Risk Control of Accidental Water Quality Deterioration in Tokyo Metropolitan Waterworks

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Abstract

The Japanese water utilities aim to supply safe and good-taste water to the customers. Recently, the source water, especially the river water, has subject to various kinds of contamination due to accidental spills; therefore, it is necessary to establish the risk control measures, such as the source water quality monitoring system, and increase the monitoring frequency. In addition, when supplied tap water quality is likely to violate the drinking water quality standards or cross connection with pipes for other utilities is detected, the water utilities must respond rapidly and appropriately. In this report, the source water quality management system and the emergency response for source water and tap water monitoring in Tokyo Metropolitan Waterworks are reported.

Keywords: emergency response, GIS (Geographic Information System), risk management, source water quality, water quality management system

1.Introduction

Water supply systems are an important lifeline supporting our life and urban activities. Tokyo Metropolitan Waterworks (TMW) takes all possible measures to supply safe, good-taste and high quality tap water twenty-four seven. Recently, the customers' request for better taste of tap water has been growing. TMW is making efforts to supply tap water with safer and better quality than ever before to meet the expectations of these customers. The efforts taken by TMW include many parameters for water quality analysis, high frequency of analysis for water quality management, proper management of water treatment, survey and experiments about water quality, and 100% coverage of the water supply systems from the Tone-Ara River basin by the advanced water treatment processes.

Nonetheless, there has been various problems in water quality management, such as the radioactive substances caused by the accidental explosion of the Fukushima Daiichi Nuclear Power Plant, accidental spill of formaldehyde in the Tone River basin, and detection of high concentration of 2-Methylisoborneor.

The time course of the number of water utilities interrupted by accidental spills is shown in Figure 1. In this figure, "interrupted by accidental spills" are the cases that required some form of responses of water utilities, e.g. suspension or restriction on water supply, interruption or restriction on intake or use of special chemical like powdered activated carbon by unpredictable changes of source water quality. The numbers of water utility interrupted by spills has been increasing recently as it can be seen in Figure 1. If this increasing tendency continues in the future, water utilities without any experience of emergency response will have to take measures against accidental spills. The contaminants discharged by the spilled c and cause of the spills in 2017 are shown in Figure 1 and in Figure 2, respectively. Figure 2 shows that oil spill and high turbidity are the contaminants that were the most and second most frequently found in spills. Figure 3 shows the causes of spills, wherein unknown causes account for 60.1%, whereas others are also high at 20.3%. The reason for unknown and others is supposed to be due to large number of small scale accidents, of which the causes are difficult to identified.

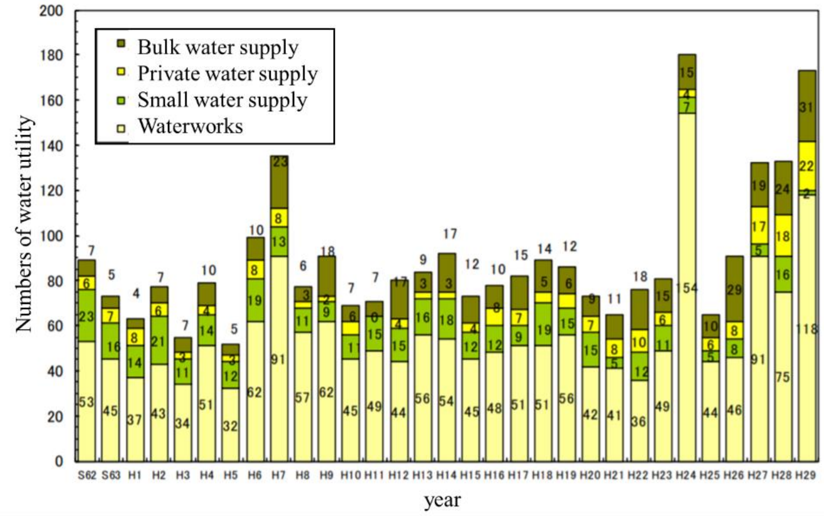

Figure 1. Time course of the number of water utilities interrupted by the accidental spills [2]

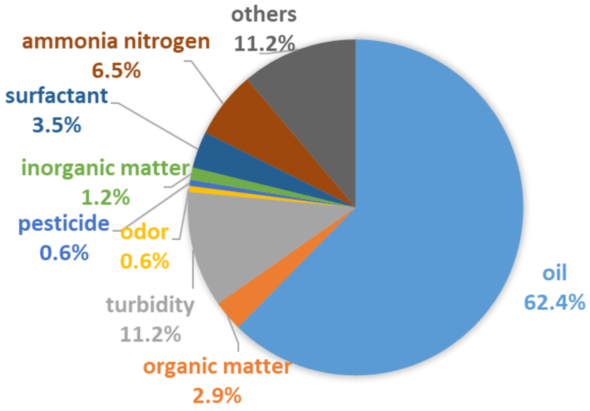

Figure 2. Spilled contaminants (2017) [2]

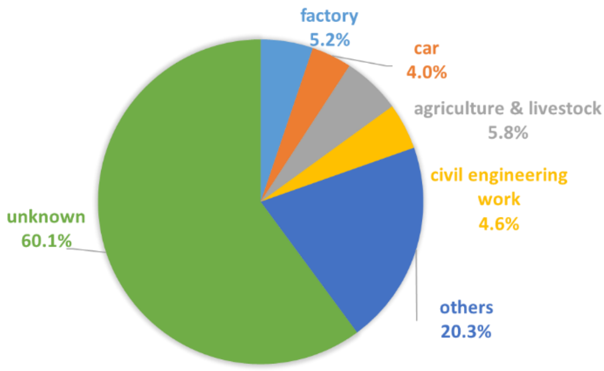

Figure 3. Causes of spill (2017) [2]

The Ministry of Health, Labor and Welfare established *Water Safety Guidelines* and requested the water utilities to establish *Water Safety Plans* for taking control of the risks of source water contamination. *Water Safety Plans* is the system aiming for safe water supply that extract and identify the risk between source water and tap water and monitor and control the risks.

Water Safety Plants requires twenty-four seven monitoring the situation of source water to supply safe water. Presently, large water utilities designated the monitoring points in the main river basins. If any harmful substances were spilled over the upstream of the intake points, monitoring of source water quality is enhanced more than usual by adding sampling and inspection points, and increasing frequency and parameters for analysis. For example, five water utilities in Tone River and Arakawa River basins: Public Enterprises Bureau of Gunma Prefecture and Saitama Prefecture, Kitachiba Water Supply Authority and Waterworks Bureau of Chiba Prefecture and Tokyo, check water quality at 86 points in the source water area. In addition, all the water quality parameters are analyzed for raw water and tap water at the water purification plants on different days by adjusting the sampling and analysis schedule so as not to take in the same week. When a water utility finds unusual source water quality, water utilities cooperate to carry out a thorough investigation to find the cause of contamination. Similar emergency responses are also carried out by water utilities of the Sagami River and Sakawa River basins. These responses are effective monitoring source water.

2. Water quality monitoring by TMW

2.1 Management of source water quality

TMW takes 97% of the source water from rivers, of which about 80% comes from Tone and Arakawa Rivers and about 20% comes from Tama River; these source waters come from almost the whole area of the Kanto region (Figure 4). TMW carries out the following managements for early warning of source water quality changes and for quick and proper emergency responses when accidental spills are reported.

1. Monthly analysis of source water quality in the main monitoring points of the rivers
2. Collecting information about factories located in the source water areas, including wastewater from those factories, and request for cooperation to prevent pollution
3. Patrolling the source water areas by mobile laboratory etc.
4. Emergency contact with relevant organizations through contact networks and investigation cooperating with relevant organizations
5. Sharing information regarding source water quality with neighboring water utilities (Public Enterprises Bureau of Gunma Prefecture, Saitama Prefecture, Chiba Prefecture and Ibaraki Prefecture and Waterworks Bureau of Utsunomiya city and Kawasaki city) through Liaison Council (WTALC) and Liaison Council for Prevention of Waste Water Pollution in Kanto Region (LCPWWPK).

The WTALC holds general and subcommittee meetings and workshops, and makes requests to the national government ministries for eutrophication control, regulation of effluents and so on. It also coordinates management of an emergency contact network. The LCPWWPK shares information of accidental spills by FAX and by the mailing system that sends e-mails to the pre-registered e-mail addresses of the water utilities.

Figure 4. Water resource of Tokyo

2.2 Management of water quality at water purification plants

To supply safe tap water, TMW takes control of all processes at the water purification plants. TMW carries out the following managements of water quality.

1. Monitoring poisonous substances in raw water and tap water by observing swimming fish in a water tank twenty-four-seven
2. Monitoring residual chlorine, turbidity, color, pH, conductivity, alkalinity, chlorine requirements, ammonia, TOC and dissolved oxygen by automatic water quality loggers in every minute and checking processing status of water treatment by water quality analysis
3. Daily water quality analysis of raw water, tap water and process water (Table 1) and monthly or yearly analysis which check more water quality parameters than daily
4. Management of chemicals used for water treatment

Table 1. Daily water quality monitoring parameters at water purification plants

Standard Plate Count Bacteria	Color	Conductivity
E. coli and fecal coliforms	Turbidity	UV260
Geosmin	Organic Carbon ($KMnO_4$)	Temperature
2-Methylisoborneol	Residual Chlorine(Free)	Water temperature
pH	Residual Chlorine	Precipitation(total : mm)
Taste	Ammonium nitrogen	
Odour	Alkalinity	

2.3 Quality control of tap water

TMW analyzes tap water with many water quality parameters monthly or yearly, and monitors tap water with automatic water quality loggers in real time to maintain tap water safety. The automatic water quality loggers are deployed at 131 points in Tokyo in each distribution system to monitor residual chlorine, turbidity, color, pH, conductivity, water temperature and pressure. TMW also controls the residual chlorine levels between 0.1mg/L and 0.4mg/L to reduce disinfection by-products and complaints from the customers. Water Quality Management Center (WQMC) and water purification plants are reducing chlorine dose as far as possible with reference to the daily monitoring results of residual chlorine in the pipelines. The concentration of chlorine at water purification plants and the monitoring points are used to establish correlation with source water quality such as water temperature, TOC, conductivity etc., stream flow conditions (rain, stream flow, melted snow, etc.), operating situation of river structure (water channel, drainage pumping system etc.), water supply operation (raw water operation, distribution system, concentration time at end automatic water quality loggers etc.) and individual function of replenishment chlorination device (injection to pipeline or distributing reservoir) for daily management of residual chlorine.

And branch offices and WQMC work together to investigate causes and solve the problem as for inquiries about water quality from customers and cross connection.

3 Accidental spills

3.1 What are accidental spills?

Accidental spills mean the cases that has impact or risk to intake by flowing pollution substances such as toxic substance, oil and so on in source water because of dewater or illegal dumping from factories around source water.

The formaldehyde contamination in May 2012 took place due to the reaction of chlorine for disinfection and hexamethylenetetramine. For this reason, TMW classifies such cases that toxic substance was generated by water treatment into accidental spills.

3.2 The number of accidental spills in source water

The number of accidental spills in source water had been around 150 and has started to decline for the last five years (Table 2). Especially the number of oil spill declined, and the number of “breakdown and damage of machine” and “traffic accident” are in cause of oil spill.

The number of interrupted supply by spills, such as interruption on intake or use of special chemicals including powdered activated carbon, has been almost the same. The reason for the significantly smaller number of supply interruption by spills than the number of spill incidents is that most of the spills are small scale and far from the water purification plants.

Table 2. The number of accidental spills and interrupted by spills in 10 years

year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of spills	176	126	164	191	200	200	171	138	132	119
Supply interrupted by spills	2	2	4	4	3	2	2	1	5	2

TMW recognizes and registers the spills in the river basin that influence the water purification plants of TMW. TMW takes water from the Tone River, Arakawa River, Edogawa River, Tama River and Sagami River basin. The ratio of spills in the Tone River basin has been the highest in last five years (Figure 5). This is because there are many factories in the Tone River basin. The types of spills are oil spill, dead fish, odor, colored water and flowing chemicals. The percentage of oil spill was 63.6% in the last five years (Figure 6). The causes of spill were traffic accident (17.0%), operation errors (16.4%), breakdown and damaged of machine (8.7%) and unknown (45.2%) (Figure 7).

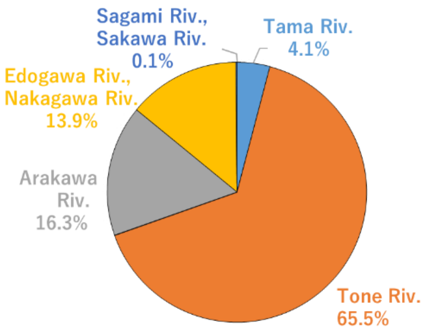

Figure 5. The ratio of spill in each river basin

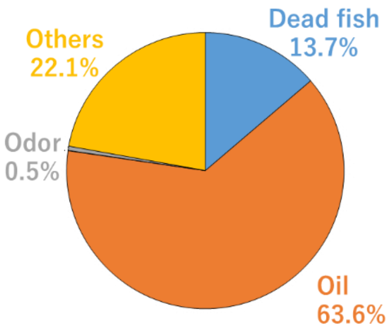

Figure 6. The ratio of spill cases

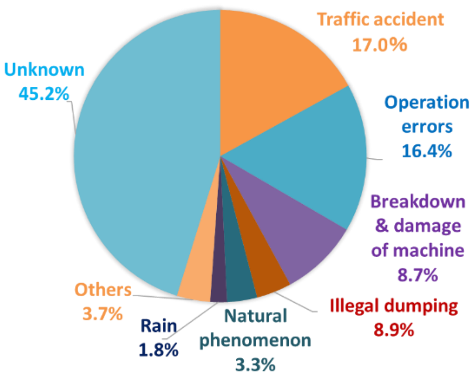

Figure 7. The ratio of spill causes

3.3 Flow chart of the emergency response to source water contamination in WQMC

The flow chart of emergency response of WQMC is shown in Figure 8. Information gathering and field investigation continue until it will be finally identified that a spill doesn't affect water intake and water treatment.

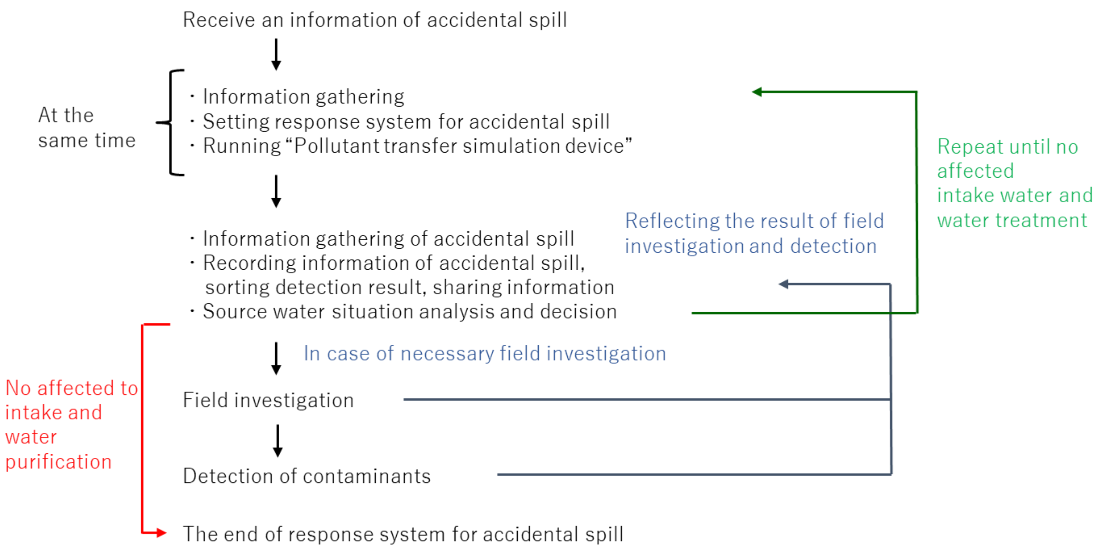

Figure 8. The flow chart of emergency response of WQMC [6]

3.4 Future task

Sometimes it takes a long time to get the result of water quality analysis of water samples taken from the accidental spill sites because the site of occurrence of spills are far from WQMC. Therefore, WQMC launched a mobile laboratory to get the result of analysis rapidly by simplified analysis methods. In 2018, WQMC installed new analyzers to increase water quality parameters in the mobile laboratory, which is explained in Chapter 5.

When a spill happens, it is necessary to share information with other departments and other water utilities depending on the spill sites. TMW uses the mailing system and FAX to contact with other water utilities. However there are some problems such as not being able to open attached files for security reasons and it takes long time to get FAX. Therefore, the five water utilities in the Tone River and Arakawa River basins are seeking introduction of an information sharing system using a cloud technology that has a large capacity and make it possible to communicate rapidly. These five utilities organize a drill on spill accidents in the source water areas annually to find problems and their solutions.

4 Water quality problems of tap water

4.1 What are water quality problems of tap water?

Water quality problems of tap water mean water quality deterioration that might affect customers' health and lives caused by supplying water that violates the water quality standards or by cross connection. The problems happened in Japan are violation of the water quality standards of standard plate count bacteria, residual chlorine and color, and occurrence of musty odor and cross connection.

4.2 Work flow of the emergency response to the problems in tap water quality in WQMC

WQMC is informed of the occurrence of a problem in tap water quality from the branch offices, inquiry from customers, abnormal value by the automatic water quality loggers and monthly analysis. When problems of tap water quality occurs, WQMC identifies the location on the pipe maps, road maps and housing maps, and check the location with the supply area map of reclaimed wastewater and the automatic water quality logger in the distribution system. Also WQMC contacts the branch offices and goes to the field investigation, takes water samples and analyzes water quality. When it is found that tap water quality is normal, the emergency response of unusual tap water is dismissed.

4.3 Future task

The number of water quality problems of tap water is less than the number of spills. However, there is possibly that the number of experienced staffs will decrease by job rotation. Therefore, WQMC produced a manual for the emergency response of unusual tap water quality and simulates the water quality problems of tap water.

There were many tasks in the initial response and explanation for customers in the case of cross connection in Adachi Ward in 2017. When water quality problem of the suppled tap water was found, the staffs must prepared for any action even at night and on holiday. WQMC holds seminars about tap water quality to staffs at the branch offices, who cooperate with WQMC when water quality problems of tap water, to explain clearly the content of the emergency response manual to enhance the partnerships with branch offices.

5 Quick response to spills utilizing mobile laboratory

5.1 What is Mobile Laboratory?

WQMC investigates contaminants using mobile laboratory (Figure 9) to analyze water quality rapidly on site when accidental spills or unusual tap water are reported. Mobile laboratory is a car loaded analyzers to analysis in the car on site. By water quality monitoring using mobile laboratory, WQMC can estimate the change of contaminant concentration over time at fixed point on site or can estimate the affected area by spills by taking samples from various sites.

Figure 9. Mobile laboratory

5.2 Analyzers and water quality parameters in mobile laboratory

The mobile laboratory is equipped with a spectrophotometer, a voltammetry, a mercury thermometer, an ion chromatography, a gas chromatography, a fluorescence spectroscopy and flow cytometry. Using these analyzers, WQMC can analyze 46 water quality parameters, including 31 health-related parameters of drinking water quality standards (Table. 3).

Table 3. Analyzable parameters in mobile laboratory

No.		water quality parameters	standaeds	analysis method
standard	1	Standard Plate Count Bacteria	≦100cfu/mL	Flow cytometry
standard	2	E. coli and fecal coliforms	not detected	
standard	3	Cadmium	≦0.003mg/L	Voltammetry
standard	4	Mercury	≦0.0005	Mercury meter
standard	5	Selenium	≦0.01mg/L	Voltammetry
standard	6	Lead	≦0.01mg/L	Voltammetry
standard	7	Arsenic	≦0.01mg/L	Voltammetry
standard	8	Chromium	≦0.05mg/L	Colorimeteric method
standard	9	Nitrite nitrogen	≦0.04mg/L	simplified water inspection product
standard	10	Cyanide	≦0.01mg/L	Colorimeteric method
standard	11	Nitrate nitrogen & Nitrite nitrogen	≦10mg/L	simplified water inspection product
standard	12	Fluoride	≦0.8mg/L	simplified water inspection product
standard	13	Boron	≦1.0mg/L	simplified water inspection product
standard	14	Carbon tetrachloride	≦0.002mg/L	Gas chromatography
standard	15	1,4-dioxan	≦0.05mg/L	Gas chromatography
standard	16	1,2-Dichloroethylene(cis)	≦0.04mg/L	Gas chromatography
standard	17	Dichloromethane	≦0.02mg/L	Gas chromatography
standard	18	Tetrachloroethylene	≦0.01mg/L	Gas chromatography
standard	19	Trichloroethylene	≦0.01mg/L	Gas chromatography
standard	20	Benzene	≦0.01mg/L	Gas chromatography
standard	21	Chlorate	≦0.6mg/L	Ion chromatography
standard	22	Monochloroacetate	≦0.02mg/L	Ion chromatography
standard	23	Chloroform	≦0.06mg/L	Ion chromatography
standard	24	Dichloroacetate	≦0.03mg/L	Ion chromatography
standard	25	Dibromochloromethane	≦0.1mg/L	Gas chromatography
standard	26	Bromate	≦0.01mg/L	Ion chromatography
standard	27	Total trihalomethanes	≦0.1mg/L	Gas chromatography
standard	28	Trichloroacetate	≦0.03mg/L	Ion chromatography
standard	29	Bromodichloromethane	≦0.03mg/L	Gas chromatography
standard	30	Bromoform	≦0.09mg/L	Gas chromatography
standard	31	Formaldehyde	≦0.08mg/L	Gas chromatography
standard	35	Copper	≦1.0mg/L	simplified water inspection product
standard	38	Chloride ion	≦200mg/L	Titration method
standard	41	Anionic surfactant	≦0.2mg/L	Colorimeteric method
standard	45	Phenols	≦0.005mg/L	Colorimeteric method
standard	47	Phenols	5.8-8.6	pH meter
standard	48	Taste	not unusual	Sensory analysis
standard	49	Odour	not unusual	Sensory analysis
standard	50	Colour	5 degree	Colorimeteric method
standard	51	Turbidity	2 degree	turbidity meter
complementary	16	Residual chlorine	≧0.1mg/L	Colorimeteric method
		Conductivity	-	conductivity sensor
		Alkalinity	-	Titration method
		Ammonium nitrogen	-	Colorimeteric method
		Dissolved oxygen	-	Titration method
		Fluorescence stregth	-	Fluorospectro photometer

*standard : Drinking water quality standards parameters
** complementary : Drinking water quality complementary parameters

5.3 Future task

Analyzable parameters are limited in the mobile laboratory. Therefore, WQMC got small analyzers to load in mobile laboratory in 2018. By introducing small analyzers, analyzable parameters are significantly increased, but the ways to overcome the limits of power supply needs to be figured out. The sources of power supply in the mobile laboratory are a rechargeable battery for analysis that can be charged from commercial power supply and a generator using liquefied petroleum (LP) gas. The analyzers consuming large amounts of electric power should not be used together and water quality parameters to be analyzed must be selected before analysis based on the situations of spills.

6 Risk management using GIS (Geographic Information System)

6.1 What is GIS?

GIS (Geographic Information System) is a system that shows and analyzes information at various position and space using PC. GIS makes it possible to plot various information on maps which are easy to understand visually. Thus, GIS is utilized in a wide range of field such as disaster management, urban planning and business strategies of sale and advertisement.

WQMC introduced GIS from 2014, and works on organization and utilization of geographic information regarding tap water and source water. Utilizing GIS, information such as occurrences of spills, distribution of factories around water sources and river structures like bridges and sluice pipe can be organized easily on map.

6.2 Activity examples of GIS

6.2.1 Risk analysis of spills

WQMC utilizes GIS for assessment of apparent and potential risks in source water. The assessment of apparent risks means to analyze occurrence tendency of spills by plotting the locations of accidental spills in the past on a map. WQMC goes to the field investigation, takes water samples and analyzes the water quality at about 30 points of the Tone River, Edogawa River, Arakawa River and Tama River basins every month to monitor the situations of source water. These monitoring points were selected with reference to spills in the past, but new monitoring points were selected by reference to current situation in 2015.

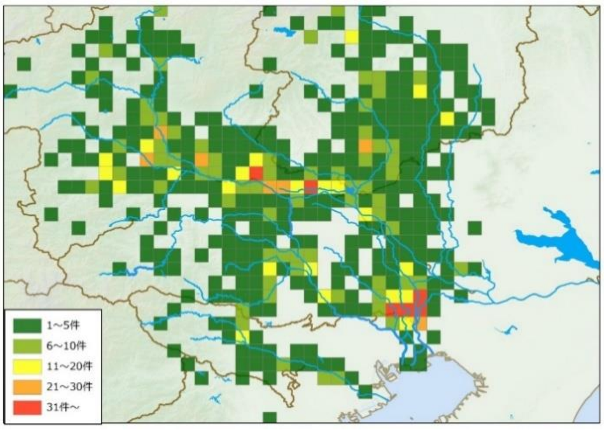

Figure 10. The distribution of spills occurrence points in 10 years[9]

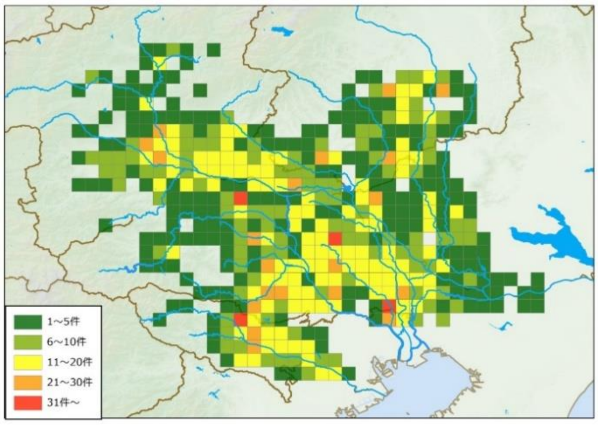

Figure 11. The distribution of PRTR registered factories[9]

Figure 10 shows recent occurrence trends of spills. First, occurrence points of spills in source water from 2006 to 2015 were plotted on map. Second, the map was cut off on 5km square and the number of spills were counted. This figure shows that there were many spills in middle basin of Tone River and Edogawa River. Specially, outflow of oil caused by traffic accident and breakdown and damage of machine is numerous.

On the other hand, Figure 11 shows the distribution of PRTR (Pollutant Release and Transfer Register) registered factories. PRTR registered factories around source water were plotted on map and the numbers of PRTR registered factories were made up each 5km square. Figure 11 shows that many PRTR registered factories are in east and south of Saitama Prefecture and in middle basin of Tama River. Figure 11 shows different characteristics from that of Figure 10; namely, there are points that have high potential risk though the number of spills is low. If the causes of spills are PRTR registered factories, finding causes is easy; but practically many causes are unknown. This is due to many small-scale spills. Conjecturing small-scale spills is limited by using only the existing database. Spills caused by PRTR registered factories have big impacts on water purification plants. Therefore, new monitoring points are selected based on Figures 10 and 11; and WQMC goes to the field investigation, takes water samples and analyzes the water samples every month now.

6.2.2 The management of tap water

GIS is also utilized to visualize each water purification plant's distribution area and management of residual chlorine concentration in the distribution network. Figure 12 shows the outline of distribution network in the 23 wards of Tokyo. Each area is colored based on the highest percentages of the distribution system and the blend ratios of waters from different systems are showed by the pie charts. The main pipes as a background are drawn based on the pipe data. This map is linked with Excel file; and by changing the blend ratio of the distribution systems in Excel file, the pie charts and color coding of the map reflect those changes automatically. Therefore, the map can be updated based on the water operation guideline at any time.

WQMC utilizes the GIS as a reference for management of residual chlorine concentration like changing concentration of replenishment chlorination.

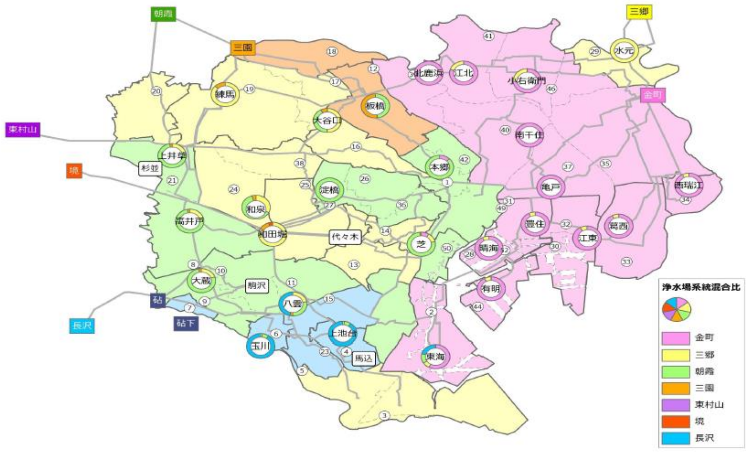

Figure 12. The outline of distribution system in 23 wards of Tokyo (April, 2020)

*Water stations that have the automatic water quality loggers the lower reaches show as pie chart and the other water stations show as square.

7. Future task

WQMC produced manuals of countermeasures for accidental spills and water quality problems of tap water. The manuals are regularly updated in accordance with the present condition. When spills happen, it is necessary to get analysis report rapidly and to come up with the next response. Therefore, simplified and rapid on-site analysis methods with the same precision as those of the official analysis methods are being developed. It is needed that risk analysis of source water is updated every few years and new monitoring points must be selected based on the results of water quality monitoring.

8. References

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[9] Tokyo Metropolitan Waterworks (2017) “Utilizing GIS for monitoring water quality”
[10] Tokyo Metropolitan Waterworks (2014) ”Optimization of source water utilizing GIS”

9. Appendix

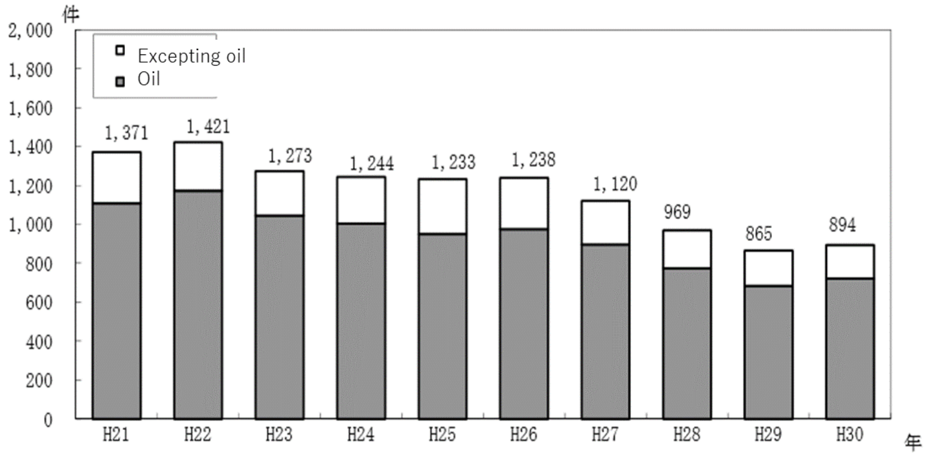

Figure 13. Time course of the number of accidental spills in class A river [1]

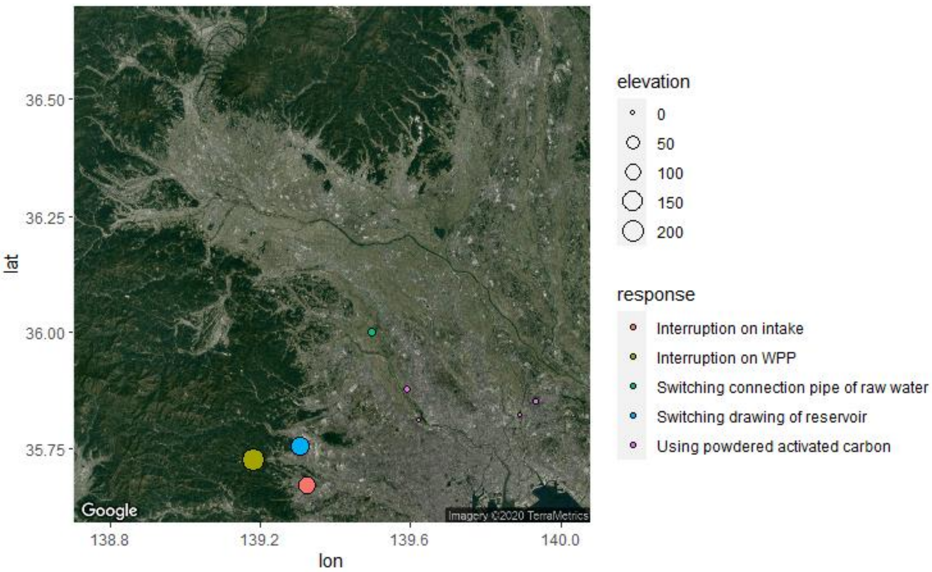

Figure 14. The distribution of spills occurrence points which caused supply interrupted in 4 years