Evaluating The Groundwater Potential of Wadi Al-Jizi, Sultanate of Oman By Intergrating Remote Sensing & GIS Techniques

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Abstract

Groundwater resources are highly stressed due to their overuse, especially in the arid region. This study is aimed at discovering potential groundwater resource zones using currently available data and state-of-the-art methods. This will lead to effective management of scarcely available and rapidly depleting groundwater resources in the Wadi Al-Jizi catchment, located in the Al-Batinah region. Data on terrain characteristics, geology, and geomorphology was integrated using remote sensing techniques and Geographical Information System (GIS). The result from this exercise was used for the identification of areas with a high potential for groundwater availability. These areas were classified into five types; namely; excellent, good, medium, low, and very low. The present study shows that the integration of all the weighted parameters shows promising results in the zonation of groundwater. This study shall be useful to the decision-makers in highlighting potential drilling as well as recharge sites in the area.

Introduction

Sultanate of Oman, with an average annual rainfall of 100mm, falls in the arid zone. The key source of freshwater is the precipitation in the mountainous area which results in the replenishment of the aquifers. Agriculture has grown tremendously over the last four decades due to the introduction of modern drilling and groundwater pumping systems. Due to the persistent water deficit caused by excessive pumping in the area, the water quality continues to deteriorate due to the intrusion of seawater. As a result, a number of farms have been abandoned and many others are currently facing salinity hazards. Over 50 percent of the country's cultivated land is located in Al-Batinah, which represents about 4% of the country's total area (Sana and Shibli 2006). Continuous population growth, climate change, heavy urbanization, and changes in land use have increased the thrust on the conventional surface water source to the extent that it has forced groundwater extraction as an alternative to surface water to cope with water scarcity (Banerjee et al. 2017, Gupta et al. 2019). An appreciable imbalance between the groundwater recharge and abstraction has resulted in groundwater deficit (Bahgwat et al. 2018). It is important to identify the areas which have a strong potential for groundwater, so that a balanced utilization and conservation strategy may be adopted for this precious water resource (Das et al. 2018). Some terrain features may indicate the presence of groundwater in sub-surface layers (Dinesan et al. 2015). The groundwater availability and dynamics depend on soil properties (soil type, porosity, hydraulic conductivity), terrain features (drainage pattern, topography, land-use), geologic and geomorphologic information (lithology, geological structure, depth of weathering, land-forms, fracture magnitude). In addition, climatic conditions and the inter-relationship of all the above factors play a vital role in the presence and dynamics of groundwater (Dinesan et al. 2015, Sharma & Shukla 2015).

In order to detect the availability, quantity, and quality of groundwater, the use of geophysics is very common. Such non-invasive methods help to map sub-surface geological structures and geological sequences. Akinlalu et al. (2017) employed a geophysical technique using Schlumberger configuration of electrodes. In the year 1992, geophysical exploration was carried out over an area of about 2000 square kilometers located in the eastern Al-Batinah region to demarcate fresh and saline water aquifers. (Young

et al. 1998). The zones with groundwater potential were explored using the available geological and geophysical methods. Given the extensive and rigorous ground measurements required by these methods, they can only be used for large-scale mapping (Maity & Mandal 2019, Suganthi et al. 2013). The ground survey forms an integral part of any conventional method used to gauge the groundwater potential (Al-Ruzouq et al. 2015, Yousuf et al. 2015).

In recent years, remote sensing and GIS have emerged as effective tools to synthesize all the available hydro-geological data and delineate potential groundwater occurrence zones. Using these methods, it is possible to delineate potential groundwater zone accurately. In addition, bias towards a single factor can be decreased. These methods are effective for exploring, analyzing, tracking, evaluating, and managing groundwater for sustainable groundwater utilization (AL-Ruzouq et al. 2015, Chaitanya et al. 2018, Das et al. 2018, Dinesan et al. 2015, Gunapuram et al. 2009, Gupta et al. 2019, Khan et al 2017, Machiwal et al. 2011, Mangesh et al. 2012, Nag & Kundu 2018, Ramu 2014, Thakur et al. 2017, Thapa et al. 2017). Fashae et al. (2017) used multi-criteria decision analysis along with remote sensing and GIS methods to locate prospective groundwater areas in SW-Nigeria. For groundwater exploration, all the available thematic maps (soil, slope, geomorphology, lithology, land use, drainage density, topography, rainfall) are combined to identify a potential groundwater zone (Agrawal & Garg 2016, Fashae et al. 2017, Thapa et al. 2017). Lubang et al. (2019) used a weighted index overlay technique created by Multi-Criteria Analysis to assigned the weights to the various map layers for his region of research to delineate Uganda's groundwater region. A simple mathematical model was used for the weighted index overlay analysis of multi-parameters (Sharma & Shukla 2015). Selvam et al. (2015) used ArcGIS 9.3 software and used appropriate scores and weights based on the relative influence of the important parameters.

As the water table is lowered by pumping rates greater than the replenishment rates, the areas undergo a significant reduction in groundwater reservoir volumes that can lead to depletion of water in other water bodies (streams, lakes, and wells) and can cause land subsidence, deterioration of water quality and greater pumping expenses (Senanayake et al. 2016). As the volume of pumped water has increased and the water levels have declined, seawater intrusion takes place because of the adverse phreatic surface gradient. As a result, there has been a critical deterioration of groundwater quality. The supply of domestic water has declined as salinity has risen to concentrations which render the water unsuitable for human consumption. The crop yield has been affected, including the date palms that usually tolerate higher salinities. Groundwater stress is very high because of enormous demand and over-exploitation. As the salinity of the soil increased, farms were abandoned. 750 wells were abandoned in some part of Al-Batinah, all within 6 km of the coastline. This emphasizes the urgent need for conservation measures to sustain this valuable wealth (MRMWR 2008). The present study is aimed at locating the potential areas for groundwater abstraction in a part of Al- Batinah using the most important factors such as soil, slope, geology, land use, and geomorphology.

Study Area

The Wadi Al-Jizi catchment is selected as the study area (located between Latitudes 26°52'88.72" N to 27°02'809.30" N and Longitudes 44°51'20.53" E to 47°42'36.85" E covered in a topographic map (**Figure.1**). It is a coastal plain groundwater aquifer, located in the Al-Batinah region in northwestern Oman (Shibli 2002). The study area is bounded by the Sea of Oman on the north, while the Al Hajer Al Gharbi mountains range lies on the south. The rain falls in the Al-Batinah region's coastal belt between the months of October and April and as a consequence of thunderstorms in the foothills and hills during the month of July (MAF & ICBA 2012). Wadi Al-Jizi catchment, with approximately 100 mm of average annual rainfall, is classified as arid. At higher altitudes in the catchment (1000 m and above) adjacent to mountains average annual rainfall is approximately 300 mm contributing to the coastal aquifer recharge (Young et al. 1998). The area is of vital importance to the Sultanate of Oman's agricultural economy and represents a large percentage of the agricultural products of the country. The primary source of freshwater that recharges the aquifer is mountain rainfall. The total the Wadi Al- Jizi catchment area is about 1,154 km², including about 519 km² of the east part. The aquifer system on the eastern part is studied that has an area of about 203 km² extending from the sea towards the Wadi Al-Jizi dam having a capacity of 5.4Mm³.

Material And Methods

Five thematic layers, namely; slope, soil, land use, geomorphology, and geology are used in the present study. First thematic maps were generated and then analyzed for groundwater prospects. The following steps were followed in the study:

1. Preparation of base map
2. Digitization of thematic maps
3. Governing factors were given weightage based on their relative importance
4. Synthesis and use of thematic maps to gauge groundwater potential

The Ministry of Defense topographic map NG40-14F1 (1:50,000 scale) was used for the preparation of the base map. This base map was used to delineate the boundaries of basins, various natural features, and for georeferencing. The satellite image was analyzed visually to delineate soil lithological units and geomorphological units. Groundwater prospects maps were prepared using ArcGIS 9.0 software. Different thematic maps were allocated corresponding weights based on their impact on groundwater storage and movement (Sharma & Shukla 2015). The weight of a variable reflects the percentage of its value in the prospective recharge scale. Since it is difficult to determine accurate recharge value for a large study area, the weight of the potential for recharge is estimated based on the significance of each factor during the recharge phase. The greater the weight of the recharge, the higher the impact factor. Each contributing factor has a degree of favorable or adverse impact in terms of groundwater recharge (Yeh et al. 2016). After assigning rank and weight to each thematic layer, the various thematic layers were

overlaid using weighted overlay assessment. Agrawal and Garg (2016) used weight allocation to several thematic layers and the classes are based solely on the expert's decision.

Results And Discussion

Soil

The most vital natural resource for human habitation activities and farming is soil. It is primarily controlled by topographic conditions, climate, vegetative cover, and the parent rock (Nag and Kundu 2018). The infiltration rate depends on the soil conditions and the water percolation from the soil surface (Bahgwat et al. 2018). The topsoil in the study area is geologically unconsolidated and resulted from weathering of rocks. Figure 2 represents six types of soils found in the study area, that is, sandy gravel, coarse gravel, fine sand, silty clay, conglomerates, and sandy loam. Sandy gravel is the dominant type of soil covering about 50.4% of the study area. The coastal area consists of, mainly, silty clay with fine sand only along the coastline the porosity and permeability of the sand and gravel are high. Since infiltration rates of coarse-grained soils are high; so highest weight is assigned to these soils. Also, clayey soils have lower infiltration rates, therefore lower weights are allocated (El Hatim 1977, Rabu et al. 1993).

Slope

The surface gradient of the watershed directly influences rainfall infiltration. Steeper slopes allow less infiltration hence less recharge to the aquifer would result. In other words, a runoff would be rapid and therefore, the possibility of rainwater percolating from the surface is reduced (Mangesh et al. 2012, Yeh et al. 2016). A slope map was derived from the topographic map using Arc GIS. The slope varies from 0.0° to more than 34.0° as shown in Fig. 3. The study area has been classified with 97.75% of the area with a minimum slope range of 0 to 6° and given the weightage of 4, while the class with a maximum slope of $28-32^\circ$ covering an area of around 0.11% is assigned a weightage of 1 which is the lowest weightage used and indicates a lower possibility of groundwater occurrence (Agrawal & Garg 2016).

Geomorphology

The geomorphology of a region relies on the structural evolution of the geological formation and reflects distinct structural features and land shapes. The structural features, as well as landforms, are identified and characterized using geomorphological maps. The groundwater movement and storage in a region depends on geomorphology as well (Chowdhary et al. 2019, Waikar and Nilawar 2014). Al-Batinah coastal plain, which is divided into two geomorphological units, is the hub for agriculture, industry, and settlement. The northern front of Al-Jabal Al-Akhdar is drained by a series of profoundly incised wadis that transform coastal terraces into gravel terraces, and finally, the coastal plain consisting of dispersed sabkhas, coastal sand dunes, fertile soil strips, and alluvial deposits (MRMWR, 2008).

The Ministry of Petroleum and Mineral, Oman Map was used to derive a geomorphology map using Arc GIS. Figure 4 shows the geomorphology of the study area. The area has the highest potential for

recharge, mainly consists of wadi terraces and land-use farming. A significant amount of rainfall is allowed to percolate and reach subsurface layers. The geomorphological features in the area can be categorized into seven units such as active wadi channels, ancient alluvium, recent alluvium, sand dunes, khabra, sand veneers, and sabkha. The geomorphology of the study area is dominated by a unit of sand veneers covering 29 % of the area. Khabra possessed an area of 20.9 % followed by 19.4 % and 18.7 % shared by the active wadi channels and recent alluvium respectively, all of these have high water potential and therefore they have been assigned higher weights.

Land Surface characteristics

Land surface characteristics such as land cover and land use not only affect the groundwater recharge but also the microclimate. The mapped categories varied between map sheets depending on the surface characteristics (Chaitanya et al. 2018). The surface characteristics map (land-use and land-cover) depend on many factors like geomorphology, ecology, climatic conditions, and anthropogenic activities that significantly affect the groundwater occurrence and distribution (Chowdhary et al. 2019). Water bodies, cultivated land, and saturated surface are very efficient groundwater recharge sources, whereas the area affected by urban development is considered less effective. Hence, the highest weight is given to water bodies and the lowest to the built area (Agrawal and Garg 2016). Land-use and land-cover data for the study area were mapped using Google Earth (Digital Globe) rectified through ENVI 4.0, image processing software, and a topographic map. The most prevalent land-use in the study area is registered as an open space (71.9%), plantation (12.7%), and built-up area (14.8%) as shown in Fig. 5. Reservoir dam had occupied least of the study area. The constructed area such as concrete surfaces, roads, and buildings that do not contribute to infiltration of the water were assigned least weightage, whereas, plantation area which plays a major role in recharge was given the highest weight.

Geology

The geology map of the study area is shown in Fig. 6 which has been prepared from the report published by the Ministry of Regional Municipalities and Water Resources. The alluvial plain of Al-Batinah lies at the base of alluvial fans. The remains of older fans are found as terraces of fluvial origin consisting of variable cemented rock beds, gravel, and sand. The primary aquifers presently utilized are high permeability wadi gravels and storativity (up to 50 m thick) and engraved into the terraces. Alluvial channels feed the coastal plain alluvium with water from the mountains. Wadi fans spread across the northern margin terraces and merge into the coastal plain's alluvium. The study has been widely covered by the alluvium possessed more than 97% of the area and assigned higher weight owing to its groundwater recharge capacity. In the coastal plain alluvium, three zones are traditionally acknowledged in reducing order of storativity and permeability: upper gravels; clayey gravels; and basal cemented gravels. The upper gravels which is the most productive unit are made up of flood-flow deposited sands, clean uncemented gravel, and boulder beds. The clayey gravels consist of clay bands coupled with gravel beds and calcareous material (Young et. al, 1998). The cemented gravel is the least permeable of the three units, but there may be a higher potential for uncemented fields in this region. All the available

literature and data regarding the study area were used to assign suitable weights to thematic maps and their individual characteristics as shown in Table 1.

Table 1
Weightage and ranks of various factors for
groundwater potential zone

Factors	Weightage	Rank
Geomorphology	20	
Active wadi		4
Recent alluvium		4
Ancient alluvium		1
Sabkha		3
Khabra		3
Sand veneers		2
Sand dunes		5
Slope	15	
Low		5
Gentle		4
Moderate		3
High		2
Very High		1
Geology	30	
Alluvium		5
Hawasinah		3
Soil	20	
Coarse gravel		4
Sandy gravel		5
Sandy loam		5
Silty clay		3
Fine sand		5
Conglomerates		1
Land use	15	
Plantation		5

Factors	Weightage	Rank
Dam		4
Open space		3
Built up area		2

Groundwater potential zoning

Groundwater potential zones, as shown in Fig. 7, were generated by overlaying weighted reclassified raster map layers of Geology, geomorphology, soil, land use, land-cover, and slope in Arc-GIS. Table 2 presents the different classes of groundwater probabilities distributed in the study area. The result reveals that the dissemination of groundwater prospects in Wadi Al-Jizi covered 11% of the study area under the 'excellent' class, whereas the area having a class of 'medium' water potential is nearly 26%. Most of the study area falls in 'good' (59.8%). The pockets of 'low' and 'very low' zones, lying near the mountains covered less than 3.5% of the total evaluated area. Four groundwater recharge dams were constructed in the region to catch surface water that would otherwise flow into the sea or is lost by evaporation and is to allow infiltrating into the ground where it will augment existing groundwater supplies. Wadi Al-Jizi dam constructed in 1989 is one of them which can retain more than 116 MCM of water also helping in enhancing the groundwater potential. Geomorphological units like active wadi channels and the latest alluvium are potential areas in the research area for groundwater exploration and growth. Wells are the most widely used means of supplying water for irrigation in Oman. As per MWR (2001), a total of 44502 wells were dug in the six wilayat of the region out of which 11331 wells were dug in Sohar wilayat. In the coastal plains, soils are particularly fertile, most of the water is used for agricultural purposes (86%), followed by drinking water (12%) and industrial use (2%). Desalination provides only a small percentage of water, most of the water need is met through hand-dug and drilled wells for extraction of local groundwater.

Table 2
Rank and weightage of
various factors for
groundwater potential
zone

Class	Weightage
Excellent	5
Good	4
Moderate	3
Low	2
Very low	1

Conclusion

An integrated approach based on remote sensing and GIS is used to locate the most suitable groundwater abstraction zones in the Wadi Al-Jizi catchment. This approach can help identify potential groundwater zones quickly and can be used in the study area as a guideline for integrated management of water resources. After identifying the suitable sites, detailed ground hydrogeologic investigations can be carried out to select the most suitable location for the sustainable abstraction of groundwater. This will also help in formulating an efficient and sustainable groundwater management plan for the management authorities and decision-makers concerned.

Declarations

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent to Publish

Not applicable

Authors' contributions

JA: Conceptualization-Original draft, program running. **AS:** Writing-review & editing, supervision, **SMT:** Data curation & Data validation and Software, **GC:** Data Curation, software, review & editing. **PK:** Data curation **HS:** Software & Data curation, **RA:** Data validation & review and editing.

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Competing interests

The authors declare no competing interests.

Data availability

The manuscript and data are the authors' original work, and the manuscript has not received prior publication and is not under consideration for publication elsewhere. The manuscript now submitted is not a copied or plagiarized version of some other published work.

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Figures

Figure 1

Location map of study area of Wadi Al-Jizi

Figure 2

Soil Map of the study area

Figure 3

Slope Map of the study area

Figure 4

Geomorphology of the study area

Figure 5

Land use /Land cover map of the study area

Figure 6

Geology map of the study area

Figure 7

Ground water potential zones of the study area