is shown in accordance with the change of the time of tide. In this picture, it is known that spreading direction of thermal effluent from nuclear power plant is dominated by tide. So to speak, it is moved widely on Southwest direction along the coast by tide when it is an ebb tide. In the meantime, it is moved widely on Northeast direction along when it is a flood tide. However, the mainstream of thermal effluent is spread on Southwest direction in the beginning period of flood tide and, it changes the direction on Northeast in the latter period of flood tide. In the same manner, the mainstream of thermal effluent is spread on Northeast direction in the beginning period of ebb tide and, it changes the direction on Southwest direction in the latter period of ebb tide.

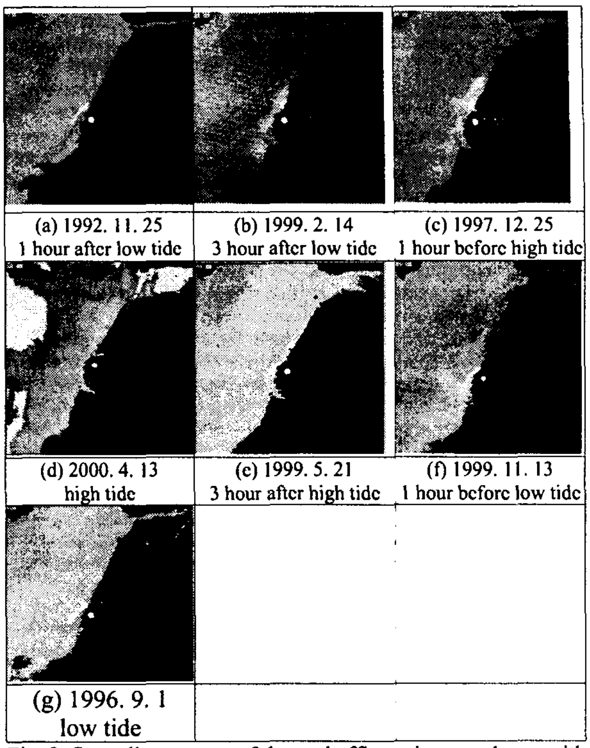


Fig. 2. Spreading pattern of thermal effluent in accordance with the change of tide

3) The spreading patter of thermal effluent before and after the construction of sea wall

Fig. 3 is an image to photograph at the similar period of tidal time and, spreading pattern before and after the establishment of sea wall can be compared in here. The photographed time for the image is from one hour past after an ebb tide and, it is the period of time to start flood tide. In Fig. 3 (b), thermal effluent discharged from outlet of nuclear power plant has a pattern as a curved circle form on Northeast direction at the end of sea wall to the west direction and, it is considered as a pattern to appear the speed of flood tide, which flows on Northeast direction at the end of sea wall, fast. Fig 3 (a) is a diagram before the foundation of sea wall and, spreading pattern like Fig 3 (b) is not shown in here.

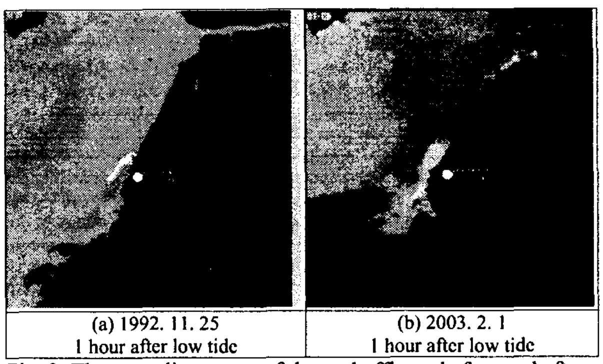


Fig. 3. The spreading patter of thermal effluent before and after the construction of sea wall

4. Conclusion

In this study, sea water surface temperature of coastal area of nuclear power plant is measured using thermal infrared band image observed from satellite, which is interrelated of Landsat from 1987(beginning period of operation of young-kwang nuclear power plant) to 2004 (at present) and, the movement and spreading pattern of thermal effluent discharged from nuclear power plant is analyzed by seasons, ebb and tide, and, before and after the establishment of sea wall. So, the following results are obtained from the study.

In the spreading of thermal effluent by seasons, it is found that spring and summer is spread further than autumn and winter. It is considered that such conditions, which have been distributed by naturally in accordance with coastline, happened because hot and thermal effluent are mixed and distributed widely. It is known the fact that tidal current dominates the spreading direction in accordance with the change of ebb and tide. Namely, when it is an ebb tide, it moves to distribute widely on South-West direction along the coast by tidal current and, when it is a flood tide, it moves to distribute on North-East direction. However, in the beginning period of flood tide, the mainstream of thermal effluent is spread on Southwest direction and, in the latter period of flood tide, it is changed the direction on Northeast. In the same manner, in the beginning period of ebb tide, the mainstream of thermal effluent is spread on Northeast direction and, in the latter period of ebb tide, it is changed the direction on Southwest. Finally, after comparing to the spreading pattern of thermal effluent before and after the foundation of sea wall, discharged thermal effluent from outlet of nuclear power plant because of the foundation of sea wall, has a pattern as a curved circle form from Northeast direction at the end of the sea wall to west direction.

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