Geo-Spatial Technology for Identifying Optimal Well Locations in Kolugala Pahalagama Grama Niladhari Division for Effective Groundwater Management

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Abstract

This study utilized Geographic Information System (GIS) technology to pinpoint optimal locations for establishing wells, addressing the issue of declining water yields in the Kolugala Pahalagama Grama Niladhari Division (GND); a geographically diverse region. The research integrated geospatial data, including geolocations of sample wells, garbage pits and quarterly water level measurements collected through field surveys. Several thematic layers, namely, geology, elevation, slope, drainage density, soil type, and land use types were analysed to delineate groundwater potential zones within the GND. Satti's analysis hierarchy was employed to assign appropriate weights to these factors, reflecting their influence on groundwater recharge and well productivity. Spatial analysis revealed that 9.64% of the area displayed very good groundwater potential, 42.17% had good potential, 39.76% showed moderate potential, and 7.23% exhibited poor potential. The distribution of existing wells was also evaluated, showing that 6% were located in very good groundwater potential zones, 56% in good groundwater potential zones and 38% in moderate groundwater potential zones. Despite this, only 34% of the wells were placed in regions suitable for the establishment of wells, while the majority, 66%, were located in unsuitable areas. Notably, 18 wells displayed lower water levels, likely due to their excessive distance from neighbouring wells. Further spatial analysis identified 29 hectares as unsuitable and 54 hectares as suitable for the future establishment of wells. These findings underscore the significance of geographic factors in the placement of wells, emphasising the need for strategic planning to ensure that wells are sited in areas with high groundwater potential, thus improving long-term water yield sustainability in the region.

Keywords: Garbage Pits, Groundwater, Geo–Spatial Technologies, Kolugala Pahalagama GND, Wells

INTRODUCTION

It's evident that Sri Lanka heavily relies on groundwater for various purposes, with a notable emphasis on addressing the critical issue of clean drinking water scarcity. The historical shift from lakes and ponds to groundwater as the primary source of drinking water can be traced back to the influence of Western colonization, with the trend becoming particularly pronounced around 1984.

As of 2022, approximately 39.6% of Sri Lankans meet their daily water needs through groundwater sources. According to Dhanapalayan's 2021 findings, the estimated groundwater potential in Sri Lanka is 780,000-hectare meters per year. Rainfall contributes to groundwater recharge, accounting for 3% - 7%, with a range of 200-600 million litres.

Sri Lanka's geological composition significantly influences the distribution of groundwater, which can be divided into three main zones. The Miocene Limestone Belt, spanning from Puttalam to Jaffna and Mullaitivu, is a critical region where water is primarily sourced through Aadiya wells. Cities like Puttalam, Jaffna, and Mullaitivu rely on these wells for their water supply. The East, West, and South-East Coasts, including cities such as Trincomalee, Batticaloa, Hambantota and Galle depend on shallow wells, typically 3-5 meters deep, as their main water source. The remaining land area, which covers approximately 80% of the country, includes major regions like Colombo, Kandy, Anuradhapura and Kurunegala, where different groundwater extraction methods are used. Adia irrigation wells are widespread in the Northwest and the North, particularly in Jaffna with over 100,000 wells, 25% of which are dedicated to irrigation purposes. Tube wells introduced in the 1980s, have expanded significantly, with over 30,000 wells established across the country. Major cities like Anuradhapura, Kurunegala and Puttalam saw the most growth, with 5,022, 3,684, and 3,268 tube wells respectively. In dry regions such as Hambantota and Polonnaruwa, cultivation wells have historically been used for agricultural purposes, with around 12,000 wells present. Finally, shallow wells and springs are prevalent in the wet zone, including areas like Colombo and Kandy where abundant groundwater is more accessible compared to the dry zone (Dhanapala,2021).

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Despite the diverse approaches to accessing groundwater for various activities, there is a notable trend in Sri Lanka where proper well-setting practices, especially for drinking water purposes, are not consistently followed. In contrast to cities like Mexico, Texas, Kansas, and Missouri, where setting up a private well requires a mandatory permit, Sri Lanka doesn't have a similar regulatory framework. In these cities, a thorough process involving informing relevant institutions, selecting suitable locations based on groundwater potential, and obtaining permits are in place to establish private wells.

In Sri Lanka, the absence of such structured programs and regulations can lead to challenges. As a developing country, the lack of mandatory permits and preliminary groundwater tests may result in the haphazard digging of wells, leading to abandonment when water dries up in a short period. This situation is often financially burdensome for the population, highlighting the need for more organized and regulated approaches to groundwater extraction to ensure sustainability and proper resource management.

The selection of a suitable location is a critical factor when establishing a private well for drinking water needs. Guidelines from the Mississippi State Department of Health (MSDH) emphasize specific distances that should be maintained to ensure the safety and quality of the groundwater. These guidelines are essential to prevent contamination and ensure the uniform extraction of fertile groundwater. The recommended distances, outlined in Table 1, are based on foot size and the proximity to potential pollution sources:

Table 1: Distances to be followed while drilling a well

Feet	Pollution sources
50 feet	-From a garbage pit
100 feet	-From underground waste disposal fields -From a grave or cemetery -From an abandoned well
300 feet	-From lagoon areas -From underground storage designed for petroleum products or chemical substances -From fertilizer storage areas

Source: Division of geology and land surveying, 1996

In light of the practices observed in some developed countries, where stringent regulations are in place, it's important for regions like Sri Lanka to consider implementing similar guidelines and standards. This approach would contribute to the sustainable development of groundwater resources and help address the challenges associated with haphazard well digging and potential water shortages.

Statement of the problem

Hatraliyadda DSD has 57 GNDs. Although there is more or less a water problem in the division, there is a different kind of problem related to groundwater in Kolugala Pahalagama GND.

According to the well census report of 2021, there are 95 wells to meet the drinking water requirement of the division. Presently, all 95 wells remain active and in use. However, approximately 20 wells have been abandoned from the past until now due to diminished water and other factors. Studies reveal that the abandonment of a single well can contaminate groundwater across about 100 miles (161 km) (Kerr,1997), posing a significant risk to aquifer quality. This issue of aquifer degradation is particularly alarming in the context of the world's escalating water scarcity crisis. Geographically, the implications of abandoned wells extend far beyond their immediate surroundings, affecting groundwater resources across a wide area.

Villagers in the division received a public tube well, courtesy of government support, but it dried up within just one and a half years. The tube well wasn't established following a groundwater assessment. Given the present economic conditions, conducting thorough inspections and establishment of wells poses a financial burden that exceeds the capabilities of both the government and the local populace. Therefore, a practical and cost-effective solution is urgently needed to address this issue.

During field observations within the division, it became evident that the community lacked adequate knowledge about proper well-establishment practices. Consequently, wells in the area experience rapid declines in water levels, particularly during the dry season. One contributing factor is the failure to maintain sufficient distances between wells. Additionally, the negligent establishment of drinking water wells in paddy lands poses health risks. Addressing these knowledge gaps and implementing appropriate well-placement strategies are crucial for ensuring sustainable access to water and mitigating health and environmental concerns.

Kolugala Pahalagama division is mainly facing problems related to the location of wells, so it is necessary to identify the groundwater potential zones for the location of wells in a place with continuous water yield, minimum distances between wells and the minimum distance from the sources of pollution. The answer to this problem can be found by identifying the most suitable zones.

Objectives

The primary objective of this research is to investigate the factors influencing the decline in well-water yield within the Kolugala Pahalagama Grama Niladhari area, employing Geospatial technology. Additionally, this study assesses the suitability of current well locations and aims to identify optimal sites for future well establishment.

LITERATURE REVIEW

The research conducted in Puthuhapuwa GND aimed to assess groundwater potential zones utilizing GIS technology, incorporating seven key thematic factors: geology, elevation, drainage density, soil, line density, and land use. The GIS analysis resulted in the development of a final groundwater potential zone map for the GND, categorized into three classes – high, moderate, and low. According to the findings, an area spanning 112,095 square meters in Puthuhapuwa GND was identified as having good groundwater potential, while 683,700 square meters exhibited moderate potential. Conversely, a significant portion, totalling 229,066 square meters, was determined to have very low groundwater levels (Kulasekara and Wijeratne, 2023).

The investigation into potential underground zones in the Kilinochchi district entailed the amalgamation of eight crucial concepts, leveraging a combination of Remote Sensing (RS), GIS, and the Analytical Hierarchy Process (AHP).

Through this comprehensive methodology, a substantially high groundwater potential zone covering 111.26 km² was successfully identified in the Kilinochchi district, specifically in Pacchileipalli DSD. Additionally, Punakari DSD exhibited a high groundwater potential, with the western part recognized as an extreme area of groundwater potential. The study underscored the significant influence of rainfall, geology, and soil factors on groundwater potential in Kilinochchi district. By integrating diverse datasets and methodologies, it aimed to provide a holistic understanding of groundwater potential in the region (Padmanandakumar, 2021).

The Kilinochchi area's groundwater potential was assessed by examining key factors such as geomorphology, geology, soil type, slope, and land use through RS and GIS technologies. These factors were assigned using the weighted overlay method, culminating in the development of a groundwater potential zone map. The results indicate that 5.32% of the groundwater is at a good level, 61.90% at a moderate level, 26.61% at a poor level, and 6.17% at a very poor level. The study identifies water geomorphological features, including alluvial plains, gently sloping areas, and forest lands, as prominent groundwater potential zones in the Kilinochchi area. This comprehensive analysis provides valuable insights for effective water resource management and planning in the region (Kumar et al., 2016).

Castillo et al., (2022) conducted a study to investigate groundwater potential zones within the semi-arid basin of San Luis Potosi, Mexico, through the integration of GIS, RS, and AHP methods. Various thematic factors, including geology, linear density, land use, wetness index, precipitation, drainage density, and slope, were transformed into a raster model. Using the AHP methodology to assign weights, the final groundwater potential zone map was generated. The findings indicate that 68.21% of the study area exhibits a low groundwater potential, while 26.30% demonstrates a moderate groundwater potential. Validation was conducted using time data from 15 regular wells, confirming the reliability of the results. Additionally, the Operating Characteristic Cycle (ROC) analysis yielded an accuracy of 0.677, emphasizing the robustness of the methodology employed in this study.

Moodley et al., (2022) aimed to assess groundwater potential zones in the Kwazulu-Natal area through a multi-criteria analysis hierarchy using GIS and RS. Thematic layers, including geology, linear density, slope, drainage density, precipitation, land use, and evaporation, were incorporated into the analysis. Weights for these layers were determined using the AHP method. To validate the generated map, a comparison was made with 113 wells using the AUC and ROC methods. The results indicate that 47.3 km² of the total study area exhibits excellent groundwater potential, while 24,405.4 km² has good groundwater potential. Moreover, 13,380.8 km² of land is identified with poor potential, and 135.6 km² of land has very poor groundwater potential, showcasing a substantial 72.6% correlation between the map and well data.

Another research, undertaken to investigate groundwater potential zones in the eastern Chad basin, primarily employing a mechanical method. The study leveraged 20 machine-learning algorithms, utilizing 488 wells within the study area as benchmarks for correlation and cross-validation parameters. Thematic layers, including wetness index, subsoil depth, distance between channels, and slope, were incorporated, and the random forest classification method was employed. The study's main findings revealed that seasonal changes derived from satellite images proved to be most effective in studying groundwater potential zones through extensive supervised classification (Victor et al., 2021).

The research conducted in Megech, within the sub-basin of Lake Tana, Blue Nile, Ethiopia, aimed to delineate groundwater potential zones and pinpoint locations crucial for sustainable water resources management. Employing GIS and RS technology, the study generated thematic maps encompassing factors such as lithology, linear density, slope, topography, soil, land cover, rainfall, and drainage density. Altitude served as proxy data to delineate the groundwater potential zones within the catchment area. The integration of an AHP and PriEST facilitated the creation of a comprehensive final map. The research findings underscored the significance of geology, linear density, slope, and geomorphology as sensitive factors influencing groundwater dynamics in the Megech region (Berhanu and Hatiye, 2020).

In 2020, Benjmel et al. conducted a study to identify optimal water catchment areas and drilling sites in the Argon Basin, situated in the Western Atlas of Morocco, to address the local water demands effectively. Leveraging RS and GIS technologies, the study incorporated 11 factors, including geology and hydrology, to generate detailed maps. The final map was constructed using an AHP hierarchy. The results revealed that 17% of the entire land exhibited favourable geopotential, while 64% was identified as a region with moderate water potential. Additionally, the study concluded that 18% of the area constituted a zone with weak potential for groundwater. The accuracy of these findings was corroborated by comparing the water potential map with data from 159 wells strategically distributed throughout the Argon Basin, validating the reliability of the research outcomes.

A comprehensive study of the groundwater potential zones in the Itwad-Khamis watershed in Saudi Arabia was conducted by a team of eight international experts. Primary data for the study was gathered through field questionnaires and interviews, drawing upon the practical knowledge and expertise of the research team. Utilizing RS technology, thematic maps were generated for geology, slope, elevation, precipitation, drainage density, linear density, terrain, climatic conditions, vegetation cover, land cover, soil texture, hydraulic conductivity, and the topographic wetness index (TWI). These datasets were geometrically mapped using ArcGIS 10.3 and ERDAS 9.2 IMAGINE, with a general projection applied. The study employed Fuzzy Analytical Hierarchy Process (FAHP) and Multi-Criteria Decision Making (MCDM) techniques in the field, analysing the distribution of wells to create a groundwater potential zone map. The results indicated that 82% of the wells were situated in areas categorized as very good and good groundwater potential zones. The overall study identified 14.6% of the area as a very good groundwater zone, 27.3% as moderate, and 20.2% as a poor groundwater zone, providing valuable insights for water resource management in the Itwad-Khamis watershed (Mallick et al., 2019).

In 2019, Etikala et al. tried to decipher the groundwater potential zones in the Tirupati area. To assess these zones, various factors such as lithology, linear density, topography, land use, drainage density, soil, rainfall, and slope were considered. Weights were assigned to these factors based on their water retention potential using the MIF hierarchy. The water potential zone map was subsequently generated utilizing the Weighted Sum overlay tool in ArcGIS. The findings of the study revealed the presence of a weak groundwater potential zone covering an area of 89.99 km2, while a moderate water potential zone extended over 181.10 km2. Additionally, the research identified 101.75 km2 as a good groundwater zone and 15.64 km2 as a very good groundwater potential zone. This mapping and zoning approach provides valuable insights for sustainable groundwater resource management in the Tirupati area.

Njeban, (2018) focused on the groundwater level in Al-Salman area, and aimed to compare spatial prediction methods for accurate groundwater level estimations. The study, conducted in 2016, involved analysing groundwater levels from 764 wells. Spatial interpolation methods, including Radial Basis Function (RBF), Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Universal Kriging (UK), and Spline Kriging (SK), were employed to identify groundwater areas. Through cross-validation, the study determined the Cors-Validation method as the most suitable, considering its lowest Root Mean Square Error (RMSE), Mean Error (ME), and the highest Coefficient of Correlation (R2). GIS technology facilitated the calculation of groundwater levels, revealing that spatial interpolation methods were most effective in representing groundwater levels. Cross-validation further validated the accuracy of the predictions, with an RMSE of 10.64, ME of 5.36, and an impressive R2 value of 0.98 for the study area. Consequently, cross-validation emerged as the preferred method for testing and validating groundwater level estimations in the Al-Salman region.

In 2017, Abdul et al., conducted a study to delineate potential underground zones within the Gerardo River watershed in the Wollo region of northern Ethiopia, employing GIS software, alongside the MCDA tool and IDRSI software. The research focused on eight critical biological and environmental factors, including geomorphology, rock structure, slope, rainfall, land use, linear density, soil, and drainage density. These factors were derived from satellite images, digital data, and meteorological sources. A comprehensive land-use map was created using satellite imagery, supplemented by field visits for topography, soil, and rock data, all integrated through GIS technology. Additionally, a Digital Elevation Model (DEM) was generated using spatial analysis tools to study slope, linear density, and drainage density. Thissen polygonal intersection facilitated the creation of a rainfall surface map. Weights were assigned to thematic maps using IDRSI software, culminating in the development of a potential groundwater map. The MCDA tool was instrumental in monitoring and evaluating the map. The study's key findings identified the central and eastern areas of the study region as high groundwater zones, while the northern and western parts of the watershed were identified as weak groundwater areas. This GIS-based approach, augmented by MCDA tools, proved effective in assessing and categorizing groundwater potential in the Gerardo River watershed.

Panahi et al. (2017) conducted a study to evaluate the groundwater resources potential in Tehran, the capital of Iran, and the largest city, Karaj, by integrating GIS and AHP. Shuttle Radar Topography Mission data were utilized to generate slope and drainage density maps, while Landsat-8 satellite images provided information for line density and land use. Geological data, soil data, and average annual rainfall data were also incorporated. The AHP hierarchy was employed to assign weights to these layers and create a map highlighting potential groundwater zones in the area. The results were validated using discharge values from 102 pumping wells installed between 2002 and 2014. The research revealed that 10.20% of the study area exhibited poor groundwater potential, with 28.25% of the discharge well data demonstrating good agreement with the modelled potential groundwater zones. This integrated GIS and AHP approach offers valuable insights for effective groundwater resource management in the Tehran and Karaj regions.

In 2012, Mukherjee et al. aimed to comprehensively analyse the hydrology of an Arid region, exploring the interconnected relationships among various factors to identify groundwater potential zones. The study incorporated essential thematic layers, including drainage density, lithology, topography, slope, soil, digital elevation, rainfall, land cover, and data from 90 wells. Thematic layers of water level were integrated, and weights were assigned using spatial analysis tools in ArcGIS 9.2 to construct a potential water map. The resulting map delineated 13.7% of the study area as a very poor water catchment area, contrasting with 5.4% identified as a very good water catchment area. Conclusively, the research findings, supplemented by well-yield data ranging from 23-40.31/s and 8.1-10.61/s, provide a holistic understanding of groundwater potential within the Arid region, offering valuable insights for informed water resource management strategies.

Rao and Jugran, (2010) conducted a study to delineate groundwater potential zones and assess groundwater quality for domestic needs in Chittoor, Andhra Pradesh, India, a region highly susceptible to drought. Utilizing remote sensing and GIS technology along with on-site field visits, the study incorporated data from various sources, including geology, linear density and geology, well locations, well yield, water table levels, and groundwater samples. Spatial analysis techniques, incorporating factors such as magnesium concentration, groundwater condition, hardness, and distance between wells, were employed to classify and analyse the geological and hydrological data. Weights were assigned to these parameters to create a purpose-specific map for the study area. The findings indicated that Chittoor city exhibited a high groundwater potential of 1.64%, but it was determined to be only moderately suitable for domestic purposes. Additionally, areas with good groundwater potential constituted 31.68% of the city. The research concluded that 62.05% of Chittoor city possesses a moderate groundwater potential, rendering it either suitable or moderately suitable for domestic use. This comprehensive assessment, integrating remote sensing, GIS technology, and field data, provides crucial insights for effective water resource management in the face of the region's pronounced susceptibility to drought.

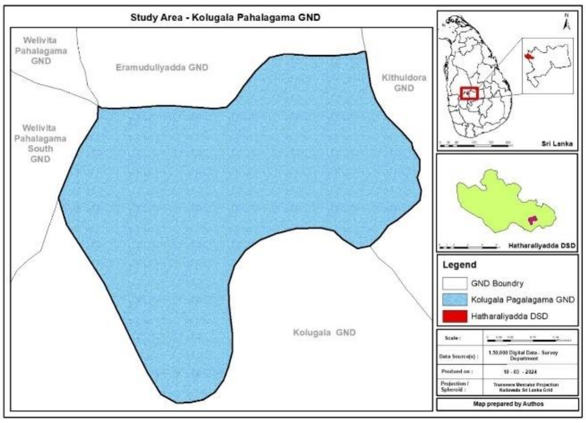
The study of groundwater in the central highlands of Eritrea has benefitted significantly from the integration of remote sensing, digital elevation models, and GIS techniques. Through the analysis of thematic layers such as rocks, linear density, topography, and slope, a comprehensive understanding of the groundwater dynamics in the region has been achieved. The research underscores the pivotal role of rock structures and landforms in influencing the yield of high groundwater. Notably, primary and secondary basaltic rocks emerge as key contributors to groundwater availability. The study highlights that areas characterized by fertile springs and wells near boreholes are particularly suitable for reliable water sources. Furthermore, the research identifies drainage channels with intrusive rocks, valley-fill deposits featuring rough landforms in metamorphosis, and biota-rich regions as having exceptional groundwater potential. In conclusion, the application of GIS technology in conjunction with remote sensing and digital elevation models has proven instrumental in unravelling the intricate interplay between geological features and groundwater resources, providing valuable insights for sustainable water management in the central highlands of Eritrea (Solomon and Quiel, 2006).

MATERIALS AND METHODS

Study area

Kolugala Pahalagama GND, designated as Division 355, covers an area of 83.2 hectares within the Hatharaliyadda divisional secretariat under the Tumpane jurisdiction of Kandy district, Sri Lanka.

Figure 1: Study area



Source: Developed by author based on 1.50000 digital data, survey department, 2017

It is geographically bordered by the Eramuduliyadda Division to the north, Kithuldora Division to the east, Kolugala Upper Division to the south, and the Pahalagama Division in Welivita to the west. The division encompasses the villages of Pulleniwatta and Kolugala Pahalagama, with its absolute location identified by coordinates 7°18'47" N latitude and 80°31'6" E longitude, according to the 2021 Resource Profile.

Creating thematic layers

ArcGIS 10.4 software played a pivotal role in the creation of thematic layers for an in-depth geospatial analysis. The process began with the utilization of a georeferenced geology map to generate a detailed geology map. The map was then digitized and converted into a raster layer, laying the foundation for the subsequent creation of a geology thematic layer that identified five distinct rock types in the study area. Contour data were harnessed to construct elevation, slope, and drainage density thematic layers. The integration of the Global Positioning System (GPS) visualizer/elevation web and Google Earth Pro software facilitated the extraction of essential data. The Inverse Distance Weighted (IDW) tool was employed to develop a surface based on GPX format datasets, subsequently converted into Triangular Irregular Networks (TIN) data using a 3D analyst tool. This TIN data was further transformed into raster data, culminating in the creation of a Digital Elevation Model (DEM).

The DEM model was then instrumental in generating the slope thematic layer through the application of the slope tool. The creation of a drainage density thematic layer involved several sequential steps, including the utilization of the "Fill tool" to address sink issues, the "direction tool" for flow direction, and flow accumulation computation. Data were organized according to Strahler's stream order, converted into vector data, and subjected to the "line density tool" to derive the drainage density.

In parallel, the land use thematic layer was developed by incorporating data from the Land Use Policy Planning Department of Sri Lanka onto the study area map. Similarly, the soil thematic layer was constructed by processing digital soil data on the study area map. The "merge tool" facilitated the isolation of the relevant area, which was then converted into raster data to finalize the soil thematic layer.

This comprehensive approach, facilitated by ArcGIS 10.4, allowed for the creation of cohesive thematic layers encompassing geology, elevation, drainage, land use, and soil characteristics. The integration of diverse data sources and advanced geospatial tools ensures a robust foundation for subsequent analyses and decision–making processes.

Creating reclassified thematic layers

Following an extensive review of relevant literature to determine the appropriate classification procedure, the subsequent step involved utilizing the "reclassify tool" within the ArcGIS software. This tool was employed to systematically reclassify the map based on the identified classification criteria derived from the literature study. The use of the "reclassify tool" ensured a precise and standardized approach to categorising the geographic data, aligning with the established classification methodology gleaned from the literature review. This step is crucial for refining and organizing spatial information according to specific criteria, laying the groundwork for more nuanced analyses and decision-making processes within the geospatial context.

Building weights and map combining

In the development of the groundwater potential zones map, a crucial step involved constructing weights through the application of Satti's Analysing Hierarchy. These weights were assigned as percentages, reflecting the influence of reclassified thematic layers on the overall determination of water potentials. The allocation of percentages followed a meticulous process, with considerations for the impact of each thematic layer on groundwater potential. The specific percentages were determined using the following equation 1 (Ranasinghe and Patabandi, 2024).

$$Impact = \left(\frac{satti's\ scale}{sum}\right) * 100 \quad (1)$$

This equation was employed to calculate the weights assigned to the relevant factors, ensuring a proportional and systematic representation of their contributions to the groundwater potential zones map.

Table 2: Percentage weights of factors affecting groundwater potential zones in the study area

Factor	Contribution to the creation of groundwater	Satti's scale (Fractions)	Satti's scale (Fractions)	Impact (%)
Geology	High	1	1	40
Soil	↓	1/2	0.5	21
Slope (Degrees)		1/3	0.33	14
Elevation (Meters)		1/4	0.25	10
Land Use		1/5	0.2	8
Drainage density (Meters/ Sq Meters)	Low	1/6	0.16	7
Total			2.44	100

Source: Ranasinghe and Patabandi, 2024

Validation

The groundwater potential zone map's validity was assessed through two distinct methods. Firstly, a comprehensive evaluation was conducted using 500 samples, employing a "segmentation and classification tool." This approach involved analysing and categorising the groundwater potential zones based on the collected data.

As a second validation method, GPS values from 50 sample wells were selected using random sampling method from a pool of 95 wells within the study area, essential for the community's daily water needs. The GPS coordinates were acquired using the "GPS waypoint" mobile app and subsequently mapped onto the study area using the "GPX tool" in ArcGIS 10.4. Quarterly water levels for these wells were calculated, and their annual average water level was determined using Excel software. This rigorous process was undertaken to further confirm the accuracy and reliability of the groundwater potential zones depicted on the map, ensuring the robustness of the findings.

Getting garbage pits' GPS points

The identification of suitable locations for well-establishment within areas with groundwater potential involved a meticulous process. Using the "GPS waypoint" mobile app, the locations of 55 garbage pits were selected through the random sampling method. Subsequently, the gathered GPS coordinates were meticulously mapped onto the study area using the "GPX tool" in ArcGIS 10.4.

Data analysis

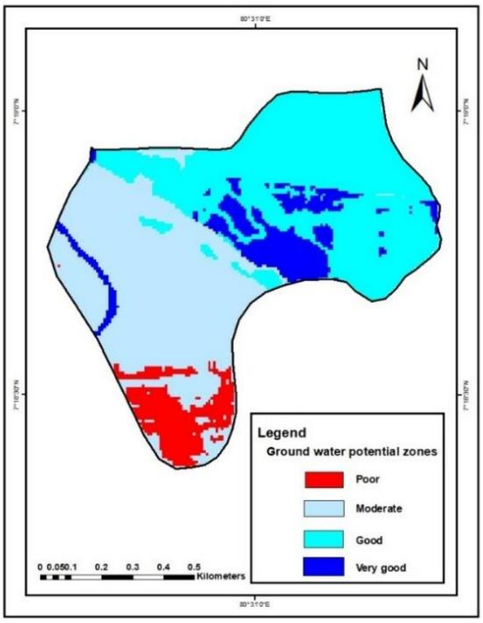
The primary tools employed for the analysis of all collected data in this study were ArcGIS 10.4 software and Excel software. These software applications played a central role in processing, interpreting, and presenting the information gathered. ArcGIS 10.4 was instrumental in creating detailed maps to visualize the spatial distribution within the datasets, providing a comprehensive understanding of geographical patterns, particularly in relation to groundwater potential zones. Simultaneously, Excel software was utilized for analytical purposes, aiding in the construction of graphs that succinctly presented key quantitative information. This combined use of ArcGIS 10.4 and Excel ensured a thorough and effective analysis of the collected data, enhancing the study's overall depth and interpretability.

RESULTS AND DISCUSSION

Groundwater potential zone

The content of Figure 2 illustrates the delineation of groundwater potential zones within the Kolugala Pahalagama GND.

Figure 2: Groundwater potential zones in Kolugala Pahalagama GND



Source: Developed by author based on 1.50000 digital data, survey department, 2017

In the study area, the assessment of groundwater potential has led to the classification of four main zones, poor, moderate, good, and very good. Each zone signifies varying levels of groundwater availability and suitability for extraction. The delineation of these zones allows for a comprehensive understanding of the spatial distribution of groundwater potential across the study area. Consequently, the identified poor zones indicate areas where groundwater resources may be limited or less reliable, while moderate zones suggest a moderate level of potential. Additionally, good and very good zones represent areas with substantial and highly favourable groundwater potential, respectively.

Correlation of well water levels with groundwater potential zones in measuring map validity

In the 2021 well census report for Kolugala Pahalgama GND, it was discovered that there are a total of 95 active wells within the administrative boundaries of the GND. Out of this pool, 50 wells were specifically chosen for in-depth analysis and study. Among these selected wells, 3 were situated within zones exhibiting high water potential, 28 were pinpointed within areas showcasing good groundwater potential, and 19 were found in regions with moderate groundwater potential.

Table 3: Relationship between groundwater potential zones and water levels in wells.

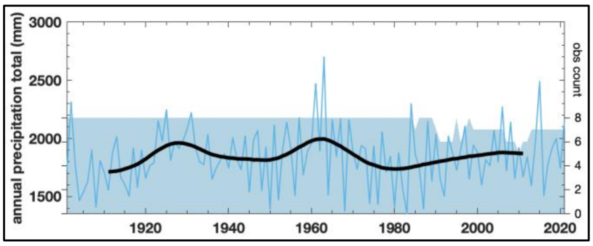
Groundwater potential zones	Mean annual water levels in sample wells
Very good groundwater potential zone	12 feet 6 inches
Good groundwater potential zone	8 feet 5 inches
Moderate groundwater potential zone	7 feet 4 inches

Source: Feld data, 2023

Status of groundwater recharge in Kolugala Pahalagama GND

Rainfall is the sole method of groundwater recharge in any area (Dhanapala,2021). The following chart illustrates rainfall levels over 120 years, from 1900 to 2020, in Kolugala Pahalagama GND.

Figure 3: Precipitation levels from 1900 to 2020 in Kologala Pahalagama GND



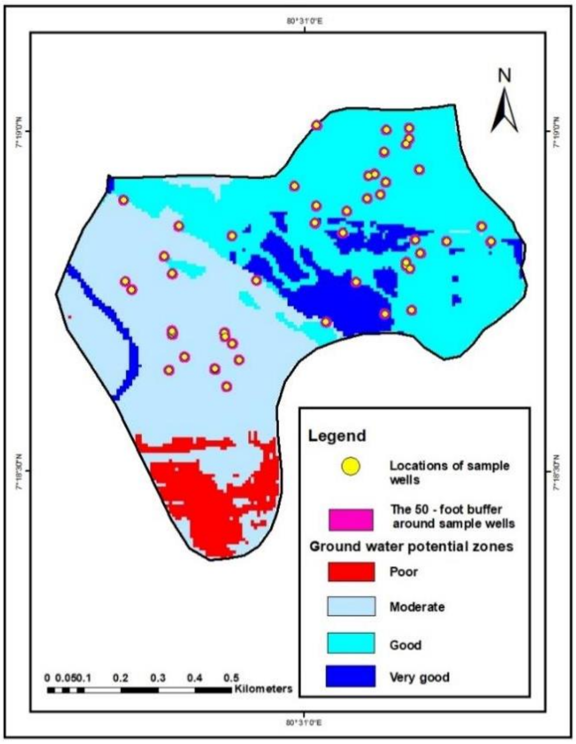
Source: University of East Anglia, 2023

Studying the graph reveals that despite a decline in rainfall from 1975 to 1983, the region still experienced substantial precipitation. Analysing the rainfall data over a 120-year period in the study area demonstrates that the aquifers have consistently received adequate water for replenishment.

Evaluating the suitability and unsuitability of wells established in the Kolugala Pahalagama GND

Based on the 2021 well census report for the Kolugala Pahalagama GND, there are a total of 95 wells catering to daily needs. From this population, 50 wells were specifically selected for a thorough study. Among these, 3 wells fall within a zone with very good groundwater potential, while 28 wells are situated in areas with good groundwater potential. Out of the 50 sample wells, 19 have been established in zones with moderate water potential. Minimum distances between wells must be maintained during the setup process, with the standard requirement being a minimum distance of 50 feet (Missouri Well Construction Rules, June 1996).

Figure 4: Sample wells and 50-foot buffer around sample wells in Kolugala Pahalagama GND



Source: Developed by author; groundwater potential zones map and field data, 2023

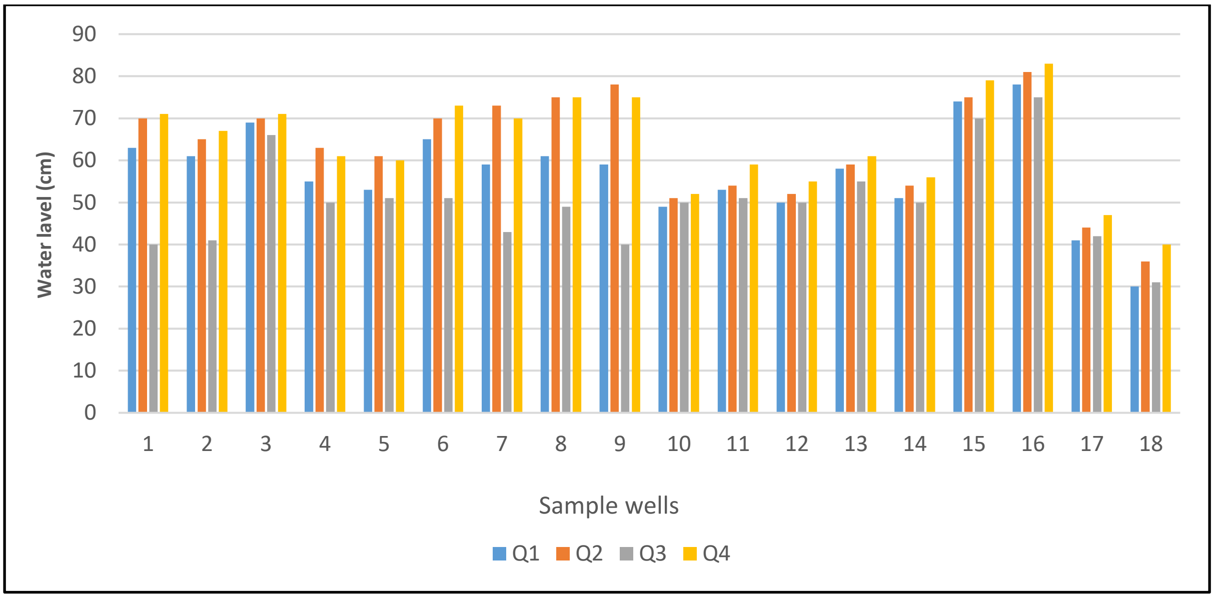
There are two main reasons for maintaining the minimum distance between two wells (Loganathan, 2019).

i. Maintaining a minimum distance of 50 feet between wells ensures that water is not drawn from the same aquifer for both wells.

ii. In some cases, even if water is drawn from the same aquifer, faster filling occurs when the wells are spaced apart, allowing for the effective replenishment of water from all directions.

According to the map, 18 out of 50 wells have failed to maintain the minimum distance requirement. The water levels of these 18 wells are categorized by quarters as follows:

Figure 5: Water level by quarters in wells without 50 feet distance between two wells 2022/2023 in Kolugala Pahalagama GND



Source: Field data, 2023

The Missouri Department of Natural Resources specifies a minimum distance of 50 feet to be upheld between a well and a garbage pit. Likewise, recommendations from the United States Environmental Protection Agency and the Department of Housing and Urban Development also advocate for maintaining a minimum distance of 50 feet between a garbage pit and a well. There are several key reasons for adhering to this 50-foot separation from the garbage pit:

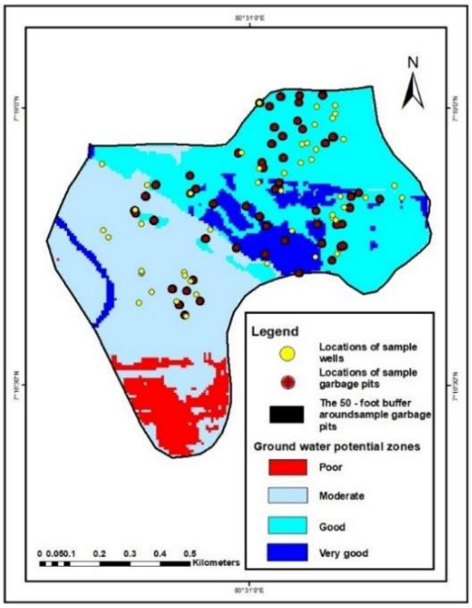
i. Prevention of mixing of E - Coli bacteria contained in sewage with water.

ii. Prevent phosphates produced from soaps and detergents from mixing with water.

iii. Preventing heavy metals from mixing with water.

can be pointed out.

Figure 6: Wells located within 50 feet of the garbage pits in Kolugala Pahalagama GND

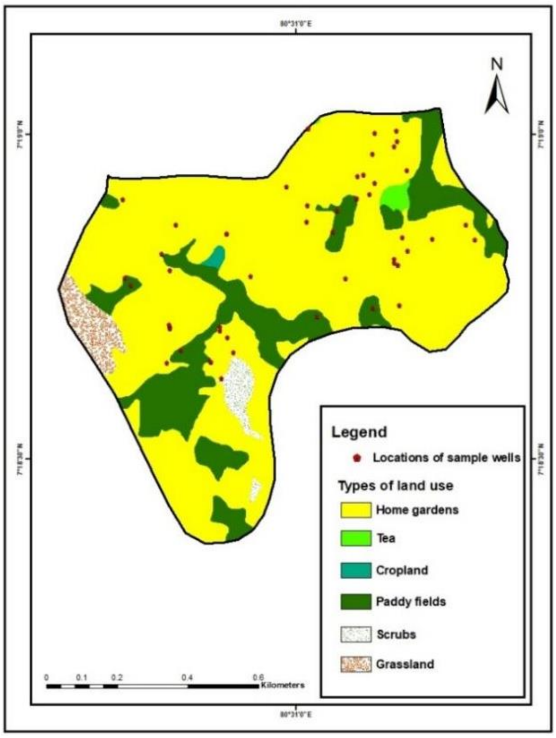


Source: Groundwater potential zones map, 2023 & field data, 2023

According to the map, it can be identified that 7 wells in the GND are within 50 feet of a garbage pit.

Also, considering how the wells are established along with land use in Kolugala Pahalagama GND, 8 out of 50 regular wells can be seen as related to paddy land use. Paddy fields belong to the category of swampy land, although a high ground water source can be obtained, it is not suitable for drinking water (Shipley et al., 2022). It can be recognized that the groundwater, when mixed with the chemicals used, is not suitable for drinking.

Figure 7: Land use and location of sample wells in Kolugala Pahalagama GND



Source: Land use & policy planning department data, 2019 & field data, 2023

Considering all factors, the suitability and unsuitability of establishing wells within the Kolugala Pahalagama GND can be summarized as follows:

Table 4: Unsuitable wells in Kolugala Pahalagama GND

Reason for unsuitable location of wells	Number of wells	Percentage
Unsuitable for drinking	15	30%
Lack of high-water yield	18	34%

Source: Field data, 2023

Based on this assessment, 17 wells, constituting 34% of the total, are situated in suitable zones, while the remaining 33 wells, accounting for 66%, are positioned in unsuitable areas.

CONCLUSION

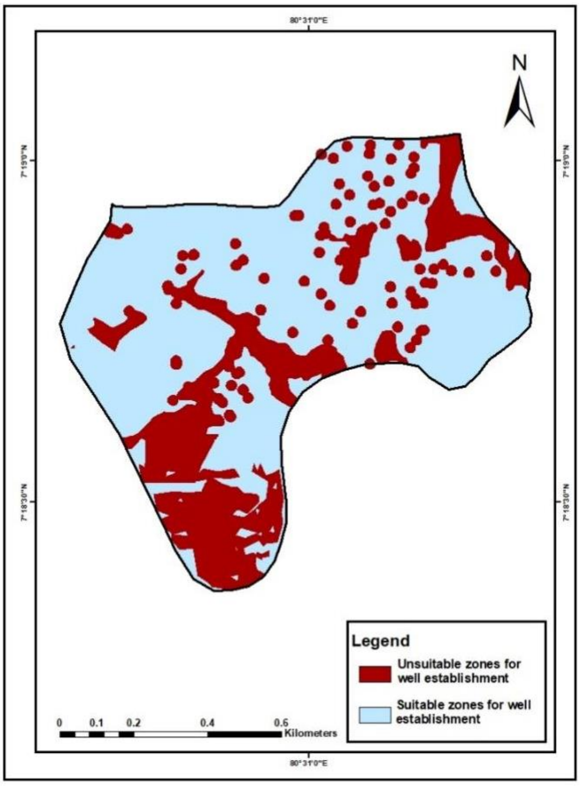
This study is focused on exploring critical factors pertinent to groundwater management, specifically examining the requisite minimum distance between two wells, the optimal spatial separation between wells and garbage pits, and the placement of wells within paddy lands. Through this investigation, the objective was to develop insights into how these factors influence groundwater conservation and sustainability in the study area.

In the surveyed area, analysis revealed the location of 18 wells that fail to adhere to the prescribed minimum distance of 50 feet between wells. Among these identified wells, a noticeable observation was the substantially lower water levels in comparison to other wells. This finding underscores the hydrogeographic significance of maintaining adequate spatial separation between wells, emphasizing the implications for groundwater availability and sustainability in the area.

The geographically focused analysis pinpointed the location of 7 wells failing to uphold the mandated 50-foot distance between garbage pits and wells. Notably, the water quality in these identified wells posed significant concerns for potability. Elevated levels of E-coli bacteria, phosphates, and heavy metals were detected, likely stemming from the infiltration of decomposed waste into the groundwater. Consequently, the proximity of garbage pits to wells exacerbates contamination risks, rendering the water unsuitable for drinking purposes. This underscores the critical need for stringent spatial planning measures to safeguard groundwater quality and public health within the studied area.

In examining fields categorized as swamps, 8 wells were observed within this terrain. Notably, findings indicate a concerning trend regarding the potential health hazards posed by chemicals utilized in paddy fields, as evident from their leaching into groundwater. During field study, a noteworthy observation emerged: the well exhibiting the highest water level was situated within a paddy field.

Figure 8: Suitable and unsuitable zones for the establishment of wells in Kolugala Pahalagama GND



Source: Groundwater potential zones map, 2023 and field data, 2023

As a whole, according to the locations and regions of the wells in the GND, it is concluded that 34% are located in suitable locations and 66% of the wells are established in unsuitable regions and locations. The study concludes that within the 83-hectare area, certain parts of the 29-hectare GND are not suitable for setting up wells. Specifically, the unsuitable areas include locations within 50 feet of garbage pits, areas within 50 feet of existing wells, land used for paddy cultivation, and regions with poor groundwater potential. These areas should be avoided for the construction of wells. Accordingly, it can be determined that only a land area of 54 hectares in the study area is suitable for setting up wells.

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