Analysis of regional BOD generation at urban point pollution sources for total water pollution management

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Abstract. The objective of this study is to estimate amount of water pollution by region in regard to TWPLMS(Total Water Pollution Lad Management System) that is currently conducted in Korea, with reference to the cases of the US and Japan. In particular, it focuses on BOD(Biochemical Oxygen Demand) and examines point pollution sources as their management system is clear and it is relatively easy to estimate improvement in water quality. As it is, data collected from sewage treatment facilities are used to estimate generation of sewage in city, and it is hard to gather data of it by specific region. To address this, the study proposes a GIS data-based methodology to analyze BOD concentration by individual buildings in city, by applying basic unit for each use of individual buildings. Specifically, the study surveys nearly 250,000 buildings in Daegu, Korea, to calculate generation of water pollution and BOD by unit area. The study identifies some 4% of the entire grid units as an area with high BOD concentration, and they account for 41% of all point pollution sources in Daegu. The study developed and tested a methodology to draw a BOD base map at the most microscopic level of point pollution sources for a broad spatial area. It is expected to provide basic data to set criteria for pollutant generation by region in regard TWPLMS, and estimate the impact of location of buildings by their specific uses.

Keywords BOD distribution • GIS • TWPLMS • BOD map • Grid network

1 Introduction

Korea legislated the Sewerage Act in the 1980s and, ever since, has made heavy investments in sewage facilities that included recent ones such as sewage improvement projects in small villages, irrigation upgrade projects, advanced treatment of sewage and integrated management and operation [2]. Despite the combined efforts of the academia world and the government and observation of allowable release standards of individual pollution source, the gross amount of sewage flowing into rivers and streams is exceeding the allowable standards for preserving water quality, an indication of the limitations faced by the existing standards.

As a preceding study, Choung Kwang Ok and Ryu Seong Pil [2] surveyed water quality concentration in three spots in Jeju Island based on usage of water consumption as a way to forecast amount of sewage. Kang, Meea et al.[4] tried to identify pollution load characteristics of non-point pollution sources in a land growing cherry trees and Choi, Joung joo and Hyun, Kyoung hak [3] surveyed amount of sanitary water in small rented apartment houses. While such efforts were demonstrated in studies at both home and abroad to estimate amount of pollution load and observe the characteristics [1,5,6,8,10,11] they were limited in covering the entire metropolitan region for a more detailed and wide survey. To address this limitation, a study was carried out with the goal to establish standards for estimating basic unit and BOD of sanitary sewage that are aligned with local characteristics. This study and many others have supported MOE to develop sanitary water concentration by establishing the estimate standards of purpose and BOD based on which buildings are classified into 14 large categories and 57 medium categories to suggest daily amount of sanitary sewage and BOD concentration [7]. Since there is no spatial data that classifies buildings by purpose, amount of sanitary sewage generated in each city was estimated by only gross amount in terminal treatment plants of sewage or by setting up a measuring instrument in a few buildings. Unfortunately, the amount of sanitary sewage caused by non-point pollutants and point pollutants cannot be identified in the gross amount in terminal treatment plants of sewage

Such being the case, it was impossible to forecast spatial distribution of sanitary sewage in terminal treatment plants of sewage, which, in turn, indicated the constraints in planning and allocating sanitary sewage load. With such limitations, this study classified buildings by purpose with the goal to develop GIS-based big data for each city and used it as the basic data to identify their spatial distribution by applying basic unit for estimating the amount of sewage and BOD. This study limited the subject to point pollutants only because they have a clear management framework and the benefits gained from improvement can be more easily measured. Among the point pollutants, the study focused on living sewage that excludes industrial wastewater and livestock wastewater. The study limited its spatial reach to Daegu Metropolitan City, which is one of the eight metropolitan cities in Korea and is subject to class 1 under the water pollution management system as it is linked to the Nakdong River water system.

The study results described below may be used as the basic information to manage regions where water pollution is constant due to point pollutants in the city.

2 Basic unit of BOD and Guidelines for Pollution Load Management

2.1 *Basic unit of BOD from Sanitary Sewage*

Sanitary sewage and BOD concentration referred in this study are subject to Clause 3, Article 34 of the Sewerage Act notified by the Ministry of Environment on January 18, 2013 and Guidelines for Estimating Sanitary Sewage of Buildings and Number of Managers for Septic Tank Treatment in compliance with Clause 2, Article 35 of the same Act [7]. The notice suggested daily amount of sanitary sewage and guidelines for estimating BOD concentration based on 14 large categories and 57 medium categories classified for buildings. Details of building classification are described in Fig. 1 below.

Classification		a[1]	b[2]
1.Residential facilities	1) Detached house, farm house, public residence	200ℓ /Person	200
	2) Apartment, townhouse, multiplex house, collective house	200ℓ /Person	200
	3) Dormitory, multi-purpose house, study house	200ℓ /Person	200
2.Culture & assembly facilities	1) Concert hall, etc.	16ℓ/m^2	150
	2) Prayer house, monastery, etc.	7.5ℓ/m^2	200
	3) Stadium, etc.	10ℓ/m^2	260
	4) Exhibition hall, etc.	16ℓ/m^2	150
	5) Race track, etc.	25ℓ/m^2	150
3. Sales & marketing facilities	1) Shop	15ℓ/m^2	250
	2) Hair salon, etc.	15ℓ/m^2	100
	3) Spa	16ℓ/m^2	100
	4) Karaoke	16ℓ/m^2	150
	5) Game club go club, etc.	25ℓ/m^2	150
	6) Department store and other large store	20ℓ/m^2	250
	7) Passenger railway facilities,	4ℓ/m^2	260
	8) Public bathing facilities	46ℓ/m^2	100
	9) Food manufacturing	30ℓ/m^2	130
	10) Restaurant	70ℓ/m^2	330
	11) Small food shops	35ℓ/m^2	100
	12) Other auxiliary facilities	30ℓ /Person	330
4.Medical facilities	1) General hospital	40ℓ/m^2	300
	2) Clinic (dentist, Oriental medical clinic)	30ℓ/m^2	300
	3) Hospital, Oriental medical hospital, health service center, etc.	18ℓ/m^2	150
5. Education, research and welfare facilities	1) Elementary school, kindergarten, etc.	6ℓ/m^2	100
	2) Middle school, high school, university, etc.	8ℓ/m^2	100
	3) Lab, test room, etc.	8ℓ/m^2	100
	4) Public library, reading room,	15ℓ/m^2	150
	5) Orphanage home, protection&care facilities	9ℓ/m^2	200
	6) Youth hostel, etc.	9ℓ/m^2	140
6. Sports facilities	1) Table tennis room, billiard room	15ℓ/m^2	100
	2) Gym, fitness club, etc.	15ℓ/m^2	100
	3) Gold driving range	15ℓ/m^2	100
	4) Golf course	30ℓ/m^2	100
	5) Water park	40ℓ/m^2	100
	6) Tennis court	3ℓ/m^2	150
	7) Gate ball facilities	1ℓ/m^2	150
7. Office facilities	1) Office (newspaper offices, other general offices)	15ℓ/m^2	100
	2) Public office, bank, post office, etc.	15ℓ/m^2	100
	3) Officetel	10ℓ/m^2	200
8. Accommodation	1) Hotel, motel, etc.	20ℓ/m^2	70
	2) Pension, private rental room, etc.	35ℓ/m^2	140
	3) Condominium, etc.	20ℓ/m^2	140
	4) Camp, etc.	9ℓ/m^2	320
9. Recreational facilities	1)Club, etc.	46ℓ/m^2	150
	2) Bar, etc.	46ℓ/m^2	250
	3) Casino, etc.	25ℓ/m^2	150
	4) Ballroom, etc.	16ℓ/m^2	150
10. Industrial facilities (Plant, workshop, manufacturing plant, etc.)		5ℓ/m^2	100
11. Auto facilities	1) Gas station, refueling station, etc.	25ℓ/m^2	260
	2) Parking lot, parking ramp	25ℓ/m^2	260
12. Facilities for public use	1) Prison, etc.	7.5ℓ/m^2	200
	2) Filming spot	15ℓ/m^2	100
	3) Military camp	7.5ℓ/m^2	200
	4) Public toilet	170ℓ/m^2	260
13.Cemetery-related facilities		16ℓ/m^2	150
14. Travel and rest facilities	1) Rest lounge	20ℓ/m^2	260
	2) Observatory	16ℓ/m^2	150

a : Daily amount of sanitary sewage , b[2] : BOD concentration (mg/ ℓ)

Fig. 1. Daily amount of sanitary sewage and guidelines for estimating BOD [11]

2.2 *System and Guidelines for Pollution Load Management*

Methods to survey distribution of pollutants to manage pollution load, issues related to improving water quality in public basins, and water drainage and sewage treatment zones are all specified in the guidelines for setting basic plan for sewerage improvement notified by the Ministry of Environment. In relation to these guidelines, there are two phases: the phase one of total pollution load management scheduled for 2004 to 2010 and the phase two from 2011 to 2015.

Meanwhile, total pollution load management quantitatively sets target water quality by water system section and estimates allowable load to achieve target water quality. In terms of management, it allocates pollution load that can be released as metropolitan, basic or individual pollutants in order to manage metropolitan river basins with greater flexibility. The Table below compares management of total water pollution load in the US and Japan, both of which are pioneers, with one of Korea (MOE's update on the total water pollution loading system).

Table. 1. Comparison of management of total water pollution load(MOE, 2011)

Nation	Japan	US	Korea
Regions	-. Tokyo Bay and closed waters with heavily polluted regions due to huge population and industrial clusters	-. Polluted water system that failed to meet target water quality standards (set for 51 states)	-. Three major water systems (Nakdong River, Geum River, Youngsan/Seomjin River) and Han River water system
Progress	-. Implemented a five-year total pollution load management plan since '79	- Introduced NPDES in '72 (point pollutants management) ※ NPDES (National Pollutant Discharge Elimination System) - Introduced TMDL in '92 (including management of non-point pollutants)	-. Phase 1 2004. 8. 1`~`2010. 12. 31 (started from metropolitan cities under the Nakdong River water system) -. Phase 2: 2011. 1. 1`~`2015. 12. 31,
Substance	-. COD, nitrogen, phosphorus	- Substances vary with water system since substances required for water quality improvement in each water system are different.	-. Phase 1 : BOD - Phase 2: BOD, total phosphorus

As indicated in the foregoing Table, substances subject to total pollution load management differ by country. The US started to manage point pollutants since 1972 and included non-point pollutant management from 1992. In Korea, BOD serves as the basis for substances used to estimate load of pollutants generated.

As such, the primary objective of this study is to identify spatial distribution of pollutants and to calculate load based on sanitary sewage and basic unit for BOD generation. Study findings suggested via GIS program will help set water quality target by zone and designate detailed sewage treatment zones that account for the BOD generation characteristics from the perspective of management.

3 Development of BOD Forecasting Method and Application in Target City

3.1 *Setting the Data Development Guidelines*

Spatial data used in this study consists of data of building structures whose purpose has been re-classified as shown in Fig 1, graphic data of seven sewage treatment zones and grid data for grid analysis. Attribute data includes basic unit, gross area of building structures and information on administrative zones. ARC GIS 9.3 is used for data overlay and analysis and spatial information is composed of shp file. Attribute data used DBF file to integrate with spatial information. Guidelines for developing lists used as basic data and their details are summarized in Table 2.
Based on basic data, on Table 2, areas where BOD is intensively generated are estimated as illustrated in Figure 2. The calculation criteria are applied to floor area attributes of a building spatial data to estimate BOD generation by building.
Gross area and basic unit for sanitary sewage generation by purpose of building structures other than housing facilities in Fig 1 may be used to apply basic unit of sanitary sewage generated by business and housing residence, which fall under attribute data in Table 2.

Table. 2. The list of developing basic data

	Category	Guidelines	Details
Spatial data	1) Data on building structures (classification by purpose)	Re-classification of building structures based on purpose in Fig 1	Housing residences classified into three types, and industries into 54 types
	2) Graphic data of sewage treatment zones	Sewage treatment zone boundary based on target city's spatial data	Shp. File on sewage treatment zone boundary in target city
	3) Grid data	500m*500m grid network (refer to basic plan for sewerage improvement)	Grid network based on auto cad and conversion into shp. File
Attribute data	Sanitary sewage generation basic unit , information on gross area and social statistics data	Basic unit in Fig 1, gross area by buildings, average number of people per household, number of household by house types	

Basic unit as sewage generated by person is suggested in Fig 1 since number of residents is the major factor of sanitary sewage in housing building structures. Hence, it is required to convert it into unit area as formula (1).

$$Q_t = \frac{A_s/(U_r \times P_{D.a})}{A_{D.t}/H_D} \quad (1)$$

In this formula (1), Q_t: Sewage amount of target building [ℓ/building·day], A_s: Gross aera of Target building [m^2], U_r: Sewage amount units by house type [ℓ/capita·day], $P_{D.a}$: The average number of people per household (Target city), $A_{D.t}$: Total gross area of residential buildings(Target city)[m^2], and H_D: The number of household(Target city).

The foregoing process can be applied to graphic data by residential type to estimate sanitary sewage of each building structure. In addition, basic unit in Table 1, which excludes housing building structures, has been applied to graphic data by industry type to estimate sanitary sewage in point pollutants in non-housing building structures. Data on building-specific BOD generation are combined with data on sewage treatment section [spatial data 2)] to estimate sewage load from household water usage by area. This enables estimation of areas where sewage loads occur. It is followed by an overlay analysis with 500m×500m grid data [spatial data 3)] to examine distribution of micro-level BOD and its characteristics, to yield final outcomes.

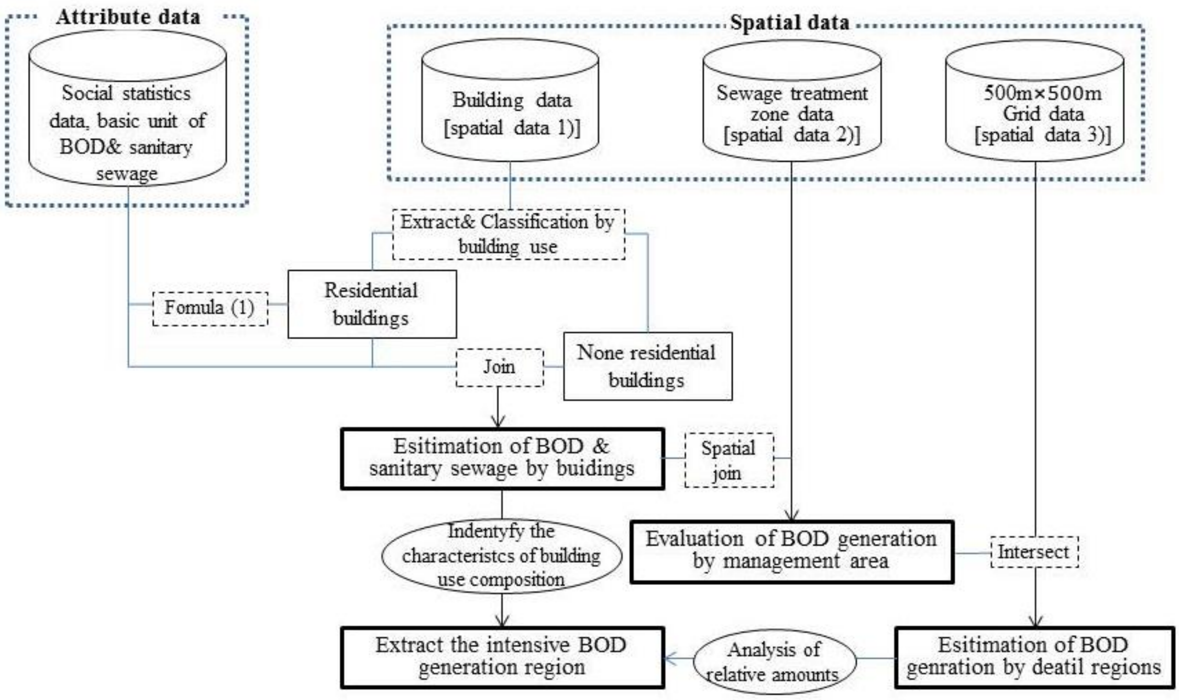

Fig. 1. Process of data development

3.2 Data Development and Application of Estimating Method

The analysis above was done for Daegu, one of three major metropolitan cities of Korea. Daegu has 8 administrative districts, and its location and boundary is as shown below.

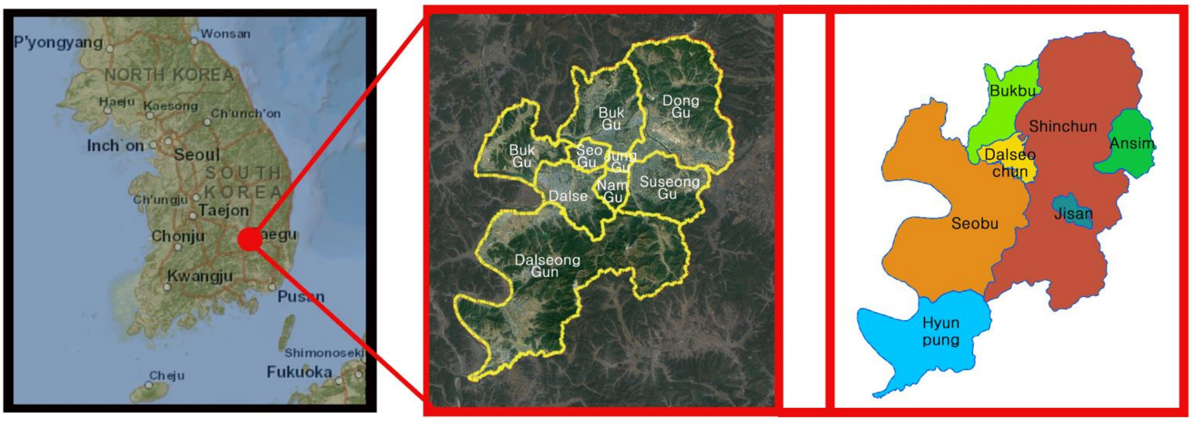

Fig. 2. Location of Daegu city, administrative boundary and sewage treatment zone

All building structures in Daegu were surveyed for the development spatial data 1) in table 2, which includes 186,000 residential buildings and 67,000 non-residential buildings. Three housing residences and 54 industries were classified as shown in Fig. 3 Step 1 in order to develop data as per 1) in Table 2 based on the guidelines set in 3.1. Based on data, generation of water pollution by each building was calculated with basic unit for each use and formula (1). The results are shown in step 2 of Figure 3.

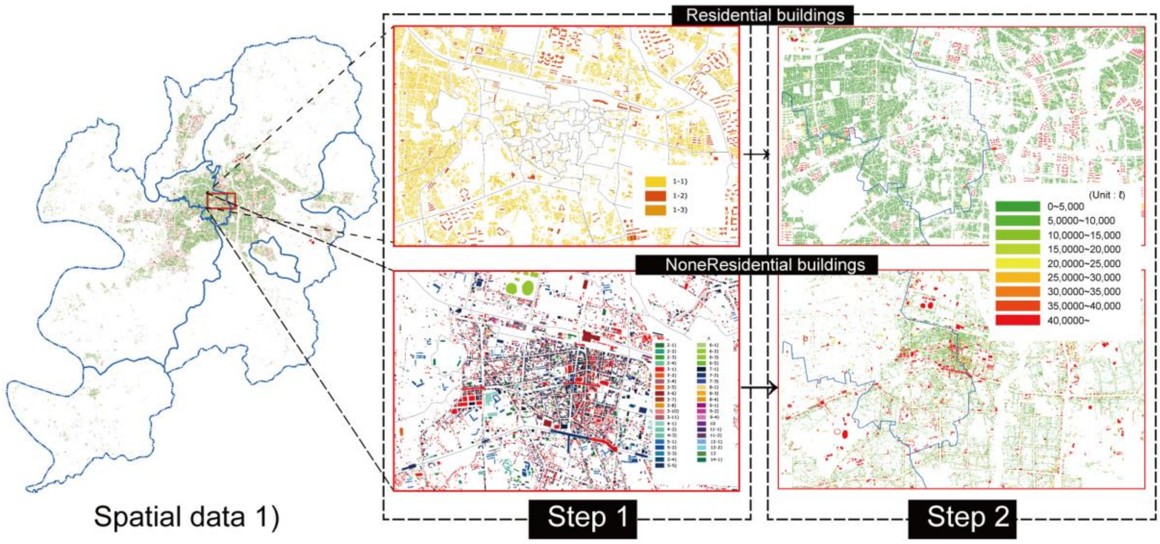

Fig. 3. Process of amount of sanitary sewage estimation by buildings

Spatial data 2) of Table 2 have been converted to shp file in order to make overlay analysis of data, which are shown in Fig. 4-a. And the spatial data 3) of Table 2 has been prepared with Auto cad and adjusted into a coordinate identical to graphic data for sewage treatment zones. Fig. 4-b is the results of grid data development in 3) of Table 2 after intersecting graphic data in sewage treatment zone in Fig. 4-a with the grid data of shp file.

Spatial data 2) and 3) are used to calculate the amount of wastewater generation of each building by sewage treatment section and detailed area (Figure 4).

a. Graphic data of sewage treatment zones(shp flle)

b. 500m x 500m grid data (shp file)

Fig. 4. Spatial data 2),3) of Table 2

4 Analysis of BOD Characteristics using Grid Network

4.1 Analysis of Sanitary Sewage & BOD's Spatial Distribution

Sanitary sewage generated in each sewage treatment plant was calculated based on sanitary sewage data of each building structure, which was already forecasted in Fig. 3. Specifically, Arc GIS' intersect function was used to identify graphic information of sewage treatment zones in Fig. 4-a and to perform overlay analysis based on which sanitary sewage generated in residential buildings and non-residential buildings were calculated and combined.

Sanitary sewage by sanitary treatment zone calculated with the following methods is shown in Table 3. Sanitary sewage generated in residential buildings was the highest in Sincheon, followed by Seobu, Bukbu, Dalseocheon, Ansim, Jisan and Hyunpung. Sanitary sewage generated in non-residential buildings was the highest in Sincheon followed by Seobu, Dalseocheon, Bukbu, Jisan, Ansim and Hyunpung.

Matching of sanitary sewage generated in point pollutants compared to capacity in each sewage treatment zones based on the foregoing results indicates that sanitary sewage in Ansim treatment zone is around 85% of facilities capacity. This percentage was the lowest in Dalseocheon where sanitary sewage generated was around 36% of facilities capacity.

For the forecasted characteristics of BOD's spatial distribution, basic unit of BOD generated was applied to graphic data of building structures classified by purpose and residential type, which is equal to the method used to forecast sanitary sewage, and multipled by sanitary sewage to estimate BOD generated. The following Table 3 shows BOD forecast by zone based on the series of processes above. BOD generation was higher in treatment zones with higher sanitary sewage.

The study, however, witnessed a regional deviation in basic unit per sanitary sewage in non-residential building structures that applied different BOD basic unit. BOD concetration per liter of sanitary sewage in non-residential building structures by treatment zone was the highest in Bukbu and Jisan treatment zones at 211mg/ ℓ and the lowest in Sincheon treatment zone at 186mg/ ℓ. This demonstrates that building structures with certain purposes that generate BOD are concentrated in a specific region and that the deviation could get wider if it is approached with a more detailed spatial area.

Table 3. Amounts of sanitary sewage&BOD by treatment zones

Treatment Zone Name	Sewage					BOD		
	Amount of sewage (unit : million m³/day)			Facilities capacity (D)(unit : million m³/day)	Sanitary sewage relative to capacity of treatment facilities(E) = (C/D)%	Amount of BOD (unit : kg/day)		
	Residential (A)	None residential (B)	Point pollutants (C)=(A+B)			Residential	None-residential	Total
Dalseochun	4.99	9.36	14.35	40	35.87	9,976.4	18,070.7	28,047.1
Shinchun	25.00	28.55	53.54	68	78.74	50,239.4	53,333.9	103,573.3
Seobu	19.30	16.39	35.70	52	68.64	38,707.1	34,659.9	73,367.0
Bukbu	6.26	3.37	9.63	17	56.65	12,573.7	6,442.3	19,016.0
Jisan	1.93	1.41	3.33	4.5	74.08	3,886.0	2,975.5	6,861.5
Ansim	2.60	1.38	3.98	4.7	84.68	5,238.9	2,862.5	8,101.4
Hyunpung	0.50	0.67	1.17	2.3	51.05	1,001.1	1,353.9	2,355.0
Total	55.59	61.13	121.71	188.5	64.57	121,622.6	119,698.7	241,321.3

4.2 *Analysis of BOD Characteristics by Purpose of Building*

Analysis of BOD distribution in 4.1 raised awareness on the need to estimate BOD from a microscopic viewpoint and analysis based on 500m x 500m grid unit was performed accordingly.

For data development, the study converted building structures(Fig5-a) into point data as shown in Fig. 5 and used grid graphic data and spatial joint in Fig. 4 to match attribute information of BOD based on grid unit. The dots(Fig5-b) in the following Figure refers to data of individual building structure that contain information on BOD and the Fig. 5-c visualizes BOD set with an equal interval in grid unit after undergoing the process on the left.

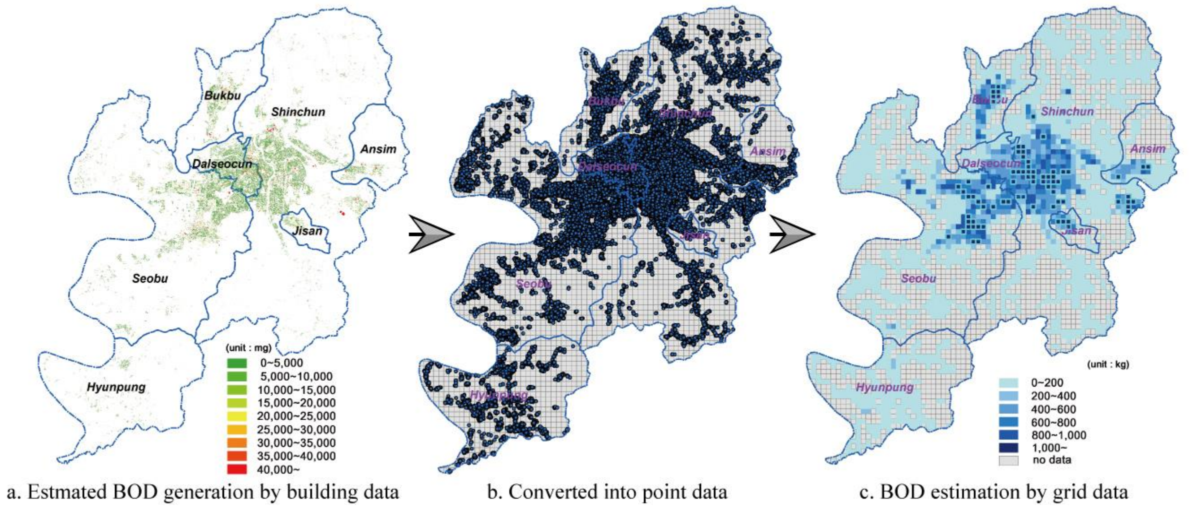

Fig 5. Prosess of BOD estimation by grid network

Regions that generate more than 1,000kg/day (the dark part in c, Fig. 5) in b, Fig. 5 were extracted in order to identify characteristics of regions with intensive BOD caused by sanitary sewage. Setup of purpose of building structures within the grid was then analyzed. There are 76 grids subject to the study, which represents around 4% of the top percentile based on BOD.

Average BOD caused by sanitary sewage in 76 grids was forecasted at approximately 1,334kg/day and an average of 300 building structures are in a single grid. As presented in Table 4, detached houses took the largest pie, followed by market shops, apartment houses and general offices. In terms of gross BOD, however, apartment houses topped the list followed by market shops and general hospitals, which is associated with gross area of building structures and basic unit by purpose. There were only ten large facilities like department stores in the grid, which were ranked 26th in frequency but BOD of individual large facility was the highest at almost 283,478kg/day. BOD was also high in officetels, stadiums and car-related facilities.

Analysis of 76 grids extracted as follows is summarized below.

Table 4. Building use composition and amount of BOD in top 4% grid

Building use classification (Consult table 1)	Frequency (A)		Amount of BOD by building use(B)		Amount of BOD by buiding (C)=(B/A)	
	n	Rank	kg/day	Rank	mg/day	Rank
1-1	8,861	1	2,605.3	7	294.0	38
3-1	5,193	2	11,258.5	2	2,168.0	22
1-2	3,120	3	65,852.3	1	21,106.5	4
7-1	2,492	4	2,677.7	6	1,074.5	28
3-10	842	5	6,011.0	3	7,139.0	9
2-1	190	6	481.8	10	2,535.8	19
1-3	189	7	176.4	20	933.4	30
5-5	162	8	421.3	13	2,600.6	18
4-3	155	9	284.4	16	1,835.2	24
7-2	150	10	811.0	9	5,406.9	11
10	149	11	23.1	29	154.9	40
8-1	145	12	248.8	17	1,715.8	26
5-1	137	13	202.3	19	1,476.4	27
11-1	109	14	467.4	11	4,287.7	14
5-4	107	15	243.8	18	2,278.1	21
5-21	103	16	392.5	14	2,279.8	20
9-2	61	17	463.0	12	7,590.6	8
3-11	52	18	51.6	25	991.9	29
3-2	37	19	14.5	32	393.0	36
11-2	33	20	298.1	15	9,033.2	7
4-2	56	21	1,028.1	8	13,914.2	6
3-5	32	22	58.5	24	1,828.1	25
4-1	26	23	4,161.9	4	160,072.6	2
3-8	23	24	108.7	21	4,724.8	12
6-2	13	25	58.6	23	4,510.8	13
3-6	10	26	2,834.8	5	283,478.0	1
5-3	10	27	7.1	33	707.3	32
14	8	28	5.0	34	628.6	33
6-3	7	29	23.2	28	3,311.6	17
7-3	6	30	90.0	22	14,998.0	5
2-4	5	31	17.3	30	3,468.0	16
3-4	5	32	3.9	35	779.0	31
2-2	5	33	2.5	36	496.8	34
12-4	4	34	25.3	26	6,331.7	10
12-1	4	35	16.7	31	4,186.1	15
6-5	3	36	1.4	38	470.4	35
6-1	2	37	0.4	39	191.3	39
2-3	1	38	24.2	27	24,190.4	3
9-1	1	39	2.0	37	1,952.7	23
9-4	1	40	0.4	40	367.2	37

5 Discussions & Conclusions

As shown in 4.2, this study identifies areas with relatively concentrated BOD based on its density, on a grid unit, which provides more microscopic data than an analysis of the smallest administrative unit of dong. To do so, GIS-based spatial data and attribute data are used to estimate sewage for each building and BOD concentration of it. The study proposes a new method that analyzes urban water pollution at a most microscopic spatial level, and expected to be institutionally applicable as it examines BOD, which is a standard pollutant for total water pollution load management system

(TWPLMS) in Korea. The study applies the methodology to the city of Daegu to identify areas with relatively concentrated BOD, that is, grid units that generate more than 1,000kg/day of BOD. Some 4% of the areas fall into this category. The study examines use of 76 identified grid units and shows clusters of particular uses and characteristics of BOD generation. Currently, in Korea, there is no institutional constrain on generation of wastewater or BOD, so the newly drawn BOD map can be used to justify quantitative regulation of BOD by grid unit. Furthermore, this method can be used to estimate impact of location of point pollution sources by their specific uses within a given unit of a relatively high BOD. The study has limitations that it only surveys point pollution sources in city. However, advanced studies in the US on TWPLMS show that points pollution sources are used for preemptive management of water quality as it enables accurate estimation of control effect. Follow-up studies are needed that take into account both point and non-point pollution sources, but for now, this study is expected to provide a ground for evaluating distribution of point pollution sources as primary step in TWPLMS.

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