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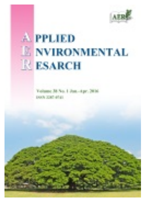

Analysis of Potential Site for Managed Aquifer Recharge Scheme in the Upper Greater Mae Klong Irrigation Project, Thailand

Yutthana Phankamolsil[1], Areeya Rittima[2,*], Sasipong Rantasewee[3], Yutthana Talaluxmana[4], Kritsanat Surakit[2], Allan Sriratana Tabucanon[5], Wudhichart Sawangphol[6], Jidapa Kraisangka[6]

[1] Environmental Engineering and Disaster Management Program, Mahidol University, Thailand
[2] Faculty of Engineering, Mahidol University, Nakhon Pathom Thailand
[3] Bureau of Groundwater Resources, Regional Office 2, Suphanburi, Thailand
[4] Faculty of Engineering, Kasetsart University, Thailand
[5] Faculty of Environment and Resource Studies, Mahidol University, Thailand
[6] Faculty of Information and Communication Technology, Mahidol University, Thailand
[*] Corresponding author: areeya.rit@mahidol.ac.th

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Abstract

This study developed a groundwater flow model to propose the possible Managed Aquifer Recharge (MAR) scheme for sustainable use of groundwater in the Upper Greater Mae Klong Irrigation Project, Thailand. The site suitability for MAR scheme was assessed through the GIS–based Multi–Criteria Decision Making (MCDM) using the Simple Additive Weighted (SAW) method. Five key relevant factors namely; groundwater drawdown, soil texture, depth to groundwater table, land slope and distance to surface water source were chosen as assessment criteria and reclassified for the analysis of site selection for MAR scheme. The results illustrate the potential site for the managed aquifer recharge scheme in the southwest of the Phanom Thuan Operation and Maintenance Project where soil texture is immensely sandy loam. The results of groundwater flow model also exhibit that 14 designated injection wells with discharge rate of 200 m^3 d^{-1}, each of which delineated in the potential area, can increase the hydraulic head in the aquifer ranging from 0.00–0.50 m during 2000–2016. In addition, a high increase of the hydraulic head in the aquifer is found nearby the locations of designated injection wells.

Keywords: Managed aquifer recharge scheme; Groundwater banking; Site suitability analysis; Greater Mae Klong Irrigation Project

Introduction

Groundwater has become a vital natural source for the sustainable water utilization in many regions worldwide. In Thailand, groundwater has been used as an alternative water source specifically for irrigation sector to supplement use of surface water in the irrigated and non–

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irrigated agricultural areas. The coordinated uses of surface water and groundwater, also called "conjunctive water uses", play an important role in engaging the farmers to receive enough irrigation water over the growing season. In addition, it can reduce the water scarcity in the cultivation fields during critical dry years when surface water is definitely limited. Therefore, the concept of conjunctive water uses has been extended enormously in some areas where availability of surface water are insufficient and difficult to access. This might be because of inappropriate physical features of the land area and persistence of hydraulics structures. In the past few decades, groundwater sources have been withdrawn potentially for municipal and industrial purposes to complement use of surface water supply especially in the central and western regions of Thailand. Seeking potential source of groundwater has become an urgent task to overcome the rising need of water and limited water supply especially in 2020 when the central Thailand predominantly experienced the severe drought. Moreover, groundwater banking which is sort of the Managed Aquifer Recharge (MAR) [1–2], has been broadly promoted and practiced particularly at the local scale of some farming areas. Groundwater bank project was introduced in Thailand to solve water shortage by replenishing water underground to save excessed water during monsoon season [3]. The water deposited in the bank is later extracted when accessibility to surface water sources is limited in drought season. Nowadays, the groundwater banking projects in Thailand are active in some specific areas where water scarcity is profoundly existed such as Kamphaeng Phet, Sukhothai Provinces [4].

The issues on groundwater replenishment for sustainable use of groundwater have been emphasized by numerous studies for the last few decades through the MAR. MAR, previously known as "Artificial Recharge", has been successfully implemented in many parts of the world. Several MAR schemes have been broadly existed to enhance recharge of groundwater [5–7]. MAR is commonly designed to allow surface water penetrating into the soil and to move downward into recharge aquifers [6]. The key elements of MAR are source of water harvesting, ground-water recharge process, groundwater recovery process, and end–use [8]. A wide range of MAR techniques are available to meet a variety of local requirements such as Aquifer Storage and Recovery (ASR), Aquifer Storage Transfer and Recovery (ASTR), Soil Aquifer Treatment (SAT), infiltration pond, infiltration galleries, percolation tank or recharge weir, rainwater harvesting, recharge releases, dry wells, bank filtration, dune filtration, underground dam, and sand dam [9]. These involve the techniques of infiltration by aiming at recharging water in the unconfined aquifer, and the techniques of well injection appropriate for deeper confined aquifers. It is stated that the most widely used MAR methods are ASR, ASTR, SAT, and river bank filtration [10]. ASR and infiltration pond have been immensely selected for MAR practices in the potential areas of Thailand. ASR is the modification of natural recharge system by injecting surface water into groundwater aquifers. Injection wells are used for ASR in the areas where surface infiltration is impracticable. However, infiltration pond which is a water impoundment over permeable soils, is encouraged as the basic MAR practices nationwide. Infiltration pond is simple in term of innovative construction which provides cost–effective operations and maintenances. However, comprehensive geotechnical investigations are required to confirm the suitability for infiltration at the selected site [11].

The studies on the site selection of MAR scheme have been vastly conducted for the past few decades. Goodarzi et al. [12] identified the potential sites for MAR using GIS and MCDM techniques in the Oshtorinan plain, Iran. Yeh et al. [13] investigated the potential zones of groundwater using the GIS technique in the Chih–Pen Creek

Basin in Eastern Taiwan. Malekmohammadi et al. [14] integrated the Multi–criteria Decision Making (MCDM), GIS, and Fuzzy Inference System (FIS) to reduce the uncertainty of infinite range of data classification for site selection of MAR scheme in the Shemil–Ashkara plain, Iran. Fuentes and Vervoort [15] assessed the site suitability and water availability for MAR project in the Namoi Basin, Australia by Multi–criteria Decision Analysis (MCDA) combined with Analytic Hierarchy Processes (AHP) and pairwise comparison.

In terms of site selection procedure of the MAR scheme, it is reported that the GIS–MCDM process has been widely carried out for various scales and settings all over the world [16]. To characterize area of interest for suitability mapping, the spatial analysis of related hydro–geospatial data is undertaken by using GIS to classify the associated thematic layers corresponding to the assigned weights implemented by MCDA approach.

In general, there are numerous multi–criteria decision–making methods such as Analytic Hierarchy Process (AHP), Electre, Topsis, Promethee, Grey theory, etc. [17]. The "Simple Additive Weighted (SAW) method" is one of the MCDA process based upon the concept of weighted summation. SAW is commonly used to solve the complicated multi–criteria decision problems. It can be extensively used for the assessment of land use suitability. The SAW method aims to find the weighted sum of performance ratings of each alternative on all assessment criteria. The alternative with the highest score performed after the overlay operation process is finally considered as the best one [18–19]. However, SAW requires the process of normalizing all the assessment criteria into the normalized scale which all the alternative ratings can be comparable. By comparing SAW method with other decision making models, it can be drawn that SAW method lies in its competence to make precise decision corresponding to the pre–defined values and preference weights [20]. The SAW method can also indicate the first rank of the same alternatives with AHP method applicable for the selection promotion process system [21]. Moreover, the simple additive weighting is capable of displaying results from weighted values and calculation based on certain criteria easily and efficiently [19].

Accordingly, this study aims at developing groundwater flow model to propose the possible MAR scheme in the Upper Greater Mae Klong Irrigation Project, Thailand. The site suitability for MAR scheme to replenish groundwater level was assessed through the GIS–based MCDM using SAW method.

The study area covers three operation and maintenance projects including Phanom Thuan, Song Phi Nong, and Bang Len where groundwater has become the alternative source mainly for agricultural uses as can be seen in Figure 1. It covers the area of 1,758 km^2 in Kanchanaburi, Suphan Buri, and Nakhon Pathom Provinces. During the severe flood in 2011, some specific areas in the upper east were considered as flooded area to retain excess water from the adjacent basins and to replenish groundwater level in this region. The main crops are rice and field crop which occupy 35.89% and 30.03% of the entire area, respectively. The remaining 34.03% are vegetables and water body. Most of the western part is upland area having the highest surface elevation of +400 m msl and gradually become flat area in the east near the mean sea level. Irrigation water has been potentially supplied to these three irrigation schemes through 1L and 2L distribution canals. Therefore, certain amount of surface water of the canal distribution system lying over the study area can be guaranteed and considered as the potential supply source for the development of MAR scheme.

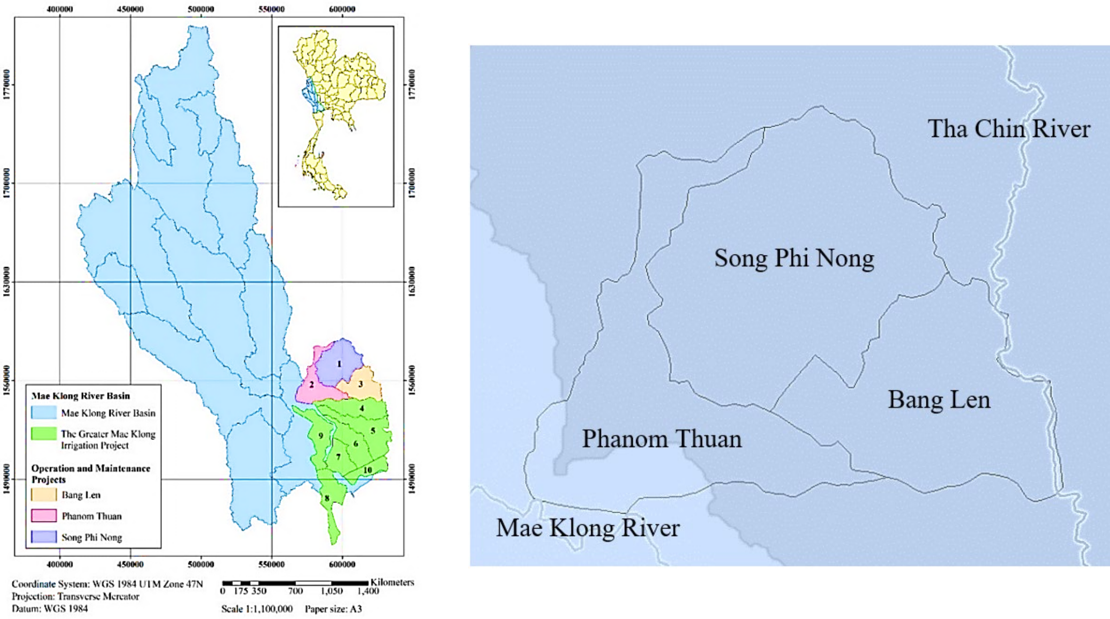

Figure 1 Location of the study area in the Mae Klong River Basin, Thailand covering 3 operation and maintenance projects; Bang Len, Phanom Thuan, Song Phi Nong.

Methodology

The methodological research framework is outlined and presented in Figure 2 consisting of three main parts; (1) groundwater flow modelling, (2) assessment of site suitability for MAR scheme, and (3) investigation of the potential site for groundwater replenishment.

1) Groundwater flow modelling

Groundwater flow modelling using MODFLOW was carried out to simulate groundwater dynamics for the assessment of site suitability for MAR scheme. The study area was modelled horizontally on a two–dimensional grid and vertically as one unconfined aquifer on the top layers and 8 confined aquifer layers below. All aquifer layers were intervened by aquitard and the bedrock was identified at the bottom layer. The vertical layers were assigned as the heterogenous layers having the specific hydrological properties. The grid was divided by rectangular cells into 49 rows and 64 columns occupying the entire area. Each rectangular cell has the size of 1,000 x 1,000 m^2 equally. The 3D model of aquifer system and layered structure are shown in Figure 3 and Table 1.

The geohydrological data during 2000–2016 were used as an input to simulate the aquifer system. Hundreds of pumping wells belonging to the government agency and private sectors were input in the groundwater flow model with an average pumping rate of 212 m^3 d^{-1} each. The observed hydraulic head data from observation wells obtained from the Department of Groundwater Resources, Thailand was also fed into the model. The distribution of pumping and observation wells is illustrated in Figure 4. It is found that the highest rate of groundwater pumping is apparently existed in the Bang Len Operation and Maintenance Project. The deepest and shallowest points of intake well screen of observation wells are at –204 and –1 m, respectively. These observation wells receive water flow from the BK, PD, NL, NB and hard rock aquifers. It is exhibited that weak seasonal influences on the hydraulic heads in dry season (Jan–Jun) and wet seasons (Jul–Dec) as well as low variability of yearly hydraulic head data are found for each observation well as shown in Figure 5 and Figure 6.

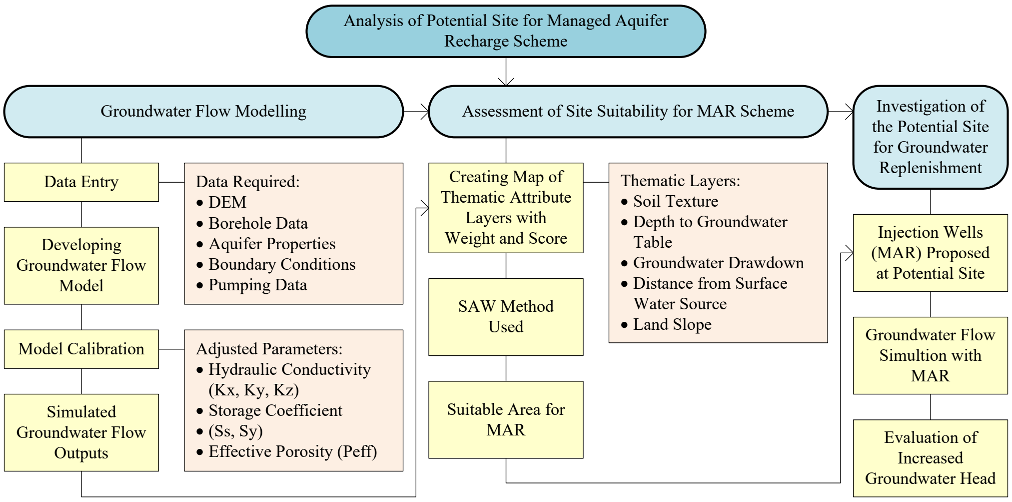

Figure 2 Methodological research framework.

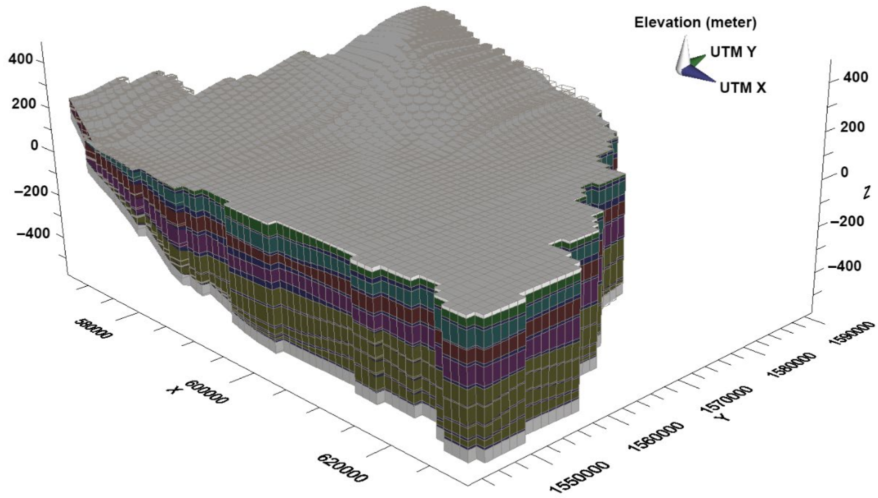

Figure 3 A 3D model of aquifer system in the study area.

Table 1 The layered structure identified in the groundwater flow model

Layer	Type	Layer No.	Thickness and other characteristics
Bangkok Clay (BKclay)	Unconfined Aquifer	1	Soft marine clay with 30 m thickness
Bangkok Aquifer (BK)	Confined Aquifer	2	20–30 m
Phra Pradeang Aquifer (PD)	Confined Aquifer	4	20–50 m
Nakhon Luang Aquifer (NL)	Confined Aquifer	6	50–60 m
Nonthaburi Aquifer (NB)	Confined Aquifer	8	60–70 m
Sam Khok Aquifer (SK)	Confined Aquifer	10	50–70 m
Phaya Thai Aquifer (PT)	Confined Aquifer	12	50–70 m
Thon Buri Aquifer (TB)	Confined Aquifer	14	30–50 m
Pak Nam Aquifer (PN)	Confined Aquifer	16	60–90 m
Rock	Confined Aquifer	18	It consists of sedimentary, granite, basalt and metamorphic rocks
Aquitard	Aquitard	3, 5, 7, 9, 11, 13, 15, 17	Hard stratum lying adjacent to aquifer layers that allows small amount of flow passing through it

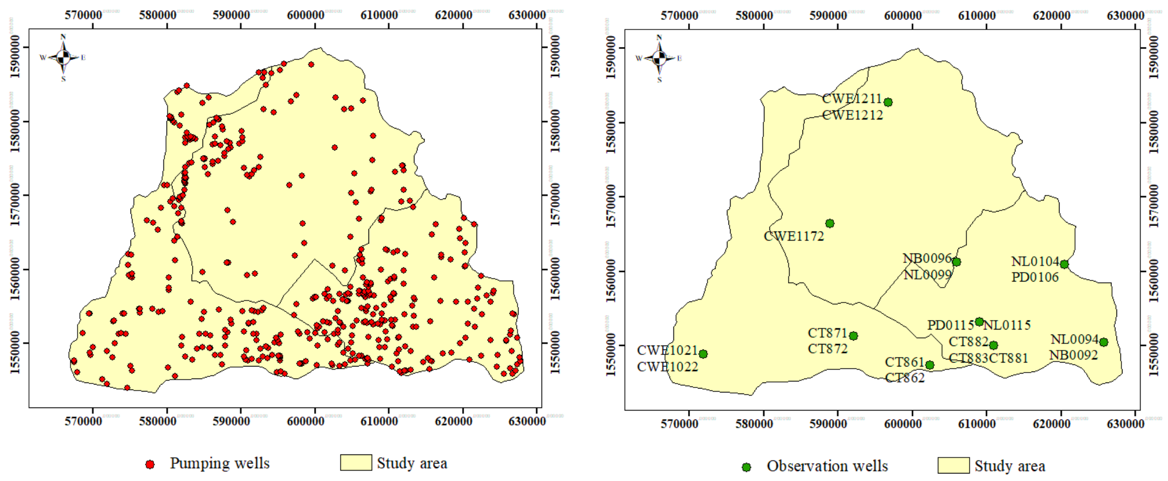

Figure 4 Distribution of groundwater pumping and observation wells in the study area.

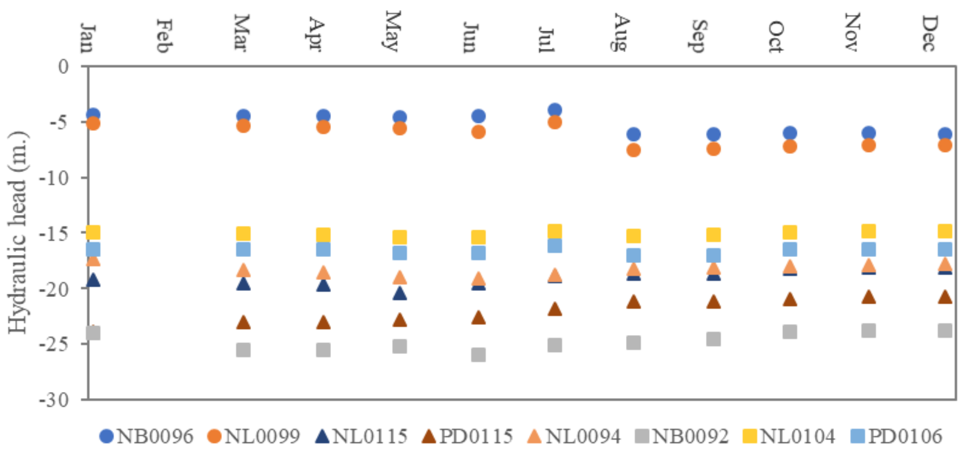

Figure 5 Monthly distribution of hydraulic heads monitored at the observation wells in 2005.

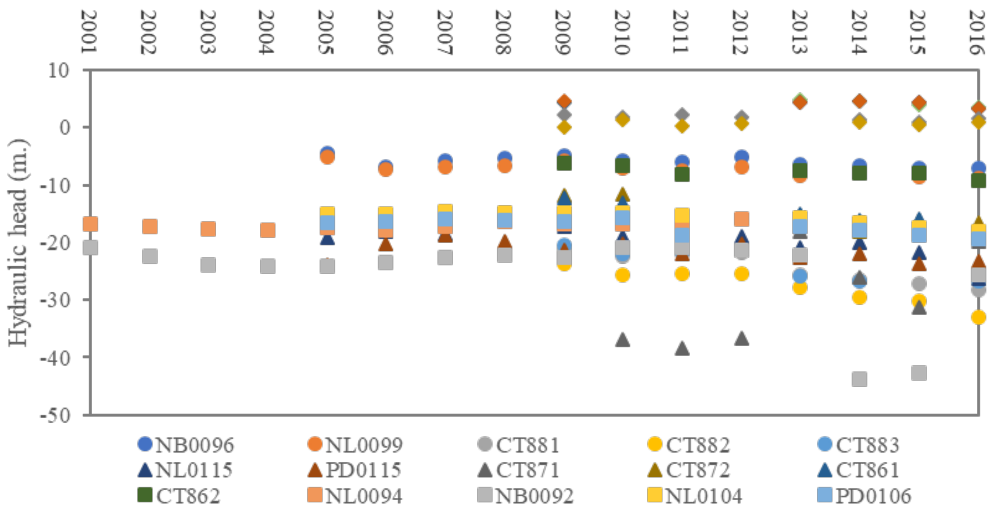

Figure 6 Yearly distribution of hydraulic heads monitored at observation wells during 2001–2016.

The top layer of groundwater flow model was defined as recharge area of precipitation and discharge area of evapotranspiration. River boundary was applied along the Tha Chin River using data from T.9 and T.13 stream gauge stations. The lowest model boundary was –600 m msl. Mountain ridge at the western border and bottom of the model were defined as impermeable boundary. General heads were specified at the northern, eastern, and southern borders using observed water levels of monitoring wells. Meanwhile, the observed data from of K.3 and K.11A stream gauge stations along the Mae Klong River were used to specify the general head at the southwest border. Evapotranspiration and recharge rates were referred to the groundwater studies done by the Department of Groundwater Resources of Thailand [22] which the values of evapotranspiration and recharge rates were varied in the specific land use types in the study area namely; paddy field, sugarcane, forest, and other as summarized in Figure 7. Recharge ponding depth was specified equal to 0 m and extinction depth of evapotranspiration was equal to 2 m.

2) Assessment of site suitability for MAR scheme

2.1) Conceptual idea and assessment methods used

To propose the MAR scheme in the study area, assessment of site suitability was conducted based upon the simulation results performed by groundwater flow model to extract key parameters of hydro–geologic properties. In addition, other influencing factors associated with site selection of MAR such as appropriateness of topographic conditions and surface water harvesting source were taken into consideration. The "Injection Wells (IW)" which is one of the MAR techniques commonly used in aquifer recharge system, was proposed at somewhere considering as the suitable site. The idea to delineate the suitable site is that the source of water of injection wells should be supplied from the canal irrigation system or diverted water from the Mae Klong Basin. In addition, soil properties such as permeability and storage capacity of the aquifer layers should be sufficient to potentially increase the amount of groundwater recharge. In the process of site selection, the SAW method using GIS was employed in determining suitable site for the establishment of injection wells. The key assessment criteria or attribute data were selected. The relative weights of attribute data were identified and normalized to common dimensionless unit using Eq. 1;

$$W_j' = \frac{W_j}{\sum_{j=1}^{n} W_j} \qquad \text{(Eq. 1)}$$

where j is the ordering number of attribute data (thematic raster layers), W_j' is the normalized weight for j^{th} attribute, and W_j is the raw weight for j^{th} attribute.

The input thematic layers were then reclassified into classes. The scores of each class were identified and normalized using Eq. 2;

$$a_{ij}' = \frac{a_{ij}}{a_{ij}^{max}} \quad ; i=1,2,\ldots,n \quad j=1,2,\ldots,m \qquad \text{(Eq. 2)}$$

where i is the ordering number of alternative (class of each thematic raster layer), j is the ordering number of attribute (thematic raster layers), a_{ij}' is the normalized score for i^{th} alternative and j^{th} attribute, a_{ij} is the raw score for i^{th} alternative and j^{th} attribute, n is number of attributes, and m is number of alternatives.

Finally, integration of the weighted thematic raster layers were made by Eq. 3;

$$A_i = \sum_{j=1}^{n} W_j' a_{ij}' \quad ; \ i=1,2,\ldots,m \qquad \text{(Eq. 3)}$$

where A_i is the value of suitability for i^{th} alternative. The output layer was created and considered as the suitability map for MAR. Each pixel has the suitability value ranging from 0 to 1.

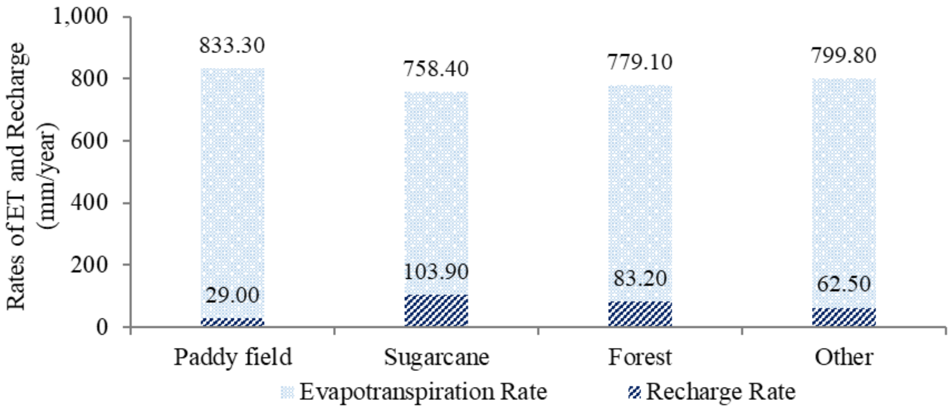

Figure 7 Evapotranspiration and recharge rates used in the groundwater flow model.

2.2) Limitations of study

Assessing the potential site for the development of MAR scheme in this study was implemented based on three main criteria; (1) surface criteria (2 factors describing the topographic conditions namely; soil texture and land slope), (2) subsurface criteria (2 factors explaining the interactions between hydro–geologic properties and groundwater abstraction namely; groundwater table and groundwater drawdown), and (3) water harvesting source by considering distance to surface water source. However, some potential factors affecting the site suitability for MAR scheme were not considered such as land–use types, hydro–meteorological data, drainage density, hydrogeological entity, level of confinement and type of geological formations, groundwater quality, and management factors, etc.

The rational selection of these five factors was made under assumptions on seeking the potential MAR site where groundwater abstraction and associated groundwater drawdown need to be synchronized incorporated with potential groundwater recharge for subsequent recovery of aquifer system. There is strong evidence that distribution of the spatial and temporal groundwater recharges are significantly governed by soil textures, land slope, physical properties of aquifers. The soil textures indicate the soil hydraulic properties such as soil–water holding capacity, permeability, and soil workability, etc. which determine the ability to penetrate water through the unsaturated soil zone and to store water in the ground. The effect of topographic gradient has considerable influence on the water infiltration from the land surface and rates of groundwater flux. The higher sloping land areas can generate quick surface runoff and entail small fraction of groundwater recharge volume due to lower rates of groundwater flux. In addition, levels of groundwater table and groundwater drawdown which describe interactions between groundwater abstraction and associated hydro–geologic properties in the study area were considered as key factors to realize the current hydro–geologic state of potential areas for the development of MAR scheme. Importantly, MAR implementation can be only practicable if source of surface water is available at a reasonable distance.

3) Investigation of the potential site for groundwater replenishment

Groundwater flow simulation with MAR scheme during 2000–2016 was conducted to investigate the potential site in term of groundwater replenishment. In this study, the injection wells was selected to recharge water to aquifers at the potential site. The number of injection wells and discharge rates were identified and its design criteria was referred to the guideline on MAR in shallow aquifers [23].

Results and discussion

1) Performances of groundwater flow modeling and groundwater simulation

Calibration process of the groundwater flow model was accomplished under both steady state and transient state conditions using 20 observation wells monitored during 2000–2016. The aim of model calibration under steady–state flow was to determine the distribution of hydraulic conductivity required to match the observed water levels. Three dimensional hydraulic conductivity is the key hydraulic parameters of groundwater flow model describing the capacity of rock or soil to transmit water. In addition, model calibration under transient flow aims to calibrate the storage coefficient and recharge parameters. The storage coefficient explains the volume of water released from storage in a unit prism of an aquifer when the head is lowered a unit distance. The accuracy of calculated hydraulic head in the model was presented by residual mean, absolute residual mean and standard error of the estimate, normalized root mean square, and correlation coefficient. Model calibration processes were terminated when accuracy level of normalized RMS was less than 10% [24].

The results of model calibration under steady–state flow condition show that the value of normalized RMS is 7.48% which is in an acceptable range. The maximum residual, minimum residual, and correlation coefficient are –6 m, –0.14 m, and 0.97, respectively. The results of model calibration under transient flow condition show that the value of normalized RMS is 8.69% which is in an acceptable range. The maximum residual, minimum residual, and correlation coefficient are –6.8 m, 0.5 m, and 0.96, respectively which can be reasonably acceptable.

The simulation results of groundwater budget during 2000–2016 exhibit the quantitative level of the historical and current uses of groundwater in this study area. It is also revealed that the natural recharge rate has remained higher than the amount of groundwater withdrawal. The total permissible yield is quantified as 185,760 m^3 d^{-1} which is relatively higher than the current rate of groundwater pumping [25]. The long–term simulation in transient mode during 2000–2016 was made under the existing conditions of number of pumping wells and rates to estimate the groundwater drawdown in confined aquifers. The contour line of groundwater drawdown in Figure 8 illustrates that the simulated drawdown ranges between –0.50 m to nearly –2.00 m starting from the upper east to the lower west. The highest drawdown is noticed in the Phanom Thuan Operation and Maintenance Project where soil type is mostly sandy loam. In addition, the flow boundary conditions identified in groundwater flow model is based on the hydrogeology and piezometry of aquifer system which groundwater moves eastward from the west to the lower east. This would result in increase to groundwater drawdown levels in this zone.

2) Weighting and scoring criteria for site suitability assessment

As aforementioned, the criteria considering for MAR site selection in this study was only based on appropriateness of topographic conditions, hydro–geologic properties, and water harvesting source. Therefore, five thematic attribute layers were considered and considerably provided; (1) soil texture, (2) depth to groundwater table in 2016, (3) groundwater drawdown (simulated from 2000–2016), (4) distance to surface water source, and (5) land slope in 2016. These thematic attribute layers were reclassified into several classes. The weight of each thematic layer and score of each class were assigned on a scale of 1 to 10. After normalized, the values of weight and score were accordingly ranged from 0 to 1. The scoring criteria were identified in association with its potential for development of MAR scheme as summarized in Table 2 and illustrated in Figure 9. These thematic layers with scores and weights were then overlaid to produce map of suitability for MAR scheme. Higher scores of suitability refer to higher potential to propose the MAR scheme.

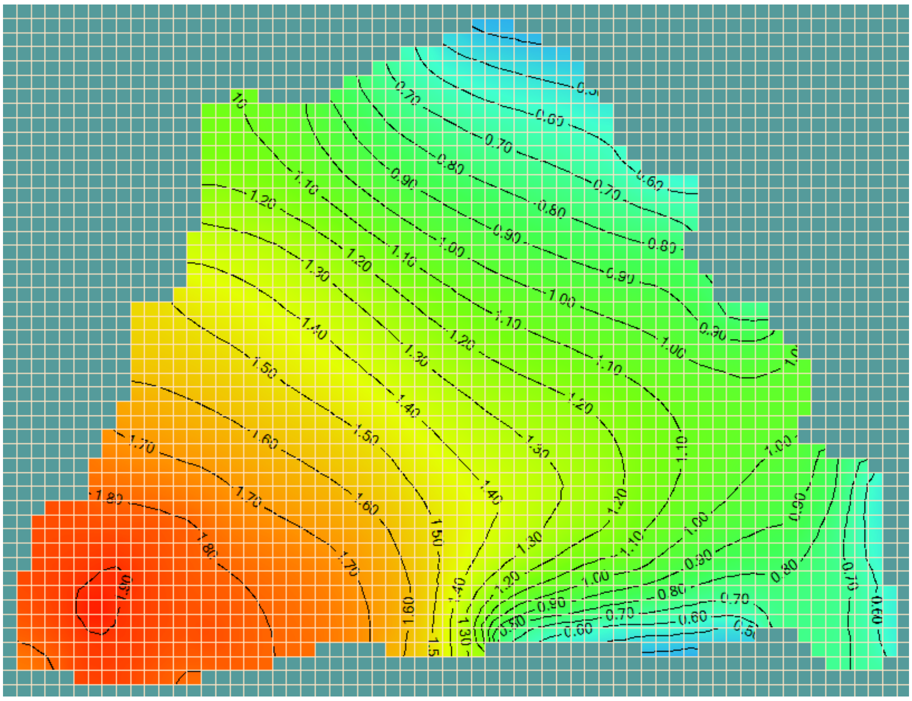

Figure 8 Contour line of groundwater drawdown under existing pumping conditions in the confined aquifers during 2000–2016.

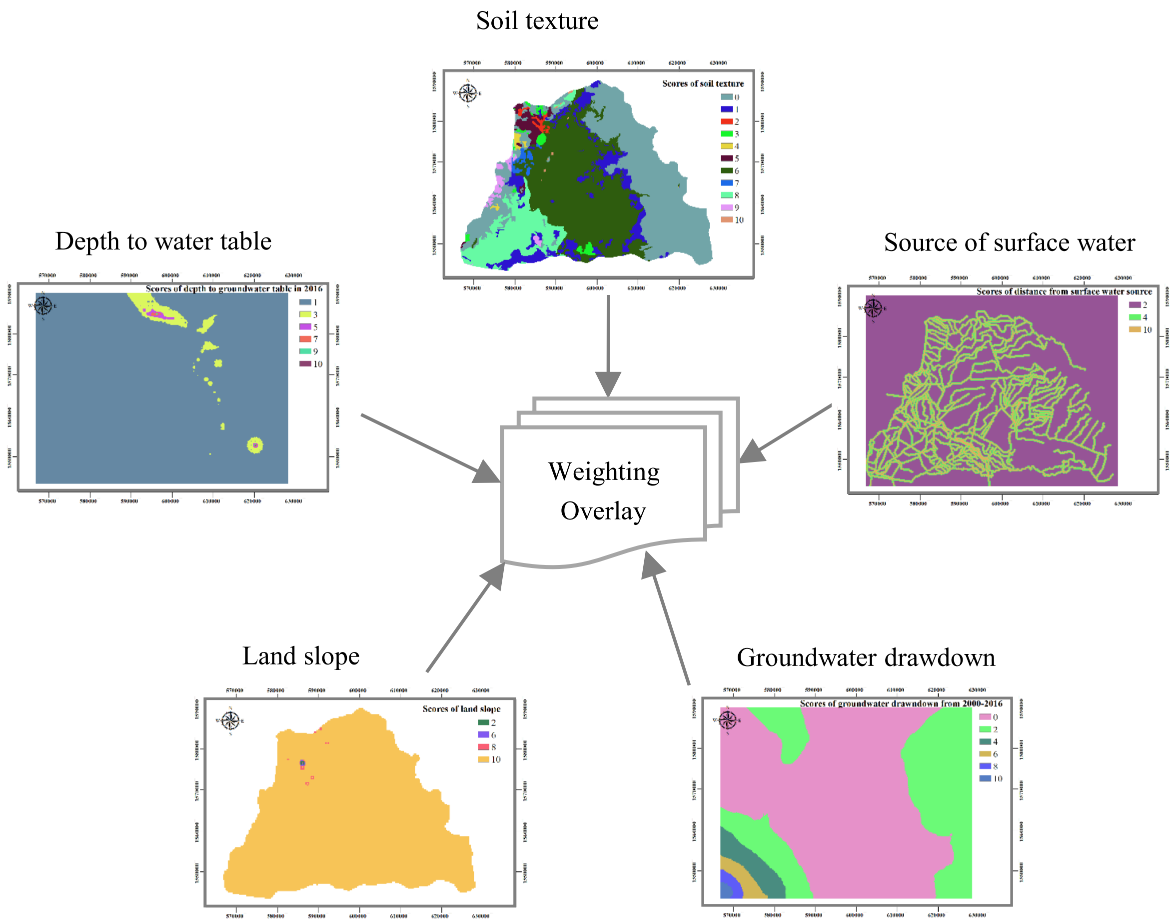

Figure 9 The score of each class of input thematic layers provided for this study.

Table 2 Summary of the input layers, weights and score ranges used in the SAW method

Layer name	Weight (W_j) (1–10)	Normalized weight (W'_j) (0–1)	Classes of layer	Raw score (a_{ij}) (0–10)	Normalized score (a'_{ij}) (0–1)
Soil texture	7	0.22581	Clay	0	0
			Silty clay	1	0.1
			Sandy clay	2	0.2
			Clay loam	3	0.3
			Silty clay loam	4	0.4
			Sandy clay loam	5	0.5
			Loam	6	0.6
			Silty loam	7	0.7
			Sandy loam	8	0.8
			Loamy sand	9	0.9
			Very stony soil	10	1
Depth to groundwater table in 2016	5	0.16129	0 – <2 m	1	0.1
			2 – <4 m	3	0.3
			4 – <6 m	5	0.5
			6 – <8 m	7	0.7
			8 – <10 m	9	0.9
			>10 m	10	1
Groundwater drawdown (from 2000–2016)	8	0.25806	<0 m	10	1
			0 – <5 m	8	0.8
			5 – <10 m	6	0.6
			10 – <15 m	4	0.4
			15 – <20 m	2	0.2
			>20 m	0	0
Distance to surface water source	5	0.16129	0 – <50 m	10	1
			50 – <100 m	8	0.8
			100 – <150 m	6	0.6
			150 – <200 m	4	0.4
			>200 m	2	0.2
Land slope	6	0.19355	0 – <2%	10	1
			2 – <4%	8	0.8
			4 – <8%	6	0.6
			8 – <12%	2	2

Classifying and weighting the thematic layers of attribute data were subjectively based on site specific information. However, in this study the input thematic layers was reclassified and weighted by referring to the review study by Malekmohammadi et al. [14]. Groundwater drawdown and soil textures were assigned with the highest weights of 0.25806 and 0.22581, respectively to give its importance to MAR and regarded as key assessment criteria. However, the weight of land slope, depth to groundwater table, and distance to surface water source were determined as the supplementary factors to MAR. The score of clay soil was ranked as the lowest value due to the conditions of low hydraulic conductivity and porosity. The main purpose of proposing the managed aquifer recharge was to increase groundwater volume and replenish groundwater level in the study area. Therefore, the deepest depth to groundwater table was considered as the highest score. Meanwhile, the shallowest depth to groundwater table was assigned as the lowest score. Scoring criteria of groundwater drawdown was specified similarly to depth to groundwater table. The area where groundwater drawdown reached the highest point, was assigned as the highest score to replenish groundwater level and to propose MAR scheme. Ideally, the surface water from canal distribution system was considered as the water supply source to inject water underground. Therefore, the assigned score was subject to distance from canal system to the suitable points. The shortest distance from the canal distribution system was assigned as the highest score. The scoring criteria of land slope was made based upon the geographical conditions in the study area. A plain which is a broad area of relatively flat land, was considered as suitable land to apply for MAR scheme. Accordingly, the area with a land slope of more than 12% was given as the lowest score. Meanwhile, land slope of the plain ranging from 0% – < 2%, was assigned as the highest score.

3) Suitability map for MAR scheme

Figure 10 shows the suitability map for MAR scheme proposed in the study area. It is noticeable that the suitable site lies in the southwest of the Phanom Thuan Operation and Maintenance Project where suitability values is varied between 0.60–0.80. The soil textures in the west are enormously sandy loam and pumping discharge is relatively high. It is also found that depth to groundwater table ranges from 0–2 m and groundwater drawdown (during 2000−2016) varies from 10–20 m. In addition, the designated location of MAR is definitely close to source of surface water from the canal distribution system in a range between 0–200 m and land slope lies from 0–2%.

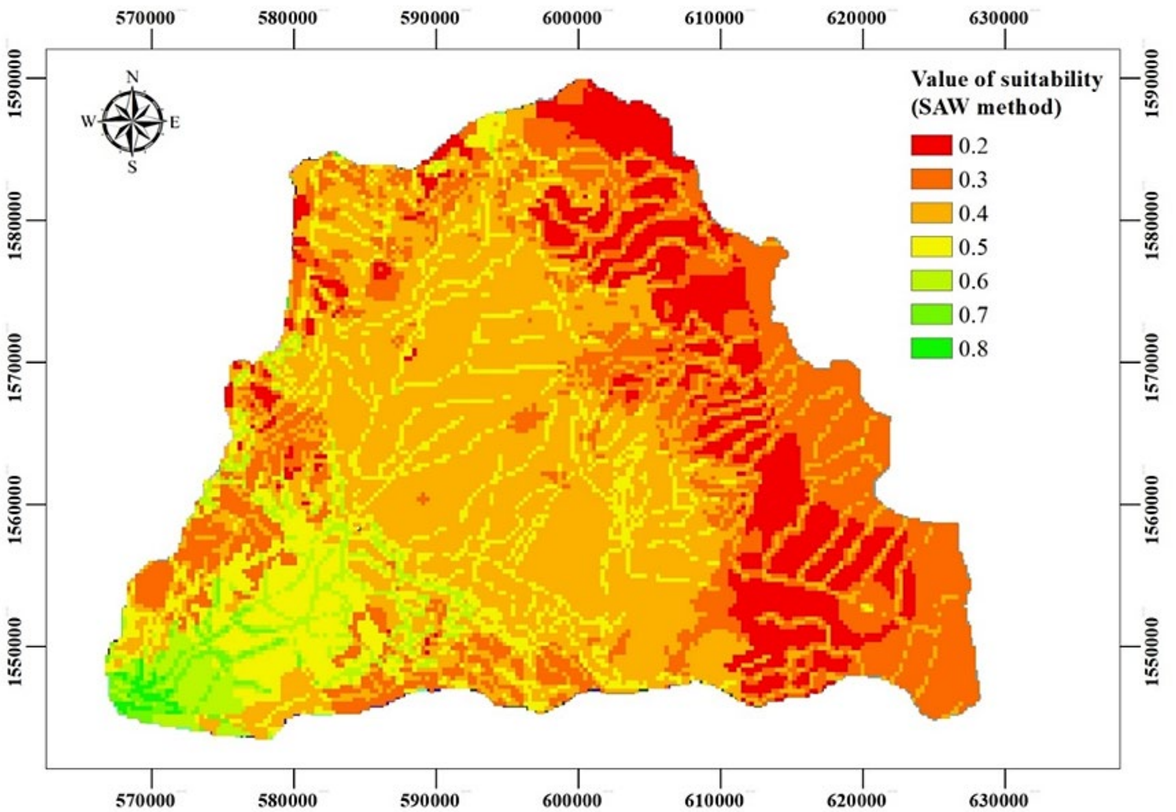

Figure 10 Suitability map for MAR scheme in the study area.

4) Groundwater flow simulation with MAR scheme

To investigate the potential of the proposed site for the development of MAR scheme, 14 designated injection wells with rate of 200 m^3 d^{-1} each were delineated in the Phanom Thuan Operation and Maintenance Project as illustrated in Figure 11. Groundwater flow simulation with MAR during 2000–2016 was then conducted. The design criteria for the designated injection wells was carried out based on the guideline on the MAR in shallow aquifers as tabulated in Table 3 [14]. The depth of designated injection wells was recommended as 8 m recharging water into the Bangkok aquifer (BK) and Phra Pradeang aquifer (PD).

The result of groundwater model simulation with MAR scheme shows the increase in hydraulic heads in all confined aquifer layers over entire area. Moreover, the maximum hydraulic heads reach to +0.50 m in the Phanom Thuan Sub–irrigation area nearby the sites of injection wells.

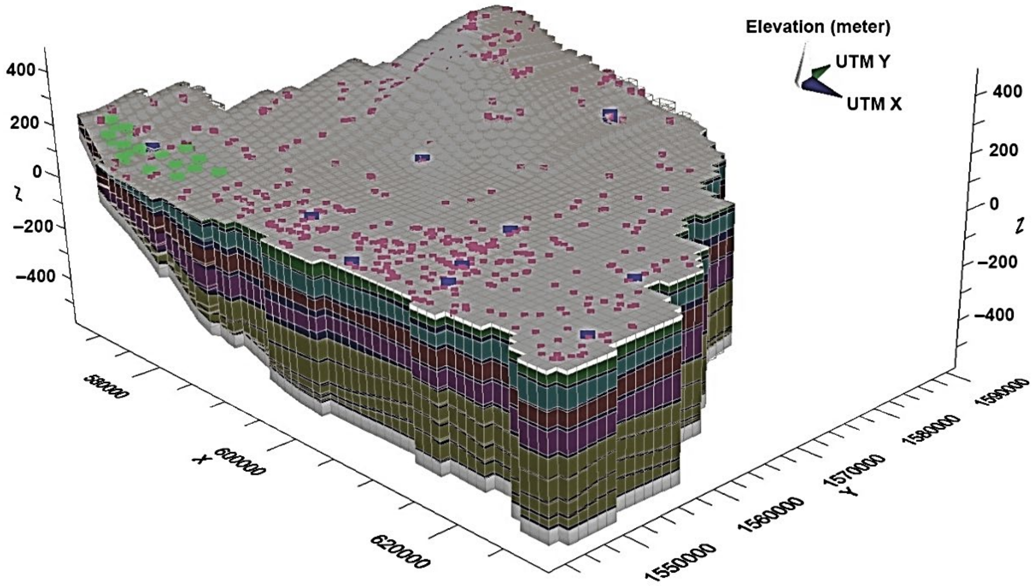

Figure 11 Location of designated injection wells proposed in the study area.

Table 3 Description of designated injection wells

Well name	UTM X (m)	UTM Y (m)	Discharge rate (m^3 d^{-1})	Top elevation (m msl)	Bottom elevation (m msl)	Top screen (m msl)	Bottom screen (m msl)
Well1	569203	1545823	200	151.32	143.32	144.32	143.32
Well2	569173	1547745	200	160.59	152.59	153.59	152.59
Well3	570314	1546724	200	115.77	107.77	108.77	107.77
Well4	571125	1547745	200	98.15	90.15	91.15	90.15
Well5	571366	1545793	200	82.11	74.11	75.11	74.11
Well6	574159	1550778	200	97.41	89.41	90.41	89.41
Well7	575270	1548886	200	63.76	55.76	56.76	55.76
Well8	577132	1549637	200	59.64	51.64	52.64	51.64
Well9	579354	1550718	200	55.49	47.49	48.49	47.49
Well10	577162	1547745	200	48.46	40.46	41.46	40.46
Well11	574219	1546754	200	53.75	45.75	46.75	45.75
Well12	573138	1548826	200	81.66	73.66	74.66	73.66
Well13	568242	1546844	200	192.91	184.91	185.91	184.91
Well14	576201	1550778	200	75.74	67.74	68.74	67.74

Conclusions

This study aims to find the potential MAR site for sustainable use of groundwater in the Upper Greater Mae Klong Irrigation Project, Thailand. The site suitability for MAR scheme was assessed through the GIS–based Multi–Criteria Decision Making (MCDM) analysis using the hydro–geospatial data obtained from the groundwater flow model as well as the physically–based data in the study area. The results illustrate the suitability map for MAR which recommends the potential site in the southwest of the Phanom Thuan Operation and Maintenance Project. Capability of recharging water into the aquifers at the potential MAR site was also verified by groundwater flow simulation with the designated injection wells. It is revealed from the results that MAR implementation on groundwater resource is important to sustainably increase groundwater availability in this region. The suitability mapping can be used to address the potential MAR site particularly for decision makers to establish crucial groundwater replenishment scheme. Moreover, other efficient MAR practices with low cost and small–scale structure can be promoted such as on–farm reservoir, infiltration pond, percolation dam, etc. at the potential site for sustainable utilization of groundwater resource.

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