

Chapter 17

Mapping Groundwater Potential Zones in UAE Using GIS-Based Hydrogeological Modeling



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17.1 Introduction

Groundwater is the main conventional freshwater resource in UAE (Fig. 17.1). This precious natural resource is nearly the sole source for irrigation water and also provide a small share of potable water for the needs of rural areas. Currently, groundwater extraction for irrigation is more than 95% of the total extraction and groundwater extraction in some areas is 3 to 4 folds of the actual crop water requirements (Fig. 17.2). Though climatic and soil conditions are not ideally suitable for agricultural and horticultural plant cultivation in most parts of the UAE, the area of irrigated land has increased considerably throughout the last two decades. Between 1994 and 2009 the cultivated land surface has approximately doubled (EAIC 2009). Plant cultivation in the UAE comprises of urban landscapes and amenities, as well as land used

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for the production of crops. In addition, the UAE maintains a considerable area of man-made forests, which serve plant and wildlife conservational purposes. With an annual average rainfall of only around 120 mm all agricultural plant production and maintenance of forests and parks in the UAE depends on irrigation water supply. Therefore, groundwater availability in the right quantity and quality, contributes to sustainable development of UAE.

The precise amount of groundwater consumed by open field crop production in the UAE is difficult to assess, as most farmers do not use water counters. Estimates vary considerably, depending on the source (Table 17.1). In each estimate there is one or more source of uncertainty. However, the rates of 2480 and 450 MCM/year are the most reasonable estimates for farms and planted forests irrigation respectively. Only 1160 MCM/year of this volume (32%) is replenished by recharge from all different sources (Sherif et al. 2021). Therefore, it is required to enforce the relevant restrictions to change the current practice and supply water in accordance with the needs of the crops. Through this management component, the lifespan of groundwater reserves would be expanded. Successful management of the very limited fresh groundwater reserve in UAE depends largely upon the following:

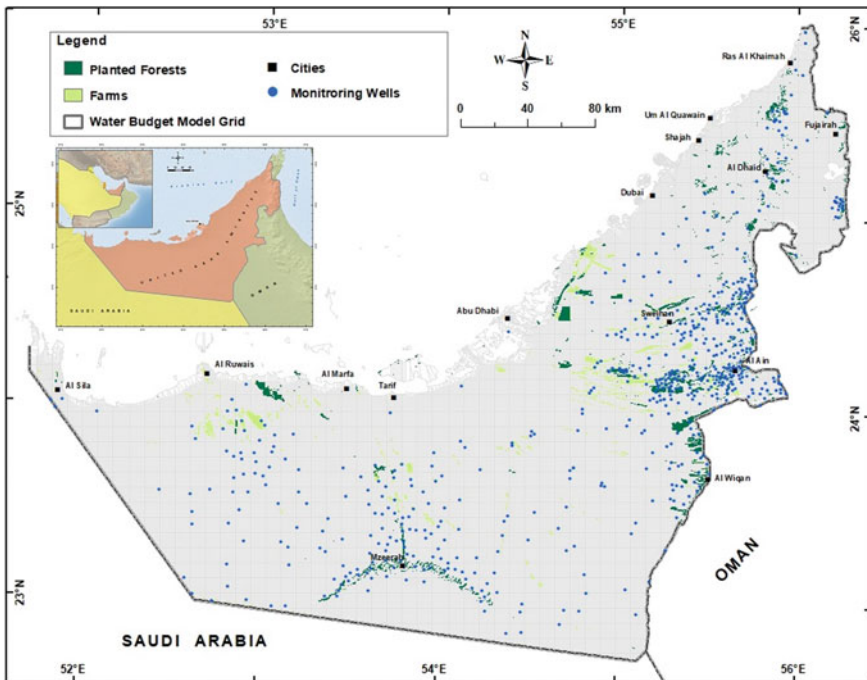


Fig. 17.1 Location map of UAE. The locations of monitoring wells, farms, planted forests, and water budget model grid are also shown (Sherif et al. 2021)

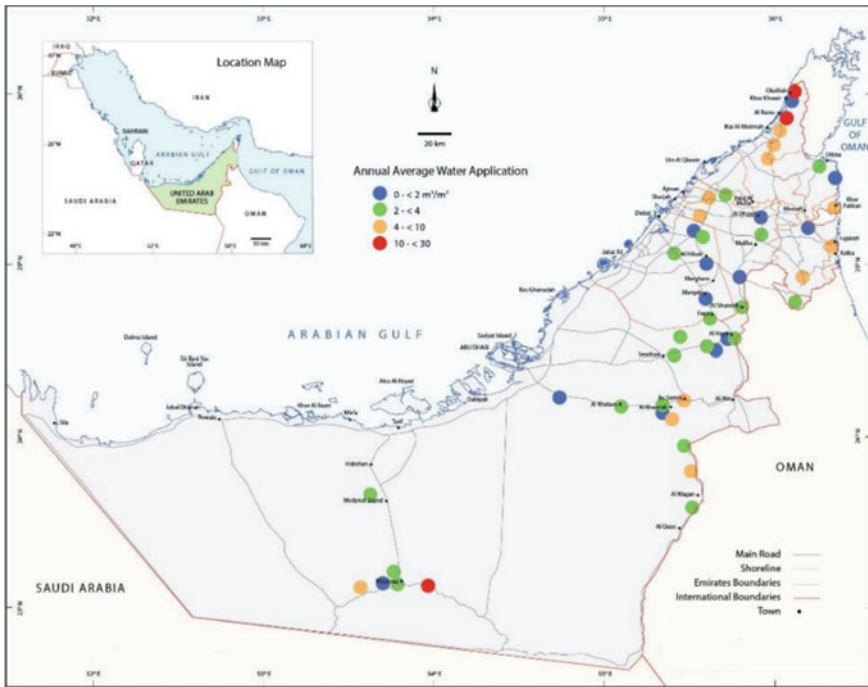


Fig. 17.2 Estimated on-farm annual water application (Hydro Atlas 2015)

- Knowledge of the volumes of groundwater reserves (quantity and quality wise) and spatial distribution of the groundwater potential zones (GWPZs).
- Estimation of the rates and sources of groundwater recharge
- Precise prediction of the impact of stresses on groundwater reserves (quantity and quality wise)
- Implementation of a new well permitting system and forcing the installment of meters at the well outlets to measure actual groundwater pumping in all farms.

Delineation of the groundwater potential zones (GWPZs) requires the analysis of several factors relates to the physiographic setting including but not limited to aquifer types and geometry, lineament density, geological structure/lithology, elevation, soil, drainage density, slope, land cover/land use, rainfall, existed water infrastructure, etc. Groundwater investigation and identifying GWPZs in each study area are both greatly facilitated by GIS. It has become simpler to provide the baseline data for designating groundwater potential zones to the extensive usage of remote sensing satellite pictures and ground truth data. Studies have shown that several researchers have used machine learning, simple additive weight (SAW), and analytical hierarchy process (AHP) with GIS to designate groundwater potential zones. The ambiguity of hydrogeological data in several aspects is reduced by the use of remote sensing and GIS technology (Melese and Belay 2022). The main objectives of the current

Table 17.1 Different estimations of groundwater abstraction for irrigation in UAE

The Study	Estimated Irrigation volume for farms and planted forests (MCM)	Remarks
The Pacific Institute (2006)	1564	The estimate was done for farms only
FAO (2009)	3300	Overestimation of the farms area
MOEW (2010)	1970–2070	The estimate was done for farms only
UAE Hydro Atlas (2015) Open field survey method GWBM	3110 (for farms only) The estimated total groundwater abstraction is 2850 MCM per year (1700 coming from groundwater storage mining and 1150 MCM coming from recharge sources). Then the annual groundwater abstraction for irrigation purposes only can be obtained by subtracting the volume of 90 MCM per year for domestic purposes from the total value	
MOEW and ICBA	2370 (for farms and planted forests irrigation)	
Sherif et al. (2021)	2764 (2314 for farms and 450 for planted forests)	

study are (1) to map the potential groundwater zones in the UAE using the analytical hierarchy process (AHP) and GIS techniques, and (2) to provide a digital geodatabase that decision-makers can use to create effective sustainable groundwater management plans to address the UAE's limited natural freshwater resources.

17.2 Hydrogeological Setting

Five aquifers make up the UAE's groundwater systems, and they are mentioned below in order of their physical setting (surface or deep) and location from north to south (Fig. 17.3): (a) Quaternary aquifer, (b) The sand dunes' aquifer, (c) Juweiza aquifer, (d) Carbonates aquifer, and (e) Fractured ophiolite aquifer. The hydraulic connections between the Quaternary and Juweiza aquifers indicate the UAE's primary groundwater system. The aquifer comprises alluvial gravels and sand on both sides of the Northern Oman Mountains (Sherif et al. 2021).

The hydrogeological map shown in Fig. 17.3 indicates that Quaternary aquifer system is the main aquifer system in UAE. The aquifer comprises alluvial gravels and sand on both sides of the northern Oman Mountains in the northern part of the country

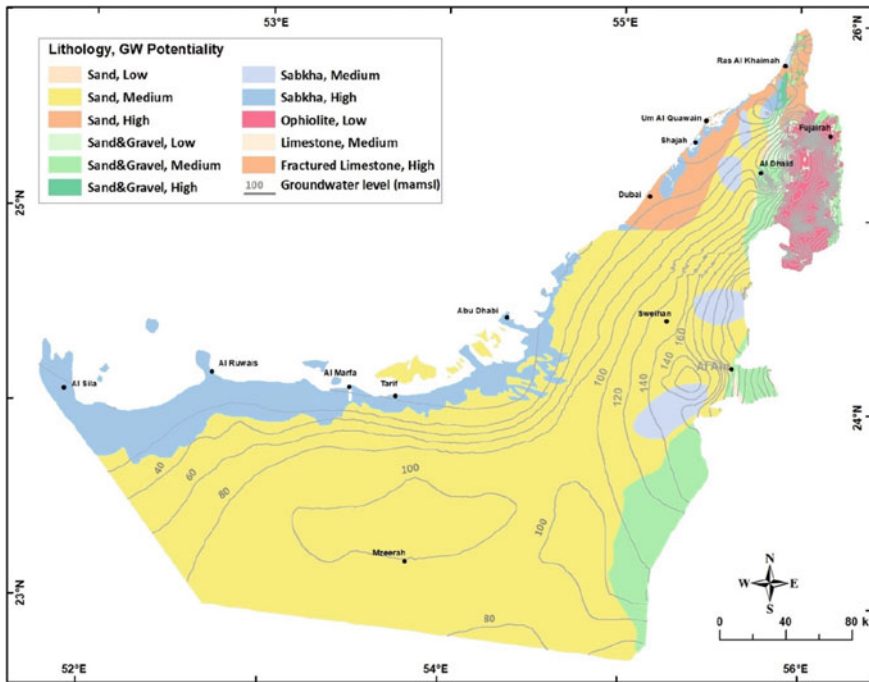


Fig. 17.3 Hydrogeological map of UAE (Sherif et al. 2021)

(Fig. 17.4). This aquifer system contains the largest reservoir of fresh groundwater storage in UAE. Groundwater can be found between 5 and more than 100 m below the surface, according to field measurements. The local terrain, aquifer boundaries and extent, groundwater abstraction, and recharge rate all affect the flow system in this aquifer. This aquifer system has a hydraulic conductivity of 10 to 40 m/day, and the TDS ranges from 500 to 150,000 mg/l in the sabkha zones (e.g., along Al Ain Abu Dhabi main road). The estimated groundwater reserve in the Quaternary aquifers across the UAE is 750,000 MCM (Sherif et al. 2021). Currently, less than 15,000 MCM of this volume is fresh groundwater reserve. Excessive groundwater abstraction from this aquifer system (2854 MCM/year) results in local cone of depressions due to the limited annual replenishment (787 MCM/year).

The carbonates aquifers in the UAE is divided into: (a) northern limestone aquifer (or Wadi Al Bih Aquifer) in Ras Al Khaima Emirate and (b) Jabal Hafit limestone aquifer south of Al Ain City in Abu Dhabi Emirate. The northern limestone aquifer is predominantly composed of fractured limestone and dolomite. Jabal Hafit aquifer is composed of a very thick limestone layer and marl interbedded with gypsum and dolomite and evaporates formations of Lower Eocene to Miocene age. The hydrologic budget of wadi Al Bih basin indicated that the total fresh groundwater reserve and annual recharge are about 14,000 and 9.57 MCM respectively. The total groundwater discharge from this aquifer is about 6 MCM in addition to annual seepage to the sea

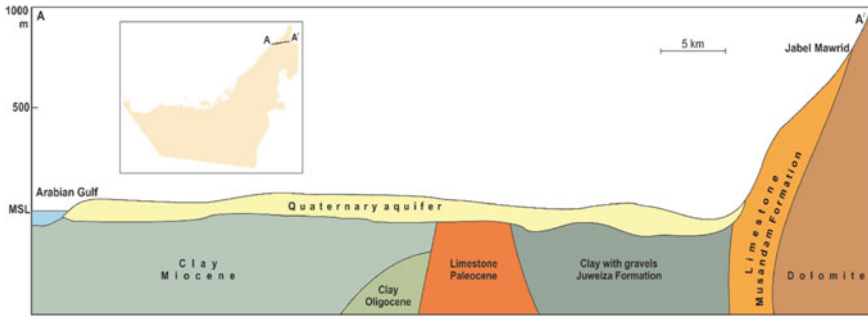


Fig. 17.4 Geological cross-section A-A' in the east-west direction showing the quaternary aquifer (Source Sherif et al. 2021)

of about 1.5 MCM. The estimated groundwater reserve of fresh to saline water categories in the carbonate aquifers across the UAE is 370,000 MCM (Sherif et al. 2021).

17.3 Materials and Methods

To estimate the groundwater reserves in this aquifer, annual groundwater recharge, and average annual groundwater abstraction for irrigation, information held in the water resources geodatabase for the Quaternary Aquifer was employed within the groundwater budget model (GWB) developed by Sherif et al. (2021) which include two new components which are groundwater recharge and abstraction for irrigation purposes. In the GWB model, the whole area of UAE (excluding islands) was divided into a regular grid of 1 km² (7049 cells) as shown in Fig. 17.1. Based on the hydrological, hydrogeological, aquifer surfaces topography under each cell, the above-mentioned volumes were calculated for each cell for years 1969, 2005, 2010, and 2015. Decrease in groundwater storage in the period 2005–2010 was also calculated and divided by 5 at each cell to get the average annual water table decline at each grid cell. By multiplying water table decline at each cell times its surface area times the specific yield, the net groundwater extraction will be obtained at this cell. Then by adding the obtained net groundwater abstraction for all cells, the total net groundwater abstraction was obtained for the whole UAE.

17.4 Results and Discussion

The groundwater salinity map of year 2015 (Fig. 17.5) and a groundwater budget model (GWB) developed by Sherif et al. (2021) were used to estimate the groundwater reserve of each water quality (fresh brackish/saline) as shown in Table 17.2. The

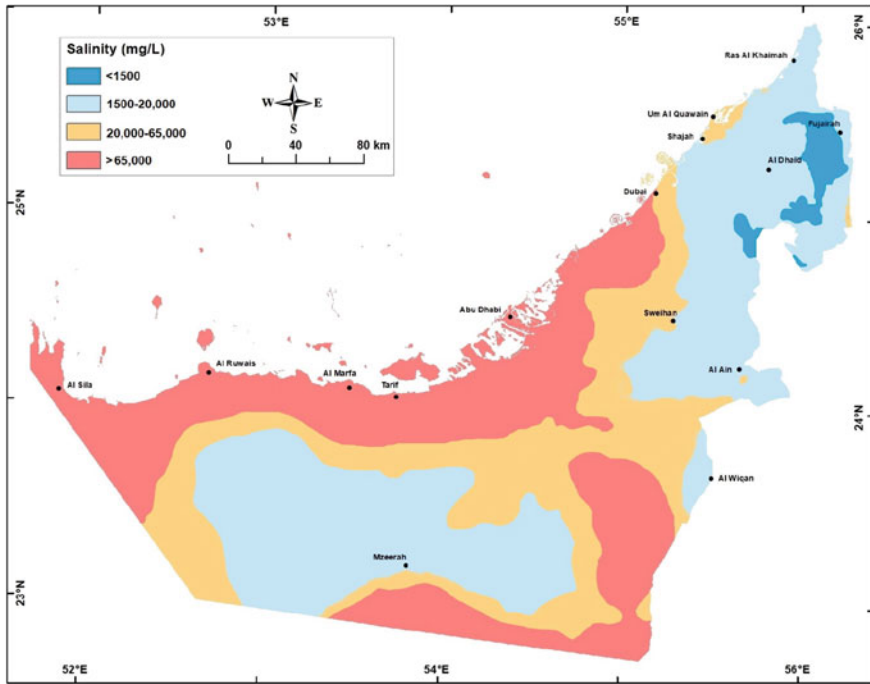


Fig. 17.5 Groundwater salinity (mg/l) in the year 2015 (Source Sherif et al. 2021)

Table 17.2 Types of groundwater storage available in the quaternary aquifer as computed from GWBM (cubic kilometers) for year 2015

Water Type	Fresh (km ³)	Brackish (km ³)	Saline (km ³)	Brine (km ³)	Total (km ³)
Salinity	(< 1500)	(> 1500–20,000)	(> 20,000–65,000)	(> 65,000)	–
2020	10	270	380	262	922

Source Sherif et al. (2021)

GWBM was also used to estimate groundwater abstraction for irrigation, remaining lifespan, and replenishment ratio in the year 2020. In the agricultural areas, the replenishment ratio is ranging from 1 to 25% (Fig. 17.6). The main advantage of this model is that it is based on an updated GIS database for the conventional and nonconventional water resources. The recharge from rain and other sources to the Quaternary aquifer was estimated using the potential recharge method with the analytical hierarchy process (AHP) submodules of the same GWBM model (Fig. 17.7). The total recharge to the Quaternary aquifer with and without augmentation is 1197 and 1001 MCM respectively (Table 17.3).

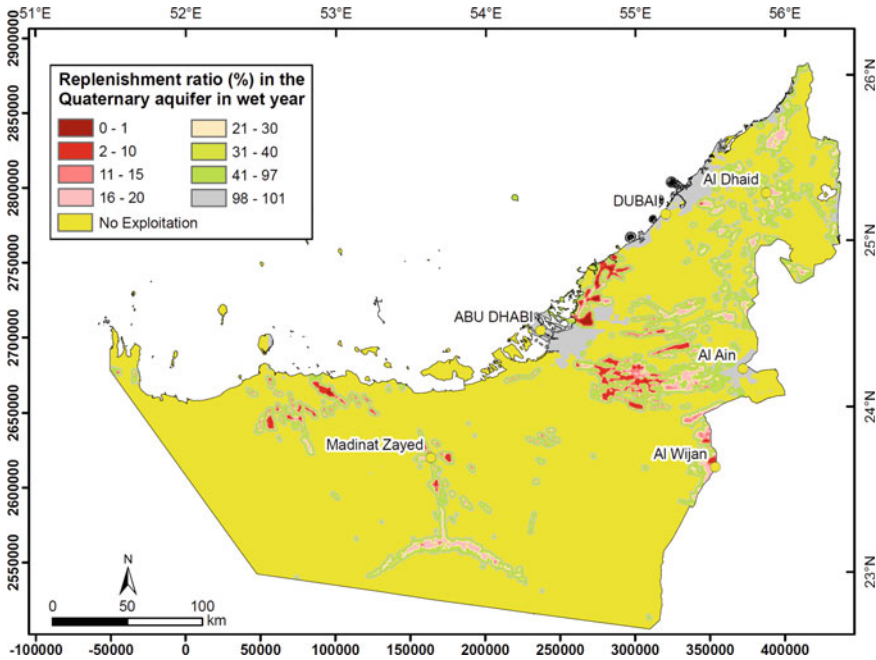


Fig. 17.6 Groundwater replenishment percentage (%) in the quaternary aquifer

The forestry, agricultural, and industries all utilized groundwater. The depletion percentage would be only 0.28% yearly if the annual decline in groundwater storage were compared to the average overall groundwater storage (fresh to saline types, 660 BCM). Since most of the yearly groundwater abstraction came from fresh groundwater storage, it is important to compare it to the current total fresh groundwater resources, which were only around 10 BCM in 2015, since this is a very alarming harbinger signaling the scarcity in agricultural water. It is crucial to remember that the metrics used to evaluate groundwater storage, including the aquifer's effective porosity, were only approximatively known.

The obtained results from the GWBM indicated that the remaining fresh groundwater resources in UAE (including mountainous areas) is less than 15,000 MCM and covering an area of 2160 km² (Fig. 17.8). Under the business-as-usual scenario (i.e., same farming and forest areas; Fig. 17.1; and same abstraction rate; Fig. 17.2) and if these resources are used for farming irrigation exclusively, the available fresh groundwater would only last for less than 5 years as technically and environmentally only 70% of available water can be abstracted. Although this is a general conclusion and it is anticipated that the fresh groundwater reserve has significantly increased following the heavy precipitation events in the water years 2019–2020 and 2021–2022, there is a critical need to manage groundwater resources in each location differently.

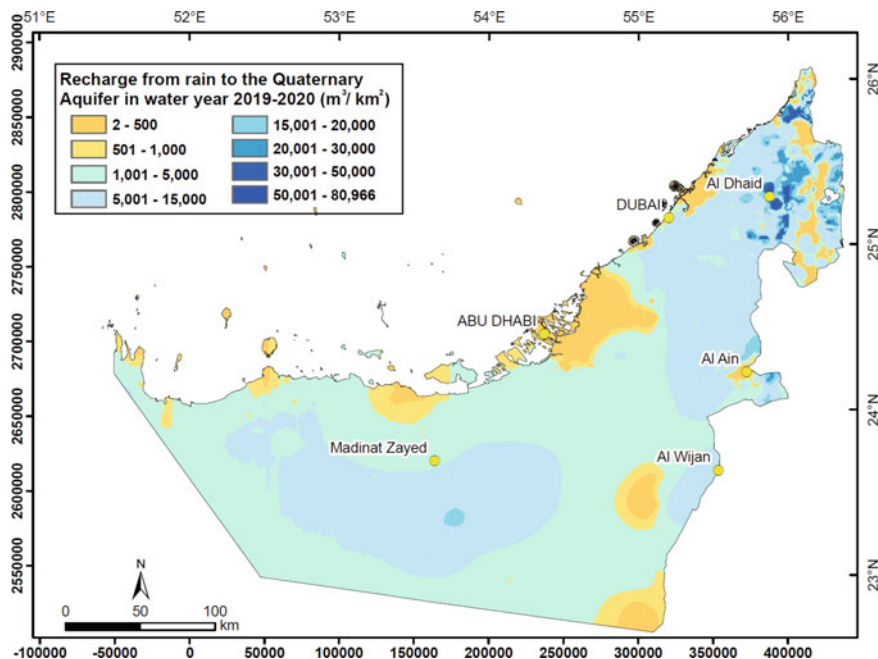


Fig. 17.7 Recharge to the quaternary aquifer in the water year 2019–2020 (m^3/km^2)

Table 17.3 Recharge to the Quaternary aquifer in the water year 2019–2020 (MCM)

Recharge type	Recharge volume (MCM)
Recharge from precipitation for a normal average rainy year with recharge augmentation	160
Recharge from precipitation for a normal average rainy year without recharge augmentation	145
Recharge from precipitation for a wet year with recharge augmentation	356
Recharge from precipitation for a wet year without recharge augmentation	326
Return flow from groundwater-fed irrigation	362
Return flow from desalination, treated wastewater, and network losses	427
Internal flux	52
Total recharge in the normal average rainy year	1001
Total recharge in the wet year	1197

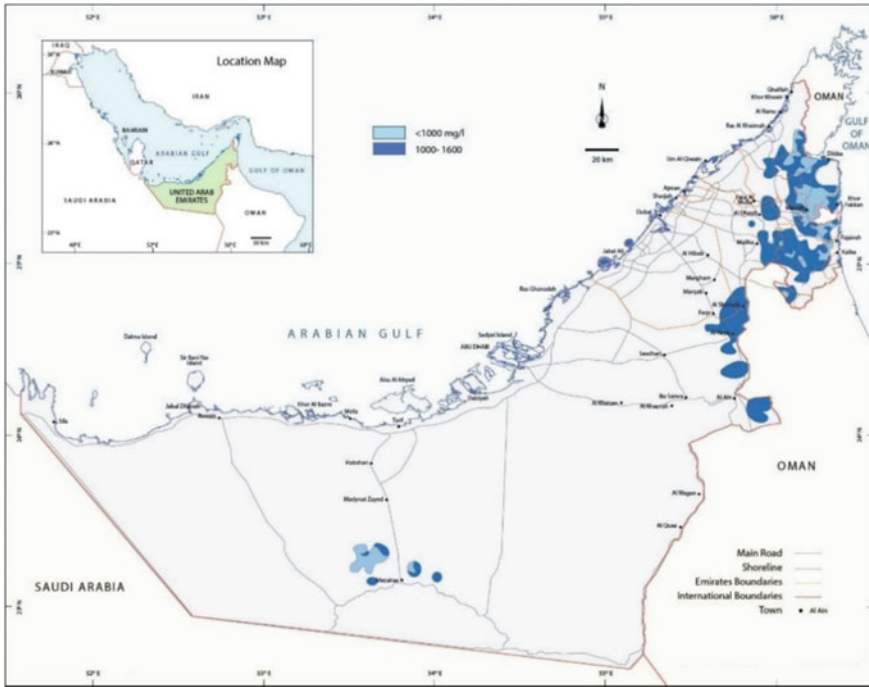


Fig. 17.8 Areal distribution of fresh groundwater resources in 2012

The following six zones can be used to categorize the groundwater conditions in farming areas (only) based on the groundwater budget, TDS in 2015, distance to existing farms (pumping wells), ratio of the present saturated thickness to the maximum saturated thickness, and remaining life duration (Fig. 17.8).

- Zone One:** TDS in 2015 < 2000 ppm. The area of this zone is 40 km² and the total fresh to slightly brackish groundwater reserve is estimated as 581 MCM.
- Zone Two:** 2000 ppm < TDS in 2015 < 5000 ppm. The area is 50 km² and the total low brackish groundwater reserve is 640 MCM.
- Zone Three:** 5000 ppm < TDS in 2015 < 10,000 ppm. The area is 934 km² and the total medium brackish groundwater reserve is 15,600 MCM.
- Zone Four:** 10,000 ppm < TDS in 2015 < 15,000 ppm. The area is 913 km² and the total highly brackish groundwater reserve is 12,400 MCM.
- Zone Five:** 15,000 ppm < TDS in 2015 < 20,000 ppm. The area is 762 km² and the total extremely brackish groundwater reserve is estimated as 8500 MCM.
- Zone Six:** TDS in 2015 > 20,000 ppm. The area of this zone is 66,256 km² and the volume of the slightly saline groundwater reserve is 716,000 MCM.

GWBM results indicated that the net groundwater extraction for farms irrigation is 2325 MCM annually. This value, however, should be adjusted to the unaccounted abstraction (e.g., the abstractions of 450 and 90 MCM per year for planted forests irrigation, and domestic use, respectively) and for recharge from all sources, which is 1150 MCM per year. By doing so, the total adjusted annual groundwater extraction for farms irrigation is coming to 2325 MCM per year of which 1175 is groundwater mining.

The UAE government is considering stringent steps to protect groundwater now that it is aware of the issue. In Abu Dhabi Emirate, for instance, agricultural activities use 72% of the water, although they only provide 1% of the country's GDP. As of right now (2021), Abu Dhabi's Agriculture, Forests, and Parks sector is the emirate's biggest water user. This sector's water consumption is steadily declining, most likely because of the use of demand side management strategies. The demands from the household and industrial sectors are rising, nevertheless. All sectors in which the water demand is on the rise rely on non-conventional water resources. However, if the coverage for irrigation demands started to shift from groundwater to the desalinated water, a sectorial competition for desalinated water may become an economic and environmental challenge. The technical, economical, and environmental feasibility of using desalinated water for farming irrigation on large scale is highly questionable. The change of agricultural pattern and the use of the brackish water and treated wastewater for irrigation seems to be more feasible. The reuse volume of the treated wastewater is currently 547 MCM/year which is 57% of the treated wastewater in year 2020 (Sherif et al. 2021). This indicate that there is an opportunity to use more of the tertiary treated water for farms irrigation and this in accordance with UAE Strategy 2036 (Fig. 17.9).

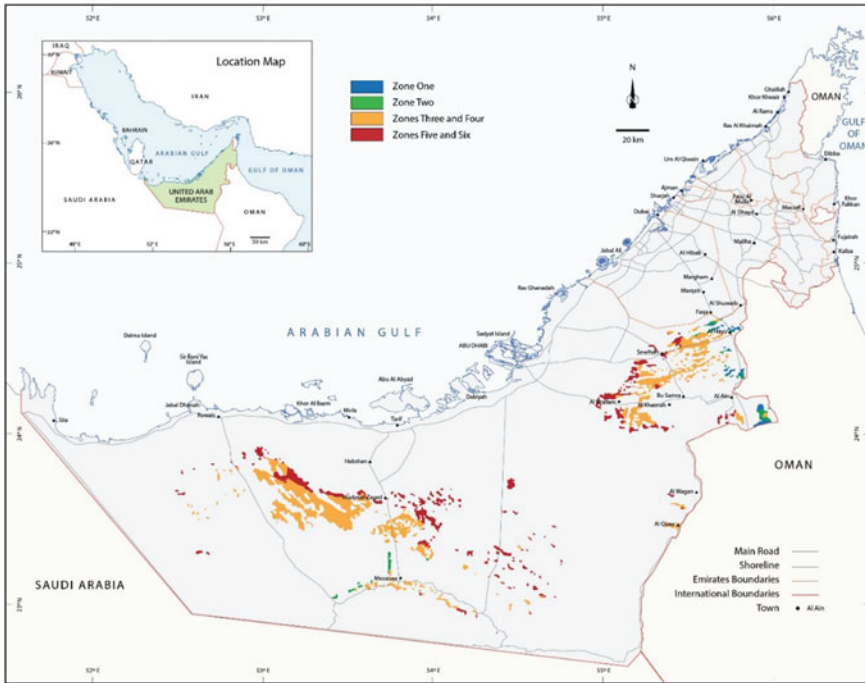


Fig. 17.9 Potential groundwater development zones

17.5 Conclusion

The remaining fresh groundwater resources are extremely scarce and have a relatively short lifespan under the status quo, especially in agricultural areas. For effective groundwater resource management to lengthen its lifespan, the few fresh groundwater potential zones were discovered. New agricultural development shouldn't use the fresh groundwater. According to the results, brackish groundwater is more plentiful than fresh groundwater. This type of water should be treated with the appropriate care as a precious resource for agriculture development with necessary precautions. The technical, economical, and environmental feasibility of using desalinated water for farming irrigation on large scale is highly questionable. The change of agricultural pattern and the use of the brackish water and treated wastewater for irrigation seems to be more feasible.

An essential first step in resource use and management is the evaluation of groundwater potential. The groundwater potential investigations include geology, rainfall, slope, soil, curvature, topographic wetness index, elevation, drainage density, land use land cover, and lineament density in UAE were successfully delineated in the

current study using GIS, and AHP technique. Results from the AHP approach determined the weight of thematic layers in the groundwater potential. The spatial analysis tool in ArcGIS 10.3 was used to overlay all the thematic maps to determine the groundwater potential zones. The obtained results indicated that the groundwater potential zone 1 (TDS less than 2000 mg/L) and zone 2 (TDS is ranging from 2000 to 5000 mg/L) occupied an area of 40 and 50 km², respectively. The estimated groundwater reserve in GWPZ1 and GWPOZ2 are 581 and 640 MCM respectively. Groundwater potential zones of medium (5000 < TDS < 10,000 mg/L) and highly brackish water (10,000 < TDS < 15,000 mg/L) cover areas of 934 and 913 km² respectively. The total groundwater reserve in zones 3 and 4 is about 28,000 MCM indicating their extreme importance as the only source of irrigation water inland with precautionary desalination. GWPZ 5(15,000 mg/L < TDS < 20,000 mg/L) covers an area of 762 km² and the total extremely brackish groundwater reserve is estimated as 8500 MCM. Zone Six (TDS in 2015 > 20,000 mg/L). The area of this zone is 66,256 km² and the volume of the slightly saline groundwater reserve is 716,000 MCM. Even though the salinity in zone 6 is more than 20,000, it is still considered as a resource if compared to the highly saline water in sabkha areas (TDS > 100,000 mg/L).

The Abu Dhabi Environment Agency (EAD) began an ambitious project to create the Abu Dhabi Environment Vision 2030 on behalf of the Executive Council in 2010 with the goal of reducing the environmental effects of anticipated socio-economic growth. When conducting business in the Emirate, the Vision offers a broad framework for consideration and environmental preservation. Both UAE Water Conservation Strategy (2010) and Abu Dhabi Environment Vision 2030 will guide government entity planning and coordination, and also inform the private sector, the Abu Dhabi population and international peers about the aspirations of Abu Dhabi and the other Emirates. The following five priority areas are outlined in the Environment Vision 2030, one of which is effective management and conservation of water resources.

Cut residential indoor and outdoor desalinated water use in half: By 2030, indoor and outdoor desalinated water use is predicted to more than triple current levels if nothing is done.

Avoid using groundwater and desalinated water for landscape irrigation: By 2030, the amount of desalinated water consumed for plantations that provide amenities is predicted to increase if nothing is done. The Abu Dhabi Environment Vision 2030 and the UAE Water Conservation Strategy (2010) are expected to replace both groundwater and desalinated water with recycled water.

Increase the longevity of groundwater reserves by twofold. If nothing is done, viable groundwater reserves will run out in conjunction with expected socioeconomic growth. The lifespan of the groundwater reserves is anticipated to be doubled with the implementation of Abu Dhabi Environment Vision 2030.

Policy imperatives for maintaining adequate demand side management for efficient water consumption patterns in all sectors, in general, and the agriculture sector, in particular, are crucial to achieving the UAE 2021 vision, MEW Water Conservation Strategy, and Abu Dhabi Environmental Vision 2030.

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