

MAPPING DEEP AND SHALLOW GROUNDWATER POTENTIAL ZONES USING GIS AND SPATIAL ANALYSIS

CASE STUDY: MONARAGALA DISTRICT, SRI LANKA

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Abstract: One of the most important steps in the proper management of the groundwater resources is the demarcation of the zones with potential for groundwater. Groundwater investigations have been found to be difficult and complex in many cases. It is necessary to demarcate the shallow and deep groundwater potentiality separately to get proper results in the groundwater investigations. Sri Lankan districts face many problems due to the scarcity of water. As the population is increasing and due to urbanization, the surface water is not sufficient to meet the water requirements. This research mainly focused on groundwater potentiality in the Monaragala district in Sri Lanka, it is covered by an area of 5708 km². Two types of GIS methods were mainly used for finding the potential zones for deep and shallow groundwater. Such as fuzzy overlay and weighted overlay method. The final results obtained in both cases were compared to find the most accurate result. Six parameters were used for the study of groundwater potentiality. They are proximity to surface water bodies, soil depth, and rainfall, aquifer type, soil group and slope for the shallow groundwater potentiality. Proximity to lineament, geology, and shallow groundwater parameters were used for profound groundwater potentiality. The final output resulting maps were classified into five major groups. Such as extremely low, low, moderate, high, and extremely high potential groups by considering the potential values obtained. The deep groundwater potential map indicates that the areas of high groundwater potential are found around the lineaments, particularly in the areas where mountain ranges are found. Hence, the effect of the lineament is very high in the availability of deep groundwater. The areas of high shallow groundwater potential are found in smaller areas around Siyambalanduwa, Katharagama, and Thanamalwila. The results obtained were validated with existing data using 100 dug wells and 220 tube wells.

Key words - Fuzzy overlay, Geology, GIS, Groundwater, Lineament, Weighted overlay

I. INTRODUCTION

Water is one of the most important components of the earth and without it life on earth is futile. All the natural and manmade processes require water directly or indirectly. Humans use water for many day-to-day activities mainly drinking and others; such as for domestic use, agriculture, and industry/tourism. Water exists in the environment in many phases such as solid, liquid, and gas. Atmospheric water, fresh water, saline water, and ice are the major reservoirs of water, and the water moves between these reservoirs through the physical process like evaporation, precipitation, consolidation, etc. Fresh water which is used by a human can be found as surface water and groundwater. Water covers 71% of the Earth's surface and from that 71%, only 3% is fresh water, but from that, around 69% exists as glaciers, 30% exists as groundwater and only 1% exists as surface water, which can be easily extracted for human usage. (Usbr.gov, 2020)

The most significant source of fresh water available is underground. Groundwater is water that is crammed in the pore spaces between rock formations and sediments under the ground. If these rocks or sediment deposits can yield a usable quantity of water, it is called an aquifer. Groundwater is one of the most important natural resources for human needs as well as for economic growth. For the conservation of water quality and the management of groundwater systems, the evaluation of the groundwater potential zones is extremely significant. Groundwater is also attracting more attention due to the issue of drought, the availability of rural water, the irrigation project, and the low-cost construction projects

There are several factors affecting groundwater potentiality. Such as lineament, geology, rainfall, soil type, soil depth, slope, surface water bodies, aquifer types, etc. When considering groundwater potentiality, it can be mainly categorized into two types. They are deep groundwater and shallow groundwater (Perera, 2005). Topographic and hydrogeological characteristics of the study area indicate whether there is a deep or shallow groundwater availability. However groundwater potentiality is mainly affected by structures (lineament), and fever is affected by other factors.

The study area considered in this research is the Monaragala district in Sri Lanka. It is one of the least developed districts in the country. Cultivation is more popular among rural people in the district of Monaragala as their livelihood. But the availability of water is not enough for day-to-day life, and agriculture works in particular. Monaragala experiences an extreme variation of

geology and topography. (JICA, 2003) So groundwater availability is spread from shallow to deep. People use tube well and dug well to fulfill their water requirements. Therefore identification of groundwater potential areas should be deeply evaluated in the district of Monaragala.

Because of the efficiency of data gathering, analysis, validation, and visualization, remote sensing and Geographic Information System (GIS) approaches are significant for site suitability analyses. As a result, a groundwater potential map can be created using GIS and remote sensing to identify potential zones to find some solutions for the water shortage problems in the Monaragala district.

NEED OF THE STUDY.

Some districts of Sri Lanka have various problems due to a lack of water. With the population growth and urbanization, surface water is not enough to meet the water requirement. Also, surface water is polluted by contaminants. So it is needed to use the groundwater resource. For sustainable use of groundwater, it is needed to have an accurate method to identify groundwater potential areas. But still, there is no correct groundwater potential map. This study provides an effective tool for mapping groundwater potential areas in the Monaragala district of Sri Lanka.

SCOPE AND LIMITATION

In the past, researchers have used various methods to identify potential areas of groundwater. The traditional approaches are mainly based on ground surveys using geophysical, geological, and hydrogeological tools which are generally expensive and time-consuming. After that researchers used Remote Sensing (RS), GIS, and Multi-Criteria Decision-Making (MCDM) techniques to identify groundwater potential areas. According to the literature review, numerous criteria can be considered when identifying groundwater potential zones. However, due to a lack of data and a time constraint, only a selected criteria were evaluated. Also, it is difficult to create some data (Lineament) same as in the real world with limited sources. Minor lineaments are difficult to identify using digital data (DEM, Hill shade, Contour). Field investigation should be conducted to identify all the lineament. Accuracy of the validation is directly depend on number of well samples and the spatial distribution of the well locations. Well distributed, high number of wells leads to high standard validation. But validation process were done by using available tube well and dug well data.

II. RESEARCH METHODOLOGY

2.1. Criteria Selection and Data Creation

The study was carried out mainly under two categories to find potential deep and shallow groundwater areas using both fuzzy and weighted overlay techniques. Aquifer types, soil depth, average annual rainfall, proximity to surface water bodies, slope and soil group considered for the shallow groundwater analysis. Geology and lineament was considered with the above criteria for the deep groundwater analysis.

2.1.1. Aquifer type

Aquifers are the main groundwater storage layers. Some layers hold high groundwater capacity while others are holding low capacity. Three major aquifer types cover the study area. About three-quarters of the total area of the Monaragala district covers a hard rock aquifer which is having lesser groundwater capacity. Regolith aquifer is the prominent aquifer type from the remaining area and alluvial aquifer covers a smaller area. The alluvial aquifer is the best groundwater holding layer.

2.1.2. Soil depth

The root space and amount of soil from which plants meet their water and nutritional demands are defined by soil depth. Deeper soils can give plants more water and nutrients than shallower soils. It means when the soil depth is increased, groundwater potentiality also will be increased. Soil depth data was created by using overburden depth values obtained from tube wells by National Water Supply and Drainage Board. Systematic risk is the only independent variable for the CAPM and inflation, interest rate, oil prices and exchange rate are the independent variables for APT model.

2.1.3. Average annual rainfall

Rainfall can be considered the major water source for the hydrological cycle. Water infiltrates through pore spaces in the soil in locations with sufficient precipitation, passing through the unsaturated zone. Water fills in more of the pore spaces in the soils as it sinks deeper until it reaches a saturation zone. So high rainfall causes a high potential groundwater availability. (Abdullahi and Garba, 2016)The study area has a considerable dry climate. Since rainfall is not largely varied over the year, average annual rainfall is considered. Rainfall data were collected from the Meteorological Department of Sri Lanka.

2.1.4. Proximity to surface water bodies

Water bodies are the natural places where a high amount of water is stored. So water can be easily infiltrated the ground through the soil particles. This water can increase soil moisture and water vapor in the surrounding area. It will cause to reduce water evaporation from the soil. Then shallow groundwater drain into the surface is minimized. Groundwater potentiality and proximity to surface water bodies have an inversely proportional relationship. The water bodies are extracted from the land use land cover data which is taken from the Land Use Policy Planning Department of Sri Lanka.

2.1.5. Slope

The slope difference plays an important role in the identification of groundwater potential areas. Areas with flatter or lesser slope is an effective criterion of groundwater potential zones, as they give better rates of water renewal than regions with greater slopes, which affect water absorption and the amount of precipitation infiltrated. Erosion, surface runoff, and material transport are all primarily caused by the slope. When the slope is the smallest, maximum penetration occurs, and when the slope is the greatest, minimum penetration occurs. Highly elevated mountainous environments with high slope values are thought to have a high water flow and weak infiltration systems. Flat areas with lesser slopes can hold more rainwater and have a higher groundwater potential capacity. SRTM DEM data were acquired from USGS (United States Geological Survey) Earth Explorer was used to creating slope map.

2.1.6. Soil group

The soil has an essential role in defining groundwater potential zones. Soil is characterized by its climate, physiography, and geology, which all play an influence on groundwater supply and discharge. The area's moisture absorption capacity is determined by the soil types and permeability. The research region is mostly covered by six primary soil types, according to Approximate Distribution of Great Soil Group map prepared by Panabokke, C.R.; Agriculture department of Sri Lanka.

2.1.7. Geology

Geology is the main consideration factor when studied about deep groundwater availability. The geology data for the study area was obtained from the Geological Survey and Mines Bureau Department. The study area lies on the highland complex and the vijayan complex. In the western and northwestern parts of the area, the Highland Complex rocks dominate. The Buttala Klippe, the Monaragala Range, the Kataragama Complex, and other highland complex outliers can be found within the Vijayan Complex in the region. Thirty-two sub-geological types can be found in the study area. They were categorized into five main geology types by considering their water storage capacity with the help of hydrogeologist opinion. Such as Pegmatite, Marble, Quartzite, Charnockite and Gneiss. Among them, Pegmatite has a low water storage capacity and marble has a higher water storage capacity.

2.1.8. Lineaments

A lineament is a landscape feature that is the result of an underlying geological structure, such as a fault, fractures, joints, streams, etc. They are the main path to water flow through the earth's geological formation. Lineaments were taken from Geology data which is collected from Geological Survey and Mines Bureau Department. Minor lineaments were not recorded in Geology data, so they were identified by different methods. SRTM DEM data were acquired from USGS (United States Geological Survey) Earth Explorer was used to create contour map, different hill shade maps, and stream network map. These data were used to create a minor lineament map in the GIS environment. Groundwater potentiality and proximity to lineaments have an inversely proportional relationship.

2.2. Assigning Fuzzy Membership Values

There were four categorical data and four continues data in this study. Fuzzy membership values were assigned to the categorical data by using expert's knowledge. "Fuzzy membership" tool was used to assign membership values for the continuous data layers. To do that fuzzy linear membership type was used. In linear membership type, membership values were calculated based on liner transformation of the input raster by assigning '0' at the minimum importance and '1' at the maximum importance. All the created criteria layers were overlaid using fuzzy overlay tool to create a shallow and deep groundwater potential maps.

2.3. Assigning Weight Values

All the created criteria layers were overlaid using weighted overlay tool to create final potential maps. Criteria were given weights according to their importance based on the expert knowledge and the literature. There, sub categories of the criteria were ranked on their importance according to one to nine scale where, 1 for the minimum potentiality and 9 for the maximum potentiality. Table 2.1 and 2.2 show the considered criteria and their final weight values for the shallow and deep groundwater analysis respectively.

Table 2.1 Weight and Ranks for criteria selected in Shallow groundwater analysis

Main Criteria	Sub Criteria	Rank	Final Weight (%)
Soil Depth (m)	0-5	1	30
	5--10	2	
	10-15	3	
	15-20	4	
	20-25	5	
	25-30	6	
	30-35	7	
	35-40	8	
	40<	9	
Aquifer Type	Hard Rock	1	25
	Regolith Aquifer	5	
	Alluvial Aquifer	9	
Annual Average Rainfall (mm)	0-1000	1	19
	1000-1250	3	
	1250-1500	5	
	1500-2000	7	
	2000-2500	9	
Proximity to Surface Water Bodies(m)	0-800	9	13
	800-1600	8	
	1600-2400	7	
	2400-3200	6	
	3200-4000	5	
	4000-4800	4	
	4800-5600	3	
	5600-7200	2	
7200<	1		
Soil group	Hard Rock	3	9
	In Situ Soil no 2	4	
	In Situ Soil no 1	5	
	Lateritic	6	
	Alluvial	9	
Slope(Degree)	0-7	9	4
	7-14	8	
	14-21	7	
	21-28	6	
	28-35	5	
	35-42	4	
	42-49	3	
	49-56	2	
	56<	1	

Table 2.2 Weight and Ranks for criteria selected in Deep groundwater analysis

Main Criteria	Sub Criteria	Rank	Final Weight (%)
Proximity summation to lineament (m)	100-200	2	30
	200-300	3	
	300-400	4	
	400-500	8	
	500-1250	9	
	Hard Rock	1	17

Aquifer Type	Regolith Aquifer	5	
	Alluvial Aquifer	9	
Geology type	Pegmatities	1	15
	Charnockite	3	
	Gneiss	5	
	Quartzites	7	
	Marble	9	
Soil Depth (m)	0-5	1	14
	5--10	2	
	10-15	3	
	15-20	4	
	20-25	5	
	25-30	6	
	30-35	7	
	35-40	8	
	40<	9	
Annual Average Rainfall(mm)	0-1000	1	8
	1000-1250	3	
	1250-1500	5	
	1500-2000	7	
	2000-2500	9	
Proximity to Surface Water Bodies(m)	0-800	9	7
	800-1600	8	
	1600-2400	7	
	2400-3200	6	
	3200-4000	5	
	4000-4800	4	
	4800-5600	3	
	5600-7200	2	
	7200<	1	
Soil Group	Hard Rock	3	6
	In Situ Soil no 2	4	
	In Situ Soil no 1	5	
	Lateritic	6	
	Alluvial	9	
Slope(Degree)	0-7	9	3
	7-14	8	
	14-21	7	
	21-28	6	
	28-35	5	
	35-42	4	
	42-49	3	
	49-56	2	
	56<	1	

All the four final groundwater potential maps created from two overlaying methods were classified into five main classes such as extremely low, low, moderate, high extremely high.

III. RESULTS AND VALIDATIONS

3.1. Shallow Groundwater

Figure 1 and 2 show shallow groundwater potential map obtained from weighted overlay and fuzzy overlay method respectively.

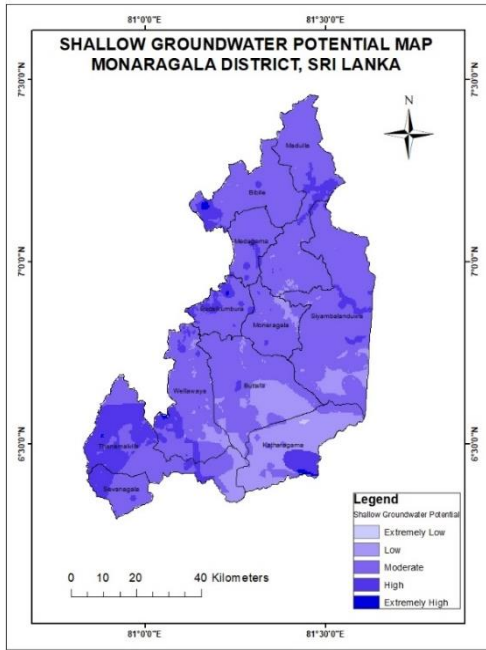


Figure 2 Shallow Groundwater Potential Map (Weighted overlay method)

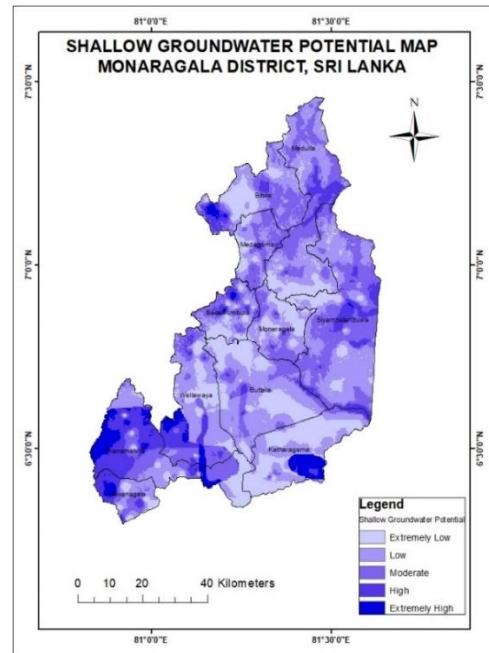


Figure 1 Shallow Groundwater Potential Map (Fuzzy overlay method)

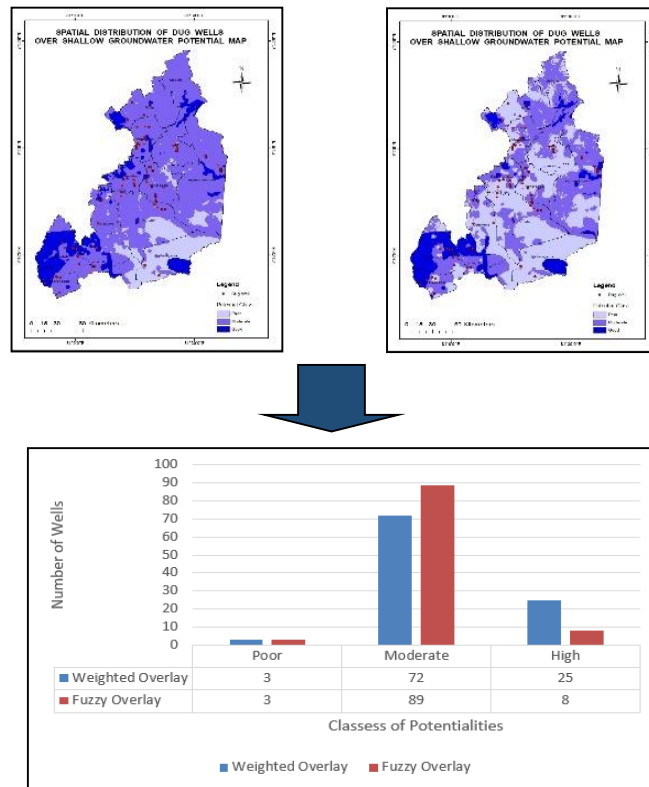
Each potential level's total area on the final maps is shown in the table 3.

Table 3 Area covered by different potential classes (Shallow groundwater)

	Weighted Overlay Area(km ²)	Fuzzy Overlay Area(km ²)
Extremely Low	3	1243
Low	829	2120
Moderate	4136	1504
High	725	602
Extremely High	15	239

100 dug wells were used to validate shallow groundwater potential maps. Outputs were validated only using spatial information of those wells. Output maps were further classified into three classes such as poor, moderate and good. To validate final map number of wells are calculated for the each potential classes. (See Figure 3)

Figure 3 Validation results for shallow groundwater potential maps



In poor potential area, same number of wells are located. In moderate potential areas 72 and 89 wells are located in weighted overlaid and fuzzy overlaid map respectively. For the high potential areas number of wells are identified as 25 and 8. Both fuzzy and weighted overlaying method gives approximate same validation.

Histogram shows, most of the wells are located in moderate potential area. Monaragala is a district having less water resources compared with the other district. So in reality, moderately groundwater potential areas are more than high potential areas.

3.2. Deep Groundwater

Figure 4 and 5 show deep groundwater potential map obtained from weighted overlay and fuzzy overlay method respectively

Figure 5 Deep Groundwater Potential Map (Weighted overlay method)

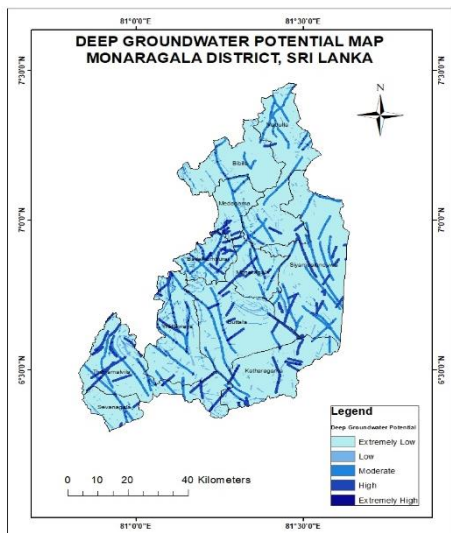
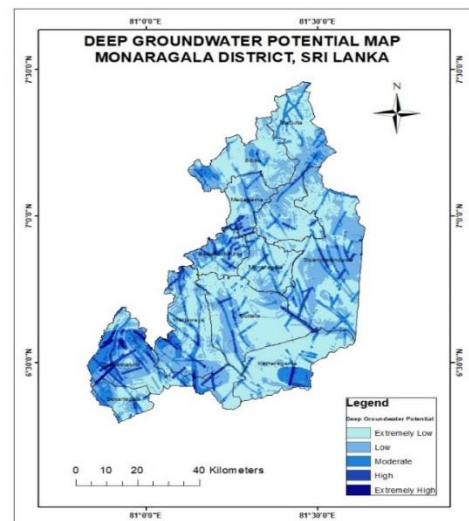


Figure 4 Deep Groundwater Potential Map (Fuzzy overlay method)



Each potential level's total area on the final maps is shown in the table 4.

Table 4 Area covered by different potential classes (Shallow groundwater)

	Weighted Overlay Area(km ²)	Fuzzy Overlay Area(km ²)
Extremely Low	152	2548
Low	4560	1963
Moderate	552	826
High	367	306
Extremely High	77	65

220 tube well data and its final yield value from the study region was used to validate the deep groundwater potential maps. Final classified potential maps were further reclassified into three classes such as poor, moderate and good. Relevant potential values for the each tube wells are extracted by using Arc GIS. Yield value is represented success rate and failure rate of tube well. When the yield is increased, water capacity also increased. To validate present study, standard yield value was selected as 30 liters per minute (lt/min) by expert's knowledge.

Figure 6 shows spatial distribution of tube wells in study region and trend histogram of success and failure rates for the obtained deep groundwater potential areas from weighted overlay method. The success rate of the tube wells is gradually increased toward the good potential locations (72.55) while failure rates reached maximum its value (55.33) in poor potential locations and fairly equal rates are for the moderate potential locations.

Figure 6 Validation results for deep groundwater potential map (Weighted overlay method)

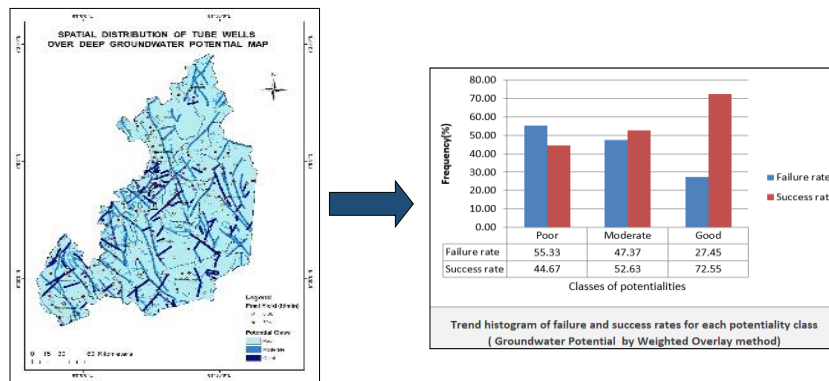
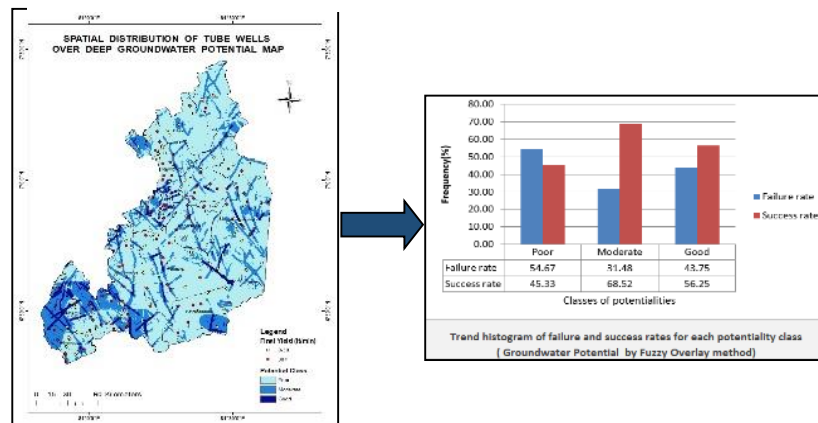


Figure 7 shows validation of deep groundwater result from fuzzy overlay method. The histogram shows the success rate of the tube wells is increased toward the good potential locations (56.25%) while failure rates reached maximum its value (54.67%) in poor potential locations. Moderate potential areas shows considerable rate difference.

Figure 7 Validation results for deep groundwater potential map (Fuzzy overlay method)



IV. CONCLUSION

The National Water Supply and Drainage Board, which are in charge of planning, managing, and conserving water resources, have been working to develop an appropriate strategy for determining the most advantageous locations for the establishment of tube wells that will be used to supply water for rural people in Sri Lanka. In order to achieve this objective, the present study created a groundwater potential map in Monaragala district.

From investigating final shallow groundwater potential maps, weighted overlay and fuzzy overlay methods were obtained considerably different results. Areas covered by different potential classes were identified as, for lower potential, 832 km² from the weighted overlay method and 3363 km² from the fuzzy overlay method. Moderate potential area was identified as 4136 km² and 1504 km² from weighted overlay and fuzzy overlay respectively. 740 km² and 841 km² area was identified as high potential (high and extremely high) areas from weighted overlay and fuzzy overlay respectively. The area differences happened due to selection of class boundaries. Although both final maps were given different areas for different potential classes, common high groundwater potential areas can be identified in both fuzzy and weighted overlaid maps. Smaller regions from Katharagama, Thanamalvila and Bible can be identified as high shallow groundwater potentiality because of the influence of its aquifer type.

From investigating final deep groundwater potential maps, low potential (extremely low and low) areas are prominent in the study region. It was 4712 km² from the weighted overlay method and 4511 km² from the fuzzy overlay method. Moderate potential area was identified as 552 km² and 826 km² from weighted overlay and fuzzy overlay respectively. 444 km² and 371 km² area was identified as high potential (high and extremely high) areas from weighted overlay and fuzzy overlay respectively. Deep groundwater potential map shows that effect of the lineament is very high for deep groundwater availability. Areas having lineaments are identified as the highly deep groundwater potential areas. Most of high success wells were established around those lineaments. So lineaments plays a vital role in deep groundwater studies. The accuracy of the result completely depend on accuracy of the lineament extraction. In addition, both methods were validated by the existing tube wells in approximately same manner.

This study suggests to the effectiveness of the GIS tool in defining groundwater potential zones and shows that it may be successfully applied elsewhere with the necessary adjustments. The overlay method that can be used to do the analysis depends on the study region and selected criteria.

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