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Drought Resilient Water Supply: Establishment of Groundwater Treatment Plant at Construction Sites in Taichung City

Shang-Hsin Ou, Yang-Chun Lin, Ke-Hao Cheng

***Abstract*—**The year 2021 marked a historic drought in Taiwan, posing unprecedented challenges due to record-low rainfall and inadequate reservoir storage. The central region experienced water scarcity, leading to the implementation of "Groundwater Utilization at Construction Sites" for drought-resilient livelihood water supply. This study focuses on the establishment process of temporary groundwater treatment plants at construction sites in Taichung City, serving as a reference for future emergency response and the utilization of construction site groundwater. To identify suitable sites for groundwater reuse projects, site selection operations were carried out based on relevant water quality regulations and assessment principles. Subsequently, the planning and design of temporary water treatment plants were conducted, considering the water quality, quantity, and on-site conditions of groundwater wells associated with construction projects. The study consolidates the major water treatment facilities at each site and addresses encountered challenges during the establishment process. Practical insights gained from operating temporary groundwater treatment plants are presented, including improvements related to stable water quality, water quantity, equipment operation, and hydraulic control. In light of possible future droughts, this study provides an outlook and recommendations to expedite and improve the setup of groundwater treatment plants at construction sites. This includes considering on-site water abstraction, treatment, and distribution conditions. The study aims to provide concise guidelines for setting up and managing temporary groundwater treatment plants at construction sites, drawing insights from Taichung City's establishment process. It offers recommendations for addressing challenges like water quality, quantity, equipment operation, and regulation compliance. By sharing these insights, it aims to aid regions facing similar emergencies, ensuring sustainable water supply and societal stability amidst water shortages and droughts.

***Keywords*—**Drought resilience, groundwater treatment, construction site, water supply.

I. Introduction

SEVERE drought conditions in Taiwan during the 2020 rainy season, combined with the absence of typhoons, led to inadequate rainfall in major reservoirs. Water storage levels significantly declined and could only be partially replenished by summer showers. This resulted in water supply reductions, restrictions, suspension of farming activities, and business closures across different regions, making it the worst drought since 1947. The Ministry of Economic Affairs implemented proactive measures to enhance water management and expedite relevant water resource projects. Groundwater from construction sites became crucial for drought mitigation, but challenges such as groundwater stability, coordination with construction schedules, water quality compliance, integration with the water supply network, and effective regulation posed difficulties. Engineers and operational managers at the Taiwan Water Corporation (TWC) faced the task of addressing these issues and coordinating with various stakeholders.

During the development process of construction sites, the extraction of groundwater to balance the foundation poses a common challenge [1]. The treatment methods for extracted groundwater vary among countries, but there are similarities. In advanced countries such as Australia, the United States, the United Kingdom, and Germany, the extracted groundwater is typically discharged into the sewer system, used for replenishing groundwater or surface water bodies, and sometimes utilized for irrigation, dust suppression, or washing purposes [2]-[5]. Due to stringent drinking water quality standards and cost considerations, it is generally not considered as a drinking water source [6], [7]. Table I summarizes the international practices for the reuse of construction site groundwater:

TABLE I
International Practices for Reuse of Construction Site Groundwater

Country	City/State	Reuse Methods
United States	Palo Alto	Discharged into storm water drains, irrigation, washing
United States	Florida	Agricultural irrigation, washing, replenishment of surface water bodies, sewer or off-site treatment
Australia	New South Wales	Concrete production, washing, tunneling water supply, irrigation, stone washing, toilet flushing
Australia	Western Australia	Replenishment of groundwater, discharge into sewer systems, evaporation, washing, cooling water, irrigation
Germany	Berlin	Injection into sewer systems, groundwater replenishment, surface water replenishment
United Kingdom	-	Discharge into sewers, reservoirs, surface water bodies, groundwater replenishment, evaporation
Qatar	-	Discharge into the sea, lagoons, groundwater replenishment, surface water supplementation, dust suppression

II. Risk Assessment

The risk assessment aimed to ensure the safety of groundwater for domestic water supply at building sites during the drought period. The assessment followed four key principles:

Shang-Hsin Ou is with the Taiwan Water Corporation, Taichung City 404403, Taiwan (R.O.C.) (e-mail: shou24@mail.water.gov.tw).

A. Comprehensive Water Quality Testing and Prioritized Usage

The first principle of the risk assessment focused on comprehensive water quality testing and prioritizing its usage. Starting from the mid-term of the 2019 drought, the TWC evaluated groundwater quality at new building sites in Taichung City. Testing involved the parameters, such as drinking water standards, turbidity, pH, iron, manganese, and conductivity. This assessment aimed to ensure a reliable and safe water supply during the drought by prioritizing groundwater from selected sites.

1. *Avoidance of potential sources of contamination:* Assessing potential contamination sources, like nearby gas stations, was crucial to prevent water quality hazards at building sites, as groundwater quality is susceptible to surrounding environmental influences.
2. *Appropriate water treatment:* The recommended water treatment process for groundwater is similar to that used in typical groundwater treatment plants. The process involves rapid filtration to remove turbidity, and if necessary, dual-media filters such as activated carbon are used. Additionally, sodium hypochlorite disinfection is employed to eliminate biological contaminants.
3. *Robust water quality monitoring:* To ensure the supply of safe domestic water from building site groundwater, each project established real-time water quality monitoring stations. These monitoring stations incorporated 24-hour automated water quality monitoring equipment, biological monitoring, and manual inspections to ensure the safety of water quality.

III. Drought Response Strategies and Action Plans

A. Method of Site Assessment

The Ministry of Economic Affairs, recognizing the urgency of the water situation, issued directives to implement the "Groundwater Utilization in Construction Sites" policy. In response, TWC expeditiously conducted site selection assessments. The site assessment procedure comprised essential steps: (1) avoiding areas susceptible to subsidence, (2) scrutinizing the registry of construction sites approved for groundwater utilization by local authorities, and (3) verifying site particulars, including location, well count, projected pumping volume, motor specifications, pumping cessation schedule, and contact information of the construction site supervisor. Further details regarding the implementation process can be found in Table II.

The overall operation process is shown in Fig. 1. When the groundwater quality does not meet drinking water standards or when the water quality meets the requirements but the site conditions are not favorable for integration into the tap water supply system, the local government plans the secondary use of water from construction site wells based on the environmental conditions and water quality test results. If necessary, they provide assistance and support in using Q-Water treatment equipment for secondary water supply to the public, municipal services (such as fire trucks, sprinkler trucks), and water supply for businesses.

TABLE II
The Site Assessment Procedure of Temporary Groundwater Treatment Plants

Item	Description
Groundwater extraction points	• Select extraction points near the main water distribution pipeline. • Ensure sufficient space (approximately 10 m x 30 m) for water treatment equipment installation. • Consider sites with appropriate drainage channels or sewage pipelines for emergency drainage and wastewater disposal.
Water quality testing	• Conduct comprehensive groundwater sampling and testing. • Ensure adherence to drinking water quality standards and exclude biological contaminants. • Prioritize sites with superior water quality characteristics.
Water quantity verification	• Use on-site ultrasonic flow meters to measure the actual water yield of each well. • Ensure a minimum water quantity of at least 4,000 cubic meters per day to provide substantial drought support.
On-site inspection	• Coordinate a site visit with relevant authorities, including the Urban Development Bureau, Environmental Protection Bureau, Transportation Bureau, and local representatives. • Confirm the location and setup of water treatment equipment. • Obtain necessary permission for emergency excavation of water pipelines. • Estimate the procurement of temporary water treatment equipment.

B. Result of Site Assessment

In March 2021, there were a total of 52 newly registered construction projects in Taichung City. Due to the presence of abundant groundwater in the gravel layer of Taichung's urban area, these construction sites require dewatering through pumping wells during excavation to lower the groundwater table for foundation construction.

After screening the 52 extraction points based on administrative divisions, 18 sites were selected. Further screening was conducted based on criteria such as the scale of groundwater pumping, proximity to potential sources of pollution such as gas stations, and proximity to water supply pipelines. Subsequently, water quality testing was performed on 15 parameters including drinking water standards, turbidity, pH, iron, manganese, and conductivity. This led to the identification of sites that met the drinking water quality standards.

Following the assessment of water quality and quantity, a total of 10 construction sites were selected for the establishment of temporary water treatment facilities. These sites underwent testing based on drinking water quality standards and water quantity measurement.

C. Temporary Groundwater Treatment Process in Construction Sites

Based on the selection of construction sites with good groundwater quality, the water treatment process only requires the installation of rapid filtration, chemical dosing, and pressurization equipment. These are accompanied by the water quality monitoring system, which includes 24-hour automated water quality monitoring equipment, biological monitoring equipment, and manual inspections. Furthermore, in accordance with the expert consultation meeting and recommendations from the Environmental Protection

Administration on the suitability of utilizing underground water in construction sites in Taichung held on April 7, 2021, the treated water that meets the drinking water quality standards is introduced into the water supply network for household consumption. The treatment process is illustrated in Fig. 2.

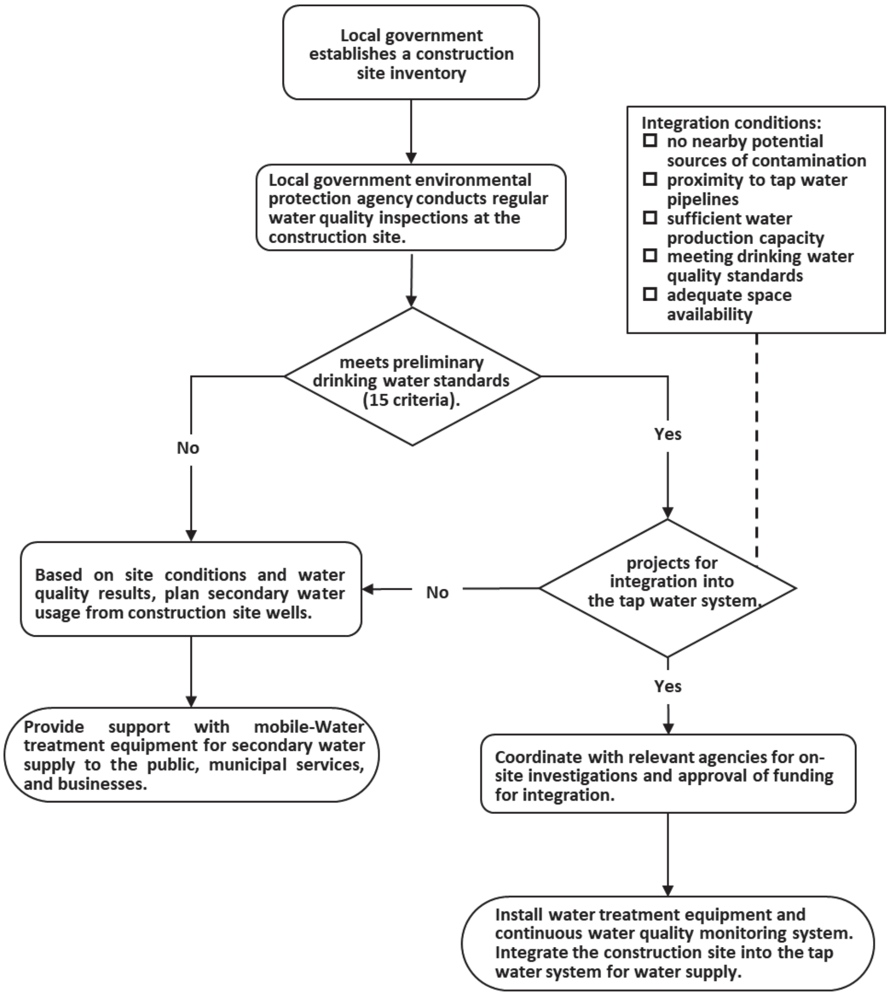

Fig. 1 The overall operation process of groundwater utilization in construction sites

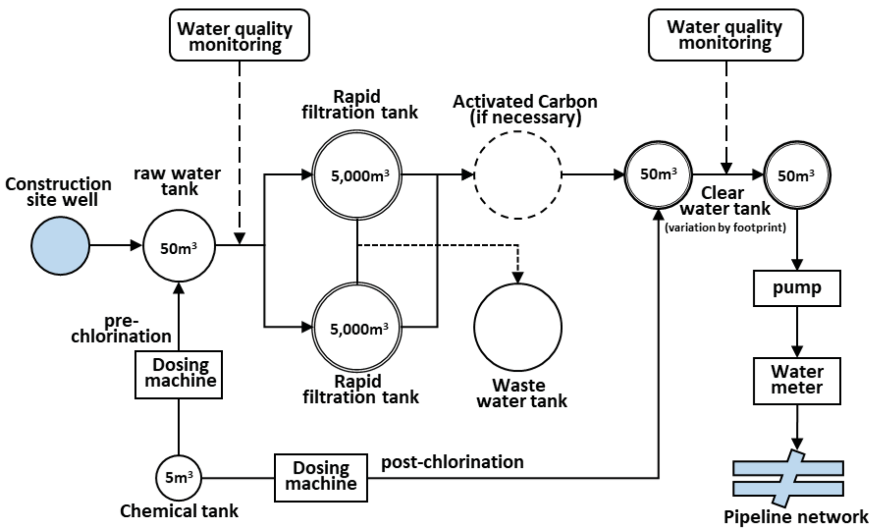

Fig. 2 Temporary Groundwater Treatment Process

This study implemented groundwater purification and water supply systems in 9 different sites with 10 construction projects. The engineering components included installing new raw water pipelines, introducing water treatment equipment (primarily rapid filtration tanks), setting up storage tanks, implementing pressurization and monitoring systems, establishing on-site pipelines and controls, arranging electrical distribution, managing construction fencing and traffic, and operating temporary wastewater treatment facilities.

The configuration of the water treatment equipment was determined based on the pumping volume of each construction site's groundwater wells. The main equipment and the corresponding designed water output are summarized in Table III. For example, at the Site A~C and Site H~J construction sites, temporary water treatment equipment was placed in nearby parking lots and surrounding roads. Configuration diagrams can be found in Fig. 3.

TABLE III
SUMMARY TABLE OF ENGINEERING EQUIPMENT FOR EMERGENCY TREATMENT OF GROUNDWATER UTILIZATION IN CONSTRUCTION SITES

	Construction Site	Rapid Filtration System				Raw water/ Distribution Water Tank		Pump		Design Capacity (CMD)
		Type/ Material	Capacity (CMD)	Filter	Amount	Capacity (m^3)	Amount	Hp	Amount	
1	Site A	PSF (FRP)	3,000	Silica sand	2	30	7	40HP	3	10,500
2	Site B	PSF (SUS)	2,500 5,000	PP fiber	3 2	50	10	30HP	4	20,000
3	Site C	PSF (FRP)	5,000	Silica sand	4	30	6	60HP	2	17,500
4	Site D	PSF (SUS)	1,920 2,880	Activated Carbon Quartz sand	4 1	30	8	60HP	4	10,000
5	Site E	PSF (SUS)	1,920 2,520	Activated Carbon Quartz sand	4 1	30	8	60HP	4	10,000
6	Site F	GSF (SUS)	2,500	Activated Carbon Quartz sand	2	30	3	25HP	2	5000
7	Site G	PSF (SUS)	2,500	PP fiber	3	50	5	30HP	2	10,000
8	Site H	PSF (SUS)	1,920 2,520	Activated Carbon Quartz sand	2 1	30	6	40HP	4	6,000
9	Site I	PSF (FRP)	5,000	Silica sand	1	30	4	40HP 30HP	2 2	4,000
10	Site J	PSF (SUS)	2,640	Manganese sand, Quartz sand	2	50	4	20HP	2	5,000

PSF, Pressure Sand Filter; GSF, Gravity Sand Filter; SUS, Stainless Steel; FRP, Fiber-reinforced plastic.

During the early stages of the drought response, simultaneous field investigations were conducted on existing wastewater treatment plants and water resource recovery centers that utilize rapid filtration systems to assess their feasibility for water supply. However, due to factors such as the original design for wastewater use, inability to meet drinking water standards, and potential perceptual issues associated with the use of these facilities for sewage treatment, short-term emergency needs were considered. Therefore, the use of new rapid filtration systems, existing sand filters for treating tap water, or single-vendor package solutions were the primary options considered.

Site A was the first temporary water treatment plant established, utilizing existing sand filtration units (3 units with a capacity of 1,500CMD) from the Water Resources Agency and existing rapid filtration systems (2 units with a capacity of 3000 CMD) from TWC's Penghu Desalination Plant. Site B's rapid filtration equipment consisted of rapid filtration systems from TWC's District 8 (2 units with a capacity of 5,000CMD) and new rapid filtration systems (3 units with a capacity of 2,500CMD) from Taoyuan Airport. For the remaining sites, procurement of new equipment was carried out according to the project schedule.

D.Installation and Operation of Emergency Water Treatment Systems and Water Quality Monitoring

During the installation process of emergency water treatment equipment, the majority of the sites were able to complete the setup of tanks and basins within approximately 7 to 10 days. The on-site construction, including the installation of external pipelines and mechanical and electrical equipment, could be completed within 11 to 15 days. Most sites were equipped with two or more rapid filtration systems, allowing for sequential water production after conducting independent water testing. Stable operation and water supply could be achieved within approximately 15 to 25 days.

Water quality was continuously monitored through a 24-hour automated water quality monitoring system, biological monitoring, and daily manual inspections of key parameters (Fig. 4). The water quality monitoring data are uploaded in real-time to both the TWC's website platform and individual mobile devices, enabling continuous access to the data. Additionally, weekly testing for fecal coliform bacteria and total colony count was conducted by the Water Quality Division of the respective district. The water quality testing results, not shown, demonstrated that the water supplied from each site was of good quality. The turbidity remained below 0.5 NTU, residual chlorine was controlled within the range of 0.3 to 0.7 mg/L, and the pH level was maintained between 6.5 and 7.5. Furthermore, other tested parameters such as heavy metals, volatile organic compounds, pesticides, and disinfection by-products were all significantly below the drinking water quality standards.

To ensure water quality safety during operations, a Standard Operating Procedure (SOP) for monitoring and managing groundwater quality in construction sites has been established. This SOP, as illustrated in Fig. 5, serves as a reference guideline for on-site water supply quality assessment and provides necessary measures to address any water quality abnormalities, thereby maintaining the stability of drinking water quality.

Fig. 3 Temporary Groundwater Treatment Project configuration

E. Challenges and Anomalies Encountered in the Operation of Temporary Water Treatment Plants

This research investigates various significant challenges faced during the operation of temporary water treatment facilities. One significant challenge involves obtaining approval from local government authorities to discharge wastewater from these facilities into the city's drainage system during emergencies, aiming to safeguard the public water supply. Another challenge is securing land consent and negotiating lease fees from private parking areas for setting up temporary water treatment facilities, often requiring coordination with local government entities. Additionally, noise reduction measures must be implemented to address potential noise issues caused by equipment operation near residential areas. Ensuring a stable power supply is also a priority, involving requesting electricity from power companies and considering backup power generation options.

Fig. 4 (a) Real-time water quality monitoring station; (b) Online water quality monitoring instrument

Fig. 6 illustrates the water production status of temporary water treatment facilities at various construction sites. The early termination of operation for each facility is primarily determined by the lease period of the site. The decrease in water production is mainly influenced by changes in groundwater turbidity due to heavy rainfall, while minor factors include maintenance of the pumping equipment.

Moreover, managing water distribution among multiple groundwater wells in construction site dewatering systems is essential for balancing industrial water needs during water scarcity periods. Operational assistance fees and electricity charges need to be paid to construction companies for their involvement in operating the dewatering systems. Lastly, abnormal climatic events, such as earthquakes or heavy rainfall, can impact groundwater quality, necessitating adjustments in filtration speeds and water production rates. By addressing these challenges, the effective operation of temporary water treatment facilities can be ensured, promoting sustainable construction practices while meeting water supply demands. The key points related to these challenges are summarized as Table IV. It helps to understand the critical factors involved in planning, operating, and managing these facilities effectively.

IV. Cost Analysis and Water Supply Strategies for Temporary Water Treatment Facilities

Due to the urgency of the drought relief project, the cost of establishing temporary water treatment facilities includes expenses related to the purification process, as well as operational fees for newly installed wastewater treatment equipment and site rental fees. As a result, the cost-effectiveness and designed water production capacity of the construction sites exhibit significant variations. However, there is a slight negative correlation between the overall construction costs and the water production capacity (as shown in Fig. 7).

The cost-benefit analysis of the construction sites indicates a range of USD$1.27 to $3.14 per ton, with an average construction benefit of approximately USD$1.92 per ton. Notably, certain operational and maintenance costs of the dewatering system and pumping equipment are borne by the construction sites. Considering a calculation based on a construction benefit of approximately 10% to 15%, the estimated groundwater production cost for the construction sites ranges from USD$2.07 to $2.23 per ton, which is more than six times higher than the current average water production cost of USD$0.37 per ton in conventional systems.

During the drought period, the Water Resources Agency gradually reduces the raw water (reservoir water) supply from the water treatment plants based on the groundwater supply from the construction sites in each phase. This measure aims to extend the operational period of reservoirs and includes the daily importation of approximately 100,000 tons of water into the existing water distribution network. Considering the average water supply of the Taichung area in 2019, which amounted to approximately 1.342 million CMD, this imported water accounts for approximately 7.45% of the total supply. This strategy effectively alleviates the water supply pressure during the drought period.

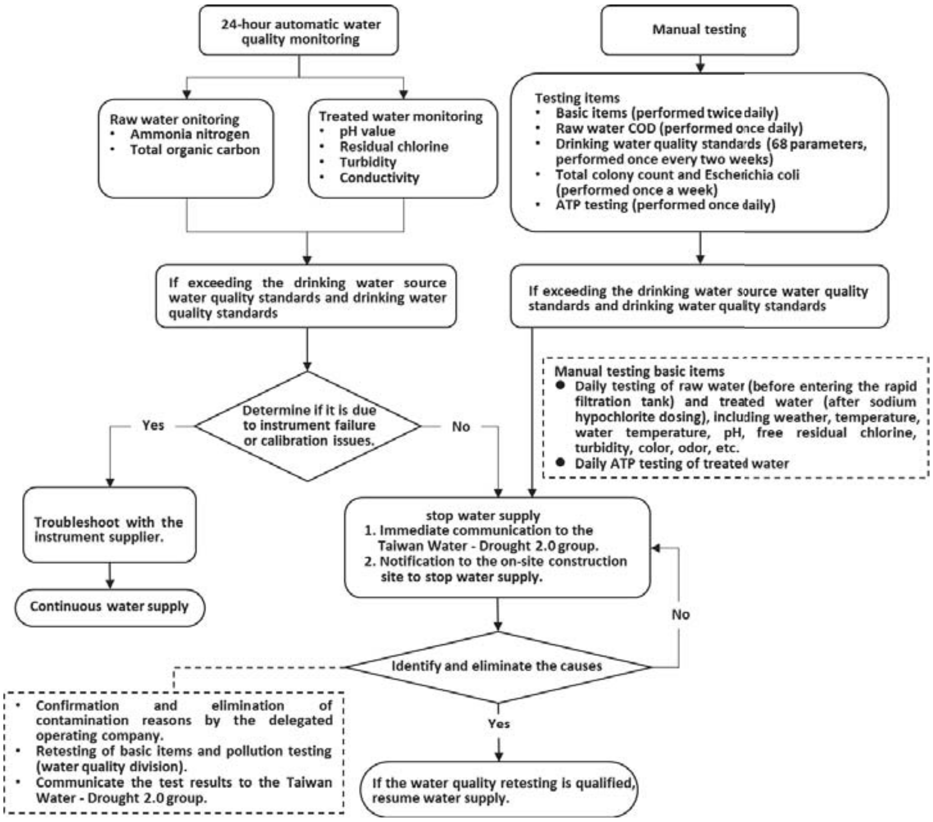

Fig. 5 SOP for Groundwater Quality Monitoring and Management in Construction Sites

TABLE IV
CHALLENGES & CONSIDERATIONS FOR TEMPORARY WATER TREATMENT FACILITIES

Category	Subcategory	Description
Regulatory Challenges	Compliance during Emergencies	Adhering to water supply regulations in emergencies.
	Wastewater Discharge Approval	Obtaining approval for wastewater discharge.
	Environmental Standards	Ensuring compliance with environmental regulations.
Planning Considerations	Land Consent & Lease	Securing land consent and lease agreements.
	Coordination with Authorities	Collaborating with local authorities for land acquisition.
	Facility Integration	Integrating facilities within construction sites.
Operational Issues	Noise Mitigation	Addressing noise concerns near residential areas.
	Stable Power Supply	Ensuring stable power supply and backups.
	Water Distribution	Managing water distribution among multiple wells.
	Responsibilities & Agreements	Defining operational responsibilities and agreements.
Management and Adaptation	Monitoring & Compliance	Ensuring compliance and monitoring performance.
	Adjusting Extraction	Modifying extraction based on groundwater quality.
	Adaptation to Climate Events	Adapting to abnormal climatic events.
	Continuous Improvement	Seeking improvement and learning from experiences.

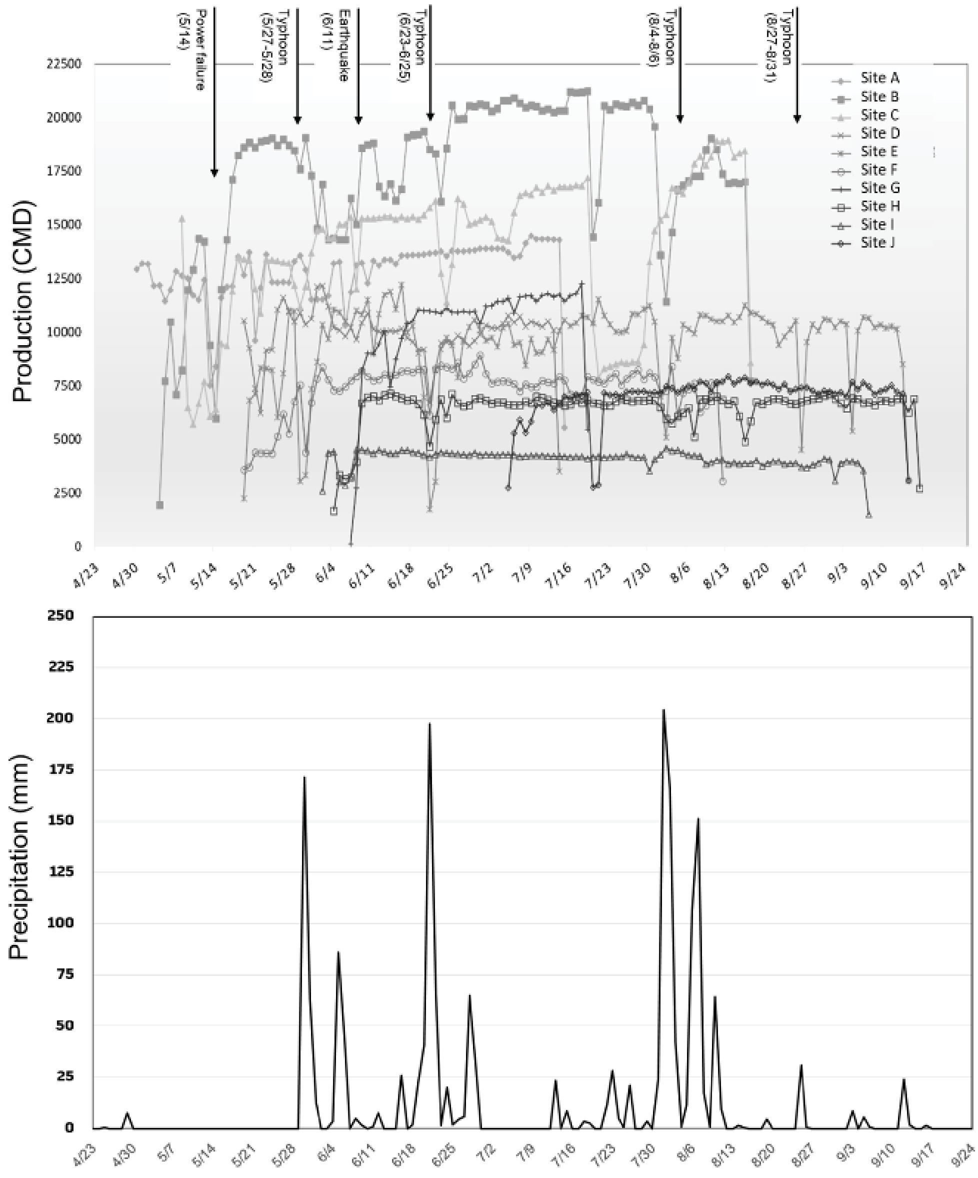

Fig. 6 Water Production Status of Temporary Water Treatment Facilities at Construction Sites

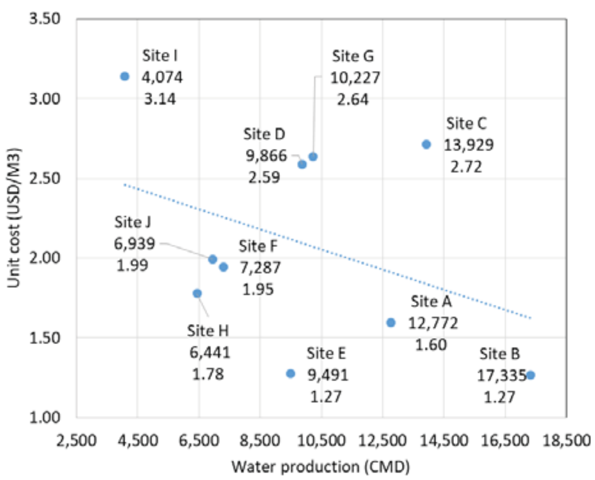

Fig. 7 The analysis of actual water production and benefits of emergency water treatment facilities at construction sites

V. Conclusion and Recommendation

A. Conclusion

This study focused on the establishment process of temporary groundwater treatment plants at construction sites in Taichung City, aiming to provide insights and recommendations for future emergency response and the utilization of construction site groundwater.

Site selection operations were conducted based on relevant water quality regulations and assessment principles to identify suitable sites for groundwater reuse projects. Subsequently, the planning and design of temporary water treatment plants were carried out, considering factors such as water quality, quantity, and on-site conditions of groundwater wells associated with construction projects.

Practical insights gained from operating temporary groundwater treatment plants were presented, including improvements related to stable water quality, water quantity, equipment operation, and hydraulic control.

Furthermore, considering the potential occurrence of future droughts, this study offers an outlook and recommendations for expediting and enhancing the establishment of groundwater treatment plants at construction sites, taking into account on-site water abstraction, treatment, and distribution conditions.

By presenting the outcomes of this study, we aim to provide practical guidelines for the establishment and management of groundwater treatment plants. Moreover, the experiences and recommendations provided can be valuable for other regions facing similar emergencies, water shortages, and drought situations.

While groundwater from construction sites plays a crucial role in drought mitigation, challenges such as groundwater stability, coordination with construction schedules, water quality compliance, integration with the water supply network, and effective regulation have posed difficulties.

B. Recommendation

In collaboration with the government's efforts to build resilience against drought, TWC has implemented the utilization of groundwater from construction sites and available surrounding space by establishing large-scale rapid sand filtration water treatment facilities. The purpose of this initiative is to increase additional water sources and provide stable tap water to Taichung City at the lowest cost and highest efficiency. However, the geographical locations and characteristics of groundwater sources vary across different construction sites. In the future, pre-designed modular water treatment facilities of varying scales and configurations can be developed based on the specific limitations and conditions of each construction site, thereby reducing the planning period for drought relief projects. The experience gained from establishing construction site groundwater treatment facilities can also serve as a contingency plan for future drought situations.

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