Integrating Lineament Density in the DRASTIC Model for Better Groundwater Assessment

(Mengintegrasikan Ketumpatan Lineamen dalam Model DRASTIC untuk Penilaian Air Tanah yang Lebih Baik)

Nursabrina Syahirah Hairudin[1], Norhayati Mat Rawi[1,2], Norsyafina Roslan[1] & Norbert Simon[1,*]

[1]*Geology Program, School of Environment & Natural Resource Sciences, Faculty of Science & Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia*
[2]*Department of Mineral and Geoscience Malaysia, Aras 9, Menara PjH, No. 2, Jalan Tun Abdul Razak, Presint 2, 62100 Putrajaya, Federal Territory, Malaysia*

ABSTRACT

Forecast of groundwater potential zones is essential, especially in areas where surface water is not sufficient during the dry season, such as the Tampin District, Negeri Sembilan, Malaysia. In the literature, the lineament parameter is often combined with a groundwater assessment model such as the DRASTIC model. However, most of these practices do not follow the procedure of assigning weight to the parameter as used in the model, so many researchers assign different ranges of weights to the lineament parameter. Therefore, this study focuses on how to systematically incorporate a lineament density map into the existing DRASTIC model based on the specific range of weight specified by the model; thus, the inclusion of more geological input will improve the model performance. DRASTIC is an abbreviation for the parameters used in the model: Depth to water; Recharge; Aquifer media; Soil media; Topography; Impact to vadose zone; and Conductivity (hydraulic). The addition of the lineament density map has successfully improved the performance of the DRASTIC model from 50 to 80% based on the distribution of 30 producing wells in the Tampin District, where the geology and lineament density play major roles in determining the potential groundwater area.

Keywords: DRASTIC; groundwater; groundwater potential; lineament density

ABSTRAK

Ramalan zon potensi air bawah tanah adalah penting terutamanya di kawasan di mana air permukaan tidak mencukupi semasa musim kering. Kebelakangan ini, daerah Tampin di Negeri Sembilan telah mengalami masalah kekurangan air dan mengenal pasti sumber air yang lain adalah penting untuk mengekalkan sistem bekalan air yang berterusan kepada penduduk di daerah ini. Oleh itu, dalam kajian ini, gabungan antara model air bawah tanah sedia ada (DRASTIC) berserta dengan peta ketumpatan lineamen digunakan untuk mengenal pasti zon yang berpotensi mengandungi air bawah tanah. DRASTIC adalah singkatan kepada parameter: kedalaman air; pengimbuhan semula; media akuifer; media tanah; topografi; kesan kepada zon vados; dan konduktiviti (hidraulik). Penambahan peta ketumpatan lineamen kepada model DRASTIC berjaya menambah baik ketepatan model ini daripada 50 ke 80% berdasarkan taburan 30 telaga di Daerah Tampin. Peta potensi air bawah tanah ini menunjukkan zon yang berpotensi terletak di barat, barat daya, timur dan bahagian tengah kawasan kajian. Berdasarkan peta tersebut, geologi dan ketumpatan lineamen memainkan peranan penting dalam penentuan air bawah tanah di Daerah Tampin.

Kata kunci: Air bawah tanah; DRASTIC; ketumpatan lineamen; potensi air bawah tanah

Introduction

Groundwater is an important source of water supply worldwide because it is renewable, widely distributed, and comparatively cleaner than surface water (Balakrishnan et al. 2011). Malaysia has its own vision on water resource management as published in the FAO-ESCAP Pilot Project on National Water Visions report (Ti & Facon 2001). In the report, Malaysia clearly stated that in support of vision 2020, the country water resources will be managed

and conserved to ensure adequate and safe water supply for the public while preserving the environment. To further strengthen the vision, groundwater exploration programmes will be conducted in river basins to identify potential aquifers. However, because of the abundance of surface water resources, the utilization of groundwater continues to be lacking. The need for groundwater as alternative water source is apparent when water shortages occurred in Kuala Lumpur, Selangor, and Negeri Sembilan in 2014 (Husain et al. 2017).

This study aims to explore potential groundwater zones in Tampin District of Negeri Sembilan, Malaysia by including the lineament parameter to improve the performance predictability of an existing groundwater model. This area has experienced several water crisis events that caused water disruptions to the public. In 2014, and 2016, several water crisis reports were made due to the critical water level in the Gemencheh Dam, which supplies water to its surrounding. For example, in 2014, the water level at the dam dramatically decreased to 98.01 m, which was near its critical level of 98 m (Ismail 2014). In 2016, the same problem occurred, when the water level in this dam reached its critical level of 94.75 m due to the prolonged hot weather (Utusan Malaysia 2016). The two reports concluded that the decrease in water level in the Gemencheh Dam occurred because of the lack of rainfall. Sheriza et al. (2011) has shown that based on their studies on rainfall pattern from 1997 to 2006, the southern part of Negeri Sembilan, where Tampin is located, received the lowest amount of rainfall among all districts. From these events and studies, it is evident that exploring other water sources as an alternative to surface water is essential for this area. Moreover, according to the review of the National Water Resources Study (2010-2050), water demand in Tampin is expected to increase for domestic demand both in urban and rural areas from 205 litre/head/day (l/h/d) to 260 (l/h/d) and 200 (l/h/d) to 2242 (l/h/d) respectively based on per capita consumption (pcc) from 2010 to 2050 (Ranhill 2011).

GIS and remote sensing techniques are promising tools for regional assessment. GIS and remote sensing have been a vital tool to many researchers worldwide to facilitate assessment on groundwater potential. For example, Malaysia has embraced this technology in many groundwater studies. Some highlighted studies are: Shirazi et al. (2015) to characterize the groundwater quality and hydrogeology in the state of Malacca; investigation on the factors that affect groundwater chemistry in Pulau Kapas (Kura et al. 2013);

probabilistic-based frequency ratio model mapping in the Langat Basin (Manap et al. 2014); and Nampak et al. (2014) to apply the evidential belief function and logistic regression models in GIS to their groundwater studies in Sungai Langat catchment.

STUDY AREA & THE GEOLOGICAL BACKGROUND

The study area covers the entire Tampin district, which has an area of approximately 855 km^2 and the highest elevation of 760 AMSL (Figure 1). It has seven residences ('Mukim'): Tampin Tengah, Repah, Keru, Tebong, Gemencheh, Ayer Kuning, and Gemas. Agriculture is the main activity, and some areas in the district are gazetted as forest reserves.

In terms of geology, based on the geological map published by the Director General of the Mineral and Geoscience Department of Malaysia (1985), the study area is underlain by several lithologies from Ordovician to Triassic age. These lithologies are intrusive granite with patches of sandstone and mudstone at the western corner, schist and phyllite, slate, shale and sandstone on the central part, conglomerate at the north, and largely dominated by sequence of sandstone, siltstone, and shale in the eastern corner. Rhyolite and dacite are also common at the centre and eastern parts of the study area.

In terms of groundwater studies, there were not much conducted in the area of Tampin, which is the study area, but many were conducted in the Negeri Sembilan that also covers the pollution potential of groundwater. The few studies on groundwater pollution are by Ab Razak et al. (2015) who reviewed research papers for possible contaminants in several states in Malaysia and found that Al residual was found in the drinking water in the state of Negeri Sembilan. Another studies using geoelectrical imaging to study groundwater pollution potential at Gemenceh waste disposal site by Samsudin et al. (2000), in which they identified polluted aquifer in the disposal area and may travel to other area based on the groundwater flow. Recent studies on possible contaminants in the Tampin groundwater system shows that generally, the groundwater is safe to use, but good management is needed because high Fe was detected in few boreholes (Rawi et al. 2020).

METHODS

As introduced in lots of studies, many influencing factors are evidently important in groundwater potential assessment. Some of these factors are geological in nature, climate attributes, and from human interaction
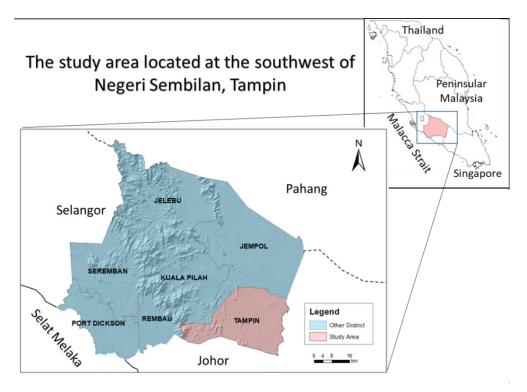
FIGURE 1. Location map of the study area, Tampin with its surrounding districts

with the land surface such as land use (Al-Bakri & Al-Jahmany 2013; Srivastava & Bhattacharya 2006; Venkateswaran & Ayyandurai 2015; Yeh et al. 2016, 2009). Combinations of factors are useful because they interact with one another to determine the occurrence of groundwater. These combinations are often conducted in GIS environment to yield a groundwater potential map (Aouragh et al. 2016; Deepa et al. 2016; Patil et al. 2014).

One simple but effective way to combine factors in GIS is based on the overlay and index procedures, which are often used in groundwater assessment because they are easily implemented, comprehensible, straighforward, and usually produce relatively accurate results in a complex geological setting (Malakootian & Nozari 2020). One of the well-known models in this category is DRASTIC model which was developed by (Aller et al. 1985), and later was modified into several extended model such as CDRASTIC, DRASTICM, and DRASTICA (Barbulescu 2020; Malakootian & Nozari 2020). Several other modifications such as adding land use parameters seems to show improvement to the original DRASTIC model (Kozłowski & Sojka 2019). However, not all modification will yield better result than the original model (Thapa et al. 2018). These extensions were made

based on the availability of data, improvement, and study area. Modification to the DRASTIC model is not limited to just changing to adding new parameters, it was also modified by combining the model with other heuristic model such as the AHP (Khan & Jhariya 2019; Paul & Das 2021). Other method includes combining the DRASTIC and geo-electrical techniques in the field to provide better and comprehensive understanding of aquifer characteristics (Shah et al. 2021).

The DRASTIC model is used to explore the groundwater potential in this study because it offers simple and straightforward methods (Jang et al. 2017). Although the DRASTIC model is used for pollution potential mapping, the model is also designed to predict groundwater potential zones. According to Aller et al. (1987), the DRASTIC model identifies groundwater movement from one place to another and can be used to make generalizations on both groundwater availability and groundwater pollution mapping.

The DRASTIC method is used to evaluate the groundwater potential zone based on seven parameters: depth to water ($\mathbf{D}$), net recharge ($\mathbf{R}$), aquifer media ($\mathbf{A}$), soil media ($\mathbf{S}$), topography, ($\mathbf{T}$), impact of vadose zone ($\mathbf{I}$), and hydraulic conductivity ($\mathbf{C}$). Each factor is mapped

and classified into variables with a scale (weight) of 1-10. In addition to this scale, a relative weighting multiplier is used to indicate the importance of each factor. The full range of factors with their respective scale and weighting multiplier can be found in Aller et al. (1987). The sum of these factors indicates the groundwater potential of an area. The computation of this method is based on the seven parameters as follows:

$$D_i = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w$$

where D_i is the DRASTIC index; r is the parameter rating; and w is the relative weighting multiplier.

The final DRASTIC map is classified into eight (8) categories based on the standard colours recommended by Aller et al. (1987) (Table 1). These colour codes represent the DRASTIC index generated from the overlay of different parameters. Based on Aller et al. (1987), warmer colours (yellow, orange, red) correspond to higher potential, and cooler colours (violet, indigo, blue) indicate lower potential. Different sources of data are used to extract information for different DRASTIC parameters. In this study, the parameters and their data sources are shown in Table 2 and Figure 2. The geology, soil and topography source maps were acquired from the Department of Minerals and Geoscience, Department of Agriculture, and Department of Survey and Mapping Malaysia, respectively. Information extracted from the boreholes/tubewells was obtained from the Department of Minerals and Geoscience, Malaysia.

TABLE 1. Recommended colour codes to represent the index range for the final DRASTIC map (modified from Aller et al. (1987))

Index range	Colour standard
< 79	Violet
80 – 99	Indigo
100 – 119	Blue
120 – 139	Dark green
140 – 159	Light green
160 – 179	Yellow
180 – 199	Orange
> 200	Red

TABLE 2. Source map to generate DRASTIC parameters

DRASTIC Parameter	Data source/map
Depth to water (D)	Borehole, tubewell, topography
Net recharge (R)	Geology, soil, slope
Aquifer media (A)	Geology, soil
Soil media (S)	Soil
Topography (T)	Topography
Impact to vadose zone (I)	Geology, soil
hydraulic conductivity (C)	Geology, soil

Source: Borehole and tubewell (Department of Mineral & Geoscience Malaysia, Negeri Sembilan); topography (SRTM); slope (SRTM); Soil (Department of Agriculture, Malaysia N.D.); geology (Director General of Geological Survey of Malaysia 1985)

Apart from the existing parameters in the DRASTIC model, this study integrates the lineament parameter into the model. The lineament in the study area was interpreted from SRTM data and transformed into a lineament density map. The lineament density was produced based on 1-km × 1-km grid cells, which were generated using the fishnet tool in ArcGIS 10.1. In the density calculation, the total length of lineaments in every 1-km^2 grid cell is used to indicate the density (Figure 3). Subsequently, the lineament density is classified into three classes: low, moderate, and high. The selection of this density range is further discussed in the result and discussion section.
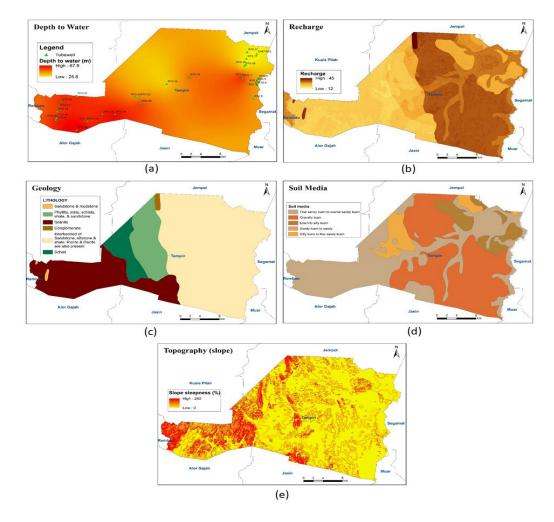

FIGURE 2. Source map to produce the groundwater potential map; (a) Depth-to-water map generated from the analysis of tubewell; (b) range of recharge map; (c) geological map; (d) soil map to produce aquifer media, impact to vadose zone and hydraulic conductivity maps; (e) slope steepness map

The groundwater potential map is validated using the distribution of wells. In the validation process, only wells within the classes that are specified as high potential are calculated. The percentage of wells in this class will determine the performance of the model.

RESULTS AND DISCUSSION

Parameter maps were classified according to the classification in the DRASTIC module by Aller et al. (1987) as presented in Table 3 and Figure 4. This study would like to highlight that the lineament parameter is originally not in the DRASTIC parameter. The discussion for each parameter in this study is as follows.

DEPTH TO WATER

The water depth calculated from the distribution of wells recorded a minimum depth of 25.8 m and a maximum depth of 67.9 m. A kriging method was employed to generalize the water depth for the entire study area. The deepest water depth is recorded at the southwest and centre parts of the study area. Most parts of the northeastern area are shallower.
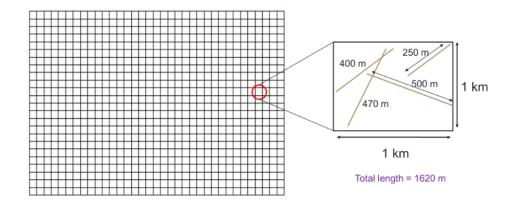
FIGURE 3. Method to calculate the lineament density in every grid cell

TABLE 3. Distribution of weight for attributes in every DRASTIC parameter generated for this study

Parameter	Medium	Rating*	Index (r x w)*
Depth to water (m)	9 – 15	5	25
	15 – 22	3	15
	22 – 30	2	10
	30+	1	5
Recharge	12 – 23	1	4
	23 – 26	3	12
	26 – 30	6	24
	30 – 37	8	32
	37 – 45	9	36
Aquifer media	Schists	3	9
	Granite	3	9
	Phyllite, slate, schists, shale, & sandstone	4	12
	Interbedded of sandstone, mudstone & shale. Rhyolite & dacite are also present	6	18
	Sandstone & mudstone	7	21
	Conglomerate	9	27
Soil media	Loam to silty loam	4	8
	Silty loam to fine sandy loam	5	10
	Fine sandy loam to coarse sandy loam	6	12
	Gravelly loam	7	14
	Sandy loam to sandy	9	18
Topography (slope %)	0 – 2	10	10
	2 – 6	9	9
	6 – 12	5	5
	12 – 18	3	3
	>18	1	1
Impact to vadose zone	Schists	3	15
	Granite	4	20
	Phyllite, slate, schists, shale, & sandstone	6	30
	Sandstone, siltstone, & shale	6	30
	Sandstone & mudstone	6	30
	Conglomerate	8	40
Conductivity (GPD/FT^2)	Schists	3	15
	Granite	4	20
	Phyllite, slate, schists, shale, & sandstone	6	30
	Sandstone, siltstone, & shale	6	30
	Sandstone & mudstone	6	30
	Conglomerate	8	40

*The rating and index (r x w) are based on suggested value and method by Aller et al. (1987)
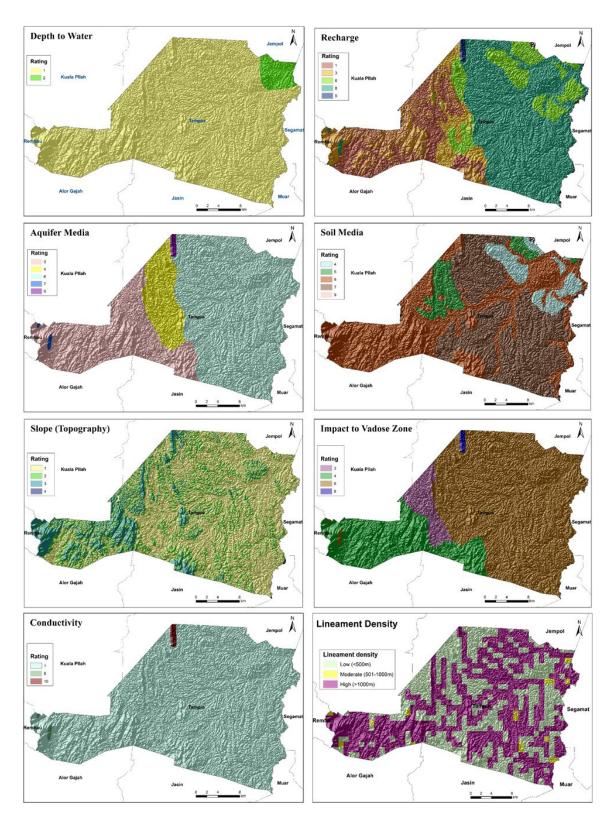
FIGURE 4. DRASTIC parameter and lineament density to generate the groundwater
potential map in Tampin

RECHARGE MAP

Groundwater or aquifer recharge is defined as movements of water from the land surface or unsaturated zone into the saturated zone (Nimmo et al. 2005). Knowing the recharge mechanism is vitally important for understanding the hydrologic cycle. Considering its importance, some authors have suggested to identify artificial recharging methods and source to maintain a long-term sustainability of water resources (Senanayake et al. 2016). The recharge map of the study area is important because it shows the replenishment levels of each area to maintain the water supplies, especially where groundwater is extracted for human use (Nimmo et al. 2005).

There are many suggested methods in the literature to model groundwater recharge. Risser et al. (2005) classified the method in recharge modelling into two distinct groups: indirect estimate, which uses model such as HELP, HYSEP, RORA, and PULSE, and direct estimate, which depends on measurements from field tools, e.g. gravity lysimeters and piezometer in the Episodic Mater Recession model (EMR) (Allocca et al. 2015). RORA is a basin scale model that uses streamflow records (Delin et al. 2007). These models require extensive field data, which presents difficulties for application in a regional scale.

Due to the lack of several data sources, this study employed a method suggested by Sesser et al. (2011). Their method is known as SVWS (Sonoma Valley Watershed Model), and the full description of this technique can be found in their technical report on Sonoma Valley Groundwater Recharge Potential Mapping Project. This method is useful for regional-scale studies and areas that lack climate and well data. The SVWS method was developed from four basic elements: vegetation, soil, slope and geology. Based on their report, the model was developed from various sources and through personal contact, so a weightage system was produced for the four elements. The geological element carries the highest weight with 50%, followed by soil (25%), slope (15%), and vegetation has the lowest weight (10%).

However, due to the lack of land use map to consider the vegetation factor, this study only considers three elements (soil, slope, and geology) to generate the recharge map. Excluding the vegetation element is not critical in the analysis because it only accounts for 10% of the total weight in the model. From the analysis, the lowest recharge value is 12 and can be observed at the southwestern section, and the highest recharge area is at the centre of the study area (Figure 4).

GEOLOGY AND RELATED FACTORS (AQUIFER MEDIA, VADOSE ZONE, HYDRAULIC CONDUCTIVITY)

Geological information basically provides the types and properties of the underlying rock or soil (Senanayake et al. 2016). Different porosities in different rock types govern their recharging capacity and effectiveness to retain water (Senanayake et al. 2016). The main factor in the significance of geological materials in groundwater assessment is the level of porosity of different geological properties. In the DRASTIC method, three parameters were derived from geological properties, which are aquifer media (**A**), impact to vadose Zone (**I**), and hydraulic conductivity (**C**).

The first parameter is the aquifer media (**A**), which refers to the consolidated or unconsolidated rock units that will yield sufficient quantities of water at the subsurface section of the ground (Aller et al. 1987). Geological materials are divided into massive single rock type, layered rock, unconsolidated mixtures, and weathered material. Due to the level of rock porosity, conglomerate has the highest weight, followed by sandstone and mudstone. The lowest weight is attributed to granite intrusive and schist due to their low porosity. The second parameter is the impact to vadose zone (**I**), the lithology and soil maps are used, and the weighting provided by the DRASTIC model for the impact to vadose zone parameter is assigned to each lithology. The highest weighting is given to conglomerate, and the lowest is given to granite and schists.

The final parameter is the hydraulic conductivity (**C**), which refers to the ability of the materials to transmit water, which controls the rate of the groundwater flow for a given hydraulic gradient (Aller et al. 1987). In this parameter, the level of porosity is very important at the interconnection of void spaces, which can occur as intergranular porosity, fracturing, or bedding plane and will indicate whether the water transmission can be smooth. Aller et al. (1987) provided guidelines on the hydraulic conductivity for different lithologies. Based on the lithologies present in the study area, conglomerate was assigned the highest weighting for conductivity, whereas granite and schist have the lowest weight. Granitic rock, in particular found to contain low to moderate volume of groundwater in some parts of Malaysia (Mohamad & Roslan 2017).

SOIL MEDIA

Soil permeability refers to the effective porosity of soil and is also an important parameter in groundwater studies (Senanayake et al. 2016). Due to their porosity, fine-

textured materials such as silts and clays can decrease the relative soil permeability (Aller et al. 1987). Thapa et al. (2017) demonstrate how soil plays an important role in delineating areas with good groundwater potential in West Bengal, India, because different soils have different texture and will interact differently when they are in contact with water. This interaction is largely affected by the soil texture, which refers to the description of the particle size distribution from fine to coarse particles and is perhaps the most important parameter for soil because it controls the water infiltration rate (Delgado & Gomez 2016).

There are 12 soil series in the study area, which resemble different types of properties. Based on the soil guidelines by the Department of Agriculture Malaysia (1993) and Pramanathan (2000), the soil series in the study area were grouped into similar soil types, and their contribution to groundwater occurrence was weighted based on their soil texture, porosity and drainage. Therefore, areas that consist of sand and coarser materials have higher weighting, and areas that are covered by finer soil have lower weighting. Any mixture of soil texture will be weighted accordingly based on the guidelines by Aller et al. (1987).

TOPOGRAPHY (SLOPE)

The slope is expressed as a slope gradient and refers to how water flows on different gradients in a slope (Senanayake et al. 2016). Higher runoff on steep slopes causes low infiltration, which makes it difficult for water retention (Srivastava & Bhattacharya 2006). The reason is that rapidly downward flowing water from a steep slope has problem in terms of time to infiltrate the ground as opposed to flat grounds, which have longer and more extensive rainwater retention (Senanayake et al. 2016).

In the DRASTIC model, the slope steepness is presented in 'percentage'. In the study area, the slope steepness is 0% (flat) to 290%, which corresponds to 71°. Most of the steeper slopes are located at the northwestern section of the study area, where the lithology is dominantly granitic. A steeper slope was assigned to a lower weight than a gentler slope.

LINEAMENT DENSITY MAP

Groundwater movement and occurrence in a watershed of a hard rock terrain is mainly controlled by the secondary porosity, which is caused by the fracturing of the rock beneath (Srivastrava & Bhattacharya 2006). Therefore, to demonstrate the effect of lineament on groundwater studies, the use of the lineament density map to infer the secondary porosity was suggested by Senanayake et al. (2016). According to them, geological discontinuities that are attributed to faults or fracture systems can act as conduits for groundwater movement and storage. They classified their lineament density map into three classes for different lineament density classes with low density (< 0.5 km/km^2), moderate ($0.5 - 1$ km/km^2), and high ($1 - 3$ km/km^2). Each class is given a weight of 1, 4, or 6 to mark its importance. Sarup et al. (2011) demonstrate that the lineament parameters can be further divided into lineament frequency and lineament intersection. These parameters are important to identify favourable zones of groundwater.

In terms of lineament association with groundwater occurrences, Nasiman et al. (1997) found close relationships among fracture patterns with the occurrence of groundwater in Negeri Sembilan. Based on their findings, the availability of groundwater is affected by the presence of fracture openings, fault zones and weathering profile of rocks. They also concluded that tubewells that were sufficiently deep to penetrate water bearing fractures may sustain a maximal yield of 1264 m^3/well/day.

In this study, the lineaments extracted from SRTM were transformed into a lineament density map with classes of low (< 500 m/km^2), moderate (501-1000 m/km^2) and high (> 1000 m/km^2). Senanayake et al. (2016) have proven that these classes of lineament density could yield satisfactory result, which indicates a groundwater potential area. These classes correspond to the total length of lineaments in a 1-km^2 grid. However, the weighting of each class is different. The three density classes are given weights of 1, 6, and 9 to differentiate their importance. A multiplier of 5 is given to this parameter to show its importance, since other studies have shown that lineament has major effect in locating groundwater sources (Yeh et al. 2009). This study assumes the following to classify the lineament density map:

(a)The classification of lineament should be based on the lineaments in each grid and not the distribution of lineaments in the study area. Hence, the classification such as natural break is not appropriate.

(b)Classification classes should depend on the grid size in accordance with the total area. The reason is that some study area may not be in a regional size; hence, classifying the lineament density using a 1-km^2 grid is not suitable.

(c)To classify the lineament density, the 'low density' class should contain the total length of lineaments below the size of the grid, and the 'high density' class should have the total length of lineaments above the size of

the grid. The 'moderate density' class can be classified between the low- and high-density classes. For example, this study uses a 1-km × 1-km grid size. The lineament density in the study area is classified into three classes: low, moderate, and high. The low-density class contains lineament length below 501 m in each grid, the moderate-density class contains 501-1000 m in each grid (not exceeding 1 km), and the high-density class contains the total lineament length above 1000 m (Table 4).

TABLE 4. Rating for lineament density used in this study.

The lineament classification is based on Senanayake et al. (2016)

Parameter	Medium	Rating*	Index (r x w)*
	<500 m	1	5
Lineament density (m/km^2)	501-1000 m	6	30
	>1000 m	9	45

WELL DISTRIBUTION

There are 30 tubewells with water yield, and their distribution is uneven especially in the centre part of Tampin. Most of these wells are located at the west, southwest, east and northeastern parts of the study area. In terms of geology, 12 wells are located in the granitic area, 14 are in the interbedded of sandstone, siltstone and shale lithologies with volcanic rock, 3 are in schist, and 1 is in an area dominated by phyllite, slate, sandstone and schist group. The well locations are used to validate the groundwater potential maps generated in this study.

GROUNDWATER POTENTIAL

Based on the classification recommended by Aller et al. (1987), the three potential classes starting from the value of 160 can be considered high-potential zones for groundwater occurrences. Thus, the yellow, orange and red zones in Figure 5 represent high-groundwater-potential sources. These areas cover 604 km^2 of the study area. Most of the high-potential zones lie within the east, central and northern parts of Tampin. The very-low-potential zones are mainly distributed at the western corner.
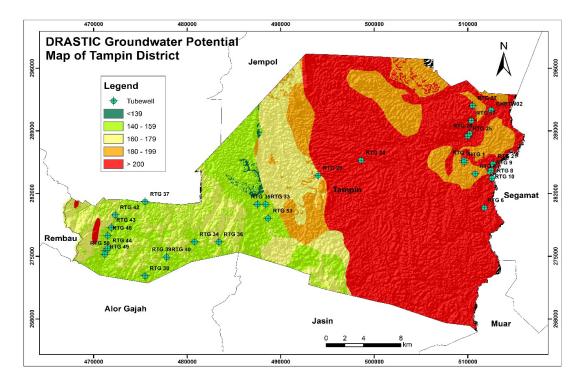

FIGURE 5. Groundwater potential map generated only from the combination of DRASTIC parameters excluding the lineament density map. The high-potential zones lie within the eastern, central and northern sections of Tampin. Fifteen (15) wells are located in the areas with groundwater potential

VALIDATION

From the distribution of wells around the study area, 15 wells were inside the high- to very-high-potential zones. This value corresponds to only 50% of the total wells that yield water in Tampin. This result is not consistent with the potential zones depicted by the map because the other 53% of wells are not within the high- and very-high-potential zones; instead, they are located in the low-potential zone. By using only the DRASTIC map, this accuracy issue is difficult to address. This study also finds that 12 of 15 wells in the low-potential zones are actually located in the granite zone, which is apparently dense with lineaments (Figure 5).

To include the lineament density map into the DRASTIC model, the initial five potential categories must

be adjusted. The categories were adjusted based on the 9.5% of the maximum value from the DRASTIC total weight for each potential category with the weighting for the lineament density map. Based on the initial DRASTIC model, there are 8 potential categories with the difference in value of 19 for each category (80 - 99, and 100 - 119). These values correspond to 9.5% of the minimum value in the final category (200). Therefore, this study uses this percentage value to categorize the final map when adding the lineament density map into the DRASTIC model.

After the lineament density map is added, the accuracy of the final potential map greatly increases from 50 to 80%, where 24 of 30 wells are located in the high-potential zones (Figure 6). This result demonstrates
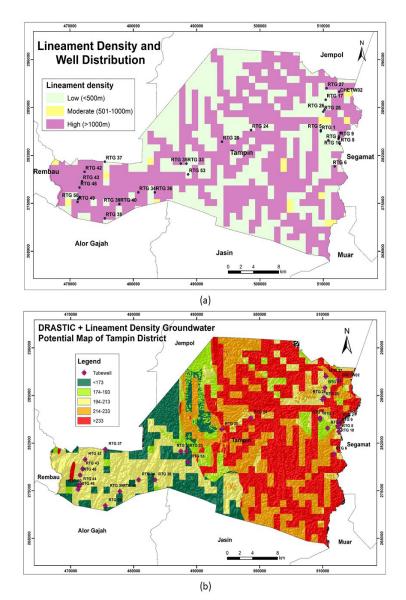

(a)

(b)

FIGURE 6. (a) Lineament density map generated based on the total length of lineament in the 1-km^2 grid and distribution of wells on different lineament density classes; (b) Final groundwater potential map based on the DRASTIC model with a lineament density map as an additional parameter. More wells are located in the promising groundwater potential zones

the importance of the lineament density parameter to improve the performance of the original DRASTIC model to delineate areas with groundwater potential. This finding is also consistent with the studies of Nasiman et al. (1997) and Senanayake et al. (2016), in which it is shown that lineaments highly contribute to the groundwater potential.

Conclusion

In this study, an approach to integrate a new parameter, which is a lineament density map into the DRASTIC model, was proposed for the Tampin District of Negeri Sembilan, Malaysia. The technique includes recommended procedures to calculate the lineament density based on the grid system and the method to include the lineament density parameter into the existing DRASTIC model. This study has produced a groundwater potential map for the Tampin District based on the combination of the original DRASTIC model with a lineament density map, which yields a high-accuracy groundwater potential map. The potential map indicates that the potential zones are located in the west, southwest, east and some parts at the centre of the study area. The geology and lineament density play important roles in determining the groundwater potential zones. The potential map generated in this study can benefit policy makers and agencies as a preliminary assessment of groundwater potential in the study area. In addition, the technique employed in this study can be practised when new parameters must be included in the existing DRASTIC model to improve its performance.

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*Corresponding author; email: norbsn@ukm.edu.my