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(Review Article)

Advancements in groundwater potential mapping through remote sensing and GIS techniques

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Abstract

Groundwater resources are crucial for the future, facing increasing demand due to environmental changes and population growth. Economical and efficient exploration methods are becoming increasingly important, especially for middle- and lower-income regions. Deeper exploration is necessary to ensure a sustainable supply for future generations. This study examines the state-of-the-art in groundwater potential mapping. By analyzing scientific articles, it explores the recent advancements in this technique, which utilizes geographic databases and remote sensing. From a methodological perspective, the rise of machine learning algorithms is particularly noteworthy. Combining these methods with human expertise offers significant potential advantages, and experts believe it will lead to more accurate mapping.

However, simply discovering groundwater is not enough. Water quality and quantity are equally important for sustainable use. Therefore, this study presents two case studies that demonstrate groundwater mapping and quality management techniques. Furthermore, due to the ever-increasing population and changing land use, continuous research is essential for a long-term perspective on groundwater availability in specific regions.

Keywords: Groundwater; GIS; Remote sensing; Water management; Machine learning

1. Introduction

Water resources are a basic necessity for security, and their development and utilization are crucial for maintaining the safety and sustenance of humanity [1-5]. The unique geographical distributions of water on our planet enable it to fulfill our diverse needs and meet our diverse global water requirements. Our freshwater supplies are insufficient in many areas to fulfill the demands of the environment, economic growth, and household consumption [6, 7]. Earth has 71% of its surface covered in water, with 97% of that water being seawater [8]. The whole population depends primarily on the 3% of freshwater that is accessible because salt water is rarely suitable for human consumption, Groundwater makes up about 30% of the freshwater resources on the planet [9-11]. More than 1.5 billion people in the world are known to depend on groundwater for their drinking water supply. Both surface and groundwater service humanity but groundwater is one of the most precious natural resources, which promotes ecological diversity, human health, and economic growth. Owing to several natural attributes, it has developed into a highly significant and trustworthy source of water supplies in all climatic zones, including urban and rural areas of developed and emerging nations. Groundwater originates from rain and melting snow and ice and is the source of water for aquifers, springs, and wells [12], Rivers, ponds, and other surface water features can serve as recharge zones for groundwater [13].

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Groundwater is a primary source of drinking water for over 2 billion people worldwide [14], Groundwater is a crucial resource for industrial purposes, supporting agricultural production and various industries like manufacturing, mining, and energy generation. Groundwater is essential to preserving biodiversity and wholesome ecosystems [15]. It ensures the biological integrity of wetlands, rivers, and lakes by offering a steady supply of water, hence sustaining the variety of plant and animal species that rely on these environments. Even in dry spells, groundwater supports plants, which enhances the general well-being and productivity of terrestrial ecosystems. Groundwater has become increasingly important over time due to an increase in demand, which has resulted in improper groundwater exploitation that has led to a water stress state. This worrying situation necessitates the development of a method that is both cost- and time-efficient for managing groundwater resources. A substantial amount of data from numerous sources is needed for a groundwater development program. To create a groundwater potential model of a study area, it is crucial to identify and quantify these traits. Due to the drought issue, rural water supply, irrigation projects, and the low cost of development it requires, groundwater is currently receiving greater attention. Despite extensive research and technological advancement, studying groundwater has remained challenging [12].

Understanding and managing natural resources can be greatly aided by the combination of topographical data processing processes and high spatial resolution remotely sensed data. It offers precise, up-to-date information on various landforms and geological formations. It also aids in the identification of drainage channels that have been impacted by human activity and natural forces. To comprehend the relationships between drainage, geology, and landform factors, a Geographic Information System (GIS) is a useful tool for analyzing both spatial and non-spatial data [16, 17] and the sustainability of water management can play a fundamental role in maintaining the source for the future challenges and the future generation [18, 19].

Excavation and well drilling can be expensive and time-consuming. Today, there are various software-based devices and methods used to detect groundwater, and new techniques and procedures are being developed daily to identify and determine groundwater [20, 21]. Groundwater management requires the use of geospatial technologies and tools, such as Remote sensing (RS) and GIS, because of their synoptic coverage, repetitive nature, and ability to analyze the spatiotemporal properties of data because the sustainability of groundwater management can play a major role to control managing of water in a specific place [22]. While they don't directly contribute to the groundwater study, RS and GIS do help identify probable groundwater potential locations based on environmental characteristics [23], and in poor countries, where hydrogeological monitoring is rarely systematic and where the potential of groundwater resources is still largely unknown, remotely collected data are particularly crucial. This is among the causes of the widespread customization of hydrogeologists throughout the globe to the use of GIS and RS.

Since there is no direct means to enable monitoring of water below the surface, studying groundwater has remained riskier. Only by examining the geological and surface factors can its presence or absence be indirectly determined [24]. Many hydrogeological themes can be used to determine the current area's groundwater potential zone. GIS and RS tools can pave new routes for research on water resources [25, 26]. Groundwater potential can be found with great power and economy when using GIS and RS. Depending on the topography, using RS and GIS programs is commonplace [27].

RS and GIS technologies provide high-resolution spatial data on various parameters that influence groundwater potential, such as land cover, soil type, topography, and drainage patterns. These data can be analyzed and integrated to create detailed maps of groundwater potential zones, reducing the uncertainty in groundwater exploration and development.

In addition to being fast, dependable, and affordable, RS data also satisfies the fundamental needs of data in the GIS domain, which are efficiency, sufficient accuracy, comprehensiveness, and uniform standards of availability [28]. Integration of the information on the controlling parameters is better achieved through GIS. While RS and GIS techniques offer powerful tools for groundwater potential mapping, they face several challenges and limitations, some key problem statements are:

- Data availability and quality due to limited access to high-resolution satellite images in some places, inaccurate or incomplete ground truth data, and limited access to subsurface data.
- Uncertainty in model and validation due to the complexity of groundwater systems, limitations of model calibration and validation and sensitivity of the model to parameter selection.
- Scalability and portability due to the possibility of moving the model to different regions, measurement models for large areas, and real-time monitoring and updating.
- Environmental, social and economic considerations due to climate change impacts, land use changes, human activities, overexploitation and sustainability.

Addressing these problems requires ongoing research and development in data acquisition, model development, data integration, and accounting for uncertainties. Additionally, collaborations between researchers, policymakers, and stakeholders are crucial for developing and implementing effective groundwater management strategies based on reliable potential maps generated using RS and GIS techniques. Accurate and reliable groundwater potential assessments are crucial for informed decision-making in water management and development [29]. The integration of RS, GIS, and geophysical technologies provides valuable information for:

- Identifying potential groundwater sources for drinking water, agriculture, and industrial applications.
- Assessing the vulnerability of groundwater resources to contamination and overexploitation.
- Developing groundwater management plans to ensure sustainable use and protection of groundwater resources.
- Prioritizing areas for groundwater exploration and development based on economic and environmental considerations.

However, Díaz-Alcaide and Martínez-Santos [30] published a paper about the advancement of groundwater potential mapping and the paper updated all the news about the topic but while the GIS software and all the technology update continuously the information about the process should be updated also which makes the update of the research necessary.

In conclusion, integrating advanced technologies such as RS, GIS, and geophysical methods into groundwater potential assessment offers significant advantages in terms of accuracy, efficiency, and cost-effectiveness. These technologies provide valuable insights into the spatial distribution and characteristics of groundwater resources, enabling informed decision-making for sustainable water management and development and the objective of this work is to summarize all the information presented clearly and concisely, for application and research.

2. Applications of Groundwater Potential Mapping

Groundwater is out of sight, and aquifers are seldom well known, even in industrialized countries. This makes it difficult to manage the resource sustainably and frequently results in widespread pollution and declining water tables [31]. One definition of groundwater mapping is a technique for the methodical planning and development of water resources [21]. Groundwater potential mapping is a valuable tool for water resource management, drought mitigation, agricultural planning, and environmental impact assessment.

2.1. Water resource management

Modern groundwater technology has many uses, but managing water resources to ensure a steady supply for future generations is one of its most significant uses.

- Optimizing groundwater extraction

Groundwater potential maps provide valuable insights into the distribution and availability of groundwater resources. Also, these techniques are reliable and representative. The outcome would help as a guide for designing a suitable groundwater exploration plan in the future and thereby help efficient planning of scarce groundwater for the study area [32].

- Protecting groundwater quality

Groundwater potential maps can identify areas vulnerable to contamination based on factors like land use and soil characteristics. These maps inform targeted groundwater quality monitoring and protection measures. Figure 1 Shows the Spatial distribution of total alkalinity in groundwater in Darbandikhan [33].

- Artificial recharge

The artificial groundwater recharge zones delineation using integrated RS and GIS techniques are reliable and can serve as guidelines for planning future artificial recharge projects for sustainable groundwater utilization [34].

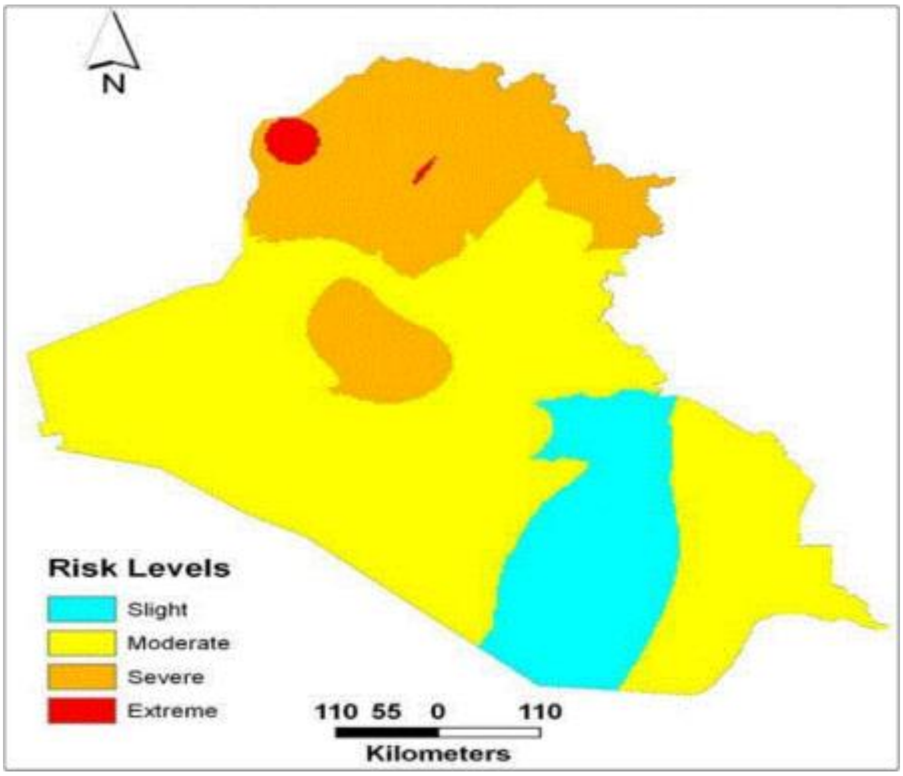

Figure 1 Spatial distribution of total alkalinity in groundwater in Darbandikhan [33]

2.2. Drought mitigation

- Identifying drought-prone areas

Maps of groundwater potential can identify regions with scarce groundwater supplies, which makes them more vulnerable to droughts; this information can be used to prioritize efforts to mitigate droughts and identify places that should be targeted for early intervention, as shown in Figure 2 adopted from Rahmi and Dimyati [35].

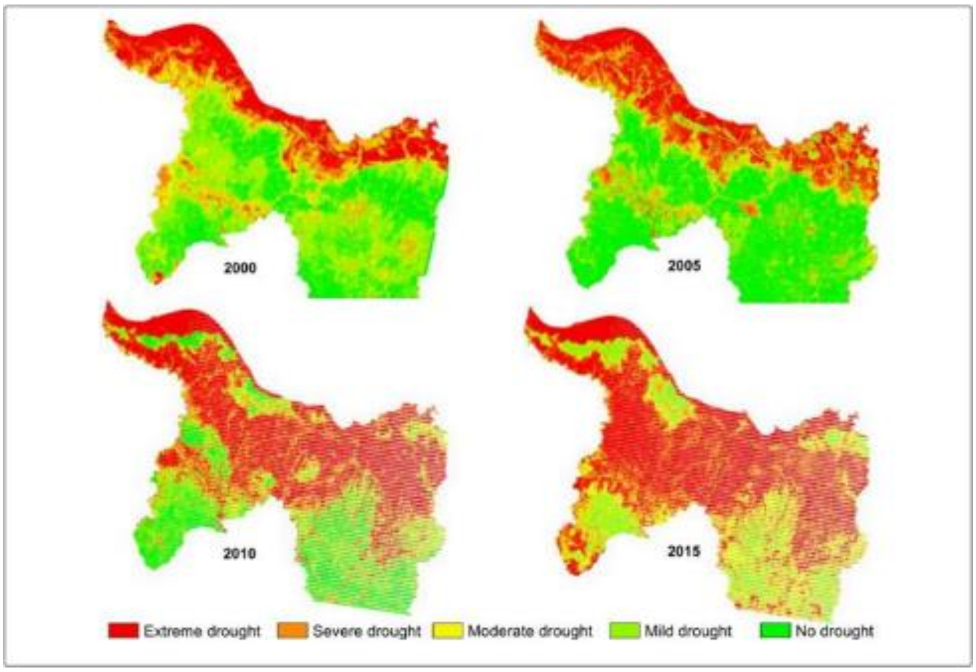

Figure 2 Drought map of Subang and Karawang [35]

- Developing drought preparedness plans

The development of distributed layers of drought indices, and their implementation in GIS technologies, will be a definite advance in assessing the spatial and temporal variability of droughts in the African continent and feed methodologies and systems to generate information directly related to management decisions and early warning systems [36]. Groundwater potential maps inform the development of drought preparedness plans by identifying alternative water sources, such as deeper aquifers or suitable locations for water storage facilities.

- Monitoring drought impacts

Tracking changes in groundwater levels using groundwater potential maps and other monitoring techniques helps assess the severity of droughts and guide effective water management strategies. As many tools can be used with GIS to generate several kinds of maps that let to monitor drought, Hammouri and El-Naqa [37] created thematic layers that depicted the spatial distribution of drought for both the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI) using satellite images and rainfall data to assess drought.

2.3. Agricultural Planning

Cropping intensity and groundwater are indeed related. Elevated crop productivity depletes groundwater levels and necessitates more groundwater for irrigation [38]. In order to maximize water consumption, boost agricultural output, and guarantee the sustainability of groundwater resources for future generations, groundwater mapping with GIS provides a useful tool for agricultural planning and groundwater management [39]. GIS-based groundwater mapping will become more and more important in assisting sustainable agriculture and food security as the world's population grows. Groundwater mapping using GIS has a wide range of applications in agricultural planning, including:

- Selecting suitable crops
- Optimizing irrigation practices
- Siting irrigation infrastructure

2.4. Environmental Impact Assessment

The process of conducting an Environmental Impact Assessment (EIA) informs a range of stakeholders, including planners and pertinent agencies, about the proposed development and its potential consequences on the surrounding environment. The GIS will supply the key tool to guarantee that the mitigation and EIA are responsive [40]. Using GIS offers useful mapping techniques, such as the holistic environmental system approach, and enhances the EIA and mitigation process overall. Below are some applications of EIA forecasting:

- Predicting groundwater contamination

Groundwater potential maps can be used to assess the vulnerability of groundwater resources to potential contamination from sources like industrial activities or agricultural practices. [41] conducted a study on the effect of the Erbil city Landfill site on groundwater contamination by formed landfill leachate in Iraq, also in Bangladesh Hossain and Piantanakulchai [42] used a combination of classification tree and GIS technology to develop an arsenic contamination risk map.

- Evaluating groundwater-dependent ecosystems

Identifying areas with high groundwater dependence, such as wetlands, using groundwater potential maps helps inform environmental impact assessments and mitigate potential impacts on these ecosystems, It is clear that the protection of ecosystems that are supported by groundwater is imperative given the growing risk of depletion of groundwater resources in most parts of the world [43].

- Planning groundwater conservation measures

Groundwater potential maps provide a basis for planning and implementing groundwater conservation measures, such as aquifer protection zones or water conservation policies, to minimize environmental impacts. Planning conservation measures for watershed development and management is the process of creating and carrying out plans in various projects to uphold and improve watershed management functions that would otherwise have an impact on the human communities, animals, and plants within watershed boundaries [44, 45].

3. Methodologies in RS and GIS for Groundwater Potential Mapping

3.1. RS Techniques

Historically, aerial photography served as the foundation for remote sensing techniques. Aerial photos have been used for mapping and terrain description since the first aerial shot was taken from a balloon in 1858. As additional types of sensors have emerged, like imaging radar and scanners, the broader phrase "remote sensing" has gained traction. The measurement of an object from a distance without making direct contact is known as remote sensing [46, 47]. RS techniques offer a valuable set of tools for groundwater exploration and mapping. These techniques allow us to study the Earth's surface and subsurface without direct physical contact, providing crucial insights into groundwater resources. There are several satellite platforms available right now that offer maybe helpful data. These include, among others, Sentinel 2, KompSAT, IKONOS, QuickBird, WorldView 4, Landsat 7 and 8, ALOS, and Pleiades. However, for groundwater investigations, Landsat is most frequently utilized. This may be attributed to several features, including its accessibility, extended time series, adequate wavelength spectrum, and precise spatial and temporal resolution. Launched in 2013, Landsat 8 is the latest satellite in the Landsat program. The Operational Land Imager (OLI) on Landsat 8 measures electromagnetic spectrum spectral responses at nine distinct wavelengths, while the Thermal Infrared Sensor (TIRS) adds two more bands to the thermal infrared spectrum, Table 1.

Table 1 Landsat 8 bands (after [48, 49]). OLI operational land imager

Band	Wavelength (μm)	Sensor	Pixel resolution(m)	Some applications
Bl. Coastal aerosol	0.43-0.45	OLI	30	Coastal and aerosol studies
B2. Blue	0.45-0.51	OLI	30	Bathymetry, soil, and vegetation
B3. Green	0.52-0.60	OLI	30	Plant vigour
B4. Red	0.63-0.68	OLI	30	Vegetation variations
B5. Near-infrared (NIR)	0.84-0.88	OLI	30	Biomass content, shorelines
B6. Short-wave infrared (SWIRI)	1.56-1.66	OLI	30	Soil moisture content and vegetation
B7. Short-wave infrared (SWIR2)	2.10-2.30	OLI	30	Soil moisture content and vegetation
B8. Panchromatic	0.50-0.68	OLI	15	Higher resolution images
B9. Cirrus	1.36-1.39	OLI	30	Cirrus clouds
B10. TIRS 1	10.60- 11.19	TIRS	100	Thermal and soil moisture mapping
B11. TIRS 2	11.50- 12.51	TIRS	100	Thermal and soil moisture mapping

Here's an overview of three key remote sensing techniques used for groundwater exploration:

3.1.1. Satellite imagery acquisition and preprocessing

Noise in the capture and transmission of satellite photos taints them. Certain significant details are also lost while attenuating the high-frequency image components to remove noise from the picture. To help you remember the important details and make the image look better [50]. Satellite imagery serves as a primary source of data for remote sensing in groundwater studies. Acquiring and preprocessing satellite imagery involves several steps such as (Data acquisition, Radiometric calibration, Geometric correction, Atmospheric correction, and Image co-registration).

3.1.2. Spectral indices for groundwater prediction

Mathematical techniques called spectral indices, including NDVI, NDWI, and others, integrate data from several spectral bands to highlight particular features in satellite photography. They are very helpful for predicting groundwater levels and analyzing vegetation. The non-dimensional vegetation index, or NDVI, is defined by the difference in reflectance between visible and near-infrared light. One of the most often used indices for tracking vegetation dynamics at the regional and global levels is this one [51]. The assessment of the density of vegetation is done using the NDVI data [52, 53].

3.1.3. Thermal infrared and radar data for subsurface mapping

Radar and thermal infrared data can look deeper below the surface to reveal information about the distribution and storage of groundwater. Thermal anomalies that could suggest the existence of groundwater in the shallow subsurface can be found using thermal infrared line scanners, which collect data on the light that is emitted, usually in the 8–14 μm range [54]. Additionally, a thermal signature of groundwater has been seen in surface water [55].

3.2. GIS Techniques

There have been several published analyses of groundwater conditions utilizing remote sensing techniques. When compared to more advanced geo-referenced thematic map analysis and interpretation methods, GIS approaches provide numerous advantages. Moreover, unlike conventional methodologies, GIS tools may take into account the range of factors that affect groundwater recharge. In a GIS system, several characteristics produced from data are integrated into themed maps [56]. GIS technology has emerged as a powerful tool for groundwater exploration, mapping, and management. It integrates geospatial data, analytical tools, and visualization capabilities to provide comprehensive insights into groundwater resources, several methods used in GIS such as:

3.2.1. Spatial analysis and interpolation methods

Spatial analysis techniques play a crucial role in understanding groundwater distribution and identifying potential exploration sites. These techniques include (proximity analysis, overlay analysis, and interpolation), also interpolation is a technique used to estimate values for locations that lack data. It creates continuous surfaces from discrete data points, providing a more comprehensive understanding of the spatial distribution of a particular variable or phenomenon such as (Nearest neighbor, Inverse distance weighting, and Kriging), the benefits of using spatial analysis and interpolation improve decision-making, resource management, environmental monitoring) [57].

This technique can be used for urban planning, agriculture, environment, and public health. By using these techniques, researchers, planners, and decision-makers can gain valuable insights into the world around us and make informed decisions for a more sustainable future. it is very important to identify a suitable interpolation method for mapping the groundwater quality because different studies in different places showed different results [58].

3.2.2. Multi-criteria decision analysis (MCDA) for potential mapping

MCDA for potential mapping refers to a methodology used to evaluate and analyze different options or alternatives based on multiple criteria or factors. It is a group of methodologies that supports decision-makers in formalizing complex decisions and assessing available options. For about 20 years, it has been utilized to analyze geographical problems with GIS [59]. One well-known example of a multicriteria decision issue is groundwater potential zoning [60]. MCDA is a powerful tool for supporting complex decision-making constrained by multiple conflicting objectives and criteria [61], Since then, groundwater potential has been evaluated globally by combining remote sensing with a GIS-based MCDA approach and the Analytic Hierarchy Process (AHP) technique.

While there are many approaches that use MCDA for groundwater potential mapping such as (AHP, Weighted overlay analysis, Fuzzy logic, Elimination and choice expressing reality (ELECTRE), PROMETHEE, …etc.) and choosing any of them depends on many factors. somewhere there is a comparison between some of these approaches for example Singh, Jha [62] used AHP and Catastrophe theory for delineating groundwater potential zones in a Canal Command of Eastern India and discovered that, compared to the Catastrophe technique, the AHP technique performed somewhat better.

3.2.3. Hydrological modeling and groundwater flow simulations

The terms hydrological modeling and groundwater flow simulations refer to computer techniques used to forecast and analyze subsurface water flow and understand the behaviors of the hydrological system which can be used for groundwater identification and mapping. In this subject there are many factors that are valuable (e.g. slope, aspect, curvature, flow accumulation, stream order, etc.) and Digital elevation models (DEM) can provide a wealth of information about the geomorphic and hydrological properties of an area [63]. After transferring all the required data about the topography, soil, land use, watershed, slope, and …etc. An entire hydrologic unit (such as a watershed) can be spatially separated into hydrologically homogeneous sub-areas by utilizing the common GIS overlaying capability to integrate several data layers by topographic overlay or spatial overlay after this step by using GIS tools groundwater flow can be detected [64].

4. Case Studies and Applications

4.1. Groundwater and agriculture potential mapping of Mewat District, Haryana, India

The first case study is “Groundwater and Agriculture Potential Mapping of Mewat District, Haryana, India” which was done by Pradeep and Krishan [65]. The researcher in this paper used GIS and AHP to assess the groundwater and agriculture potential zones in Haryana’s southern region of Mewat district and They discovered that study area ranging from very low to excellent potential zones. It has been found that 69% and 60% of the area has moderate to good groundwater and agriculture potential, respectively, and 20% and 22% of the area has excellent and agriculture potential, respectively.

Geographical, the district covers an area of 1507 sq. km and ranks 16th in the state and 544th in the Country in terms of size (Figure 1). It is located at 28 °12′ N latitude, 77 °3′ E longitude, and 199 m above sea level. They use RS and GIS with satellite data, Google Earth data and conventional maps, and LANDSAT 8 sensor pictures to prepare seven thematic layers namely Geomorphology, Soil, Slope, Drainage Density, Land Use/Land Cover, Lineament Density, and Geology created for groundwater potential zonation based on the availability of groundwater, and six thematic layers namely Digital Elevation Model (DEM), Slope, Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Soil Moisture Index (SMI), and Rainfall was created for agriculture potential zonation as these factors affect the potentiality for agriculture. By overlaying all of the layers using a weighted overlay tool in the spatial analyst toolbox in ArcGIS 10.8.2, the Groundwater Potential Zones and the Agriculture Potential Zones were extracted.

After assigning weights to each of their generated theme maps such as (Geomorphology, Soil, Slope, Drainage Density, Land Use/Land Cover, Lineament Density, and Geology created for groundwater potential zone) Table 2, and (Digital Elevation Model (DEM), Slope, Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Soil Moisture Index (SMI), and Rainfall was created for agriculture potential zone) Table 3, the groundwater and agriculture potential zones were delineated by integrating all the spatial layers using a weighted overlay approach. Before the overlaying operation, all spatial layers were classified into a uniform ranking pattern ranging from 1 to 5, where 1 represents poor potential and 5 represents excellent potential.

Table 2 Assigned weights and ranks for groundwater potential adopted from Pradeep and Krishan *[65]*

No.	Theme	Field	Weight	% Influence
1	Geomorphology	Moderately dissected structural hills and valleys	2	21
		Low structural hills and valleys	2	
		Residual hills and valleys	1	
		Pediment pediplain complex	3	
		Older alluvial plain	5	
		River	5	
		Aeolian plain	5	
		Dam and reservoir	5	
		Aeolian dissected dune complex	2	
		Pond	5	
		Waterbodies	5	
2	Geology	AJBARGH group (carbonaceous shales and arenites)	3	17
		Undifferentiated fluvial aeolian sediments	5	
		Alwar group (granites)	1	
3	Slope	Nearly level (<1%)	5	15
		Very gentle (1–6%)	4	
		Gentle (6–20%)	3	

		Steep (20–40%)	2	
		Very steep (>40%)	1	
4	Soil	Yermosols	1	13
		Luvisols	5	
		Lithosols	4	
		Cambisols	3	
5	LULC	Built up area	2	11
		Water body	5	
		Vegetation	5	
		Barren land	1	
6	Drainage density	Very low (<1 km/km2)	5	11
		Low (1–2 km/km2)	4	
		Medium (2–3 km/km2)	3	
		High (3–5 km/km2)	2	
		Very high (>5 km/km2)	1	
7	Lineament density	Very low (0.54–1.09 km/km2)	1	12
		Low (1.09–1.64 km/km2)	2	
		Medium (1.64–2.18 km/km2)	3	
		High (2.18–2.65 km/km2)	4	
		Very high (2.65–3.12 km/km2)	5	

Table 3 Assigned weights and ranks for agriculture potential adopted from *[1]*

No.	**Theme**	**Field**	**Weight**	**% Influence**
1	Land surface temperature	1 (5–10 °C)	5	23
		2 (10–20 °C)	4	
		3 (20–30 °C)	3	
		4 (30–40 °C)	2	
		5 (40–49 °C)	1	
2	Soil moisture index	1	1	21
		2	2	
		3	3	
		4	4	
		5	5	
3	Slope	1 (<1%)	5	14
		2 (1–6%)	4	
		3 (6–20%)	3	
		4 (20–40%)	2	

		5 (>40%)	1	
4	DEM	1	4	14
		2	2	
5	Rainfall	1 (120 mm)	2	15
		2 (270 mm)	3	
		3 (390 mm)	5	
6	NDVI	1	1	13
		2	2	
		3	3	
		4	4	
		5	5	

For the pair-wase comparison, the equation used in the study is Eq.(1) which depends on the xi being the normalized weight of the ith class/feature of the theme, wj being the normalized weight of the jth theme, m being the total number of themes, and n is the total number of classes in a theme.

$$\text{GWP} = \sum_{i=1}^{n}(wj * xi) \quad \text{.........} \ (1)$$

The final map was divided into four agriculture potential zones: very poor, poor to moderate, moderate to very good, and excellent. After the six maps were combined Figure 3. also, for the groundwater the study area has four different zones from very poor, poor to moderate, moderate to very good, and excellent after the seven maps were combined Figure 4.

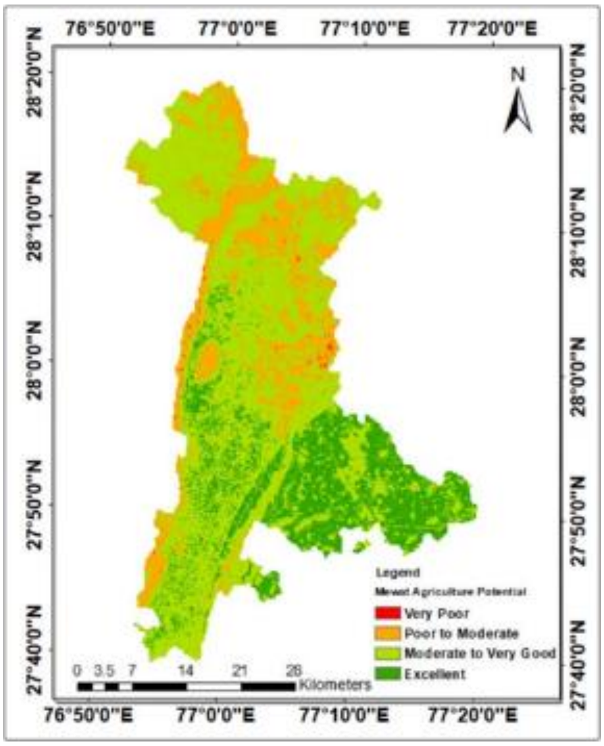

Figure 3 Agriculture potential map of study area in Postel [1]

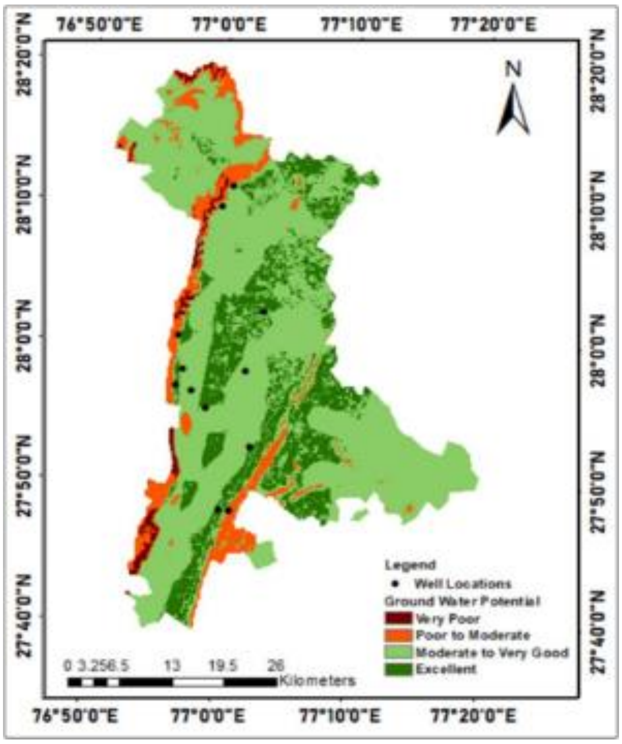

Figure 4 Well location map with groundwater potential zones in Postel [1]

4.2. Quality Management for Groundwater by Assessment of Aquifer Vulnerability to Contamination in Erbil City

The second case study is "Quality Management for Groundwater by Assessment of Aquifer Vulnerability to Contamination in Erbil City" which was done by Wali and Alwan [66]. The researcher in this paper used the DRASTIC method within the GIS environment to evaluate the vulnerability of the aquifer to pollution in Erbil city, to discover the groundwater vulnerable zones to pollution in the aquifer of the study area and to provide spatial analysis of the parameters and conditions under which groundwater may become polluted and they found that The aquifer media, which is made up of sand and gravel, makes the southeast of the researched area extremely vulnerable to pollution. It is also discovered that the soil media has the greatest influence on the calculation.

According to Rupert [67], the DRASTIC method depends on seven parameters they are: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and hydraulic Conductivity of the aquifer. The focal point of the investigation is Erbil City, the capital of the Iraqi Kurdistan Region and the hub of the Erbil Governorate. Situated between 36°07'08" and 36°13'08") in latitude and 43°57'06" to 44°09'00") in longitude, the area of this region is about 145 km^2. they collected data from 63 domestic well sections within Erbil City by Wali and Alwan [66]. The information contained the following: hydraulic conductivity, soil media, aquifer media, vadose zone (unsaturated zone) media, and water depth for each well within the study region. One of the most widely used methods to assess groundwater vulnerability to a wide range of potential contaminants is DRASTIC [68]. This work has been done according to the Broad classification of aquifer vulnerability (Table 4) by Aller and Thornhill [69]. Each DRASTIC component is given a relative weight in the first phase, with 1 denoting a less important influence and 5 representing the most substantial impact. In the second phase, each element has to be separated into ranges or media types that have an influence on pollution potential, these ranges or media types receive ratings between 1 and 10, with 10 being the highest pollutant potential and 1 being the lowest pollution potential. Also, they give the highest weight of 5 to the Depth of Water and the lowest weight of 1 to the topography [69].

Table 5 shows how each DRASTIC component has been split into important media kinds or ranges that affect the possibility of contamination. Ratings: The relative importance of each range in terms of the potential for pollution has been determined by comparing it to the other ranges for each DRASTIC component.

Table 4 Weights of the factors in the DRASTIC method [66]

Name abbreviation	DRASTIC method
D: Depth to Water	5
R: Net Recharge	4
A: Aquifer Media	3
S: Soil Media	2
T: Topography	1
I: Impact of the vadose zone	5
C: Hydraulic Conductivity	3

Researchers used two methods to determine the net recharge percolated to the basin for Erbil plain conditions first method is "Method of analysis of Rainfall-Recharge Relationships (R.R.R)", second method is "Maximum Water Surplus Method". Maps that were taken out of the research region using GIS software indicate that nearly all of the area under examination has a moderate level of vulnerability. These values are concentrated in the middle of the investigated area; the south-eastern and higher center regions of Erbil city have high levels of susceptibility, while relatively few areas in the north and south of the city have low levels of risk.

Ultimately, the majority of the locations under investigation had a moderate level of sensitivity to contamination. According to the study's findings, 3.8% of the entire region is located in the low-vulnerability zone, with 104 to 120 in the range of the DRASTIC index. Additionally, 1.5% of the total land is in the high vulnerability zone, with a DRASTIC index ranging between 137 and 153, and approximately 94.7% of the territory is in the moderately susceptible zone, with a DRASTIC index ranging between 121 and 136. The correlation coefficients between DRASTIC and the parameters for soil media, hydraulic conductivity, the impact of the vadose zone, and aquifer media are, in order, 0.707, 0.564, 0.518, and 0.320. According to a correlation study, the DRASTIC Index and depth to water do not correspond.

Table 5 Ranks and weights for factors and their influencing classes [66]

Theme	Class	Rank
Depth to groundwater (m)	0 and 1.5	10
	1.5 - 4.5	9
	9 4.5 – 9	7
	Sep-15	5
	15 – 23	3
	23 – 30	2
	More than 30	1
Net Recharge (mm/year)	Less than 50	1
	50 – 100	3
	100 – 175	6
	175 – 250	8
	More than 250	9
Aquifer media	Massive shale	2
	Metamorphic/ Igneous	3
	Weathered metamorphic/ Igneous	4
	Glacial Till	5
	Bedded sandstone, limestone, shale	6
	Massive sandstone, massive limestone	6
	Sand and gravel	8
	Basalt	9
	Karst limestone	10
Depth to groundwater (m)	0 and 1.5	10
	1.5 - 4.5	9
	9 4.5 - 9	7
	Sep-15	5
	15 - 23	3
	23 - 30	2
	More than 30	1
Net Recharge (mm/year)	Less than 50	1
	50 - 100	3
	100 - 175	6
	175 - 250	8
	More than 250	9
Depth to groundwater (m)	0 and 1.5	10
	1.5 - 4.5	9

	9 4.5 - 9	7
	Sep-15	5
	15 - 23	3
	23 - 30	2
	More than 30	1
Net Recharge (mm/year)	Less than 50	1
	50 - 100	3
	100 - 175	6
	175 - 250	8
	More than 250	9
Aquifer media	Massive shale	2
	Metamorphic/ Igneous	3
	Weathered metamorphic/ Igneous	4
	Glacial Till	5
	Bedded sandstone, limestone, shale	6
	Massive sandstone, massive limestone	6
	Sand and gravel	8
	Basalt	9
	Karst limestone	10

5. Sustainability and climate change effects on the water sources, especially on the groundwater

The basic element of life, water, is increasingly under pressure from climate change as well as human demands and groundwater is a key resource to sustain life, global warming increases the frequency and intensity of hydrological extremes, so it is becoming clear that global warming is a significant predictor of water availability and future water supply worldwide including precipitation and evaporation [70, 71]. Extremes like drought can affect natural flows and groundwater. They may also exacerbate social inequality by denying the poor access to water, among other problems [72].

Groundwater is special among water sources since it is a subterranean reserve that is sometimes thought of as a cushion against variations in surface water. Human usage of groundwater is currently increasing despite the depletion of groundwater supplies [73, 74]. Many models and studies implicitly assume that groundwater supplies are less vulnerable to climate change than surface waters because groundwater systems frequently store much larger volumes of water than do surface water systems and because groundwater systems are frequently the primary supply options when others fail during droughts [75].

However, the sustainability of this valuable resource is closely related to the continuing story of climate change as well as our consumption habits. Achieving sustainable groundwater management while considering social, economic, and environmental concerns is a difficult task that calls for the collaboration of experts from several fields. Figure 5 (also shown in Figure 5 of Mustafa, A Sharif [22], adapted from https://reservoir-prima.org/about-us) shows the diagram to achieve sustainability of groundwater management.

The concept of sustainability in water management hinges on a key principle is balancing current needs with long-term availability. From the perspective of water usage and management, not all groundwater is created equal; when creating water management plans, the appropriateness of the water, as determined by its quality, is a crucial factor. Furthermore, precise data on the three-dimensional distribution and concentrations of possible contaminants both naturally occurring and those originating from human activity are needed to determine the suitability (or unsuitability) of a given body of water [76]. The sustainability of water supplies has been the subject of several studies. According to research by Halim, F.A.Sharif [77], pressure from climate change and population growth are two variables that impact the sustainability of water resources and contribute to the spread of illness among people through water.

Also, changes in Earth's climate may have an impact on groundwater's quantity and quality. According to scientific consensus, rising greenhouse gas concentrations in the Earth's atmosphere have caused changes in the planet's climate, which will continue in the future [75]. Comprehending the relationship between climate change and fresh groundwater depletion is important for unique regional features. Developing countries with a high reliance on agriculture, are particularly vulnerable because of population increase, which raises the need for energy, freshwater, and food [78].

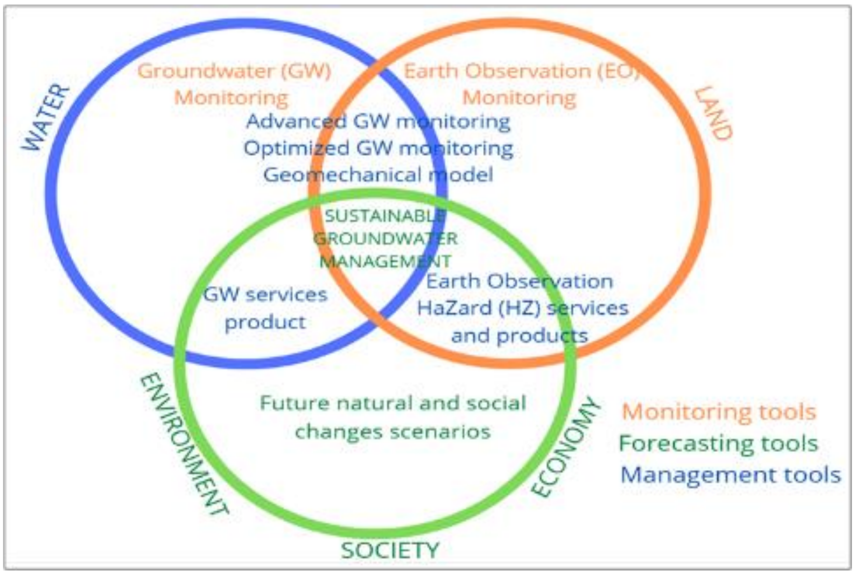

Figure 5 Diagram of Sustainability of Groundwater Management as cited by Mustafa, A Sharif [22]

Figure 6 Diagram advancement in groundwater potential mapping aspects

As we understand, the best way to prevent or mitigate the impact of climate change on groundwater is sustainable management of water resources, so using geographic databases such as RS and GIS is one of the most successful options that require less cost and time, and the method is very successful. With that, all the advancements in groundwater potential mapping can be helpful in many aspects which in the end leads to the protection of the environment that is required for a better life on our planet as shown in Figure 6.

6. Challenges and Future Directions

The most effective technique for identifying and tracking environmental and climatic change globally is satellite RS. Nevertheless, there are very few ways in which RS may "see below the ground surface" and identify characteristics that directly affect groundwater conditions. Satellite-based measurements of the gravity field linked to variations in groundwater storage are notable outliers to this rule. Groundwater management is difficult due to insufficient groundwater monitoring networks and a lack of knowledge on volumetric groundwater extraction [79]. The mapping of groundwater potential through the use of GIS and remote sensing techniques presents enormous potential for sustainable management of water resources [80]. Though hopeful future directions promise promising gains in this discipline, there are still substantial problems to be addressed. Here's a deep dive into both:

6.1. Challenges

6.1.1. Data Acquisition and Quality

Due to the limited high-resolution satellite data, many regions lack access to the fine-scale imagery crucial for identifying subtle features indicative of groundwater potential. Incomplete or inaccurate ground-truth data, scarcity, inaccuracy, and incompleteness of groundwater well data and aquifer properties hinder model calibration and validation. On the other side there are significant uncertainties since the planet is highly heterogeneous and typical data sets are scattered and varied [81]. Then limited access to subsurface data because direct measurements of subsurface geological formations and aquifer parameters are expensive and time-consuming, impacting model accuracy.

6.1.2. Model Development and Uncertainty

The multifaceted nature of groundwater systems, influenced by numerous factors, makes developing accurate and reliable models a complex task. Also, the lack of sufficient ground-truth data restricts rigorous model calibration and validation, leading to uncertainties in potential maps. The groundwater system's projections are never exactly what is observed. Consequently, the fundamental challenge in precisely characterizing groundwater flow and solute transport activities is the inherent uncertainty of groundwater simulation [82]. Furthermore, the complexity of groundwater systems and its many affecting elements cause uncertainty in model results. Limitations in validation and calibration add even more uncertainty to these figures. Then groundwater models are sensitive to the selection and weighting of parameters for different factors, significantly influencing map accuracy.

6.1.3. Scalability and Transferability

Groundwater models built for specific regions may not be directly applicable to other regions with differing geological and hydrological characteristics. Also, scaling models from local to regional or national scales can be difficult due to data limitations and computational complexity. deployment of groundwater monitoring in real-time Due to obstacles relating to cost and/or lack of customization, previously developed techniques have not gained general adoption Calderwood, Pauloo [83] that’s why integrating real-time data from sensors and monitoring systems into models for dynamic updates of potential maps can be challenging.

6.1.4. Environmental and Socioeconomic Considerations

Climate change significantly influences groundwater potential, and it will impact groundwater supplies in many locations and aquifers in unique and varied ways. There are significant uncertainties about how climate change may impact recharge, storage, and discharge, even at the scale of a single aquifer [75]. This necessitates the integration of climate change scenarios into models for future predictions. Additionally, hand-use changes and human activities like agriculture, urbanization, and water extraction impact groundwater potential, requiring the integration of socioeconomic data into models [84]. Groundwater potential maps should be used with sustainability considerations to prevent overexploitation and depletion.

6.2. Future Directions

- Technological advancements in satellite imaging: Higher resolution images and new sensor technologies (e.g., LiDAR) can offer more detailed information about surface features and potential groundwater indicators as Shrestha, Mittelstet [85] uses LiDAR as an approach for groundwater level assessment and prediction in the Nebraska Sand Hills.

- Improved ground-truth data collection: Innovative tools like geophysical surveys and advanced remote sensing techniques can enhance the accuracy and availability of ground-truth data.
- Machine learning and artificial intelligence: Integrating machine learning algorithms into models can improve accuracy, automate data analysis, and reduce dependence on expert knowledge (e.g. Machine learning algorithms can automatically extract relevant features from raw data, such as contours, lineaments, slope, vegetation indices, and drainage patterns from remote sensing imagery, streamlining the analysis process. Southwest China Yu, Wen [86] used Hybrid-Wavelet Artificial Intelligence Models for Monthly Groundwater Depth Forecasting in Extreme Arid Regions.
- Open-source software and platforms for exchanging data: Encouraging simple access to resources will foster teamwork in research and raise the standard of groundwater potential mapping projects as a whole.
- Addressing environmental and socioeconomic factors: Developing models that account for climate change impacts, land-use changes, and human activities will ensure sustainable water resource management.
- Real-time monitoring systems: Connecting models with real-time data from sensors and monitoring networks will enable dynamic updates of potential maps and facilitate proactive groundwater management.

By tackling these challenges and embracing future directions, we can harness the power of remote sensing and GIS techniques to unlock a deeper understanding of groundwater potential and ensure sustainable water resources for generations to come.

Additionally, consider exploring these specific advancements within each future direction:

- Advanced data fusion techniques: Exploiting synergies between different data sources like hyperspectral and LiDAR data to improve feature extraction and accuracy.
- Unsupervised machine learning algorithms: Utilizing these algorithms to discover hidden patterns and relationships within data without the need for pre-labeled data.
- Cloud computing and distributed processing: Leveraging cloud platforms to handle the immense computational power required for large-scale models and real-time data processing.
- Citizen science and crowdsourcing: Engaging local communities in data collection and validation efforts to improve data coverage and accessibility.

7. Conclusions

This study provides an updated summary of groundwater potential techniques, drawing on recent advancements in the field. The extensive volume of scholarly publications highlights both the applicability of these techniques and the critical need to better understand groundwater resources in our rapidly changing world. Mapping groundwater potential offers an efficient and cost-effective way to identify promising areas for development by integrating various data sources. While particularly valuable in remote regions, these maps are not a substitute for field investigations. Challenges remain in accurately representing groundwater occurrence on maps. The crucial task at hand is to create high-quality maps that can inform water policy decisions. A promising development for the near future lies in the emergence of machine-learning techniques. Combining these techniques with human expertise has the potential to significantly improve the accuracy of groundwater potential mapping. Wider adoption of such combined approaches can only lead to more precise maps.

Compliance with ethical standards

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There is no conflict of interest with any financial organization regarding the material discussed in the article.

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