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Site Selection Criteria of UTES Systems in Hot Climate

Critères de sélection du site des systèmes UTES dans un climat chaud

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ABSTRACT: Underground Thermal Energy Storage UTES systems are widely used around the world. The reason is that UTES is essential in utilizing Renewable Energy sources (RE). The efficiency of the energy system relies strongly on the efficiency of the storage system. Therefore, in the installation of a hyper-energy system, a lot of attention is to be paid in improving the storage system. In order to design an efficient storage system, firstly, standard criteria are to be investigated. These explain the process of making high efficiency storage system that must be specified. The criteria, mainly, depends on: best type and best location. These two variables are in high interference with each other. The bond between the two variables is represented by the geological, hydrological, meteorological, soil, hydrogeological properties/factors of the site. These factors are specified by geo-energy mapping. Despite the importance of this type of mapping, there is no specific criteria/formula that defines the choice. This paper aims to: give a brief literature review for UTES systems (types, classification, advantages/disadvantages for each type, and examples of an installed system). In addition, some factors within geo-energy mapping are highlighted and standard criteria to achieve good storage system are suggested. The suggested criterion comprises a process to transfer the quantity values to quality values according to the expert opinion. The suggested criteria are defined through the following stages: selecting the best type of UTES systems according to hydro-geological in site conditions; using the analytical hierarchy process to rank the best location to install the storage system and then using ArcMap (GIS-Software) to provide representative results as maps. Karbala Province (Iraq) is the study area used here.

RÉSUMÉ: Les systèmes de stockage souterrain d'énergie thermique (abréviation UTES systèm en anglais) sont largement utilisés dans le monde en raison de leur corrélation essentielle avec les sources d’énergie renouvelables (ER). L’efficacité du système énergétique dépend fortement de l’efficacité du système de stockage auquel il est associé. Par conséquent, lors de l'installation d'un système d'hyper-énergie, une grande attention doit être accordée à l'amélioration du système de stockage. Pour produire un système de stockage efficace, il convient tout d'abord d'examiner les critères standard qui expliquent le processus de développement de systèmes de stockage à haute efficacité qui doivent être spécifiés. Les critères dépendent principalement du meilleur type d’installation et du meilleur emplacement, deux variables sont fortement corrélées. La relation entre ces deux variables est représentée par les propriétés / facteurs géologiques, hydrologiques, météorologiques, du sol et du site. Ces facteurs sont spécifiés par la cartographie géo-énergétique. Malgré l'importance de ce type de cartographie, aucun critères ou standards spécifiques ne les définit.Cet article vise à: faire une brève revue de la littérature sur UTES systèm (types, classification, avantages / limites pour chaque type et exemples de système installé). En outre, certains facteurs de la cartographie géo-énergétique sont présentés et des critères de standardisation sont suggères pour obtenir de bon systèmes de stockage. Les critères proposés comprennent un processus permettant de transférer les valeurs quantitatives en valeurs de qualitatives basées sur l'avis de l'experts. Les critères proposés sont définis par les étapes suivantes: sélection du meilleur type d'UTES systèm en fonction des conditions hydrogéologiques du site; en utilisant le système de hiérarchie analytique pour classer le meilleur emplacement pour installer le système de stockage, puis en utilisant ArcMap (logiciel SIG) pour fournir des résultats représentatifs sous forme de cartes. La province de Karbala (Irak) est notre zone d'étude.

Keywords: undeground thermal energy storage; site selection; geo-energy mapping; analytical heirarchy process; DRASTIC index.

1 INTRODUCTION

Renewable energy proved to be a successful alternative to fossil fuel during the last decades. In spite of all its benefits (e.g. Miguez et al., 2006), it possesses a main disadvantage because it is intermittent (Xu et al., 2014). To overcome this drawback, energy systems are complemented by a storage system (Dincer et al., 1997). The efficiency of renewable systems relies strongly on the combined storage systems, which has to be optimized.

Underground thermal energy storage (UTES) systems are widely used around the world (Kaygusuz, 1999) in Heating, Ventilation, and Air Conditioning (HVAC) applications. Therefore, it becomes very important to determine the efficient UTES system. There are six types of UTES systems: borehole; aquifer; cavern; tubes in clay; pit; and tank (Nordell, 2000; Hesaraki et al., 2015). Optimal UTES system relies on its type and location. Hence, deciding UTES system type is an important consideration. The efficiency of UTES system depends strongly on two variables: site specific factors and the storage system type. Therefore, to find the optimal storage system, its type must be specified first. The best type can be decided by decision makers according to site specific factors. After the problem of identifying the best type has been settled, the best location for the selected type can be decided. A method is proposed in this paper to find the suitable location for installing a specific type of UTES system since there is no identified method. The proposed method is presented in Methodology sec.

2 METHODOLOGY

Only one of the six UTES types, the tank system, is not site dependent. In spite of the vital role of site selection on the efficiency of the system, there is no specific method to be followed. The suggested method is a synthesis of two methods: Analytical Hierarchy Process AHP (Saaty, 1990) and DRASTIC (Aller, 1987). According to this method, the process can be clarified into two main stages.

The first stage of the process, is producing the equation that evaluates the suitability of UTES system according to the site specific factors. The equation can be written as follows:

$$S = \sum_{i=1}^{n} W_i R_i \quad (1)$$

Where S is the site suitability index, W_i is the weight of the in-site factor, and R_i is the rating of the factor.

The **second stage** is represented by using Arc Map/GIS software to perform equation (1) on the region, and presenting the results as a map. The resultant map depicts the suitability of the region for the specified UTES system.

To accomplish these two stages, the following steps can be identified:

2.1 AHP (weighting mode)

In this stage, the effect (weight) of each in-site factor on site suitability is determined. In this process Analytical Hierarchy Process, AHP can be used. AHP considers decision makers judgement in evaluating the weight of each factor. AHP includes normalizing the calculated weights, i.e. the summation of all weights equals one. AHP method can be described as follows (Saaty, 2008):

2.1.1 Define the problem

Define the UTES system type and the controlling factors, e.g. seepage velocity and transmissivity, that have effects on the site selection.

2.1.2 Arranging

Arrange the factors from the high effect to low effect giving each controlling factor an index from 1 to 9 (see table 1). There are many applications that can be valid (Saaty, 2008). In spite of that, this scale can be changed according to the opinion of the decision makers in the geo-energy mapping field.

2.1.3 Pairwise matrix

Construct the pairwise comparison matrix which states the relationships between each two factors, see figure 1.

Table 1. Fundamental scale (Saaty, 1990)

Intensity of importance	**Description**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent judgment

2.1.4 Weighting

Use the pairwise matrix to find the weight of each factor. The weight of the factor is the relative importance or degree of relative importance amongst the elements (Jayant, 2018). It can be found by using the following equation (Chabuk, 2016):

$$W_i = \sqrt[n]{P} \qquad (2)$$

Where W_i is the weight of the i^{th} factor, P is the product of i^{th} row elements, n is the number of factors, it equals to number of rows or columns within the matrix.

To find the normalized weight, equation 3 is used (Saaty, 1990):

$$W_{in} = \frac{W_i}{\sum_i^n W_i} \qquad (3)$$

Where: W_{in} is the i^{th} normalized weight factor.

$$\begin{Bmatrix} a_{1,1} & a_{1,2} & a_{1,3} & \cdots & \cdots & a_{1,n} \\ a_{2,1} & a_{2,2} & a_{2,3} & \cdots & \cdots & a_{2,n} \\ a_{3,1} & a_{3,2} & a_{3,3} & \cdots & a_{i,j} & a_{3,n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m,1} & a_{m,2} & a_{m,3} & \cdots & \cdots & a_{m,n} \end{Bmatrix} \begin{Bmatrix} W_1 \\ W_2 \\ W_3 \\ \cdots \\ \cdots \\ W_n \end{Bmatrix} \quad \text{Such that} \quad \begin{Bmatrix} 1 & a_{1,2} & a_{1,3} & \cdots & \cdots & a_{1,n} \\ 1/a_{1,2} & 1 & a_{2,3} & \cdots & \cdots & a_{2,n} \\ 1/a_{1,3} & 1/a_{2,3} & 1 & \cdots & \cdots & a_{3,n} \\ \cdots & \cdots & \cdots & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & 1 & \cdots \\ 1/a_{1,n} & 1/a_{2,n} & 1/a_{3,n} & \cdots & \cdots & 1 \end{Bmatrix} \begin{Bmatrix} W_1 \\ W_2 \\ W_3 \\ \cdots \\ \cdots \\ W_n \end{Bmatrix}$$

Figure 1. Pairwise comparison matrix

2.2 AHP (check mode)

The consistency of the matrix must be evaluated. To verify the consistency of the matrix, the following steps are used (Saaty, 1990; Chabuk et al, 2016):

2.2.1 Lambda (λ_{max})

Lambda (λ_{max}, maximum eigenvalue) is an important verifying parameter in AHP. It is used for calculating the consistency ratio CR of the estimated vector in order to validate whether the pair-wise comparison matrix provides a completely consistent evaluation (Jayant, 2018). It is calculated as follow:

$$\lambda_{max} = \sum_{j=1}^{n}\left[W_J \sum_{i=1}^{m} a_{ij}\right] \quad (4)$$

Where W_{nJ} is the normalized J^{th} weight, $a_{i,j}$ is the weight effect for the parameter ij.

2.2.2 Consistency index

After finding (λ_{max}) consistency index (CI) can be found by the following equation (Saaty, 1980):

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (5)$$

Where n is the order of matrix as stated before.

2.2.3 Consistancy ratio

Then consistency ratio is calculated by using the following equation (Saaty, 1980)

$$CR = \frac{CI}{RI} \quad (6)$$

Where: CR is the consistency ratio; CI is the consistency index; and RI is the random index.

Random index depends upon the order of the matrix. It can be found by using table 2.

Table 2. Random index for different matrix orders (Saaty, 1980 Chang et al., 2007)

Order	RI	Order	RI
1	0	9	1.45
2	0	10	1.49
3	0.58	11	1.51
4	0.9	12	1.48
5	1.12	13	1.56
6	1.24	14	1.57
7	1.32	15	1.59
8	1.41		

2.2.4 Comparing

The last step is comparing the calculated CR with the standards values (maximum values). The maximum values of CR depend on the orders of the matrix; it is 0.05 for the 3rd order; 0.08 for 4th order; and 0.1 for 5th order and more (Jayant, 2017). The consistency ratio should be less than the maximum values otherwise the matrix will be inconsistent.

2.3 DRASTIC mode

By verifying the consistency of pairwise matrix, the next part which is related to DRASTIX index method can be initiated. It contains:

2.3.1 Ranging

In ranging, each controlling factor is divided into either numerical ranges or significant types according to the impact on site selection (Aller et al, 1987). This step depends on the decision makers' judgement. And results in a qualitative and quantitative assessment. Here the factors Groundwater and Bedrock depth, Transmissivity, Groundwater salinity, and Thermal and Hydraulic Conductivity are of type quantity. Soil and Groundwater type, Aquifer media and type and the Vadose zone media are quality based site specific factors. Each of them can be divided into identified ranges.

2.3.2 Rating

After completing ranging, rating of each range is performed. Rating depends on the relative significance of each range on site selection. The rating includes both types of ranges: quantity and quality based ranges. The rating is executed by assigning an index for each range. The assigned index ranges from 1 to 10, according to the relative importance of that range. High index (e.g. 10) means significant importance, whilst the low index (e.g. 1) means low importance. It is possible to normalize rating by dividing rating parameters by 10 (The maximum scale for rating). The site suitability index in this case ranges from 0 to 1.

The method that explained in this paper **is not** based 0 to 1 scale, **but** it is based on 1 to 10 scale. By executing rating, equation 1 becomes ready to perform by ArcMap/GIS.

2.4 ArcMap/GIS mode

After rating, ArcMap/GIS software is used to depict the results of equation 1 as map. At this stage, the method has the following steps:

2.4.1 Prepering the data

First, the data from the wells within the study area is prepared as excel files. The data include site coordinates and the values of in-site parameters. The excel files are then imported by ArcMap/GIS software.

2.4.2 Interpolation

Then, the maps of different in-site parameters are produced by using Interpolation tool within Spatial Analysis tools. The produced maps are classified into ranges according ranging step (2.3.1).

2.4.3 Reclassifying.

The maps in step (2.4.2) are reclassified according to rating classes in step (2.3.2), by using Reclass tool within Spatial Analysis tools.

2.4.4 Map algebra

Finally, Raster calculator tool within Spatial Analysis tools\Map Algebra is used to produce the site selection map. This tool requires all the input maps are raster maps. The resultant map contains pixels that possess 1 to 10 ranking. The most suitable site has the highest rank.

3 CASE STUDY

To explain the suggested method, Karbala province (within Iraq) was considered (Figure 2). Karbala province is one of the most importance cities in Iraq. Its area is 5034 km^2; its population is about 1 million people, and millions of visitors come to this city for religious purposes. Despite all these important factors, it has a serious problem of electricity deficiency, due to the overload that is generated from using air to air heat pumps in summer and winter.

It is believed that this problem can be significantly solved by using UTES systems. The problems now are: which type of UTES systems types can be used; and where can it be installed. To explain how the suggested method can contribute to decide the suitable site, a study area of 400 km^2 within Karbala city is selected (Figure 2).

The suitable site can be identified by using the suggested method. If aquifer storage system is considered to be the suitable type, the controlling site specific parameters are depth to groundwater; seepage velocity; transmissivity; aquifer thickness; type of aquifer; volume of the aquifer; types of groundwater; and temperature of groundwater. To simplify the problem, let’s take four effecting parameters, they are: Depth to groundwater; transmissivity; and seepage velocity and aquifer saturated thickness. These parameters were arranged according to their effect on site selection, and the pairwise matrix was produced (Table 3).

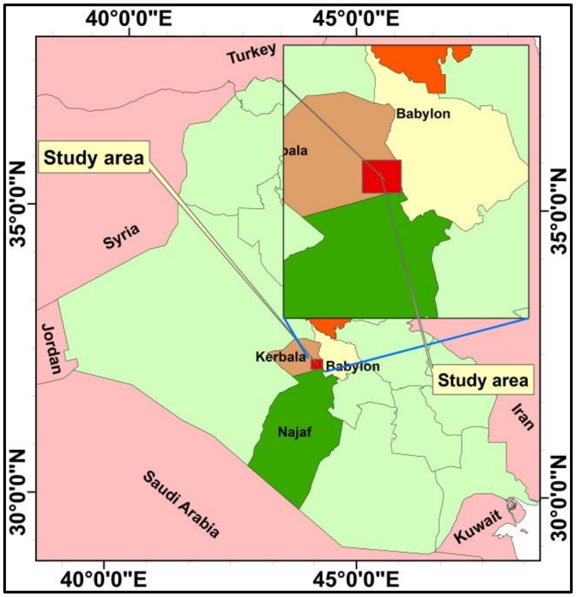

Figure 2. Karbala province location, and study area

Pairwise matrix was used to calculate the weight factors (*W*) and the normalized weights (W_n), (Table 3).

To verify the consistency of pairwise matrix, λ_{max} was calculated using equation 4. In this case λ_{max} is 4.1705. Then, λ_{max} was used to calculate consistency index CI using equation 5. Consistency index CI in this case is 0.0568. Then the consistency rate CR was calculated using equation 6. The random index (RI) for 4^{th} order matrix is (0.9)(Table 2). The resultant consistency rate CR was 6.3%. Since CR is less than 10% then the matrix has acceptable consistency.

The next step in the suggested method is ranging. Ranging should be performed by the aiming of the decision makers. It is assumed that each parameter is as stated in table 4. After that, rating should be executed. Rating for the considered study area case is presented in table 4.

After rating, ArcMap was used to produce the ranged maps (Figures 3, 4, 5, and 6). The data were obtained from the maps produced by Al-Ani (2004). Then Reclass tool within ArcMapsoftware was used to find the rated maps. Rated maps are presented, again, on figures 3, 4, 5, and 6 by altering the legend to the second one in each map, see the referred figures.

4 RESULT AND DISCUSSION

Using the raster calculator and rated maps 3-6, suitable site map can be produced (Figure7). The resultant map depicts the most suitable site to install an aquifer system. The most suitable site is within the red color with index rates from 8 to 9. More accuracy for site selection can be produced by increasing the ranges within the map in figure 7, and let the last range become narrower, say e.g. 8.8 and 9. The weights matrix (Table 3) demonstrates that the depth to GW factor is the predominant factor with a normalized weight of 0.654. The other factors have less weights, i.e. less importance on site selecting. Since CR (6.3%) is less than 10% then the matrix has acceptable consistency. When CR equals to zero then the matrix is fully consistent.

Table 3. Pairwise matrix for the study area case

	Depth to groundwater	**Seepage velocity**	**Transmissivity**	**Saturated thickness**	**Weight(*W*)**	**Normalized weights (W_n)**
Depth to groundwater	1	7	5	9	4.213	0.654
Seepage velocity	1/7	1	1/3	3	0.615	0.096
Transmissivity	1/5	3	1	5	1.316	0.204
Saturated thickness	1/9	1/3	1/5	1	0.293	0.046

Table 4. Parameters ranging and rating for Karbala region

Parameter	Ranges	Rating	Parameter	Ranges	Rating
Depth to groundwater (mbgs)	0-2.5	2	Transmissivity (m2/d)	20-130	3
	2.5-15	4		130-240	5
	15-30	9		240-350	7
	30-50	6		350-460	9
Seepage velocity (m/d)	0-0.02	10	Saturated thickness (m)	18 -25	3
	002-0.04	8		25-33	5
	0.04-0.08	6		33-41	7
	0.08-0.18	2		41-49	9

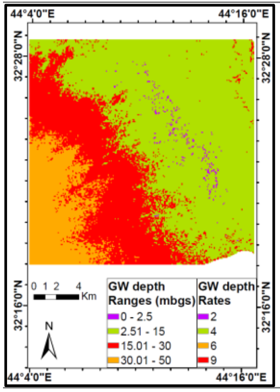

Figure 3. Groundwater depth ranged and rated maps of the sudy area shown in Figure 2.

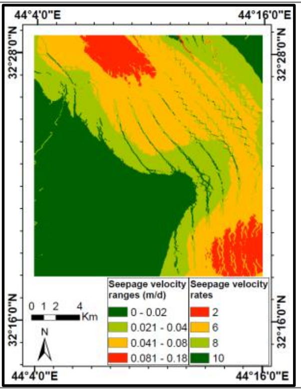

Figure 4. Seepage velocity ranged and rated maps.

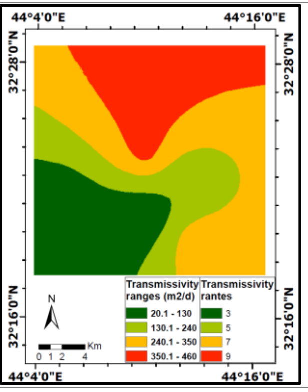

Figure 5. Transmissivity ranged and rated maps.

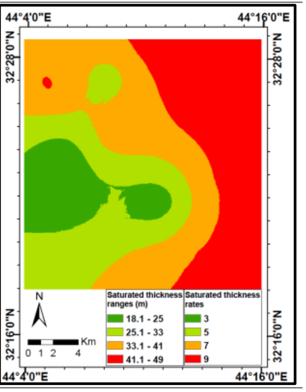

Figure 6. Aquifer saturated thickness ranged and rated maps.

5 CONCLUSIONS

AHP can help in taking the decisions in different applications, one of them UTES system site selection. It optimizes the utilized effort to decide the best location of UTES system according to site specific factors. ArcMap/GIS software can be used to demonstrate the results from AHP in effective way. AHP can be applied on the sub-divisions within each factor, i.e. ranges of each factor, to produce weighted rating factors. In this case the suitability index will be within the range of 0 to 1.

Also, this method can be modified to find the best type amongst UTES system types. Then the illustrated method can be used to find the best location for the selected type.

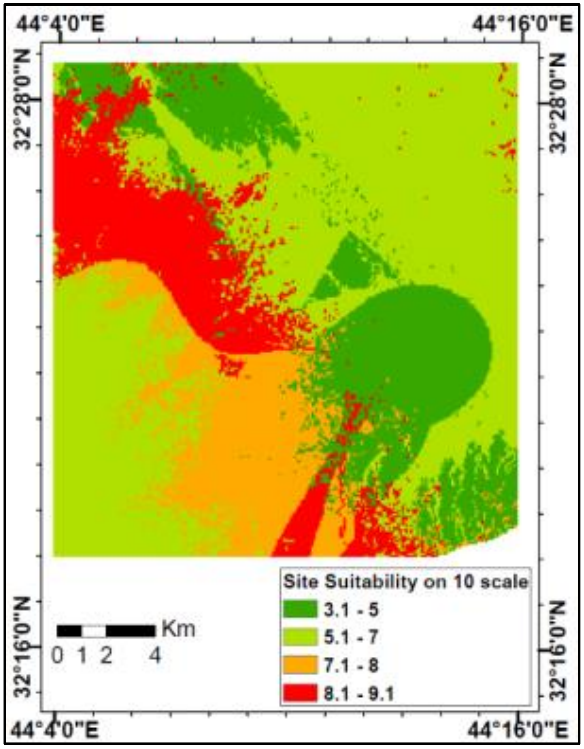

Figure7. Suitable site map.

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