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ORIGINAL ARTICLE

New system for the assessment of annual groundwater recharge from rainfall in the United Arab Emirates

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Abstract
In this study, the first groundwater recharge map for United Arab Emirates (UAE) was developed using the recharge potential and water table fluctuation methods. Recharge potential estimates were made using information about infiltration rate, soil type, ground slope, geological and hydrogeological factors, and the availability of rainfall harvesting infrastructure and were validated by measurements of water table rise in alluvial aquifers in wadis. Based on this information, the total recharge in the UAE is estimated to be about 133 million cubic meters per year (MCM/year). Annual recharge rates are calculated to vary between 1 and 28% of precipitation in the different regions of UAE depending on several natural and manmade parameters including, among others, recharge enhancing infrastructure. Estimates from the two methods are 98% in agreement; which suggests that the recharge potential method is suitable for estimating aquifer's recharge in UAE and arid regions. The water table fluctuation method was found to be more suitable for assessing recharge through gravel plains and wadis in mountainous areas.

Keywords Groundwater recharge · Recharge potential · Water table fluctuation · GIS · Water management

Introduction

In arid and semi-arid regions, groundwater recharge is highly variable in both space and time. Additionally, the most appropriate technique for measuring recharge may vary from one location to another depending on rainfall characteristics, topography, land use, soil type, geology, hydrological parameters, and others. Several quantitative methods are well established in the hydrological science domain for evaluating recharge, but they mostly represent local conditions only. For example, the direct recharge is measured by lysimeters and seepage meters which provide estimates at local levels that may be not representative of the entire aquifer system. Therefore, it is important to consider a recharge estimation technique that includes the spatial scale. In this study, a GIS approach is used to integrate five spatial contributing factors: drainage structure intersections, geology, ground surface slope, lithology, and land use. The distribution and quantity of recharge is determined by weighting these factors in space and integrating them in a GIS function.

The water table fluctuation (WTF) method is used in this study to validate the recharge potential map. The WTF is considered to be one of the most accurate, easy to use, and cost-effective methods of estimating aquifer recharge (Xu and Beekman 2003; Machiwal and Jha 2015). Its accuracy depends on the availability of reliable specific yield estimates of the aquifers as well as representative water table fluctuation data (Healy and Cook 2002; Xu and Beekman 2003). For this reason, and with the availability of long records of data and accurate specific yields determined by time-drawdown pumping tests, WTF is considered for validation purposes.

The purpose of this paper is to develop the first most accurate groundwater recharge map over UAE using the potential recharge method. The developed map is validated

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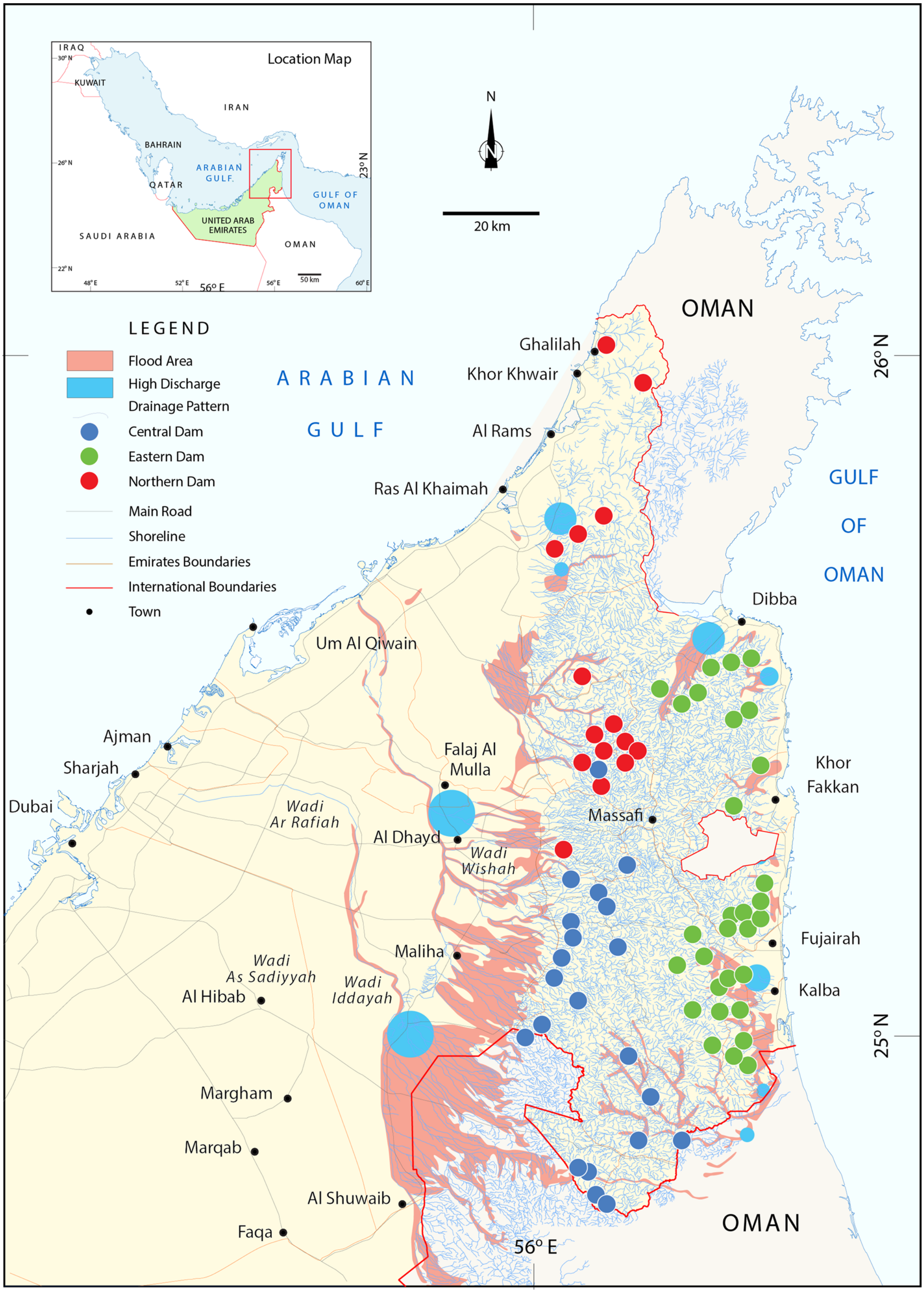

Fig. 1 Location map of UAE and major geomorphologic units with flooding and high discharge areas

using the WTF method at selected locations where water level and specific yield measurements are available.

Study area

The United Arab Emirates (UAE) is located in the south-eastern part of the Arabian Peninsula between 51°30′00″E to 57°30′00″E and 22°30′00″N to 26°30′00″N with a total area of 83,600 km^2 (Fig. 1). The region has a hyper-arid climate, a high rate of potential evapotranspiration, and limited renewable freshwater resources. Rainfall is scattered and infrequent with an average annual mean of less than (120) mm/year. Non-conventional water sources including desalinated water and treated sewage water are increasingly recognized as being dependable resources for water supply to overcome the limitations of the natural renewable resources in the region. Many dams have been constructed across the main wadis in the region to harvest surface water runoff and to increase groundwater recharge. In UAE, more than 120 retention and detention dams of different sizes have been constructed during the last four decades.

UAE geomorphological features include gravel plains, sand dunes, coastal zones, mountains, and drainage basins. These features have major role in controlling the movement of surface water and groundwater. The geology is composed mainly of Quaternary, Tertiary, and Cretaceous strata that influence runoff volumes, infiltration rates, and water quality.

Aquifer system

The groundwater system in the UAE is divided into two major aquifer types: an upper renewable surficial aquifer consisting of shallow, unconsolidated alluvial and eolian deposits, and a non-renewable lower deep aquifer that consists of consolidated and fractured rocks (Halcrow and

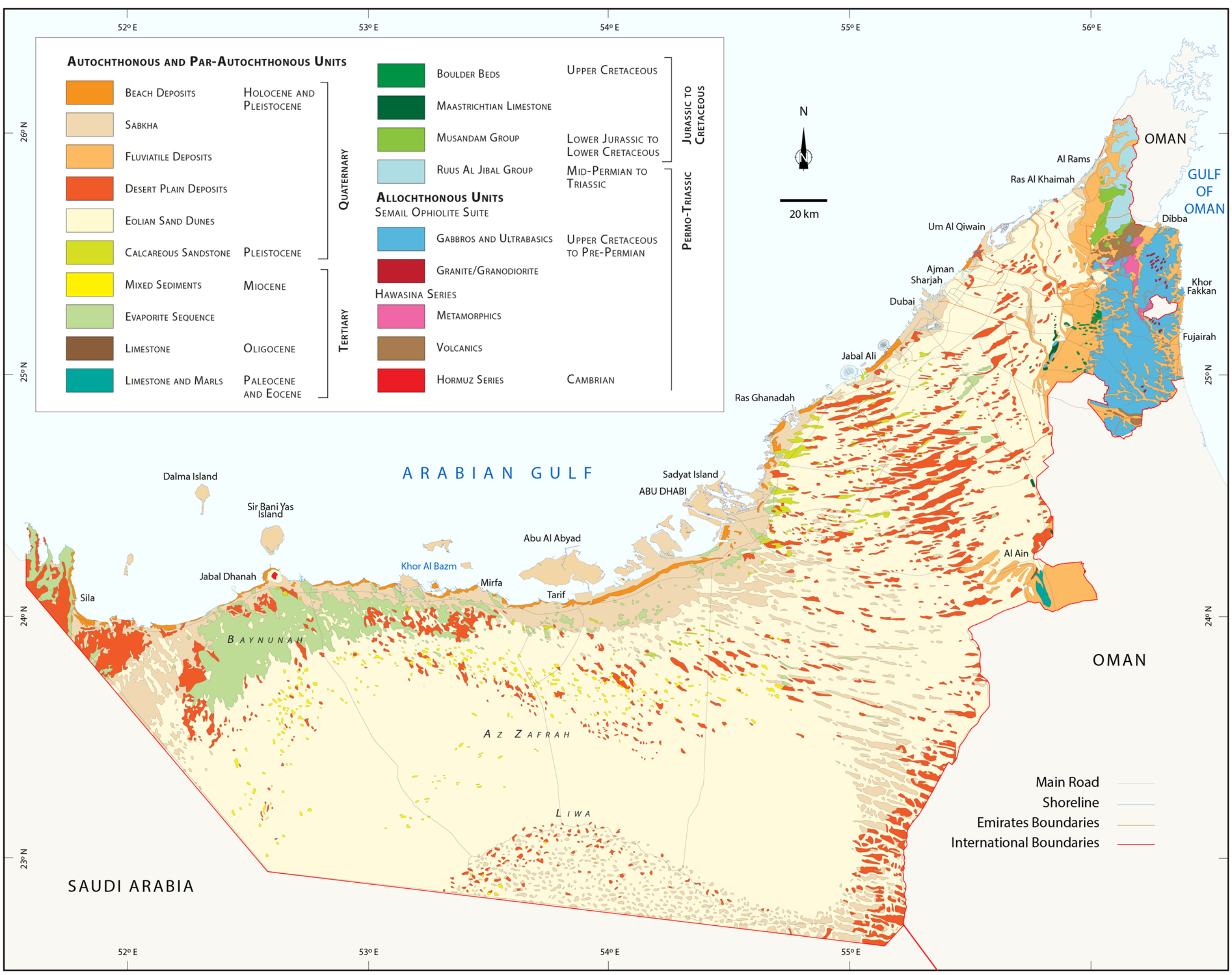

Fig. 2 Geological map of UAE (modified from British Geological Survey and UAE Ministry of Energy 2006)

Partners 1969; Imes et al. 1993; Elmahdy and Mohamed 2012, 2013). Renewable water resources are formed by percolating rainfall and surface runoff (Sherif et al. 2011) and the non-renewable groundwater resource formed during two ancient wet periods, from 6000 to 9000 and 25,000–30,000 years ago (Wood and Imes 1995a, b). Thus, recharge varies significantly, both over time from 1 year to another and spatially from one region to another due to variations in the distribution and intensity of precipitation during a rainfall event, the effects of high evaporation rates, and the effects of surface runoff from mountain areas. Previous studies indicate that only 10–14% of total precipitation infiltrates into the surficial aquifer in the UAE (ESCWA 2003).

Previous recharge estimates

Groundwater recharge is a fundamental component of the water balance studies. No studies have been conducted recently on the direct precipitation and lateral flow from neighboring countries to estimate groundwater recharge in UAE. The most recent recharge investigation was conducted by IWACO in 1986 within the farmwork of a broader project to study the groundwater resources in UAE. The WTF method was used and the total annual groundwater recharge in UAE was estimated to be in the order of 120 MCM/year. The results are more representative to aquifers beneath the alluvial gravel plains and in the eastern part of the country, but may not be adequate for the sandy desert areas where the infiltration rates are relatively higher than elsewhere which would allow for high recharge rates.

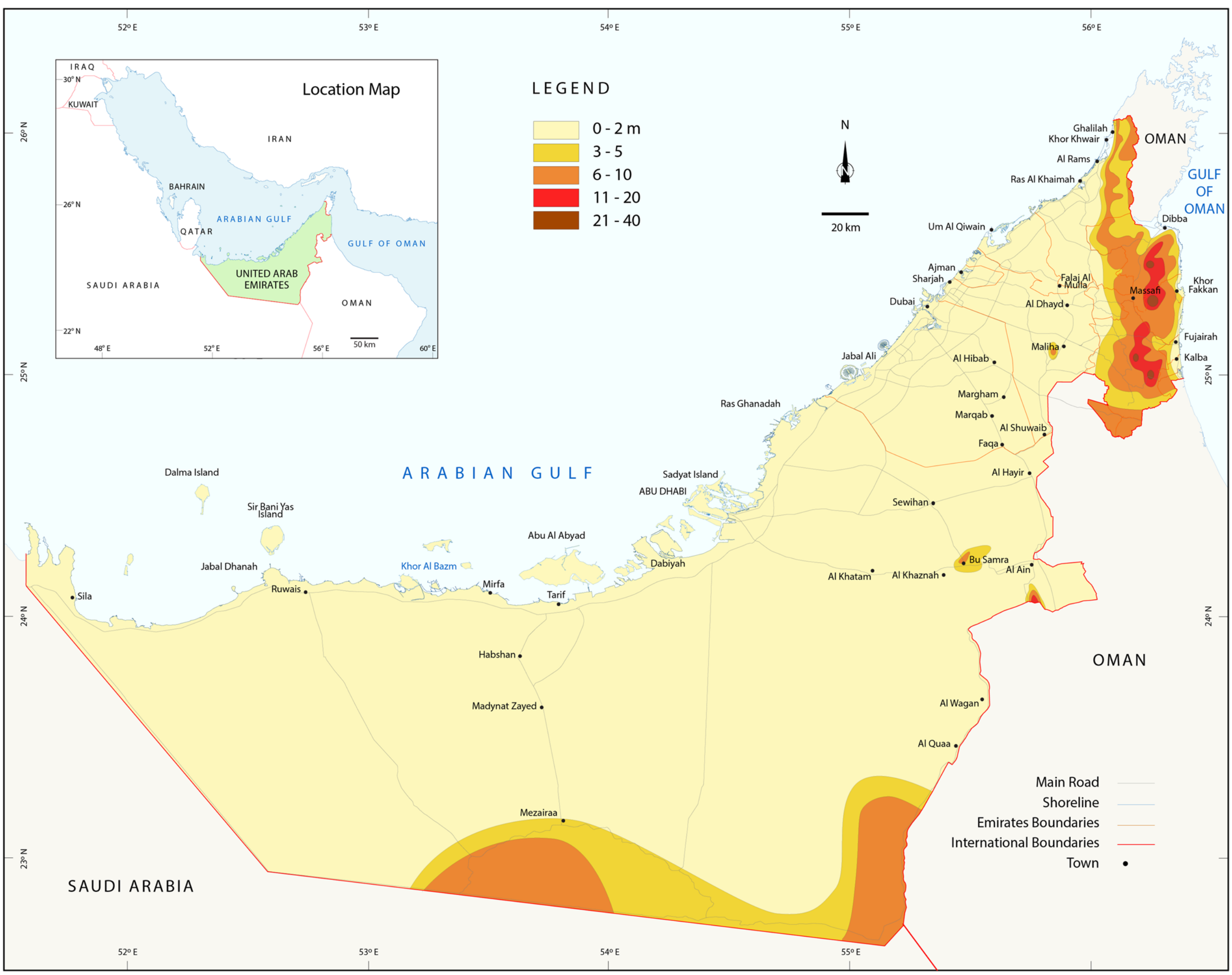

Fig. 3 Ground surface slope

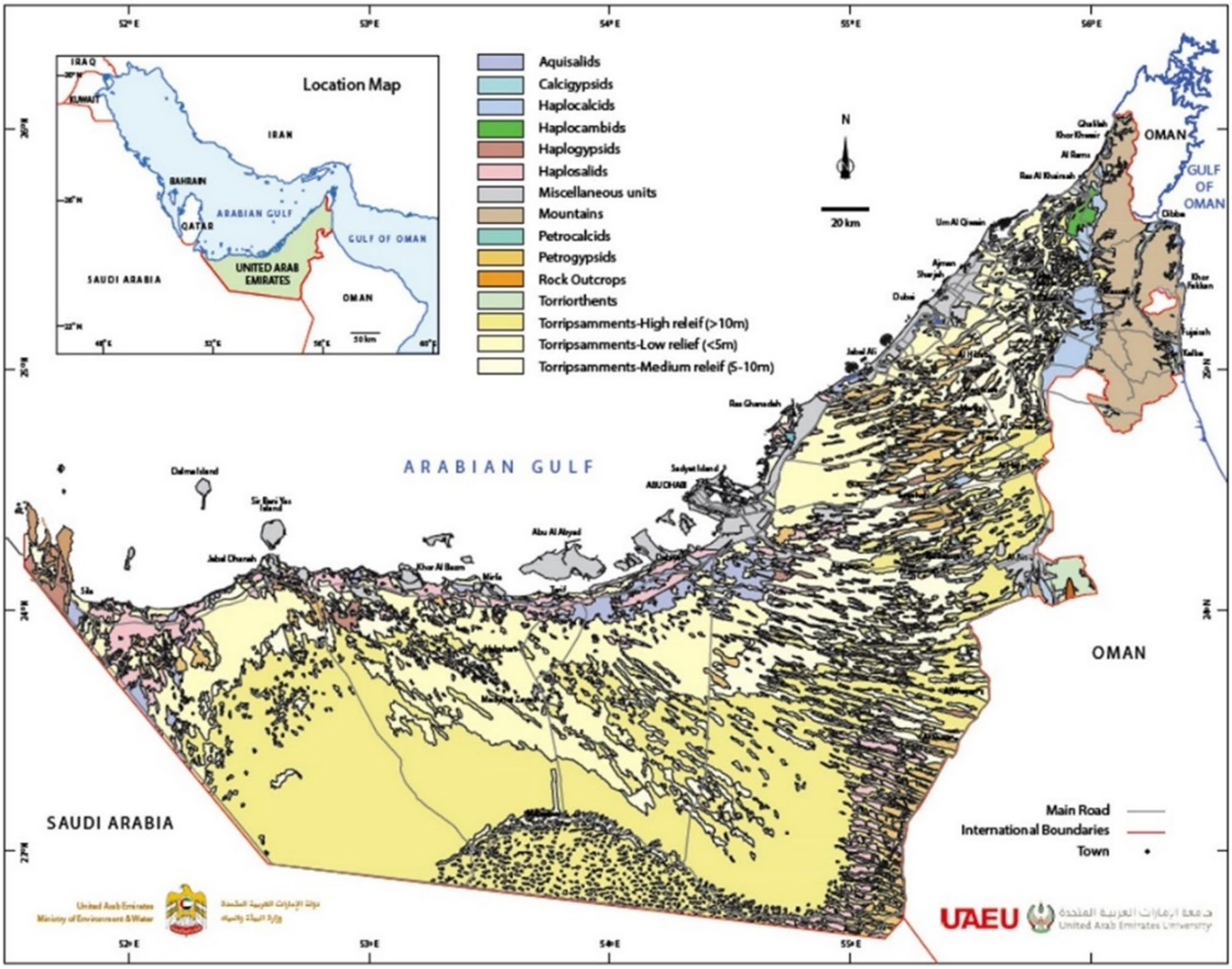

Fig. 4 Lithology and soil type map (EAD 2012)

Methodology

Data sources

Thematic layers such as drainage structure intersections (Fig. 1), geological structure (Fig. 2), ground surface slope (Fig. 3), lithology and soil type (Fig. 4), and land use (Fig. 5) for 2015 were employed in this study for estimating the recharge potential across the UAE.

Groundwater levels measured at twelve monitoring stations (Table 1) for the period 2002–2010 were analyzed to obtain enough data to create the hydrographs required. During this period, 12 significant rainfall events took place. Some stations have earlier data going back to 1985 and some have records up to the date of study. Due to the large volume of available data, randomly selected rainfall events are presented in the following sections for illustrative purposes. Water level data and all other related information and maps were provided by the UAE Ministry of Environment and Water.

Recharge estimation methods

Recharge potential

Geospatial techniques are becoming an important tool for water studies as they provide information over time and space and enable these data to be analyzed in an effective manner (De Silva 1998; Kinzelbach et al. 2002; Nagarajan and Singh 2009; Subagunasekar and Sashikkumar 2012). The recharge potential method is based on knowledge-driven factor analysis where it integrates different thematic layers and develops empirical relations between annual precipitation and annual recharge. The integration of such techniques provides the spatial distribution of recharge zones and calculates the total rates (Chenini and Ben 2010).

In principle, the simplest method used for estimating potential (gross) recharge R, is given as

$$R = 0.01 I_p P, \quad (1)$$

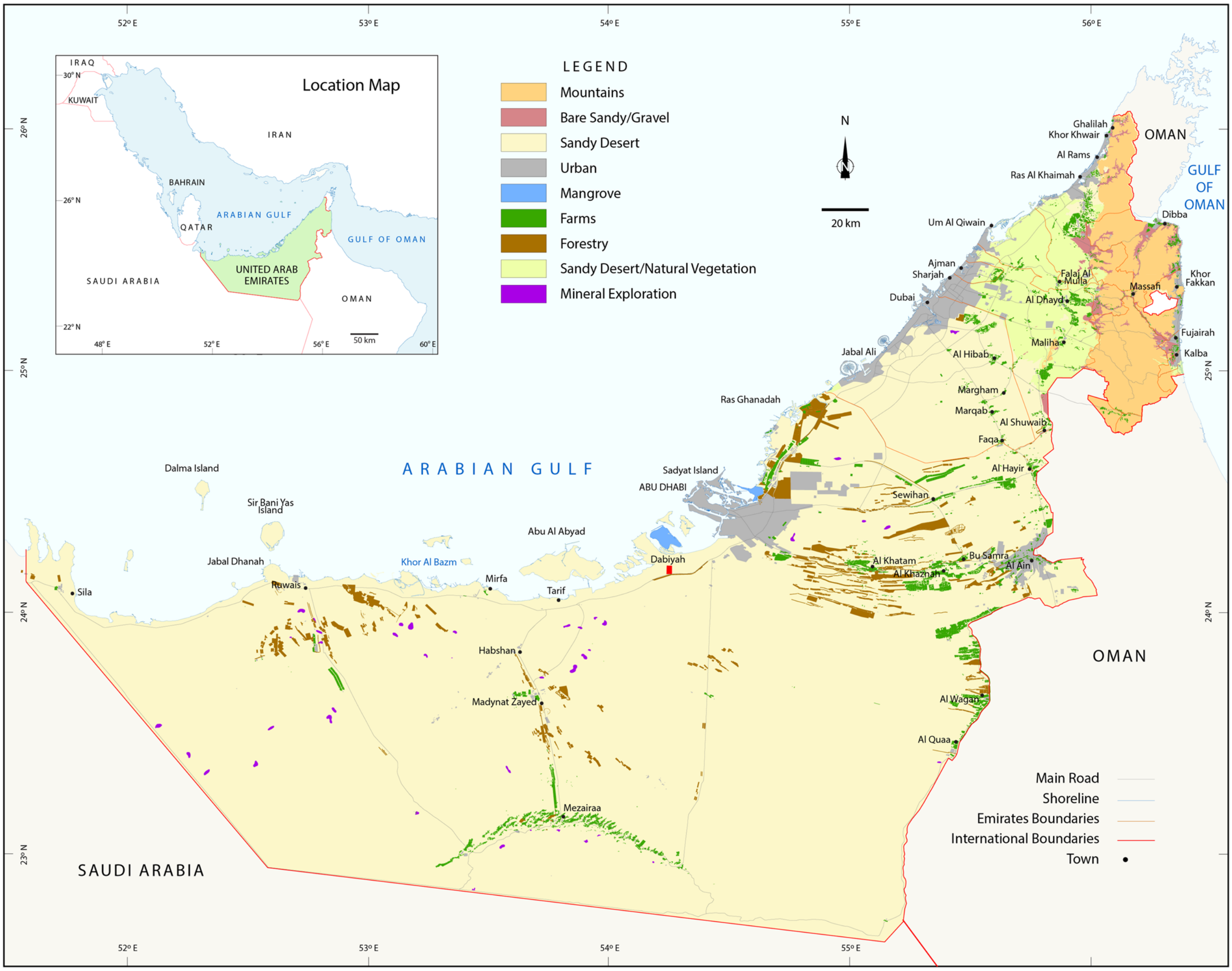

Fig. 5 Land use map of UAE

where I_P is the infiltration percentage expressed as integers from 0 to 100 and P is the average annual precipitation rate in millimeters. This relation has been modified by Sophocleous and McAllister (1987) and Sophocleou (1992) to determine the ground water recharge in limited climatological homogenous areas as

$$R = a(P - b)0.01, \tag{2}$$

where 'a' is the recharge percentage (from 0 to 100) and 'b' is a constant. The values of 'a' and 'b' are assigned based on the precipitation rates. The Crosbie et al. (2001) method has been slightly modified to apply over the UAE arid environment and the limited data availability. The infiltration rates measured at 340 sites across UAE for 2012 were used to construct a GIS map of infiltration rates. Other related GIS maps were also used as an input to Eqs. 3 and 4 to estimate potential groundwater recharge at each 1 km^2 grid cell over the entire country. A weighted linear combination method was then used to develop a groundwater recharge potential index of each pixel in the area using the following equation:

$$R_i = \left[\left(\frac{I_i}{I_{\max}} RP_{\max}\right) + C_{f(i)}\right] 0.00001 P_i A_i, \tag{3}$$

where R_i is the potential recharge volume in cubic meters for cell i with an area A_i (1 km^2), $RP_{\max}$ is the maximum reported recharge percentage of annual rainfall in UAE (20%) which is based on lithology, P_i is the average annual precipitation rate at cell i in mm, I_i and $I_{\max}$ are the infiltration at cell i and the maximum reported infiltration rates in UAE in mm/h, and $C_{f(i)}$ is the sum of the natural or artificial recharge augmentation coefficients of the cell.

A joint environmental isotopes study conducted by UAE Ministry of Environment and Water and International Atomic Energy Agency in Vienna (MOEW and

Table 1 Selected well locations

Region/area	UTM coordinates	
	Easting (m)	Northing (m)
Eastern region		
Ham (BHF-1)	429,211	2,779,164
Zikt (Zikt-3)	429,934	2,822,044
Gravel plain		
Al Bih (BIH-1)	407,022	2,853,518
PTawyean (TW-1)	404,611	2,827,819
Manama (GP-3)	400,542	2,805,039
Mdam (MDM-1)	379,507	2,765,820
Habab (RK-14)	399,294	2,830,787
Mountain region		
Siji (GP-14)	399,962	2,792,309
Musfut (MFT-1)	405,600	2,747,383
Desert foreland		
Falaj Al Mulla (FM-1)	383,845	2,808,175
Al Awer (AW1)	351,628	2,783,629

Table 2 Empirical recharge augmentation coefficient percentage values

Coefficient	Augmentation percentage (%)
Drainage intersection and geological structure of cell *i* (DI)	0–2
Geological structures of cell *i* (GS)	0–2
Major fault line and fracture/fracture intersection	0–2
Land use	0–2

IAEA 2005) estimated a recharge percentage of 28% in a reservoir area made of alluvial gravels behind an earth-filled dam in Fujairah emirate. The difference between the estimated maximum recharge percentage in all other areas of UAE (20%) and the estimated recharge percentage by that study which is 8% was attributed to the effect of the dam and the fact that the alluvial gravel layer in this area is clay free and relatively flat. Thus, the $C_{f(i)}$ value was considered to vary between 0 and 8% and given by the following empirical relationship:

$$C_{f(i)} = \mathrm{DI}(i) + \mathrm{GS}(i) + \mathrm{MFL}(i) + \mathrm{LU}(i), \quad (4)$$

where DI(i) is the drainage intersection and geological structure of cell i, GS(i) is the geological structure of cell i, MFL(i) is the major fault line/fracture of cell i, and LU(i) is the land use of cell i.

The recharge percentage values that were assigned to each coefficient influencing groundwater recharge potential are given in Table 2.

Water table fluctuation method

The water table fluctuation (WTF) method estimates groundwater recharge through the analysis of water level changes in monitoring wells. It is based on the principle that rises in groundwater levels in unconfined aquifers are due to recharge across the water table (Healy and Cook 2002; Sharda et al. 2006). To apply the method, the specific yield of the aquifer where water table fluctuations are taking place needs to be known. Typically, the WTF method is most often applied for short-term water level rises that occur in response to individual storms, conditions that commonly occur in humid regions with shallow water tables. The equation applied is

$$R = S_y\left(\frac{\mathrm{d}h}{\mathrm{d}t}\right) = S_y\left(\frac{\Delta h}{\Delta t}\right), \quad (5)$$

where R is the groundwater recharge, S_y is the specific yield, h is the water table height, and t is the time.

Moon et al. (2004) and Risser et al. (2005) suggest that the response of water table to recharge can be calculated by determining the ratio of water table rise to total rainfall for all rainfall events. Based on this, a modified WTF equation is proposed to estimate groundwater recharge as the product of specific yield by the ratio of the water level rise over the cumulative precipitation within the period that causes the water level rise, given by

$$\text{Recharge factor} = \left(\frac{\Delta h_1 + \Delta h_2 \ldots \Delta h_n}{P_1 + P_2 \ldots\ldots P_n}\right)S_y = \left(\frac{\sum_{i=1}^{n} \Delta h_i}{\sum_{i=1}^{n} P_i}\right)S_y, \quad (6)$$

where Δh is the water level rise for each precipitation event and P is the precipitation for each time interval.

This relation between rainfall and recharge has been described in several previous papers, e.g., Sophocleous (1992), Scanlon et al. (2002), Taylor and Howard (1996), and Sami and Hughes (1996).

Results and discussion

Recharge potential

Infiltration rates (Fig. 6) and the vertical hydraulic conductivity of the upper layer of the unsaturated and saturated soil would significantly determine the ability of the system to be recharged from rainfall.

Previous estimates of infiltration rates in the UAE range from 10 mm to more than 1000 mm/h (IWACO 1986; JICA 1996; Sherif et al. 2005, and; EAD 2012). The drainage pattern in the region, particularly the major drainage features that originate on the regional fault lines in the mountainous

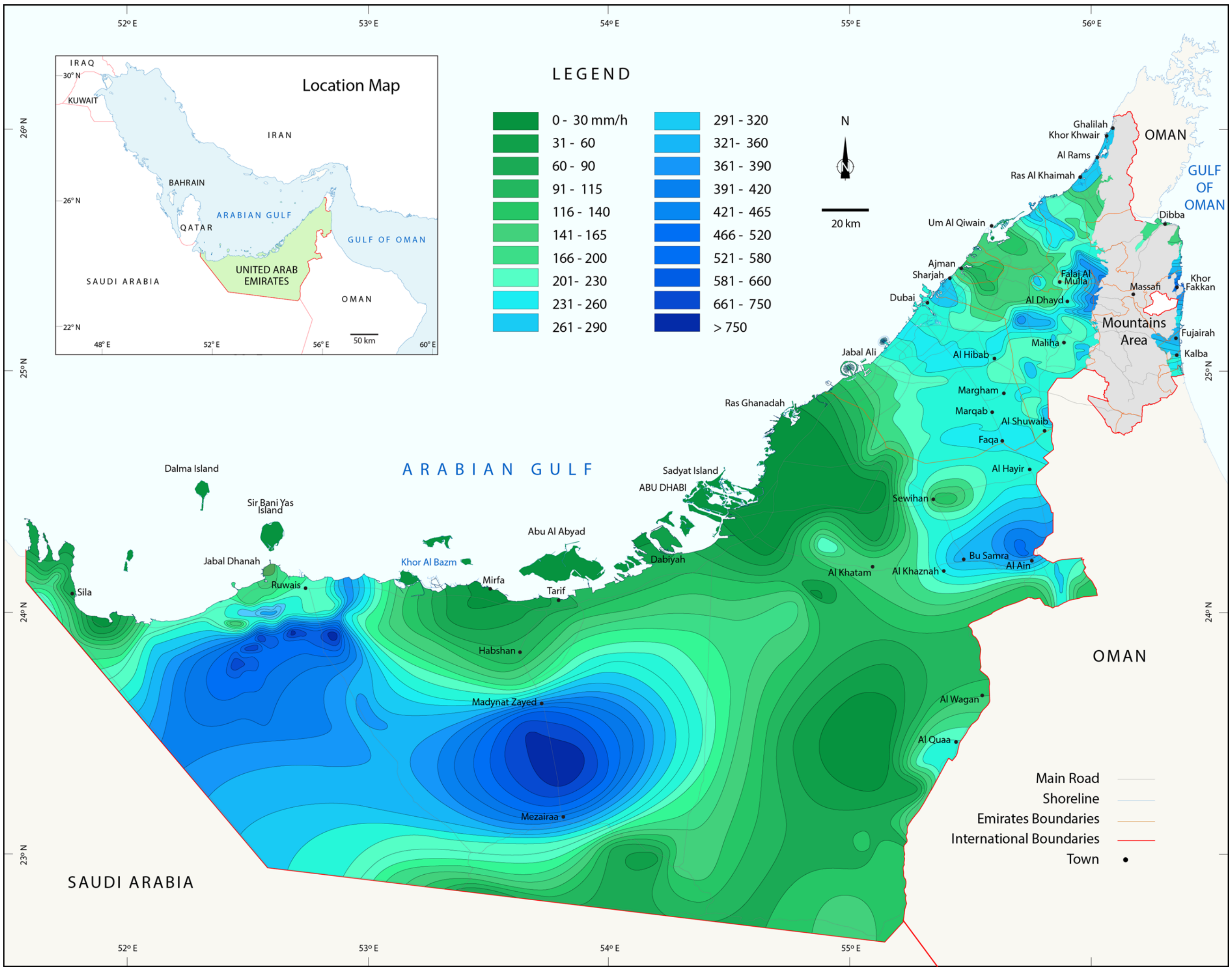

Fig. 6 Spatial distribution of measured infiltration rates

area of the Eastern Region significantly affect infiltration rates. This implies that

1. Ancient rivers have eroded and carried out large amount of sediments from their sources in the Oman Mountains and deposited them in the western lowland in the form of wide plains and alluvial fans. During the recent dry climate, prevailing northwesterly winds have reshaped the finer fluvial deposits (mainly sand grains) into sheets and dunes. This clarifies why the western area of the northern UAE was originally composed of extensive fluvial deposits that are today masked by a sand cover. It is believed that the area hosted large amount of water during wet periods in the Pleistocene as indicated by El Baz (1998).
2. Groundwater recharge to the aquifers beneath the eastern gravel plains is likely to be high due to the high density of drainage–faults intersections
3. A local and confined fractured-rock aquifer may exist in coastal faulted sandstone in the west that receives recharge during rainfall events (IWACO 1986; CRS and SEWA 2006).

The watersheds of Wadis Ar-Rafiah and Wadi Limhah in Maliyah and Al Dhaid are most likely to be important sources of groundwater recharge as their outlets join several major wadis and are considered to be areas where large volumes of surface water accumulate after rainfall events.

All of the above factors directly or indirectly control the volume and distribution of void spaces in the soil and sub soil, and consequently influence the rate of infiltration. The resultant rate of groundwater recharge is estimated (Fig. 7)

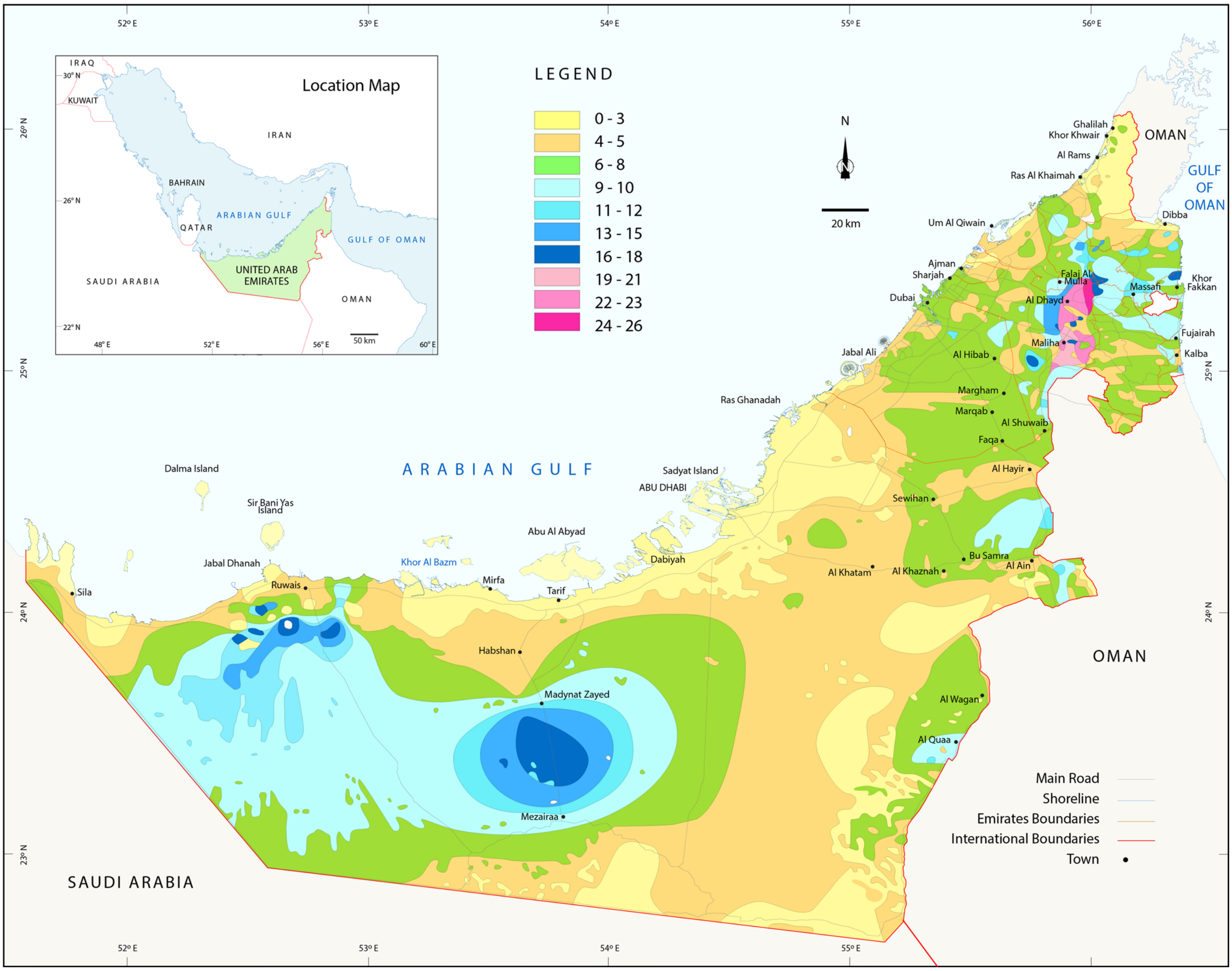

Fig. 7 Estimated rainfall recharge percentage of annual rainfall

to range from 0% of annual rainfall in the desert areas to 28% of annual rainfall in the gravel plains in the East and around Liwa in the south. Variations in recharge in the region depend mainly on the soil type and the unsaturated zone thickness.

The produced map agrees well with the recharge potential map developed by CRS and SEWA (2006) for the eastern region using the recharge potential method and remote sensing techniques (Fig. 8). The areas determined to have high recharge rates in this study correspond well with high recharge potential areas identified in the CRS and SEWA study, and the low ranges in both maps correspond to the same desert areas.

Water table fluctuation

The monthly hydrographs of some the available wells across the UAE (Fig. 9) were used to estimate the average groundwater level changes. During periods when no rainfall took place, groundwater levels were extrapolated to their expected lowest levels. The value of Δh was then estimated to be the difference between the peak water level and the extrapolated antecedent level prior to a rainfall event. Isolated recharge events for recharge depths at five selected wells are presented in Fig. 10a–e.

Based on the Δh estimates, the recharge factor was then calculated. It is defined as the ratio of rainfall to the recharge depth. The rainfall recharge factors estimated for the eastern,

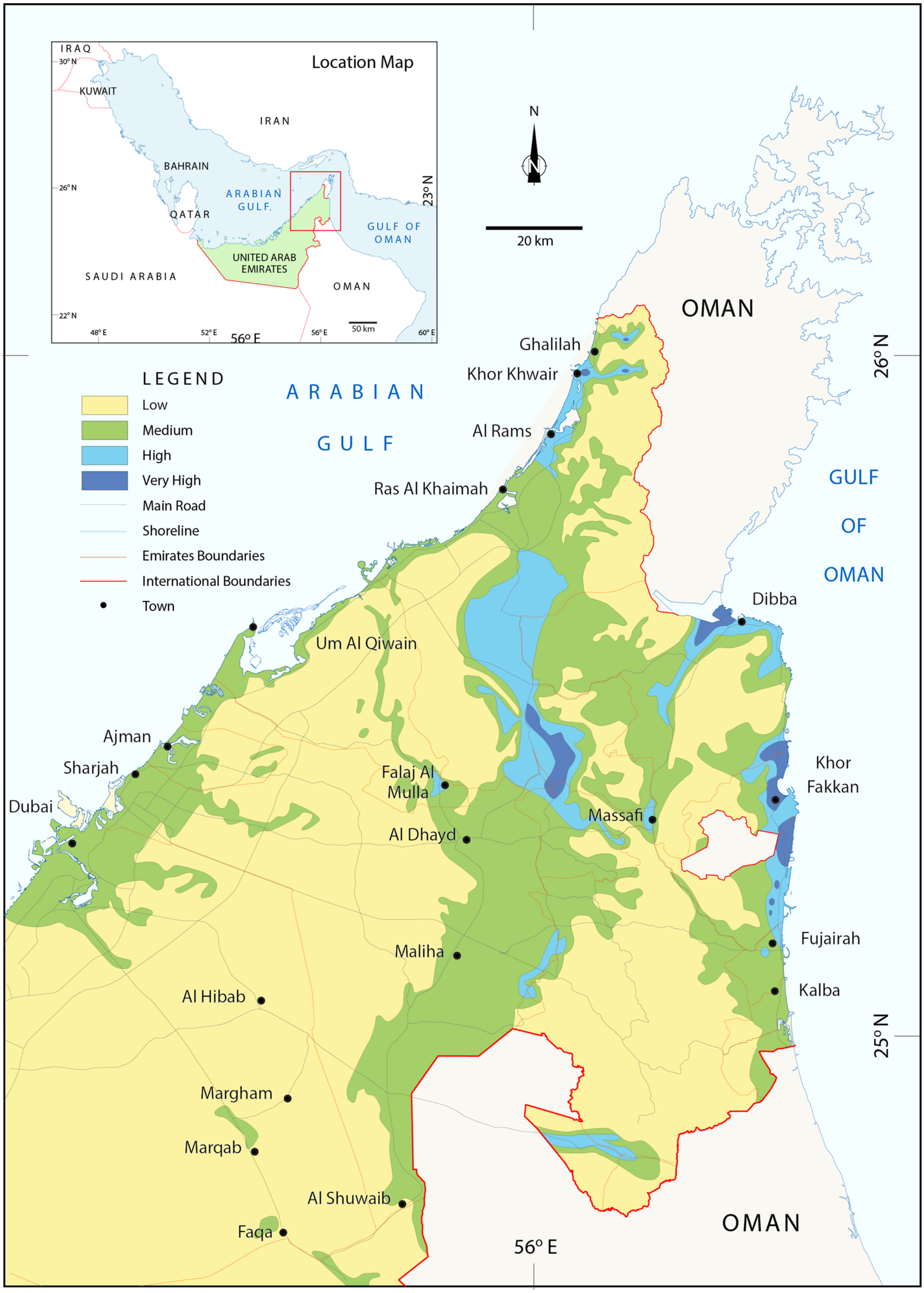

Fig. 8 Recharge potentiality estimated by remote sensing techniques (CRS and SEWA 2006)

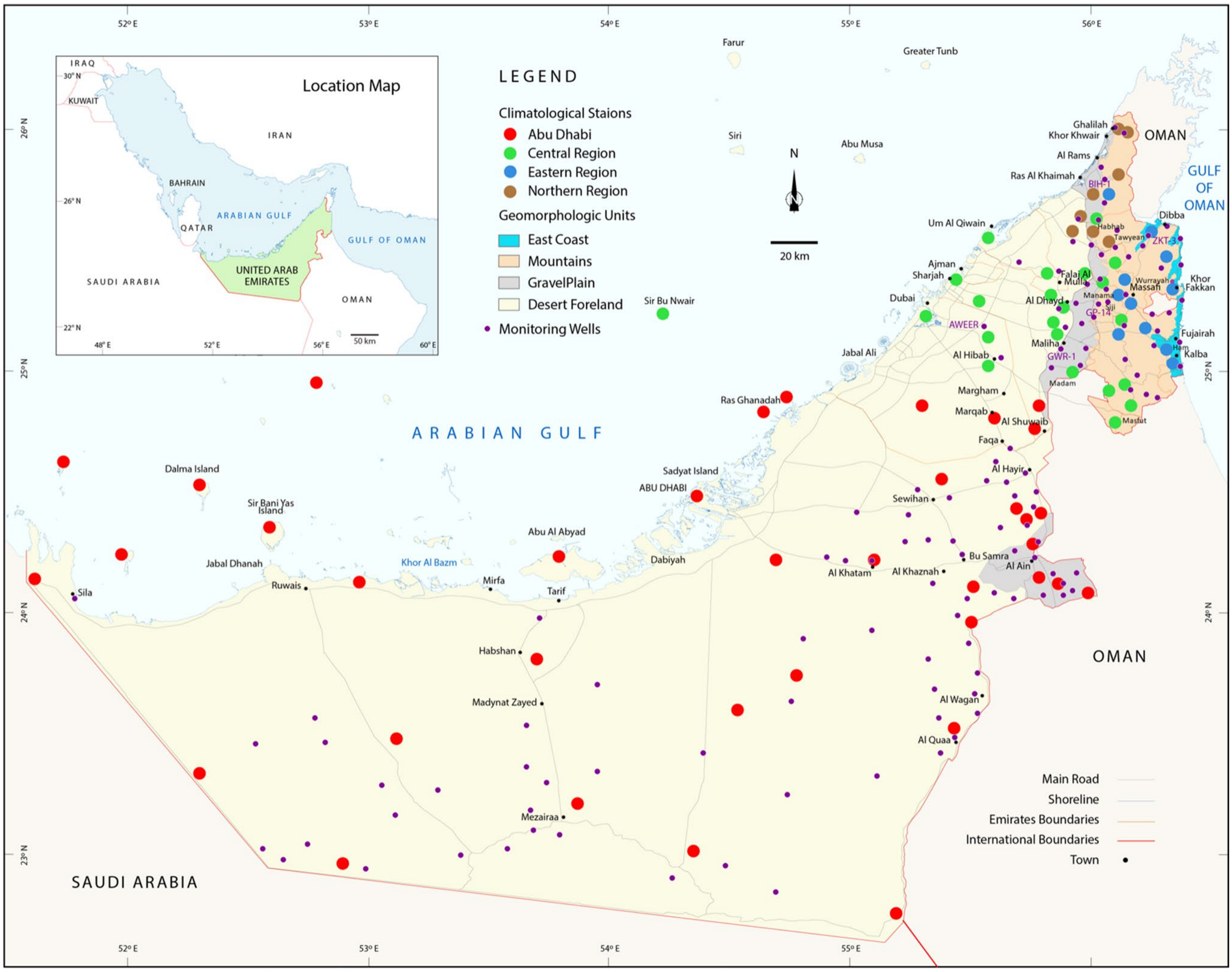

Fig. 9 Location of climatological stations monitoring wells in UAE

mountain, desert foreland, and gravel plains areas of the UAE are presented in Tables 3, 4, 5 and 6, respectively.

The estimated recharge factors vary between 5% in the desert forelands to 12% of rainfall in the eastern part of the UAE depending on the soil type, aquifer material, and depth to water table. A linear relationship between rainfall and rainfall recharge depth for all the selected areas shows a high coefficient of determination, R^2 (Table 7).

Discussion

For an average precipitation year of 130 mm, the recharge rate using the WTF is estimated to be about 1,857 m^3/km^2 and the estimated volume of recharge for the whole UAE is about 155 MCM per year. This value is higher than the total recharge volume estimated by IWACO (1986) of about 120 MCM/year. This may be attributed to the following reasons:

(a) Recharge factors in IWACO study were determined from a very limited number of well records (only 12 wells)
(b) The specific yield values used for the wells are not representative of the aquifer
(c) The WTF method is only applicable in areas with shallow water tables that display considerable rises and declines (USGS 2005; Healy and Cook 2002; Weeks 2002). In the desert area that forms 90% of the UAE, water table fluctuations occur slowly and/or are negligible due to low infiltration rates (as presented in Fig. 6) and high evaporation rates.
(d) The WTF method is only likely to be applicable in the eastern region in the UAE and in areas underlain by alluvial gravels where table fluctuations are more distinct and occur more rapidly.

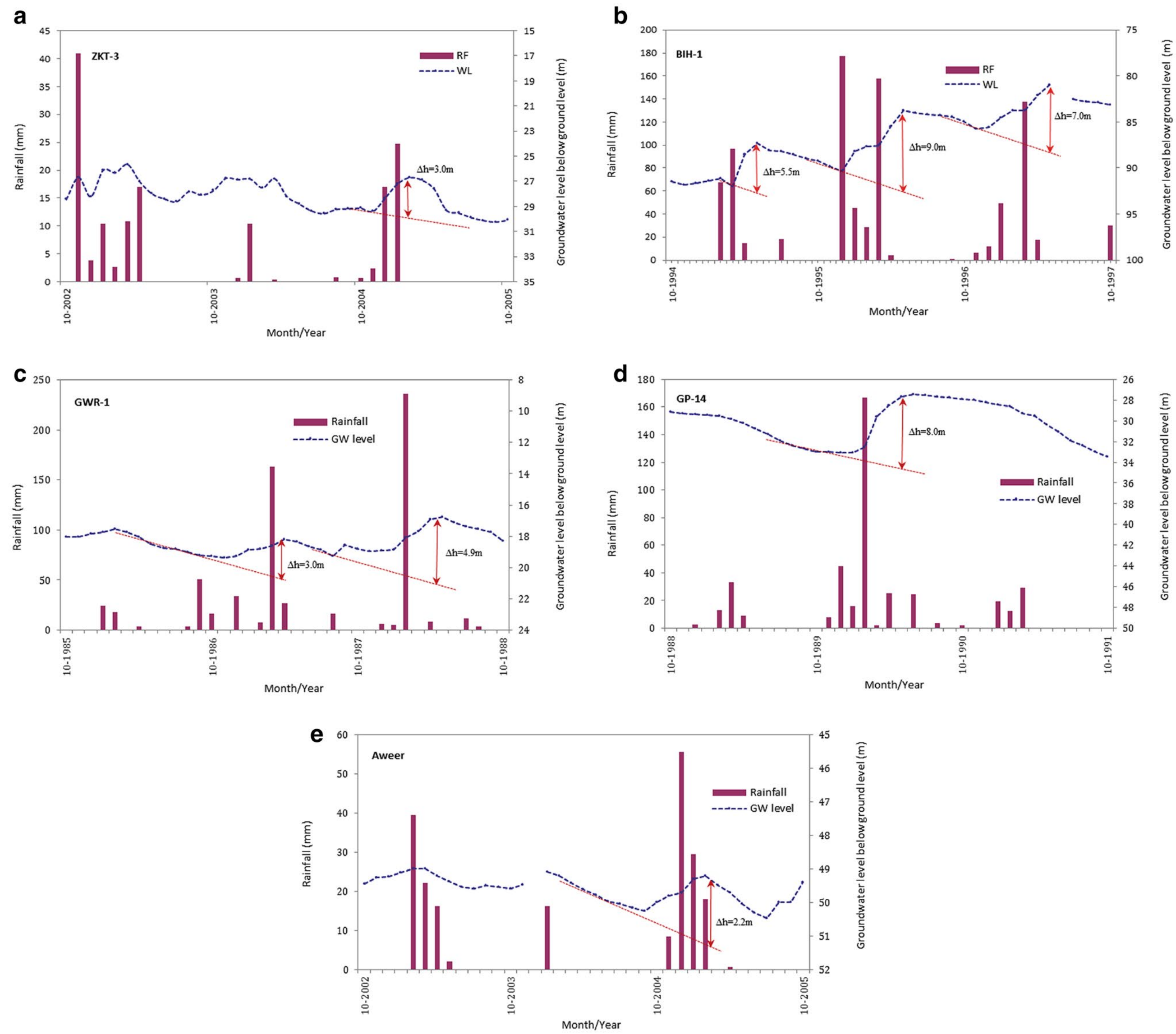

Fig. 10 **a**: (Δh) estimation for Zikt climatologically station (ZK-3). **b** (Δh) estimation for Al Bih climatological station (Bih-1). **c** (Δh) estimation for Al Madam climatological station (GWR-1). **d** (Δh) estimation for Siji climatological station (GP-14). **e** (Δh) estimation for Aweer climatological station

As a result, the WTF method was only applied at local and specific points to validate the developed recharge potential map (Fig. 11). Considering these adjustments, the total recharge volume using the recharge potential method is estimated to be 133 MCM per year which is in a better agreement with the value of 120 MCM made by IWACO (1986). A recharge volume of 20.5 MCM is obtained for the area extending from Falaj Al Mouaala to Maliha. This value is also close agreement with the values of 22.7 and 21.7 MCM estimated by IWACO (1986) and by JICA (1996), respectively.

At the local scale, rainfall recharge rates estimated by the WTF and recharge potential were compared for validation (Table 8). The maximum difference (3.5%) was observed in the case of the arid Siji area and the minimum difference was (0.2%) at Manama. The difference of mean values between the methods is 1.8% and the standard deviation is 1.0%. This indicates that both WTF and recharge potential empirical methods are in a good agreement and can be effectively used in arid regions.

The new developed recharge map (Fig. 11) has the following unique features:

1. It is the first digital and quantitative recharge map for the whole UAE

Table 3 Rainfall recharge factor for the eastern region

Rainfall (mm)	Rainfall recharge (mm)	Recharge factor	Rainfall (mm)	Rainfall recharge (mm)	Recharge factor
Ham area			*Zikt area*		
45.0	5.2	0.12	60	5	0.09
179.4	26.0	0.14	85	8	0.09
70.8	6.0	0.08	44	6	0.14
95.6	8.8	0.09	288	35	0.12
94.4	9.1	0.10			
293.0	34.5	0.12			
211.0	23.4	0.11			
148.0	21.5	0.14			
287.0	37.7	0.13			
Average recharge factor		0.118	Average recharge factor		0.111

Table 4 Rainfall recharge factor for the mountain region

Rainfall (mm)	Rainfall recharge (mm)	Recharge factor	Rainfall (mm)	Rainfall recharge (mm)	Recharge factor
Siji			*Masfut*		
242	21.0	0.09	300	25.5	0.09
288	24.0	0.08	60	3.60	0.06
220	18.0	0.08	131	11.25	0.09
131	9.75	0.07	175	15.00	0.09
			50	3.00	0.06
			114	6.60	0.06
			298	24.60	0.08
			200	14.25	0.07
Average recharge factor		0.08	Average recharge factor		0.074

Table 5 Rainfall recharge factor for the desert foreland

Rainfall (mm)	Rainfall recharge (mm)	Recharge factor	Rainfall (mm)	Rainfall recharge (mm)	Recharge factor
Falaj Muaalla			*Al Aweer*		
380	13.5	0.04	165	11	0.07
187	9	0.05	75	6.25	0.08
102	6	0.06	320	17.5	0.05
223	11	0.05	80	7.5	0.09
196	9.0	0.05	125	11	0.09
Average recharge facto		0.048	Average recharge facto		0.077

Table 6 Rainfall recharge factor for the gravel plain

Rainfall (mm)	Rainfall recharge (mm)	Recharge factor	Rainfall (mm)	Rainfall recharge (mm)	Recharge factor
Al Bih			*Tawyean*		
234.2	29.6	0.13	106.8	8.75	0.08
201.0	17.6	0.09	225	13.75	0.06
65.0	7.2	0.11	71.1	4.75	0.07
180.0	22.0	0.12	225	10.5	0.05
222.4	18.0	0.08	56.3	4.2	0.07
223.0	28.0	0.13	40.2	3.3	0.08
109.7	10.4	0.09	71.4	5.0	0.07
27.6	4.0	0.14			
190.6	20.0	0.10			
Average recharge factor		0.111	Average recharge factor		0.069
Manama			*Madam*		
322	42.0	0.13	205	13.5	0.07
213	17.3	0.08	266	13.5	0.05
226	28.5	0.13	95	7.875	0.08
80	6.0	0.08	299	13.5	0.05
415	48.8	0.12	226	13.5	0.06
390	30.0	0.08	205	15.75	0.08
			435	23.85	0.05
			300	19.125	0.06
Average recharge factor		0.101	Average recharge factor		0.062
Habab					
150	9.2	0.06			
123	8	0.07			
90	5.2	0.06			
115	12	0.10			
234	18	0.08			
118	12	0.10			
444	36	0.08			
130	8	0.06			
280	17.2	0.06			
Average recharge factor		0.075			

2. Recharge volume can be estimated over the smallest scale of 1 km^2 for the whole country while taking into account variable rainfall, surface storage and land use conditions in space and time
3. The developed empirical relationship is valid for dry, average, and wet years
4. The recharge map can be used conveniently for water budget calculations and groundwater flow modeling studies at a local or regional scale
5. This map is a dynamic map and thus easily updated or modified as well as easily used as a decision support system (DSS) tool for water resources management.

However, the resultant recharge map may be further improved by:

(a) Increasing the accuracy of records and applying high spatial resolution imageries to derive the spatial thematic inputs.

Table 7 Established relationship between rainfall and recharge

Area	Relationship	R^2
East coast		
Ham	$RR_{HAM} = 0.1324 \times R_{HAM}$	0.9646
Zikt	$RR_{Zikt} = 0.1186 \times R_{Zikt)}$	0.9865
Gravel plains		
Bih	$RR_{BIH} = 0.1078 \times R_{BIH}$	0.8440
Tawyean	$RR_{Taw} = 0.584 \times R_{Taw}$	0.8198
Manama(GP-3)	$RR_{Manama} = 0.1056 \times R_{Manama}$	0.7814
Madam (GWR-1)	$RR_{Madam} = 0.0575 \times R_{Madam}$	0.7016
Habhab (RK-14)	$RR_{Habhab} = 0.0754 \times R_{Habhab}$	0.9213
Mountains		
Siji (GP-14)	$RR_{Siji} = 0.0832 \times R_{Siji}$	0.9808
Masfut	$RR_{Masfut} = 0.0807 \times R_{Masfut}$	0.9695
Desert foreland		
F. Al Muaalla	$RR_{F.Muaalla} = 0.0419 \times R_{F.Muaalla}$	0.5595
Aweer	$RR_{Aweer} = 0.0627 \times R_{Aweer}$	0.6655

RR rainfall recharge (mm), *R* rainfall (mm)

(b) Apply longer historical records of precipitation to accurately calibrate the typical average rainfall rates for dry, average, and wet years.

(c) Integrate additional thematic layers such as soil moisture and actual evapotranspiration.

Conclusion

Groundwater recharge in the UAE is estimated to provide about 133 MCM/ year and recharge rates vary between 5% in the desert forelands and 12% of rainfall in the eastern region of the country. The recharge potential method using GIS and remote sensing techniques has proven to be more suitable of estimating recharge than the water table fluctuation method over the arid region of the UAE to spatiality map recharge over the different climatic regions. The new recharge map for the UAE will enable a more reliable estimation of recharge than

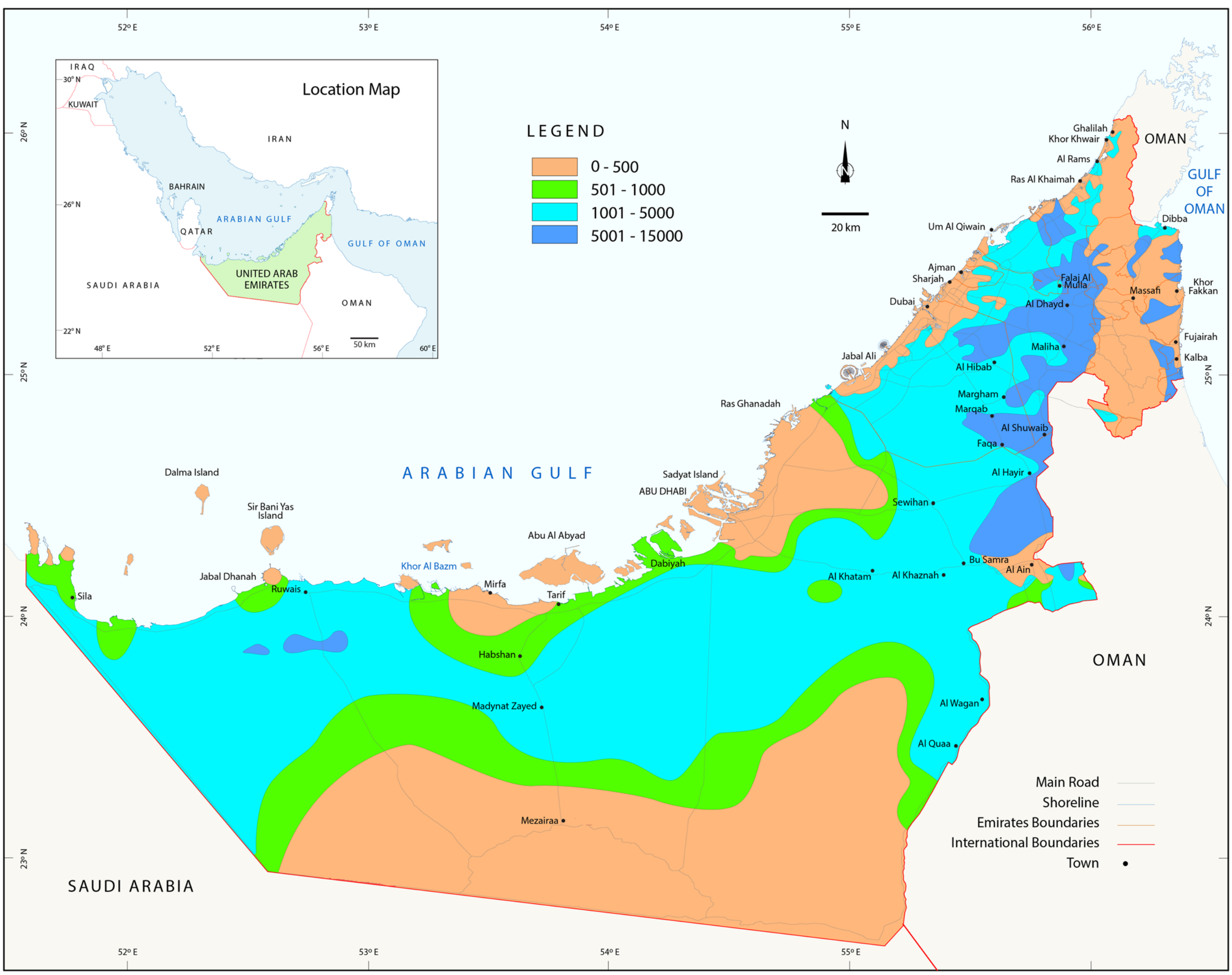

Fig. 11 Estimated rainfall recharge in volume (m^3/km^2) for the average rainy year

Table 8 Comparison between WTF and recharge potential methods

Location	Rainfall recharge in percent			Discrepancy
	Water table fluctuation method		Potential method	
	Range	Average	Average	
Ham	8–14	11.9	9.0	2.9
Zikt	7–14	9.7	9.0	0.7
Bih	9–14	11.2	9.0	2.2
Tawyean	5–8	6.9	4.8	2.1
Manama(GP-3)	8–13	9.9	9.7	0.2
Madam (GWR-1)	5–8	6.2	4.8	1.4
Habhab (RK-14)	6–10	7.5	5.0	2.5
Siji (GP-14)	7–10	8.5	5.0	3.5
Masfut	5–9	7.4	7.0	0.4
F.Mulla	4–9	5.9	3.4	2.5
Aweer	4–9	7.5	5.6	1.9

the WTF method in desert regions where water table fluctuations are relatively small.

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