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INVESTIGATION OF AN ODOR SOURCE IN CHANGWON CITY USING MULTI-MONITORING METHODS. A CASE STUDY OF KOREA

It is a regular occurrence for residents living near industrial plants to complain regarding odor problems. Those plants may also try to protect themselves from liability by demonstrating some environmental evidence. An investigation to prove whether the accused industrial complex is the major source of released odors among several potential sources of odor problems was carried out using the combination of measurement techniques. The multi-monitoring methods comprise utilizations of olfactory system, questionnaire, electronic detector and chemical analysis. This study demonstrated the achievement of integrating scientific monitoring methods to support the enforcement of odor acts for management in the industrial city.

1. INTRODUCTION

In 2010, the Korean government officially established a new mega city, Changwon, by having accomplished a voluntary unity of the three cities of Changwon, Masan, and Jinhae. The fundamental aim for the founding of this unified city is a balanced environment, integrating Changwon's strong industrial foundation and urban infrastructure, Masan's cultural value and naval port city, and Jinhae's oceanic resources. Due to Changwon's properties as an economic city surrounded by landscape for nature-based tourism, trade and industry with over 3800 enterprises, there has been a rapid increase in both GRDP and population. With the target to become an environmental capital and

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role model for other cities in Korea, a 15-year strategic plan for 2006–2020 has been launched with several eco-city projects. However, the existence of the Changwon National Industrial Complex (CNIC) since 1974, together with the increase of factories scattered around Changwon as the key propulsion for the development of city creating employment for 82 445 people [2] may become an impediment to a green city program.

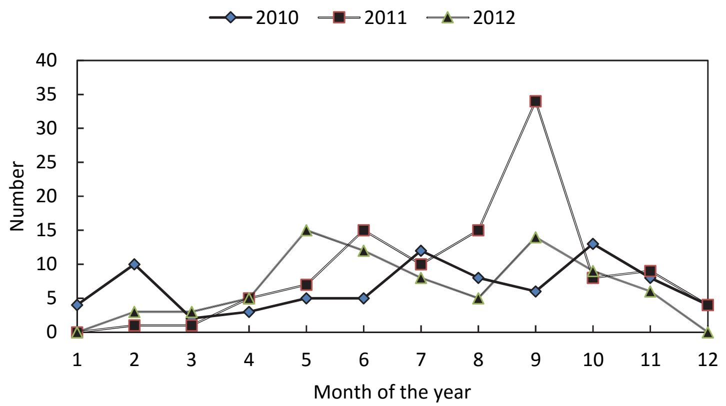

Fig. 1. The number of odor complaints 2010–2012 [1]

As of now, not only problems exist due to high CO_2 and particulate matter concentrations [1], but also there are a high number of complaints of odor nuisances over the years as shown in Fig. 1. Civil complaints had been mostly attributed to CNIC while the manufacturers in this zone claimed that the amount of pollutants and other substances being discharged had been controlled under regulation. Moreover, factories are located not only in the industrial zone, but also outside of it together with other possible sources of odor production in residential areas, e.g. the fresh food market, butcher shop, waste storage area, sewage treatment facilities, etc. Being in charge of the Changwon City Hall (CCH)'s commitment to improve air quality to reach the standard level of developed cities by 2015, an investigation of odor complaints has been triggered. The aims of this investigation are to determine the source of the odor and to determine the proper way to eliminate that source for the occupants' quality of life [1].

Odor is volatilized chemical compound(s) or any substance(s), sensed by olfactory system, which can cause either pleasant or unpleasant feelings. Odor is counted as a type of atmospheric pollution since it can cause annoyances and physical symptoms, e.g. loss of appetite, gastrointestinal disorders, allergic phenomena, etc. Nevertheless, there are several differences between odor and other atmospheric pollutants. For example, odor has the unique property of being able to disappear instantaneously, compared to others. Some toxic substances are scentless while non-toxic substances can be smelly especially for people who are sensitive to them. As a result, atmospheric and environmental protection laws are normally legislated for odor emission in particular term according to its specific characteristics [3–5]. In agreement with Korean legislation of odor prevention, there is none other than just sending warning by an area authority (such as the CCH) to factories emitting the odor beyond the standard level. However, there is a special case whereby a problem area can be identified as an odor management area. For that, two main evidences must first be obtained; civil petitions for 3 continuous years (i) and obvious scientific verification identifying the area's factories as the source of the odor problem (ii). Accordingly, local authorities of the area can consider the case and make an official announcement for the enforcement by themselves since unpleasant odors are a regional problem, and not a nationwide one. Afterwards, the permission levels of the restricted area for the punishment can be judged according to the authority's arbitration [5, 6].

In this paper, the odor investigation using multi-monitoring methods in support of law enforcement for control in the industrial city of Changwon is presented along with its current consequences in terms of environmental protection. Reasons for selecting each monitoring technique as well as reviews of the literature are given in subsequent respective sections.

2. MATERIALS AND METHODS

Site description. Changwon city covers an area of 744.3 km^2 and has a population of 1 092 167 (404,602 households) [1]. Its population density is almost three times the country's population density [7]. The CNIC is located in the southwest zone of Changwon city, with basin-floor topography surrounded by mountains (Fig. 2).

It encompasses 25.3 km^2 and has seen a rapid increase in the total number of factories (from 1730 to over 2000 in 2 years from 2009 to 2011) comprising machinery, electronic, transport equipment, steel, petroleum and chemical, food, pulp and paper, garment, etc. [2]. There is no buffer zone between the residential and manufacturing areas in close vicinity. Doubtless, the suspect position in citizen complaints as the root source of malodor production had been firstly given to nearby industrial areas like the CNIC [8, 9]. Based on this assumption, to suitably diagnose the problem, the preliminary study was therefore started in this area.

2.2. METHODS AND EQUIPMENT

Each country/city might have specific details regarding the odor definition, measurement methods, permission values, etc. in relevant legislation depending on the congruity of its own location. For example, there is no specific location for the enforcement of odor regulations in several countries but in New South Wales (AU), Korea, etc., limit of odor is prescribed by zone of detection (such as urban, rural, area source). The odor limit in residential areas in Colorado (USA) is 7 odor unit (OU)/m^3 while that in Philadelphia (USA) is 20 OU/m^3 [3, 6, 10]. In order to reveal whether the offence had occurred by CNIC and to support complaints realistically and legally based upon the area of study, several types of odor inspection, including Korea's standard measurements [6], were coherently applied in this study. The selected methods comprise direct sensory method, social participation, electronic odor sensor, air dilution sensory method, and chemical analysis. As required throughout the period of project, research staffs were recruited and most of them were university students.

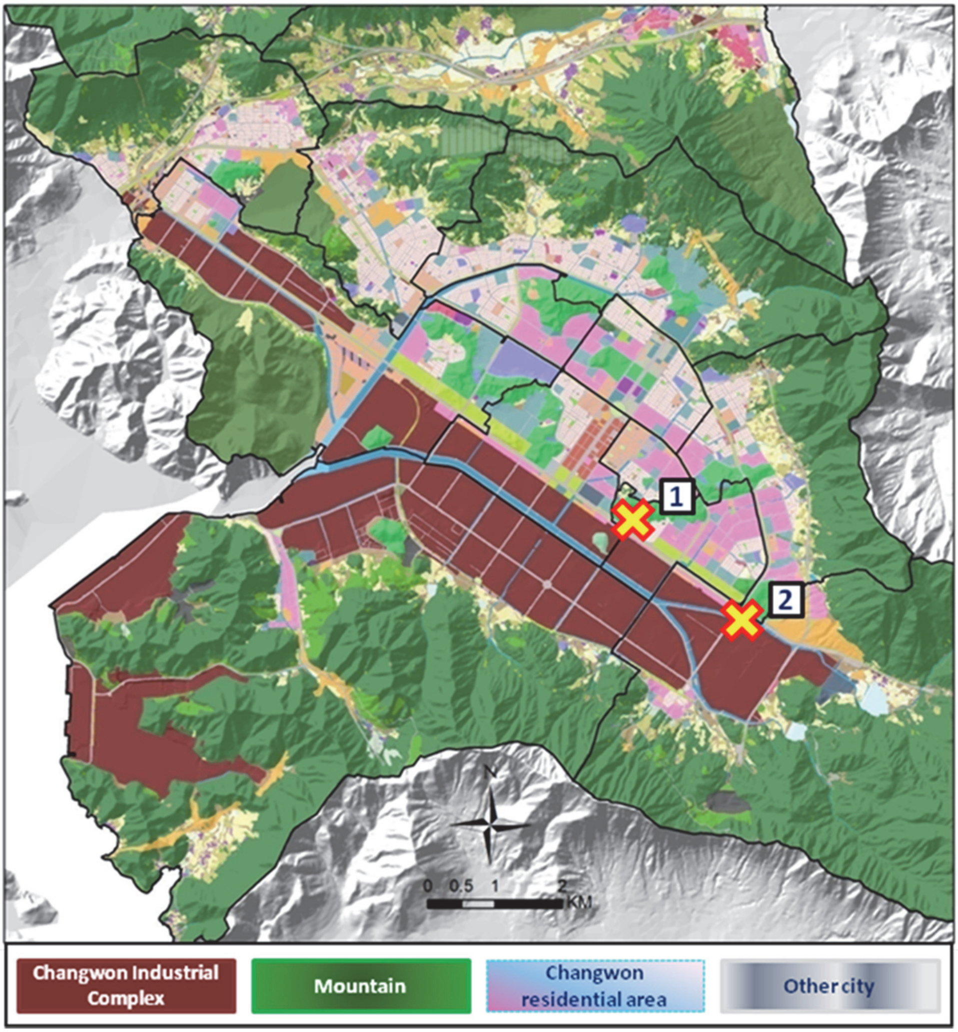

Fig. 2. Map of the Changwon city and locations of installed real-time odor sensors: Sangnam dong, 2nd floor [X_1], Seongsan dong, 4th floor [X_2]

Preliminary survey. The objectives of the preliminary survey were to prove the public's odor complaints about the operation of industrial plants in the CNIC and to provide the necessary data for circumspect planning in the next step, considering five factors of odor nuisance known as FIDOL: frequency, intensity, duration, offensiveness, and location [10].

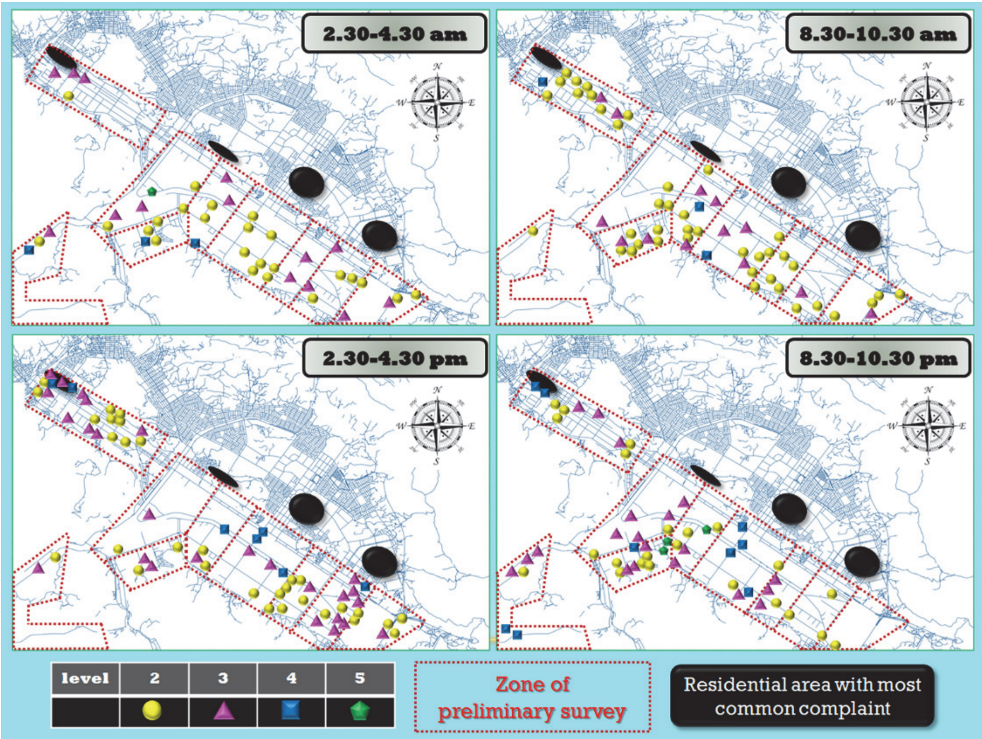

Fig. 3. Presence and intensity level of odors in the CNIC area;
examination by the direct sensory method

For two weeks, 6 members of the research team separately rode bicycles on streets around the CNIC area to study the route and to design the activity schedule. Then, direct sensory method, a standard tool of measurement in the Korean regulation [6], was exercised by dividing the CNIC area into 9 zones (Fig. 3) to gather information collected by research staffs riding bicycles along the designed routes for ca. 3 weeks. With concern for diurnal cycle, the inspections in this step were taken 4 times a day, both day and nightshifts. Two volunteers for each zone spent just around 2 h per visit (one group/shift/day or 72 members/day) so as to avoid the olfactory fatigue for the panellists. Due to dissimilarity of each human's perceptual ability, there were 6 levels (0–5) of odor ranging from "none", "slight", "noticeable", "strong", "very strong", and "unbearable" which would be tested as the reference for research staffs by using 0.0, 0.1, 0.4, 1.5, 70.0, and 300.0 cm^3 of *n*-butanol in 1 dm^3 of water before the survey. It would be checked in the form wherever any odor was sensed and the volunteers had to identify type of smell if recognizable. Odor intensity at any location should be less than level 2 [5, 6, 10].

Social participation. Interview with stakeholders and use of questionnaires are one of the most common tools found when people consider undertaking a research project including the study of odor problems or the development of odor monitoring techniques [11, 12]. To use the residents experience as one of the measuring tools in this study, a questionnaire was prepared including information regarding respondent's personal characteristics, odor exposure's distinctiveness and free commenting for adverse effect. The total number of completed interviews was 452 samples with an approximate duration of 20 min each. The survey was randomly made via both telephone and in-person interview with citizens residing around the CNIC. The survey objectives were clearly explained every time before the start of interview to promote transparency in response willingness. The interviewees could select a convenient time for their interview and provide additional information anytime later. It was noted by respondents in this survey that perception of strange/foul odors would not include fumes.

Electronic nose/real-time odor monitoring system. A method of odor measurement to avoid inevitable partiality, e.g. bias, prejudice, injustice, etc., of human judgment and non-continuous nature of sampling is important as cross-check analysis. It is more useful in this case study for the continuous analysis at receptors since dispersion modelling, an accepted method for odor impact assessment, is not suitable [4, 13, 14]. An accurate emission inventory for the modelling is hardly acquired due to a large number of factories (more than 2000 sites as aforementioned). Process of emission source sampling is time consuming. Therefore, at 2 different locations with the premises that had been highly complained about due to unpleasant smell shown as a cross mark in Fig. 2, real-time odor sensors (Scientec Lab Center: model no. SLC-ON-23200) were installed on top of the buildings in the affected areas. This electronic nose system is based on metal oxide semiconductor sensors, sensitive to a large spectrum of volatile compounds [15], with an input flow rate of air ca. 1.5 dm^3/min. The result can be entirely presented in OU/m^3 every 5 min of continuous monitoring. The measurement data for this analysis were collected for 6 months from April to September 2012 so as to identify the concentration and direction of odor diffusion into the civil petition area.

Air dilution sensory method. Odor sensory analysis, another standard measurement in the Korean regulation [6], is a major method used to measure odor concentration by using a human olfactory system which can recognize actual odors [4, 14]. This sensory test had been enacted in two places, i.e. boundary and outlet of factory. 3–20 dm^3 of air from selected sources were sampled by using a Teflon bag and kept at room temperature

(15–25 °C) and away from direct sunlight before performing a test within 48 h. Odor samples would be diluted with pure air step-by-step from 3, 10, 30, 100, 300 times and so forth until the smell could not be detected by any odor panel. For accuracy in utilizing the human sense of smell as a measuring tool, pre-screening test for each panelist was implemented to obtain at least 5 qualified members each time. The screening test used 4 standard odors, i.e., 1.0 wt. % acetic acid, 0.1 wt. % trimethylamine, 0.32 wt. % methyl cyclopentenolone, 1.0 wt. % β-penylethylalcohol, and odor free air to evaluate the accuracy of each participant's olfactory abilities. Volunteers were required to be at least 19 years of age, avoiding any strong smell such as smoking, gum, strong-flavored drinks, pungent foods, etc. [6]. An example of the calculation using the sensory test results to determine odor concentration and the maximum permission in OU/m^3 for factories in residential and industrial complex areas is shown in Table 1. The lowest and highest scores from the test were ignored to minimize human error. The final score for this example is 14.4, under the permission values for any sampling location [6].

Table 1

Calculation method and permission level of odor release. Regulation in Korea [6]

Panel member	First test (×10)	Second test (×10)	Third test (×30)	Fourth test (×100)	Odor concentration [OU/m^3]
A	○	○	×		10 (no smell at ×30; concentration = ×10)
B	○	○	×		10
C	○	○	○	×	30
D	×	×			3 (lowest score: disregarded)
E	○	○	○	○	100 (highest score: disregarded)
Final score = $(a_1 \times a_2 \times a_3 \times \ldots \times a_n)^{1/n}$					$(10 \times 30 \times 10)^{1/3} = 14.4$
Company' gas outlet (e.g. stack)			industrial area		permission <1000
			residential		permission <500
Company's boundary (e.g. enclosure)			industrial areas		permission <20
			residential		permission <15

× – no smell, ○ – smell, *a* – test result of odor concentration which is not disregarded.

Concerning the criteria to choose the place for exercising air dilution sensory method, CCH firstly provided a list of factories willing to be examined and then the research staffs would conduct a walkthrough survey after getting briefed on production process and pollution control system from each factory. The odor sampling at selected location for both boundary and outlet of factory could be done immediately or later according as the research team's consideration. Apart from the obtained list, the research team could also propose the factory name, accused as the critical source of odor release, based on the results from preliminary survey and questionnaire to CCH for carrying out the dilution sensory test.

Chemical analysis. The chemical analysis was carried out with the aim of identifying and quantifying 22 compounds, designated as the major odorants under the regulation of the Ministry of the Environment of Korea [16], at critical points of residential area and factory outlets. Susaya et al. describe all sampling methods for the quantification of these 22 malodor components. The method may help to identify major types/activities (and locations) of factories releasing compounds which cause annoyance or ill feelings to the citizens once (i) chemical compositions of samples at sources and receptors are known, and (ii) the combination of this analysis with other odor measurements to determine the correlation between odor concentration and specific chemical substances is implemented. Therefore, the selection of emission sources (factories) for chemical analysis also depends on the results of previous investigation methods, where places with high concentration are firstly focused. In the same time, support of the CCH and allowance of each factory to approach sampling points is still necessary.

3. RESULTS AND DISCUSSION

3.1. PRELIMINARY SURVEY

For the assessments relevant to the exploitation of the human olfactory system (direct sensory test as well as dilution sensory method), staffs were tested to qualify the Korean standard before. Panelists, consisting of 64 male and 20 female members with a median age of 25 years (range 22–30 years), were all able to identify chemicals types and levels under the standard requirements with an average correctness of 71.4% [6].

The results of the direct sensory test in the CNIC area for 4 periods of day collecting within ca. 3 weeks are shown in Fig. 3. All colored signs represent the occurrences of abnormal odor with a higher intensity than the allowance of the Korean government's standard (<level 2). It can be noticed that very high intensities like level 4–5, which mean too strong and unbearable smells, were mostly detected during early evening time (8:30–10:30 pm), compared to other periods. This corresponds to some civil complaints with detail that the smells seem stronger in early night.

Higher pollution levels normally occur at night because lower temperatures can cause the reduction of advective transport of air pollutants, which then accumulate close to the generating source. A planetary boundary layer, the lowest part of atmosphere, is also related to the distribution of air pollution. Transport of atmospheric pollutants is mostly at this level while its height is regularly lower during the nighttime resulting in more concentrated air pollution, compared to during the day [18–20]. Another possible cause suggested by the civil petitions is that some factories might be trying to save on the cost of odor control by directly releasing air pollutants into the atmosphere, demanding further investigation. There were various cases of such illegal practices to control industrial pollution in the past as recently reported in [11]. From all periods of the test for 3 weeks, the final figure of perceived odor with intensities beyond the Korean standard was 218 times, distributed to every zone (but different time), and the identifiable smells were mostly paint, metal oil, and food waste. Unfortunately, there is no zoning system for the types of factories in this industrial area. It is still not possible to point out any specific sources of odor problem from the identified smells and its location. However, the results from the direct sensory test as preliminary survey were helpful to confirm the adverse public complaints, indicating a need for more detailed investigation.

3.2. QUESTIONNAIRE

The characteristics of the respondents living near the CNIC and their odor perceptions (sense of any smell) are shown in Table 2.

Table 2

Characteristics of respondents by distance from the CNIC, by odor perception

Characteristic	All		Distance zone [km]						Odor perception	
			<1.2		1.2–2.4		>2.4			
Number of interviewee	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
	452	100.0	257	56.9	159	35.2	36	8.0	232	100
Sex										
Male	154	34.1	80	31.1	62	39.0	12	33.3	71	30.6
Female	298	65.9	177	68.9	97	61.0	24	66.7	161	69.4
Age										
21–30	51	11.3	27	10.5	19	11.9	5	13.9	24	10.3
31–40	89	19.7	40	15.6	35	22.0	14	38.9	48	20.7
41–50	128	28.3	76	29.6	42	26.4	10	27.8	70	30.2
51–60	142	31.4	91	35.4	46	28.9	5	13.9	68	29.3
61–70	32	7.1	18	7.0	12	7.5	2	5.6	18	7.8
>70	10	2.2	5	1.9	5	3.1	0	0.0	4	1.7
Socio-economic status										
Student	25	5.5	16	6.2	6	3.8	3	8.3	12	5.2
Manual workers	18	4.0	8	3.1	9	5.7	1	2.8	10	4.3
Storekeeper	102	22.6	63	24.5	32	20.1	7	19.4	55	23.7
Office job	106	23.5	58	22.6	42	26.4	6	16.7	60	25.9
Housewife	174	38.5	96	37.4	60	37.7	18	50.0	82	35.3
Other	27	6.0	16	6.2	10	6.3	1	2.8	13	5.6
Odor perception										
No	220	48.7	92	35.8	99	62.3	29	80.6		
Yes	232	51.3	165	64.2	60	37.7	7	19.4		

None of them had just arrived the city within 3 years. 66% of all respondents were females and 60% of them were 41–60 years old with the same issue as Nicolas et al. that no age of available people who accept to volunteer was under 20. The biggest group of careers respectively was housewife, office job, and storekeeper, who usually stay inside the building. 51% of people from the survey were used to perceive unpleasant odors. By 3 distances; less than 1.2 km, 1.2–2.4 km, and more than 2.4 km, set in this study as innermost, intermediate, and outermost zone; the number of respondents was 257, 159, and 36, respectively.

In the innermost and intermediate zones which were the majority of respondents, the proportions of respondents by gender, age, and careers were in similar proportion with the total number of interviewees and with the interviewees who ever experienced the bad smells. This might be attributed to insignificant effects of characteristics of gender, age, and career on the perception of odor, consistent with an earlier study in terms of age [11]. Female respondents were more sensitive [11], corresponding to this study result but the difference between genders appeared in Table 2 is not significant, same as mentioned by Gostelow et al. [13]. For outermost zone which constituted just a minority group in the survey, it has a significantly higher proportion of respondents of the careers in status of housewife and of the age in range from 31–40 years old, compared to the other zones while no representation of age over 70 years old was involved. The closer the distance to the CNIC is, the higher the number of interviewees who perceived the odors. This supports the civil complaints to the CCH that the CNIC is the source of unpleasant odors for this residential zone.

More details about the odor's characteristics as well as its occurring period and adverse effects from odor perception were reported by the distance zone in Table 3. It should be noted that the total number in some of these topics were higher than that of the interviewees who reported on odor perception. This is because each respondent was allowed to select more than one choice for each topic. It was apparent that the distance zones were consistently associated with all of these topics. The total number of all topics in the innermost zone was highest providing more evidence identifying the CNIC as the source of odor discharge. The topic of odor level could not be denoted in a scientific way since without training, each respondent would have an individual attitude and sensitivity to the level of odor. However, it at least demonstrated the stronger perception of people in the closest zone to odor problems.

For all zones, the number of odor perception was higher in the summer season than that of other seasons. This is possible due to the direction of prevailing winds in this region. Contrary to all other seasons, the wind during the summer time predominantly blows from the southwest and could sweep through the factories to the residential area [21, 22]. Another possibility is due to people's practice of opening windows more in the summer season. For the period of day, the study did not clearly specify whether day or nighttime had a higher odor concentration. 76% of the answers were for the period of midday until midnight. This might be the time that most of the interviewees were exposed to the odors owing to their daily schedules and they might not realize that exposure was occurring during sleep [12]. The identifiable type of odor which could be caused by the operation of factories in the CNIC was high, at about 70%. Part of the perceived odors could usually be found just in manufacturing areas such as grinding metal, burning rubber, etc. For free comments about the effects of odor, results could be categorized into 4 groups, i.e. mental effect (the leading complaint), health, economic, and education effects.

Table 3

Self-reported odor experience by distance zone

Self-reported odor experience	Odor perception		Distance zone [km]					
			<1.2		1.2–2.4		>2.4	
Number of interviewee	*n*	[%]	*n*	[%]	*n*	[%]	*n*	[%]
	232	100.0	89	38.4	136	58.6	7	3.0
Level of smell (missing 2 anwers)								
Low	49	21.3	24	10.4	23	10.0	2	0.9
High, bearable	138	60.0	101	43.9	32	13.9	5	2.2
Unbearable	43	18.7	38	16.5	5	2.2	0	0.0
Total	230	100.0	163	70.9	60	26.1	7	3.0
Season (missing: 3 answers[a])								
Spring	33	10.6	27	8.7	5	1.6	1	0.3
Summer	207	66.3	144	46.2	56	17.9	7	2.2
Autumn	40	12.8	33	10.6	5	1.6	2	0.6
Winter	32	10.3	27	8.7	4	1.3	1	0.3
Total	312	100.0	231	74.0	70	22.4	11	3.5
Period of day (missing: 7 answers[a])								
12 am–6 am	17	7.1	15	6.3	2	0.8	0	0.0
6 am–12 pm	41	17.2	21	8.8	18	7.6	2	0.8
12 pm–6 pm	88	37.0	62	26.1	23	9.7	3	1.3
6 pm–12 am	92	38.7	71	29.8	18	7.6	3	1.3
Total	238	100.0	169	71.0	61	25.6	8	3.4
Type of odor								
Chemicals	69	17.8	55	14.2	8	2.1	6	1.6
Fish	26	6.7	22	5.7	4	1.0	0	0.0
Paint and thinner	9	2.3	6	1.6	2	0.5	1	0.3
Food	72	18.6	38	9.8	32	8.3	2	0.5
Grinding metal	32	8.3	30	7.8	2	0.5	0	0.0
Burning rubber	35	9.0	31	8.0	3	0.8	1	0.3
Other burning materials	27	7.0	18	4.7	8	2.1	1	0.3
Ambiguous odor	117	30.2	88	22.7	24	6.2	5	1.3
Total	387	100.0	288	74.4	83	21.4	16	4.1

[a]Interviewers could not clearly answer in this topic and preferred to skip question.

Aside from mental and health effects, ordinary issues from odor pollutants, the respondents' common opinions relating to economic and education problems included the reduction of house and land prices, a reduction in restaurant customers, lack of concentration to study, and so on.

The numbers of interviewees especially for the outermost zone, which can be considered as the reference area, may be too low for the interpretation of result while the effort to obtain participation of citizen in each zone is equal with no bias. This point may imply the slightest concern and experience of smelly odor perception, compared to the other zones. Nevertheless, the questionnaire results from neighborhood volunteers are sufficiently useful to support the results from other experiments for unprejudiced investigation [12].

3.3. REAL-TIME ODOR SENSING SYSTEM

From April to September 2012, odor concentration was measured using a real-time odor sensing system every 5 min at the second floor of the Sangnam dong area [X_1] and at the fourth floor of the Seongsan dong area [X_2] (Fig. 2). Besides no detected odor, the number of detected odors OU/m^3 is presented in two ranges: (ND < $s \le 15$, and $15 < s$, where s is the sampling value) for 4 periods of a day as shown in Table 4.

Table 4

Odor concentration using the real-time odor sensing system at installed locations

Location	Period	ND	$s \le 15$ [OU/m^3]	$s > 15$ [OU/m^3]	Total	Maximum value [OU/m^3]
Sangnam dong	12 am–6 am	4	179	0	183	10.2
	6 am–12 pm	2	171	10	183	32.0
	12 pm–6 pm	3	180	0	183	12.9
	6 pm–12 am	3	180	0	183	7.5
	total	12	710	10	732	32.0
Seongsan dong	12 am–6 am	6	176	1	183	16.6
	6 am–12 pm	3	180	0	183	8.4
	12 pm–6 pm	4	178	1	183	16.3
	6 pm–12 am	5	172	6	183	19.3
	total	18	706	8	732	19.3

ND – not detected, s – sampling value.

There is no standard determined for only the residential area but logically at least it should be lower than the Korean government's standard value at enclosure of factory's boundary in residential zone (or <15 OU/m^3). Considering both [X_1] and [X_2], odors at the concentration over 15 OU/m^3 were detected in every period just in different areas of

Changwon city. The obvious periods with this range of odor concentration and the highest detected value for [X_1] and [X_2] were 6 am–12 pm (32 OU/m^3) and 6 pm–12 am (19 OU/m^3), respectively. The result for the larger number of high odor concentration in the period 6 pm–12 am, compared to others, corresponds to the result of the analyses by the direct sensory test and questionnaire. Yet, it has low association in the period of 6 am–12 pm with the two previous methods of investigation. However, the objective and target area of survey of these three methods are not quite the same. At least, it can be concluded in this section that the odors at too high concentration over the acceptable rate appeared in every period of time.

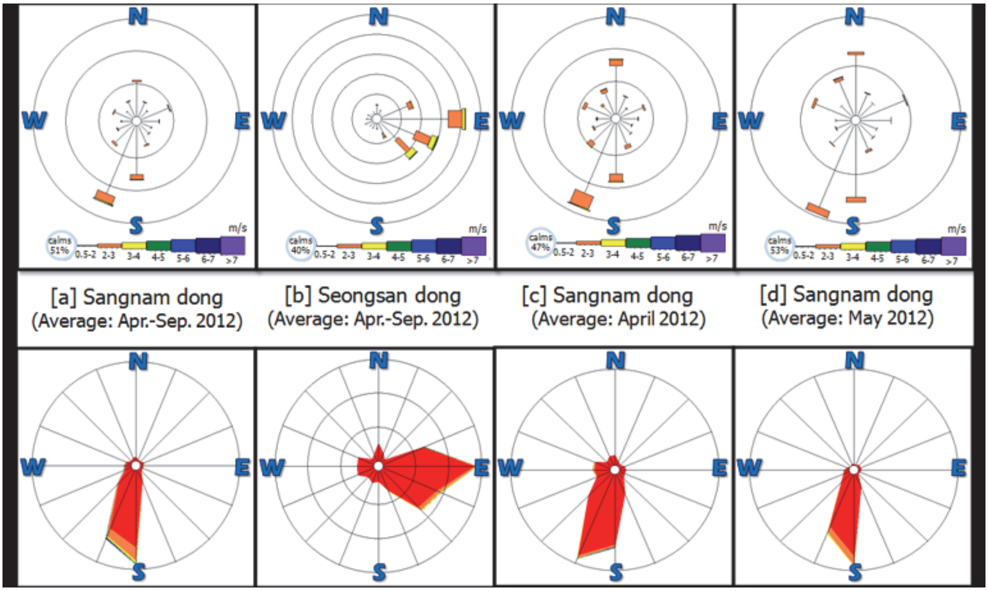

Fig. 4. Wind roses (above) and pollution roses (below) measured using the electronic nose

In Figure 4, the direction of odor transport to each installed sensor (4 pictures below) is presented together with the direction of wind (4 pictures above). For [a] and [b], the sampling results are plotted from the data during the whole measurement period (April –September 2012) of both [X_1] and [X_2], respectively while for [c] and [d], the results are plotted based on the data in just April and May for [X_1], respectively. It can be seen that the odor dispersions for [a], [b], [c], and [d] were from South-Southwest (SSW), East, SSW, and SSW, respectively which all were the directions from the CNIC area, as shown in Fig. 2. Apparent examples to exemplify that the major source of odor spread to these residential areas were blew from the CNIC are shown in [c] and [d]. Even it also had a major wind pattern from North for both months, the absolute opposite wind direction to the CNIC, odor diffusions to [c] and [d] appeared to be from just SSW.

3.4. AIR DILUTION SENSORY METHOD

This method provides a solution to monitor odor levels at high concentrations for verifying compliance with standards and regulations. The investigation was conducted in the CNIC, industrial complex area. Therefore, the standards for outlet and boundary of each company are less than 1000 and 20 OU/m^3, respectively [6].

Boundary of company. During May 11–23, odor concentration was measured by the air dilution sensory method at industries' enclosure. The industries were selected based on the results of former investigation especially from preliminary study by a direct sensory test. The number of samplings with measurement results below and beyond the allowance of the Korean government's standard as well as the highest concentration measured during four periods a day is presented in Table 5.

Table 5

Odor concentration by the air dilution sensory method at enclosure of a factory

Period	Number of samplings	Below standard	Beyond standard	Maximum value [OU/m^3]
12 am–6 am	6	6	–	18
6 am–12 pm	5	2	3	79
12 pm–6 pm	4	4	–	18
6 pm–12 am	7	4	3	42
Total	22	16	6	Maximum permission <20

Based on 22 samplings during 13 days, the results of the detection went beyond the Korean standard 3 times at the period from 6 am to midday and also 3 times from 6 pm to midnight which both were the same periods found in the section of the real-time odor sensing system. Even the number of results beyond the standard was equal, the maximum concentration value of the period from 6 am to midday is almost 2 times higher than that of the period from 6 pm to midnight. This proved that the smelly odors were released from some emission sources near factories' enclosure with no/poor air pollution treatment, not only at nighttime according to the residents' supposition, but also possibly during the daytime.

Factory outlet. In cooperation with the CCH, supported by the scientific evidence from the investigation as hereinbefore specified, a factory outlet such as stack was approached for odor measurement by the air dilution sensory method for 54 companies from May to October, 2012. It spent about 6 months for this number of samples, too low for an accuracy of simulation if modelling of odor dispersion would be utilized for the assessment, considering from the total number of factories (more than 2000 sites).

Table 6

Odor concentration and 22 major malodorous compounds[a] under the Korean regulation at the outlets of factories

Compound	Permission[c]	Paint and dye (2 types)	Casting (2 types)	Heat treatment (2 types)	Food (2 types)	Coating (4 types)	Reference[d]
Ammonia	2000	70.2	22.6	11.6	58.6	274.0	0.2–4.1×10[6e]
Hydrogen sulfide	60	22.1	9.3	4.8	*635.4*	6.7	0.01–39510[f]
Methyl mercaptan	4	3.1	1.6	1.5	*19.4*	1.7	0.004–2305[f, g]
Dimethyl sulfide	50	1.8	3.2	1.0	5.2	0.9	0.003–952[g]
Dimethyl disulfide	30	2.0	3.9	2.6	4.4	7.2	0.001–11 090[e,g]
Acetaldehyde	100	1053.2	10.1	1007.9	111.6	407.1	0.03–2503[f]
Propionaldehyde	100	53.4	ND	*111.5*	81.3	13.1	0.20–121[f]
n-Butyraldehyde	30	*155.9*	3.2	*91.3*	7.2	*105.4*	0.26–1,299[f]
i-Valeraldehyde	6	*13.2*	ND	*7.1*	1.8	4.2	0.25–15.8[f]
n-Valeraldehyde	20	*64.8*	ND	*37.1*	ND	3.0	0.26–111[f]
Trimethylamine	20	ND	ND	ND	1.0	ND	0.002–46.4[f]
Styrene	800	2.8	4.6	29.2	3.2	28.4	0.08–5,293[f]
Toluene	30 000	81.4	163.7	129.7	66.8	615.9	–
m, *p*-Xylene	2000	79.0	426.5	51.3	48.0	720.2	–
o-Xylene	2000	35.7	196.2	26.1	18.7	453.4	–
Methyl ethyl ketone	35 000	71.2	4.1	120.9	5.0	106.4	–
Methyl isobutyl ketone	3000	10.1	4.3	10.7	6.3	326.9	–
Butyl acetate	4000	73.4	4.5	2.4	8.5	312.3	–
Isobutyl alcohol	4000	316.0	2.2	5.8	1.6	401.6	–
Propionic acid	70	ND	ND	ND	ND	ND	–
n-Butyric acid	2	ND	ND	ND	ND	ND	–
n-Valeric acid	2	ND	ND	0.2	*2.5*	ND	–
Isovaleric acid	4	ND	ND	ND	ND	4.0	–
Odor concentration (OU/m^3)[b]	1000	1889 <5/28>	10 000 <1/6>	2080 <2/4>	6000 <2/3>	1144 <1/1>	

[a]Description of the analytical methods is reported in [6, 16, 17].
[b]Measured by the odor sensory method.
[c]Refers to [6, 16].
[d]Range of detectable values taken from the literature, measured at the odor emission sources in industrial area by the chemical analysis.
[e]Refers to [23].
[f]Refers to [24].
[g]Refers to [9].
Values in italics – detected value > permission rate, () – total no. of samplings (factories) measured by the chemical analysis, < > – no. of samplings with detected value over the permission rate/total No. of samplings measured by the sensory method, ND – not detected.

The number of sampling for various factory types with the results of measurements below and beyond the allowance of the Korean government's standard, as well as the highest concentration measured for each factory type is shown in Table 6. The results are presented together with the measurement of chemical compounds for the comparison (only the types of factories with the results over the permission rates for odor or chemical concentration) which is later discussed in the next section. From 54 locations of sampling, results from the detection exceeded the Korean standard for 11 factories and some of them were suggested by the residents from the questionnaire. This showed the benefit of using questionnaire to help in the investigation to indicate the critical emission sources. The industrial type with the highest percentage of factory-releasing odor concentration beyond the Korean standard was paint and dye (5 factories), but it was just 15% from the total number of samplings for this industrial type (33 samplings). At almost the same percentage (17% of the total number of samplings) with just one above standard case of casting foundry factory, the value of measurement was high at 10 000 OU/m^3, which was also the highest value from all overall measurements.

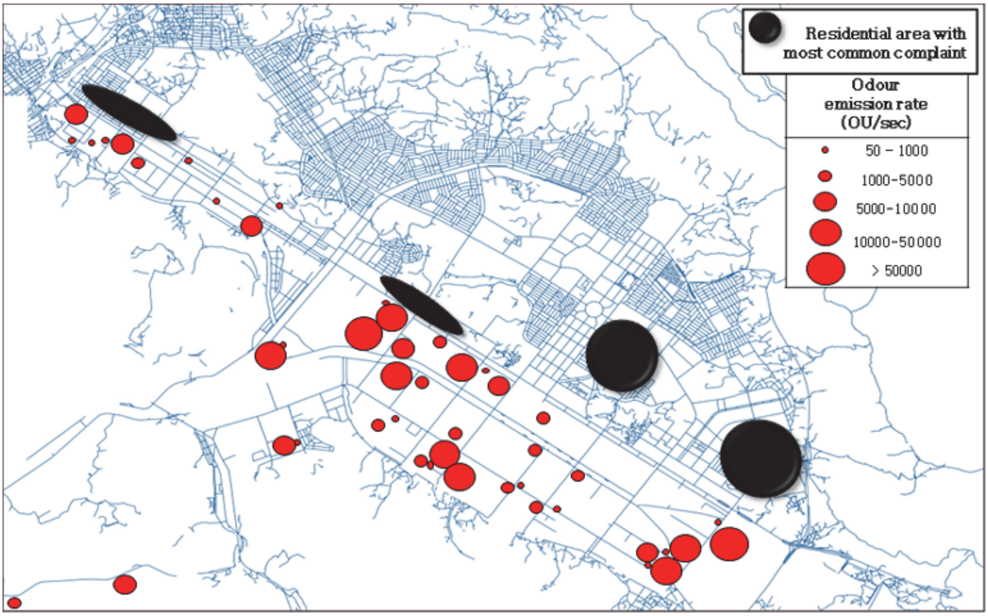

Fig. 5. Presence and intensity of odors area in OU/s;
examination by the air dilution sensory method at factory outlets in the CNIC

In Figure 5, the distribution of measurements of the odor emission rate is illustrated, the outcome of odor concentration (OU/m^3) and the volumetric flow of emission source (m^3/sec) [4]. Excluding over 2000 units of factories, from just 54 factories with admittance of odor measurement, it can be seen from Fig. 5 that the odor problem was already at a severe stage. A critical issue is a loophole in the law. A bigger size of red circle does not specify the source of odor production at over the standard rate. For concentration of odor, they might release it within the limit of the law. However, if the volumetric flow of emission from outlet is high, it can cause terrible results as presented in Fig. 5 either. Thus, any solution to alleviate the intensity as well as the revision of odor regulation should be initiated as soon as practicable.

3.5. CHEMICAL ANALYSIS

This method is aimed at monitoring the concentration of specific types of chemical compounds at factory outlets and at residential areas so as to be in compliance with standards and regulations. There is no restriction for the type of manufacturing in the CNIC. It is thus difficult to foresee what compounds are the sources of odor in the city. Therefore, an analysis of all malodorous compounds under the provisions of the current federal law is necessary for a sufficient investigation. Due to limitation of this study with respect to the number of sampling for all 22 compounds under the Korean regulation, the most critical location and time were prioritized for the criteria to select sampling, and dependent upon the results of former steps. The standards for outlets and residences as well as a comparison of sampling results between this method in conjunction with the odor sensory method and a real-time odor sensing system are presented in Tables 6 and 7, respectively.

Factory outlet. The results of the chemical analysis presented in Table 6 are the highest measured values of each compound and factory type. As aforementioned, the factories presented in Table 6 are only those that released odor or chemicals concentrated over the standard. However, it should be remarked here that only the casting factory with the highest odor concentration exhibited the presence of all chemicals within the permissive standard while the results of the others were all over the permissive standard. Paint and dye, heat treatment, food, and coating exhibited 4, 5, 4, and 2 types of chemical compounds over the permissive standard, respectively. The measurements were not conducted in the same time; however, they all were completed during normal operation time, which safely assumes that the released emissions should be the regular rate. However, it is possible that the results of the chemical analysis may sometimes show no correlation with the odor concentration measured by other methods similar to this case. This could be due to interaction of chemicals producing synergistic or antagonistic effect, or an odor effect from non-analytical compounds, etc. [4, 5, 24].

Ranges of detectable values for some chemicals in Korea's cases have been compared with the literature data. All results in this study are within the range; in other words, not higher than any of maximum values of the reviewed data recorded in areas with similar types of industries/activities, releasing the same kinds of emissions, producing much higher amounts, while there are many types of factories within the CNIC.

Table 7

Odor concentration and 22 major malodorous compounds under the Korean regulation at residential areas Sangnam dong and Seongsan dong

Compound[a]	Permission[b]	Sangnam dong[c]				Seongsan dong[c]				Reference[d]
		Average	Max.	SD	*r*	Average	Max.	SD	*r*	
Ammonia	1000	36.9	38.9	54.4	0.2	15.6	33.2	7.8	0.7	3.50–90.13[e]
Hydrogen sulfide	20	0.1	0.3	0.1	0.1	0.2	0.7	0.2	ND	0.05–12.9[f]
Methyl mercaptan	20	0.1	0.3	0.2	–0.4	0.1	0.4	0.2	–0.1	0.018–5.69[f]
Dimethyl sulfide	10	0.2	0.5	0.2	0.1	0.2	0.4	0.2	–0.4	0.02–6.39[f]
Dimethyl disulfide	9	ND	ND	ND	–	ND	0.1	ND	–0.4	0.019–5.26[f]
Acetaldehyde	50	3.0	6.1	1.8	–0.2	2.9	4.2	1.1	0.1	0.01–3.87[e]
Propionaldehyde	50	0.2	1.0	0.4	–0.2	0.2	1.7	0.6	0.3	–
n-Butyraldehyde	9	1.4	3.0	1.3	–0.6	1.7	2.7	1.1	0.1	0.01–0.33[e]
i-Valeraldehyde	3	0.1	0.7	0.3	0.9	ND	ND	ND	–	–
n-Valeraldehyde	9	ND	ND	ND	–	0.2	1.2	0.4	0.6	–
Trimethylamine	5	ND	ND	ND	–	ND	ND	ND	–	0.01–0.26[e]
Styrene	400	0.4	0.8	0.3	0.3	0.4	0.8	0.3	–0.3	0.01–0.02[g]
Toluene	10000	2.9	7.3	2.5	–0.3	3.5	15.2	5.2	0.3	0.26–0.74[g]
m, *p*-Xylene	1000	2.6	10.2	3.4	–0.3	2.1	12.2	4.1	0.2	–
o-Xylene	1000	1.3	3.9	1.2	–0.2	1.1	4.9	1.5	0.1	0.17–0.42[g]
Methyl ethyl ketone	13000	0.8	1.3	0.3	0.2	0.8	1.9	0.6	0.6	0.55–0.60[g]
Methyl isobutyl ketone	1000	0.5	0.9	0.2	0.0	0.4	1.4	0.4	0.3	0.03[g]
Butyl acetate	1000	0.8	2.2	0.7	–0.2	0.8	2.7	1.0	0.4	–
Isobutyl alcohol	900	0.7	1.5	0.5	–0.1	0.6	2.7	0.9	–0.1	–
Propionic acid	30	ND	ND	ND	–	ND	ND	ND	–	–
n-Butyric acid	1	ND	ND	ND	–	ND	ND	ND	–	–
n-Valeric acid	0.9	ND	ND	ND	–	ND	ND	ND	–	–
Isovaleric acid	1	ND	ND	ND	–	ND	ND	ND	–	–

[a]Description of the analytical methods is reported in [6, 16, 17].

[b]Refers to [6, 16],

[c]Odor and concentration measured on December 3rd, 10th, 17th and 24th, 2012: 2 am, 8 am, 2 pm, and 8 pm.

[d]Range of detectable values from literatures, measured at urban environment by the chemical analysis.

[e]Refers to [5].

[f]Refers to [25].

[g]Refers to [8].

Max. – maximum detected value, SD – standard deviation, *r* – correlation coefficient calculated from the results of malodorous compounds and odor concentration measured using a real-time odor sensing system, ND – not detected.

Residential area. The relationship between odor concentration and 22 major malodorous compounds measured in the residential area was assessed and shown in Table 7. The measurements for the comparison were conducted on September 3rd, 10th, 17th and 24th, 2012 during the periods 2–3 am, 8–9 am, 2–3 pm, and 8–9 pm. All measurements were taken on Mondays, when usually the emission rate was highest (due to engine start-up for some factories). Also, the number of complaints in September was specifically the second highest during the year 2012. However, maximum values for each analyzed compound at both places with a high number of complaints are still all lower than the permissive values. As previously noted, the mixing of compounds may cause a synergistic effect, hard to evaluate. At least, the reason for a significant number of complaints in both areas may be obtained from the correlation coefficient between odor concentration and each malodorous compound. The correlation coefficient between the odor concentration with *i*-valeraldehyde at [X_1] is 0.9 while that with ammonia, *n*-valeraldehyde, and methyl ethyl ketone at [X_2] are at 0.7, 0.6, and 0.6, respectively, considered as a medium-high relationship. *i*-Valeraldehyde (emitted from paint and dye and heat treatment factories) and *n*-valeraldehyde (emitted from paint and dye, heat treatment, and coating factories) have been released over the standard (Table 6). Thus, these two compounds represent the probable sources of the odor problem according to the available data, and would be useful for further investigation and initializing mitigation.

Nevertheless, the result from review of measurement data in this topic is distinct from the previous one, ie. chemical analysis at the factory outlet because many kinds of compounds detected in the residential area were over the highest values as discussed in the current literature.

3.6. CURRENT SUBSEQUENCE ON THE OPERATION OF THE COMBINED METHODS

Aside from a significant number of complaints over three continuous years, robust scientific evidence for identifying the problem area as an odor management area is necessary as explained. Currently, there is no specific rule for the selection of method. Each employed method in this study has its own limitations and serves different purposes. Firstly, for direct sensory method, the reliability of results is the lowest when compared to other methods because the volunteers who participated in this step were divided into subgroups and investigated their zone separately. Although the test to verify the volunteers' judgments were conducted before the survey, there were still factors causing differences in each group such as, bike riding speeds, style and carefulness, wind characteristics at each zone, etc. Even so, this method is needed to bear out the existence and level of the problem in the alleged area while it cannot specify that it is the source causing the odor problem in the residential area, such as at [X_1] and [X_2].

Secondly, for questionnaire, it effectively provides qualitative data from residents' experience, including additional information or opinions apart from the survey questions. Based on the results of using questionnaire, it can be implied that CNIC is the origin of odor problem from the inverse proportion between the percentage of interviewees who ever experienced malodor in each zone and the distance from CNIC to interviewees' place. However, quantitative data like the odor concentration at the released sources and at receptors is not acquirable from using questionnaire. Another possible disadvantage of the questionnaire is a superficial answer of some interviewees which is unverifiable.

Thirdly, for a real-time odor system, it can provide results about the concentration of odor diffusion into the installed points as representative of residential area. It can also be a useful cross-check on identifying that CNIC is the origin of odor released into the civil petition area from detecting the direction of incoming odors. Its disadvantage is the limited range of detectable concentration while human nose is more sensitive. Therefore, it should not be applied individually.

Fourthly, for air dilution sensory method, it is the tool to address the enterprises originating odors at too high concentrations over the standard rate. However, pursuant to the Korean regulation, this method should be conducted by a trusted third party and therefore it is not a simple task to obtain continuous measurement results for any sampling location except only in specific case. Lastly, for chemical analysis, it is meaningful for a direct evaluation of concentrations of various odorants for the understanding of fundamental aspects of odorant emissions from a large-scale industrial complex especially. Meanwhile, there can be some other malodorous compounds releasing in the study area but they are not included in the detection. Nonetheless, the integrated utilization of all selected monitoring methods can markedly identify frequency, intensity, duration, offensiveness, and location of odor nuisance in this case study.

Only in the case that a problem area is identified as an odor management area, the permission levels under the condition of the restricted area at a factory's boundary and outlet in industrial complexes can be adjusted in the range of 15–20 and 500–1000 OU/m^3, respectively. As well, under the same condition, the permission at the factory's boundary and outlet in outer industrial complex simultaneously become in the range of 10–15 and 300–500 OU/m^3, respectively. Factories that cannot control the odor concentration at an investigated place or facility within one year under the adjusted standard may be fined or suspended by command of authorized representatives. Odor management in the determined area is next sustained by examining the status on a regular basis by the assigned inspection institute [6]. At current stage after the results of the aforementioned methods has been reported, several factories with the measurement results beyond the allowance of the government's standard have already started making prevention plans and taking serious actions for reducing odor emissions. Those actions have been performed and publicized even though the consideration process for regulating Changwon city as an odor management area has not yet been completed and there is no punishment in the current stage. The reason might be due to the factories' realization from apparent evidence that the enforcement of the odor management area in Changwon city was certain after a period of time. Thus, their early preparedness was prudent for reducing the risk of unexpected problems and potential disrepute.

4. CONCLUSIONS

In the study, a task to address the odor sources assigned by the CCH, the local authority, has been conducted, with an expectation to solve the problem through the enforcement of Korean legislation by exalting the city status to an odor restricted area. The results from direct sensory method, installed real-time odor system, experiences of citizens by questionnaire, and sampling by air dilution sensory method as well as by chemical analysis, all cumulatively illustrated that the odors originated from the CNIC's location. Important benefits in this current stage of research are the improvement in odor control by factories as well as public awareness in the situation of odor and other pollution problems in Changwon city. The combination of techniques and the current positive subsequence are examples of employing odor measurement methods for the practical management of odor in industrial city, even not governed under the same regulation with the case. The designed multi-monitoring techniques can also ensure fairness to all parties including accused manufacturers for sustainable development. The last important point that should be highlighted from this study is the necessity of scientific knowledge for formulating policy or enacting legislation, particularly relating to environmental issues.

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