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MANAGED AQUIFER RECHARGE FEASIBILITY USING WEIGHT FACTOR INDEX METHOD IN SUPHANBURI, THAILAND

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ABSTRACT: Managed Aquifer Recharge (MAR) is a technique used to intentionally enhance groundwater recharge by directing surface water or treated wastewater into underground aquifers. MAR offers several advantages for sustainable water resources management and ecosystems, namely, groundwater replenishment, drought resilience, and flood protection. Suphanburi Thailand faced challenges related to both floods and droughts because of variable rainfall patterns and hydrological conditions. Then, MAR is a good challenge for flood control and drought protection. This research aims to develop the model and find the optimal location and recharge type for set-managed aquifer recharge in Suphanburi, Thailand. Data, such as climate, land used, hydrology, and hydrogeology were carried out and provided the optional location to construct MAR. The model was developed using the Weight Factor Index Method. The results revealed that the suitable location for MAR was in the Tha Chin River area, due to the high rainfall, which allows for the storage of large quantities of water during the rainy season in the MAR in the event of groundwater shortages. Proper recharge of the river can dilute contaminants in groundwater and improve groundwater quality. The findings provided valuable guidelines for planners, decision-makers, and hydrogeologists in designing future artificial recharge projects within a similar area, ensuring a reliable water supply and the sustainable use of groundwater over the long term. In conclusion, the integration of WFI and GIS is recognized as an effective method for limited data, and location, and reducing errors.

Keywords: Managed Aquifer Recharge Feasibility, Flood and Drought Solving, Weight Factor Index Method, Optimal Location

1. INTRODUCTION

Water scarcity is a critical issue in many regions, necessitating innovative solutions for sustainable water management. Managed Aquifer Recharge (MAR) emerged as a promising technique to enhance groundwater resources by intentionally infiltrating surface water into aquifers [1]. MAR involves intentional recharge of water to aquifers for subsequent recovery or environmental benefit and is implemented using various techniques such as spreading basins, infiltration galleries, injection wells, and recharge ponds [2]. MAR helped mitigate the impacts of over-extraction, counteract subsidence, and maintain baseflows in rivers and streams. It also served as a strategic approach to storing excess surface water during periods of surplus for use during droughts or peak demand periods. Additionally, MAR enhanced the resilience of water supply systems against climate variability and change [3].

Recently, the application of MAR has been notably successful in many regions, for example, Ulibarri et al. assessed the feasibility of MAR [4] and Scanlon et al. used the MAR to enhance drought resilience in California [5]. Page et al. and Li et al. reclaimed wastewater using MAR for agriculture areas [6, 7]. Moreno et al., Ganot et al., Brunner et al. and Ayala et al. also applied MAR for water sustainability [8-11]. These MAR projects replenished overdrawn aquifers and enhanced water security, employing techniques such as floodwater spreading, dedicated recharge basins, and the use of retired agricultural lands for water infiltration. These efforts stabilized groundwater levels and improved water quality by reducing concentrations of nitrates and other contaminants [12].

Despite the progress made, there remains a critical gap in our understanding of the optimal locations for MAR. For example, Mohammed et al. integrated multiple criteria decision making and weighted linear combination methods to determine the identify suitable zone for groundwater recharge in Iraq and found that the granular provide a good and very good zone for MAR [13]. Dina et al. provided the index factors using geoinformatics system based on water balance and regulation GIS to delineate potential recharge zones in Indonesia and results confirmed that the hydrological expectations contributed to the recharge and discharge zone for MAR [14]. Therefore, this study aims to address this gap by providing a thorough analysis using conceptual and numerical hydrogeological modeling through the Weight Factor Index (WFI) method, particularly in other areas like Suphanburi, Thailand.

The integration of WFI and GIS provided a powerful capability for spatial analysis and mapping, the WFI method produced detailed and informative hazard assessments. GIS-enabled the integration, management, and analysis of spatial data, facilitating the identification of patterns and relationships.

Together, these tools enable a comprehensive evaluation of MAR feasibility, considering both the physical characteristics of the aquifer system and the spatial distribution of potential recharge areas. This integrated approach ensures that the site selection for MAR is scientifically sound and practically viable, enhancing the reliability of the study's outcomes.

The success of MAR projects depends on a thorough understanding of the hydrogeological conditions, appropriate site selection, and careful management to avoid issues such as water quality degradation and ecological disturbances. Thus, MAR represents a vital component of integrated water resource management, offering a sustainable solution to the growing challenges of water scarcity and variability [12].

2. RESEARCH SIGNIFICANCE

The significance of this research was to address critical water management challenges in Suphanburi, Thailand, by leveraging MAR to mitigate both flood and drought conditions. Traditional flood mitigation infrastructure is costly and may not provide comprehensive solutions for both flooding and drought. Also implementing MAR offers a dual benefit: it can effectively manage excess water during heavy rainfall periods, reduce the risk of floods, and store water underground for use during dry periods, enhancing drought resilience. This research identifies the optimal locations to maximize the benefits of MAR in Suphanburi. The findings support the notion that MAR is a cost-effective and sustainable approach to integrated water resource management in areas facing similar hydrological challenges.

3. DATA COLLECTION AND METHODS

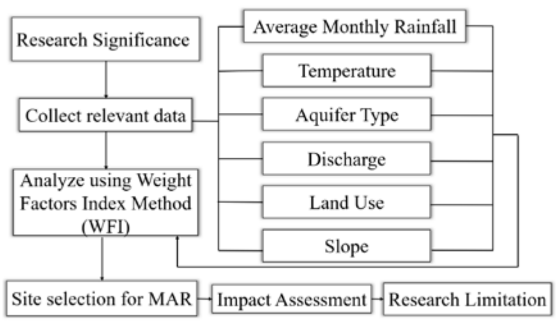

Fig. 1 Flowchart of the research

The flowchart is shown in Fig. 1. The data were collected from the Thailand Royal Survey Department, Thailand Land Development Department, Thailand Department of Groundwater Resources, and Local Government Agency. The data was identified as the criteria for the MAR. The WFI method was used to analyze the optimal location for installing MAR. It was necessary to determine the weights and scores of each factor. In this study, the factors of the MAR were recharge and discharge zone rainfall, temperature, soil and terrain slope, and land use after the WFI method was used for rating and weighting and was analyzed in the selected site location. Then, the highest score was the optimal site location to install the MAR.

3.1 Study Area

Suphanburi locates in the central part of Thailand, approximately 100 km northwest of Bangkok (Capital City of Thailand). Suphanburi covers an area of about 5,360 km2 and is predominantly flat. Most of Suphanburi is between 2 m – 200 m above sea level, with the overall altitude below 50 m. The topography is characterized by extensive floodplains and alluvial deposits, making it highly suitable for agriculture.

The Tha Chin River, a major water source, flows through the province, playing an important role in its irrigation and water supply systems. The selection of five sites—Suphanburi City Center, U Thong Agricultural Area, Pho Phraya Industrial Zone, Tha Chin River, and Dan Chang District—ensures comprehensive and accurate data collection for MAR in Suphanburi. Each site represents distinct land uses and hydrogeological conditions, providing a diverse range of data.

Figure 2 illustrates the location of these five selection sites. In residential areas like Suphanburi City Center, recharge involves using treated surface or reclaimed water injected into aquifers through wells, which helps meet domestic water needs and maintain groundwater levels. The U Thong Agricultural Area utilizes surface water for irrigation, naturally recharging groundwater through soil infiltration, a cost-effective method that supports agricultural activities. The Tha Chin River benefits from constructed wetlands or riverbed modifications to enhance natural infiltration, maintaining river ecosystem health. In the Pho Phraya Industrial Zone, treated industrial wastewater is recharged into aquifers, reducing surface water use and replenishing groundwater. Lastly, the Dan Chang District at higher altitudes uses rainwater harvesting and small reservoirs for groundwater recharge, considering topographical and climatic factors. By selecting diverse monitoring sites, the study captures a broad spectrum of geological, hydrological, and land use conditions, addressing various water management needs and challenges specific to each area. This approach facilitates the development of tailored MAR strategies that are scientifically sound and practically viable, enhancing the sustainability of water resources in Suphanburi. Understanding geographic information and elevation across these regions aids effectively planning MAR projects to combat water scarcity and promote sustainable development.

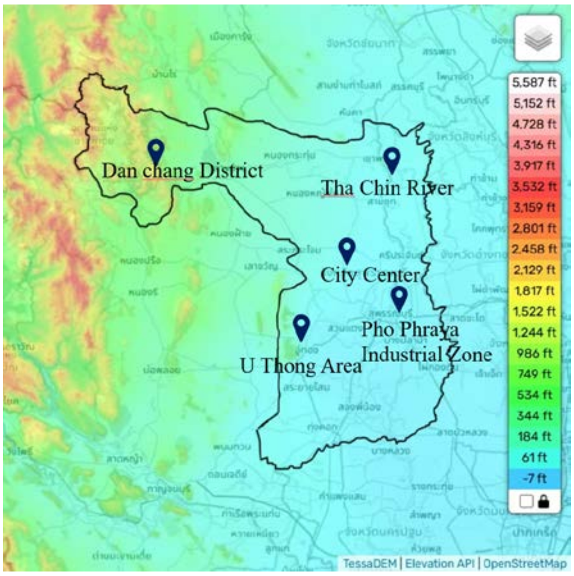

Fig. 2 Five selection sites in Suphanburi

3.2 Geological and Hydrogeological Data

Geology is dominated by Quaternary alluvial deposits, which are primarily composed of clay, silt, sand, and gravel. These deposits were laid down by the extensive river systems that traverse the central plains. The underlying bedrock is generally composed of older sedimentary rocks, including sandstone and shale, from the Mesozoic era. The alluvial deposits create a fertile soil layer that supports the province's agricultural productivity.

Hydrogeology is characterized by a complex system of shallow and deep aquifers. The shallow aquifers are mainly unconfined and consist of permeable alluvial deposits, making them easily recharged by surface water. However, they are also more susceptible to contamination. The deeper aquifers are typically confined or semi-confined, with greater storage capacity and slower recharge rates. These aquifers are crucial for the region's water supply, especially during the dry season.

3.3 Climate

Suphanburi is in a tropical climate, which is typical of central Thailand. Figure 3 shows the average annual rainfall in Suphanburi from 1,100 to 1,300 mm from 2005 to 2022 [18]. The heavy rainfall typically occurs in September and October. During the dry season, rainfall is sparse, leading to potential water scarcity issues for agriculture and domestic use. This variability in rainfall underscores the need for effective water management strategies, such as MAR, to ensure water availability throughout the year. The average annual temperature in Suphanburi ranged from 26°C to 30°C. The hottest month is typically April, with temperatures often exceeding 35°C. During the cooler months of December and January, temperatures can drop to around 20°C. The high temperatures during the dry season contribute to increased evaporation rates, further exacerbating water scarcity. In response to this phenomenon, MAR can provide a variety of solutions that can help alleviate water scarcity and guarantee the sustainable use of water resources.

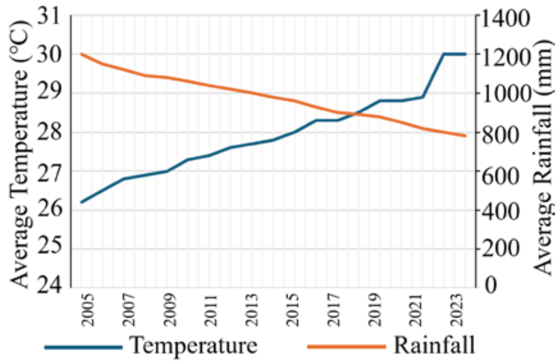

Fig. 3 Average temperature and annual rainfall in Suphanburi

3.4 Land Use

Figure 4 shows that most of the land used in Suphanburi was agricultural land, approximately 70% of the total area. This consists of rice paddies and other crops like sugarcane and maize. It significantly contributes to groundwater recharge through the percolation of irrigation water. Implementing MAR in this area can help sustain groundwater levels by replenishing aquifers during the rainy season. Urban and built-up areas account for around 15% of Suphanburi, posing challenges for MAR due to impervious surfaces that reduce natural infiltration and increase surface runoff. These areas offer opportunities for MAR such as recharging wells and permeable pavements to enhance inject rainfall and manage stormwater. Forested and natural vegetation areas, which cover approx. 10%, naturally supports MAR by promoting infiltration and reducing surface runoff. Water bodies, including rivers, canals, and reservoirs, make up about 5%. They provide direct sources of water for recharge.

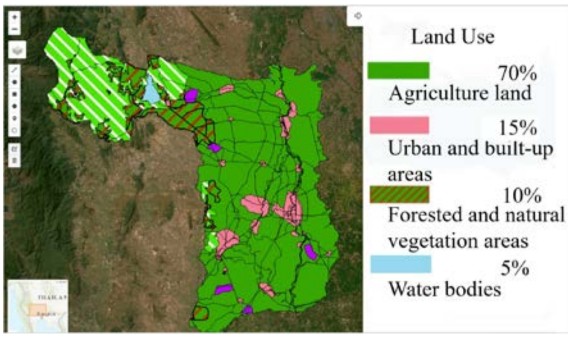

Fig. 4 Land use in Suphanburi

3.5 Historical Flood and Drought

Historical floods and droughts provided information on the frequency and intensity of extreme weather events [19]. By analyzing these records, it is possible to select the optimal timing and location of replenishment and to avoid replenishment during floods or droughts to improve replenishment efficiency and safety.

Figure 5 showed that the river flood risk in Suphanburi was categorized as high, and low risk in Dan Chang District and medium risk in Nong Yasai. The urban flood risk of Suphanburi was high, especially in Sam Chuk, Muang Suphanburi, and Bang Plama. This means that potentially destructive and life-threatening river floods will occur at least once in the next 10 years [15].

Suphanburi experienced several significant flood events in recent years. For instance, in June 2024, Suphanburi experienced flooding due to overflow from the Krasiao Reservoir again, leading to the submergence of several low-lying areas along the Tha Chin River. The continuous heavy rain and excess water from the dam spillways exacerbated the situation. Additionally, in October 2021, the province faced severe flooding described as the worst in a decade. This flooding was caused by heavy rains, water discharges from the Chao Phraya Dam in Chainat, and runoff from the Krasiao Reservoir [16]. The overflow from the Krasiao Reservoir led to the Tha Chin River flooding, affecting nearly 70,000 people in ten districts and causing rapid inundation that caught many residents off guard. In addition, in 2017, a wastewater flood from an ethanol factory in the Dan Chang District of Suphanburi caused environmental and health issues. The overflow of wastewater reservoirs at the plant led to the destruction of crops and harm to the health of over 590 families from 35 villages [17].

Historical flood records revealed potential contamination risks during floods. When designing and operating recharge systems, measures can be taken to prevent contaminants from entering underground aquifers during floods and to ensure safe recharge water quality.

Suphaburi also faced the drought experience. Thailand Drought Explorer reported that Suphanburi typically experienced a dry season from November to April, characterized by low rainfall and high temperatures. This period is particularly severe in the northwestern region of Suphanburi, which is highly susceptible to drought because of climate change. Many areas in this region struggle with inadequate irrigation, and deep groundwater exploration has proven less successful due to the scarcity of groundwater.

Figure 6 shows the Combined Drought Indicator (CDI) method, developed by Jager and Jürgen from 2005 to 2015 [18]. The impact of drought in Suphanburi extended beyond agriculture. Water scarcity affects the daily lives of residents, limiting access to potable water and increasing the cost of living. Efforts to mitigate drought effects include improved water management practices and the development of drought-resistant crop varieties. However, the increasing frequency and severity of droughts due to climate change necessitate more comprehensive and sustainable solutions to ensure water security and agricultural resilience in the region.

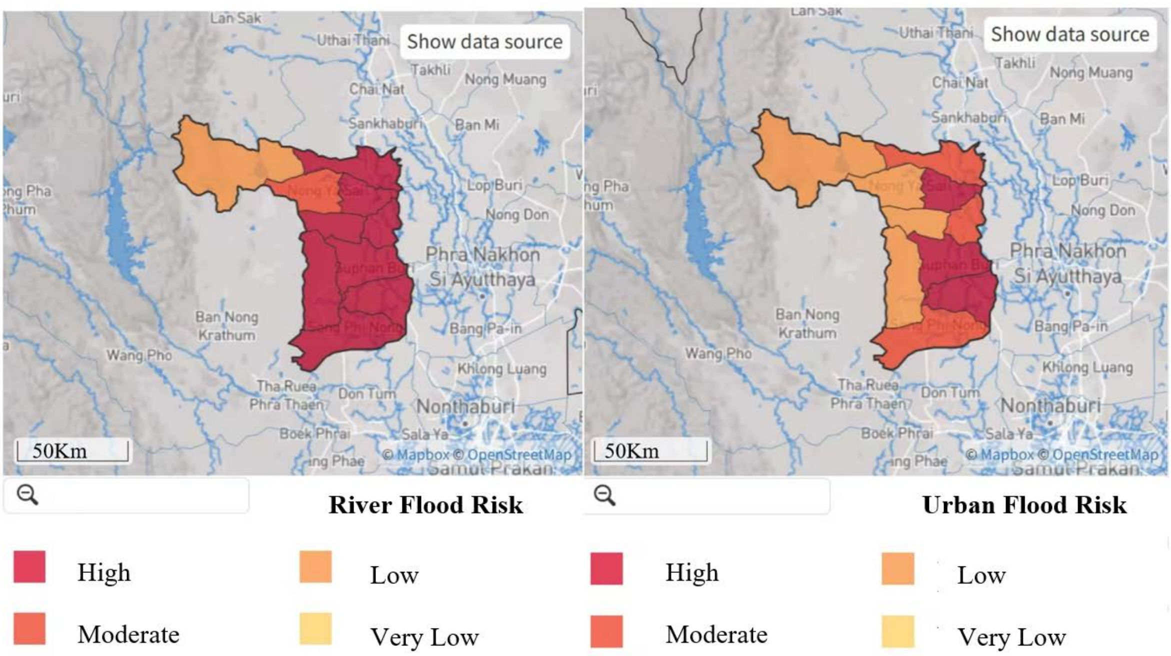

Fig. 5 River and Urban Flood Risks in Suphanburi [17]

In this case, suitable locations can be selected for MAR to solve the frequent droughts in the region and to enhance the region's resistance and adaptability to climate change. Through the effective implementation of MAR, it is possible to enhance the efficiency and level of water resource management in arid areas, promote sustainable development, and improve people's quality of life, while protecting and restoring the ecological environment.

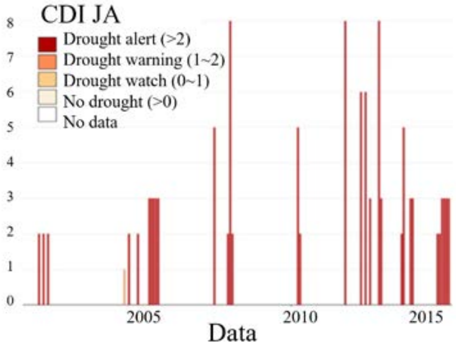

Fig. 6 Combined Drought Indicator (CDI) in Suphanburi [18]

3.6 Groundwater Situation

Groundwater in Suphanburi was used extensively for irrigation, domestic consumption, and industrial purposes. Over-extraction of groundwater led to land subsidence and reduced baseflow in rivers.

Figure 7 shows the groundwater level trend in the next 5 years [22]. The decline and condition of the groundwater level in the coming years is projected. If not remedied, then the groundwater level at this temple will be dropped to 87 m by 2031. which will have serious consequences such as ground subsidence, tilting of buildings, deformation of bridges and roads, and may even lead to the backing up of seawater, contaminating the freshwater resources of the Suphanburi area.

3.7 Identification of Factors

Determine the data analysis of the MAR location in the Suphanburi through overlayed analysis and calculate the total score for each different point. As shown in Eq.1

$$S=W_1R_1+W_2R_2+W_3R_3+...+W_iR_i \quad (1)$$

Where S = total score of a suitable location for MAR, W_i=coefficient weight, R_i= the rating

The factors in this research for MAR assessment were average monthly rainfall, monthly temperature, recharge, and discharge zones, land use, and terrain slope. These were selected because they contributed to the quantity of groundwater recharge that needs to be managed by the MAR systems.

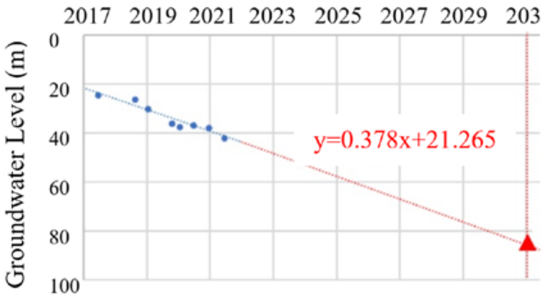

Fig. 7 Prediction of groundwater level in Suphanburi

This research, the factors, and their weights are determined through a combination of literature review, and statistical analysis [20-24]. Malekmohammadi et al., Valverde et al., and Escalante et al. selected MAR sites using geology, slope, runoff, and groundwater depth, as criteria and using statistical analysis [20-22]. Rahman et al. and Hussaini et al. used land use slope infiltration, and groundwater depth, as criteria and using GIS analysis [23,24]. When rainfall was heavy, the land use as forest led to water infiltration, in turn, led to increased recharge.

Table 1. Criteria for MAR assessments

Factor	Data (x)	W_i	R_i
Average Monthly Rainfall (mm)	>200	5.76	5
	185-200		4
	175-185		3
	165-175		2
	<165		1
Temperature (°C)	>35.53	3.24	4
	30.17 -35.53		3
	25.23 -30.17		2
	<25.23		1
Aquifer Type	Rock	2.76	2
	Soil		1
Discharge (m^3/day)	>130	2.55	4
	100-130		3
	50-100		2
	<50		1
Land Use	Agriculture land	2.32	4
	Urban areas		3
	Forest		2
	Waterbody		1
Slope (%)	0–0.3	1.22	2
	>0.3		1

Table 1 shows the data available, weighting, and rating for mar assessments. W_i is determined through three processes. First, important indicators or parameters relevant to the study objectives are selected. For groundwater recharge management, these parameters may include soil permeability, groundwater table, land use, rainfall, etc. Historical data made by a multidisciplinary team of experts is collected and each indicator is rated according to its importance to the overall assessment. Experts can assign initial weights to each indicator based on their experience and expertise. Collect ratings from all experts and determine the final weights for each indicator.

Different indicators have different attributes and scales, leading to different R_i of their evaluation levels. Some indicators have a more complex range of variation in practical application and require more grades to refine the distinction. Some indicators have more historical or observational data, allowing for a more fine-grained grading, while others may have limited data and can only be roughly graded.

The R_i of each indicator should be adapted to its actual application scenario and data characteristics. The mandatory use of the same number of grades may not accurately reflect the actual situation of each indicator. Moreover, too many grades may complicate the assessment process, which is not conducive to practical application and decision-making.

3.8 Weight Assignment and Standardization

Key factors to set up the optimal location for MAR. Each factor is assigned a weight based on its relative importance in contributing to recharge and discharge conditions. Table 2 utilized the average of the total scores (S) to determine the level of scores for the MAR feasibility, divided into five levels using average value and standard deviation in the normal distribution curve.

This research collected data for the feasibility of MAR to inform the decision-making. Climate data, including rainfall and temperature, is essential to understand water availability and rates. Land use data reveals the impact of water runoff and infiltration. Flood patterns identify potential sources for recharge and designing systems to mitigate flood risks. Hydrogeology data, detailing aquifer characteristics and groundwater levels, is vital for assessing the recharge potential and ensuring the sustainability of groundwater resources. Together, this comprehensive data set enables the development of accurate models and effective MAR strategies.

Table 2. The score for the MAR feasibility

Total Score	MAR Feasibility
S＜24.57	Very Unsuitable
24.57<S<33.53	Unsuitable
33.53<S<51.45	Moderate
51.45<S<60.41	Suitable
S>60.41	Very Suitable

4. RESULTS AND DISCUSSION

4.1 Optimization of MAR Locations

Optimization of MAR Locations with the WFI method, scores were calculated for the five selection sites, as illustrated in Fig. 8, which were compared to arrive at the potential location of the MAR.

The Dan Chang area is at a very high elevation and has poor discharge capacity so when selecting a MAR location, care should be taken to avoid flooding directly impacting the recharge facilities and to ensure that excess stormwater can be quickly discharged. The Tha Chin River receives high rainfall and the aquifer is a well-permeable soil, where MAR is installed, which increases the rate of water infiltration and reduces surface runoff. Construction of flood control levees around the Tha Chin River area to reduce the impact of flooding on the recharge facilities.

In Supanburi's City Center, with its high average temperature, high density of buildings, limited open space, potential sources of pollution, and other challenges, the selection of the location of the MAR is particularly important. Surface runoff can be reduced by utilizing existing urban infrastructure to collect and filter rainwater, allowing it to infiltrate through the ground and into the ground.

In the agriculturally developed U Thong district, the use of existing irrigation canals and drainage systems to reduce infrastructure costs and improve water use efficiency, the selection of farmland in cooperation with farmers, and the improvement of irrigation efficiency and yields of farmland through groundwater replenishment can optimize the environmental and economic benefits generated by MAR.

Selection of MAR location in Pho Phraya Industrial Zone requires detailed identification and assessment of pollution sources, such as factory discharges, waste disposal sites, and chemical storage. In the design of water recharge facilities, anti-seepage measures, such as the use of impermeable membranes and the construction of protective dikes, are taken to prevent pollutants from seeping into groundwater.

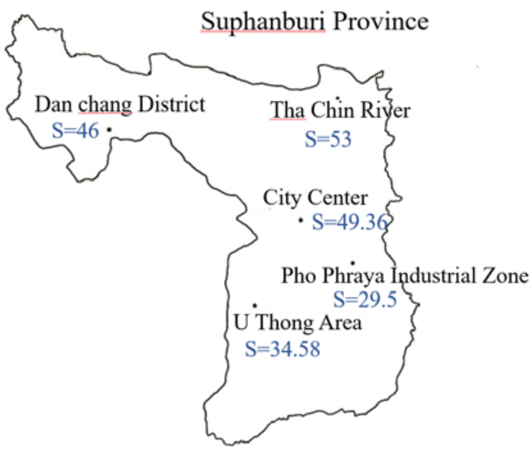

Fig. 8 Mapping and scores of the five selection sites

Table 3. Criteria and Score for MAR

Factor	Dan Chang District	The Chin River	City Center	U Thong Agriculture Area	Pho Phraya Industrial Zone
Average Monthly Rainfall (mm)	189	201	177	195	154
Temperature (°C)	29.25	29.5	31.75	29	28.7
Aquifer Type	Rock	Soil	Soil	Rock	Soil
Discharge (m³/day)	51.2	132.33	142.68	53.65	89.26
Land use	Forest	Water Body	Urban	Agriculture	Urban
Slope	>0.3%	0-0.3%	0-0.3%	0-0.3%	0-0.3%
Score	46.0	53.0	49.36	34.58	29.5

4.2 Impact Assessment

Table 3 showed that MAR presents a promising solution for enhancing water security in Suphanburi by capturing and storing excess rainwater during the rainy season and supplying it during the dry season. The natural filtration processes that occur during recharge can also improve water quality, enhancing the overall health of the aquifer and providing safer water for the community. In addition, MAR contributed to climate change resilience as well [25]. This adaptability made water management, environment, and ecosystem valuable. However, the implementation of MAR systems for other areas involved substantial costs, posing a significant disadvantage. Initial expenditures include the construction of infrastructure such as recharge basins, infiltration, and monitoring systems. These costs can be considerable for local governments and communities, particularly in regions with limited financial resources. Additionally, excessive recharge can lead to waterlogging and soil salinization, adversely affecting agricultural lands and natural vegetation [26]. The contaminated recharge can degrade groundwater quality, necessitating rigorous monitoring and treatment protocols [27]. Additionally, improper recharge practices may induce land subsidence, causing damage to infrastructure and altering natural landscapes [28].

5. CONCLUSION

This research was carried out to identify a suitable location for Managed Aquifer Recharge (MAR) using the Weight Factor Index (WFI) method, meaning the various multiple criteria decision-making, in Suphanburi, Thailand. The integration of six criteria i.e., rainfall, temperature, recharge rate, discharge zone, land use, and slope, provided a powerful support for sustainable water resource management, appropriate site selection, and careful water management.

The result revealed that the suitable location for MAR was in the Tha Chin River, due to the high rainfall, which allows for the storage of large quantities of water during the rainy season in the MAR in the event of groundwater shortages. The Tha Chin River has medium to high permeability to ensure rapid penetration of water into underground aquifers. The river has highly permeable soil that facilitates rapid groundwater recharge. In addition, the Tha Chin River was in a low-lying area and the topographic conditions were favorable for the construction of recharge facilities and the introduction of water. Proper recharge of the river can dilute contaminants in groundwater and improve groundwater quality.

The findings of this research provided valuable guidelines for planners, decision-makers, and hydrogeologists in designing future artificial recharge projects within a similar area, ensuring a reliable water supply and the sustainable use of groundwater over the long term.

In conclusion, the integration of WFI and GIS is recognized as an effective method for limited data, and location and reducing errors. In the future research could focus more on the suitable sites proposed in this study and incorporate additional criteria for environmental, economic, and social factors, as well as water-source availability and accessibility. Evaluating groundwater recharge requires detailed parameters, equations, soil properties, and aquifer characteristics. Therefore, this is a preliminary consideration for groundwater recharge of aquifers in the Suphanburi area.

6. RESEARCH LIMITATION

The study did not include the advection of water quality. Then, it cannot estimate the effect of recharge on water quality. The improvement for future work was added to the solute concentration and transport effect, for example, placing MAR projects within landfill areas that might be a feasible option for reducing the rate of future water quality. At the same time, the weight factor index method relies on high-quality data. If the data are inaccurate or incomplete, the reliability of the assessment results will be affected. The assignment of weights and scores usually involves a certain amount of subjective judgment, which can lead to biased results. The method may not be able to fully consider all influencing factors. For example, complex factors such as geological features, land use change, climate change, etc. may not be adequately quantified. The special geographic and climatic conditions of Suphanburi may make it difficult to directly apply the methodology's success in other regions. In future studies, the breadth and depth of data collection should be strengthened, and the accuracy and completeness of the data should be ensured through cross-validation and on-site surveys. Organize the participation of multidisciplinary experts in the determination of weights and scores to reduce the subjective bias of a single expert. Combine the weighting factor index method with other assessment methods (e.g., multi-criteria decision analysis, numerical simulation, etc.) to improve the comprehensiveness and accuracy of the assessment results.

7. ACKNOWLEDGMENTS

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