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ORIGINAL PAPER

Geographical information systems and remote sensing methods in the estimation of potential dew volume and its utilization in the United Arab Emirates

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Abstract
In a fast growing region of Middle East and with rapid depletion of fossil groundwater, possibilities for dew utilization as a limited renewable water resource play an important role in the water management of the United Arab Emirates. Despite projected changes in air temperature and rainfall, geographical and topographical features of the UAE show some potential for dew harvesting, mostly at the altitudes higher than 1000 m and some isolated oasis areas. With the help of geographical information system (GIS), remote sensing, and numerical and theoretical methods, approximate volumes of dew were estimated. Meteorological data was inputted together with theoretical and numerical calculations into grids by using pixelization processes. Methods such as zonal statistics, kriging, semi-kriging, and interpolation were implemented through GIS software. Another method used in this research is supervised classification and normalized difference vegetation index (NDVI) which is being determined by means of software IDRISI terra set. After finishing all the proposed methods applied in this research, four belts of potential dew use were presented. The Arabian Desert in the territory of the United Arab Emirates has no potential for dew utilization. The zone close to the oases has very low possibility of dew use. The hilly-mountainous area between 500 and 800 m.a.s.l. has medium possibility for dew use. There is a high possibility for dew use on mountain Al Hajar, occupying the area higher than 800 m; 1.3% of the whole country's territory has excellent potential for dew use. In this part of the country, theoretically, it is possible to use dew for farming and partial watering. Experimental study together with GIS, remote sensing, and numerical analysis may extend knowledge about dew properties. Although this research includes theoretical calculations of dew utilization and has some limitations, it still presents a new insight into climate cycles in this part of the Arabian Peninsula and a way to understand them better.

Keywords United Arab Emirates · Dew volume · GIS · Remote sensing · Utilization · Dew volume

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Introduction

Water scarcity associated with depletion and ecological degradation of global freshwater resources leads to intensive consideration of increase in utilization of nonconventional sustainable resources such as dew. Tomaszkiewicz et al. (2015) point out that dew utilization is of great importance when dealing with this kind of environmental problems. Respective authors state that this kind of meteorological phenomenon is frequently overlooked as a viable water resource and that during the last 20 years it has experienced an increase when it comes to modern dew harvesting. Nilsson (1996), Muselli et al. (2002), Beysens et al. (2003), and Beysens (2018) discuss that relatively small, non-negligible dew yields may have important impact during dry periods in arid and semiarid regions. According to Ahmed et al. (2017) and Nazzal et al. (2019), sustainable management of water resources is an important issue to address in arid countries such as the United Arab Emirates (UAE). Numerous factors that encompass limited rainfall, high evaporation, and lack of surface water have high impact on surface and groundwater resources. Also, rapid urbanization and intensive human activities additionally affect availability of water resources in the UAE (Nazzal et al. 2019). Therefore, as pointed out by Chowdhury et al. (2016), the management of water resources under the natural stresses of very low rainfall, high evaporation rate, and limited nonrenewable groundwater is a great challenge in this part of the world. Wehbe et al. (2017) strongly point out that the lack of renewable water resources in arid regions of the UAE requires precise monitoring of the sporadic rainfall events, but results of this study suggest that estimation of dew potential can be useful and challenging in terms of identification and utilization of alternative water resources with significant variability over space and time. According to the U.S. Energy Information Administration (EIA) report from 2017, climate change and fossil fuel resource depletion have driven the UAE to reconsider and restructure its energy plan up to 2050 and to look for more sustainable energy resources. Two key factors for building an environmentally sustainable surrounding in the country encompass climate change and water scarcity (throughout water footprint) issues. This is why the UAE government has recognized that renewable energy should play a more prominent role in the future (Lim et al. 2018), and that dew potential estimation and utilization can find their place when dealing with water scarcity in arid environments.

There are numerous difficulties in estimating and analyzing dew potential. Three hypothetical regions were identified as distortion of dew properties. These problems include, among other, various pressures in the system dew point pressure-capillarity condensation (Yang and Richter 2020). Another problem in estimation of dew volume is in the heat transfer performance. Radiant cooling panels with the average area of $0.16\ m^2$ included in this research showed solid results of dew accumulations. Condensation of moisture on the radiant cooling panels was noted to increase the heat transfer quantity, but there is still a question on which panel, surface, and material should be used for better utilization of dew. Different materials may be very successful in dew volume collecting, for example, gypsum (Yin et al. 2013). In recent times, advanced mathematical methods are employed in order to find better solutions for dew exploitation. Neural networks and optimization algorithms are being used to improve the precision of the analysis of dew characteristics. The efficiencies of the proposed hybrid networks were authenticated against standard tuned by a Levenberg–Marquardt back-propagation algorithm, extreme learning machine, and support vector machine models in the analysis of dew properties. This research showed high possibility for dew use in arid and semiarid climate zones (Naganna et al. 2019; Shiri et al. 2014). Excluding estimation of dew potential use, it is very important to find daily dew points curve. Ten machine learning models together with optimized algorithms were used to find daily dew point values. Another method used in this research was Kernel-based nonlinear extension of Arps decline model. Results showed that all models exhibited a poor accuracy with T_{mean} if this parameter is the only inputted one, but a combination with minimum three parameters ($T_{\max}$, $T_{\min}$, and P_a) showed significant accuracy. For the dew point estimation ($T_{\max}$, $T_{\min}$, $RH_{\max}$, $RH_{\min}$, and P_a), a model with certain advantages, but disadvantages as well, is being used, if the following parameters are taken ($T_{\max}$, $T_{\min}$, $T_{\min}$, and $RH_{\min}$). All results showed that based extreme machine learning model gave the best results (Dong et al. 2020). Dew having penetrated into soil presents the soil moisture. The atmospheric water vapor hardly influenced the soil water at 30-cm depth and the deeper soil layer. Stable isotope profiles δD-δ18O of the soil water showed that the dew condensed from atmospheric is commonly up to 20 cm of the soil layer. That shows the possibility of dew utilization in low layer of soil (Zhu and Jiang 2016). Different use of artificial neural network models may be generalized in better approach to the possibility for dew utilization.

The climatic data encompassed 8 years of daily records of air temperature, sunshine hours, wind speed, saturation vapor pressure, relative humidity, and in the end, dew point temperature from three weather stations. Daegu, Pohang, and Ulsan in South Korea were used in the study. The study showed successful potential for estimating dew point, using T_{mean} and R_H. In Iran arid regions, dew volume was estimated by means of three types of algorithms. They are gene expression programming (GEP), multivariate adaptive regression splines (MARS), and support vector machine (SVM). These methods are compared with nine meteorological stations, three of them belonging to the arid region. The estimated input (measurement data) and output (theoretical data) showed similarity of about 90% in calculation of dew volume (Fathollahzadeh Attar et al. 2018). Climate changes had strong influence on potable water in all regions. In one study, trends of the annual and seasonal relative humidity and dew point temperature time series have been investigated for 15 stations all over Bangladesh during 1961–2010. The percentage of stations showing a significant trend is moderate in the case of relative humidity but is a lot higher in the dew point temperature series at the 95 % confidence limit. On average, relative humidity is increasing by 0.53, 0.86, and 1.18 % per decade, especially in the western part of the country (Mortuza et al. 2014). Dew point temperature is very precise condition of atmospheric moisture. In one research in Northern Great Plains, four different regression-based approaches were adopted and applied to all sites. All calculations in this research showed index of dew points between 0 and 1. Root mean square error varied between 3.23, 2.55, and 0.97, respectively. The mean absolute error in this research varied between 2.6, 2.0, and 0.98. Even if these errors were concluded, this method would be quite useful in estimating dew point (Hubbard et al. 2003).

According to Jung et al. (2011), the region of Middle East is already experiencing high water stress, with projections that suggest that this condition will progress in the future due to climate change. The reports of the IPCC also suggest that the region is expected to get warmer across all seasons by the middle of the twenty-first century (Chowdhury et al. 2016). In the work of Elhakeem et al. (2015), an increase of annual mean maximum temperature in the range between 2.79 and 3.8°C was predicted to occur by 2080 in the UAE. Respective authors also identify possible decrease of annual precipitation in the range between 16.8 and 37%. In addition, numerous studies indicated that the annual rainfall has significantly decreased since 1998 (e.g., Murad 2010; Ouarda et al. 2014; Sherif et al. 2014; Mahmoud et al. 2019). Increased air temperatures along with high possibility of rainfall decrease will affect the existing water resources problems. In the last few decades, Arabian Peninsula, especially the UAE, is under intensive research on defining water budget and future sustainable measures of water utilization. Large cities such as Abu Dhabi (the capital) and Dubai are heavily affected by dry periods over decades. The water resources in the whole territory of UAE are in the phase of constant monitoring and observations. Understanding precipitation variability over arid and semiarid regions may give better insight into the occurrence of flash floods, drought, etc. and qualitative measures for their mitigation (Wehbe et al. 2017). Therefore, the UAE government is striving to find alternative water resources. Dew harvesting can be one of the solutions but with certain obstacles regarding its harvesting. The first one refers to the identification of areas in the country with certain dew volume potential for the utilization in the agricultural sector.

Another problem is associated with the separation of water from the harvested dew (Maestre-Valero et al. 2011; Valjarević et al. 2020), and pointed out that dew is one of the atmospheric moisture phenomena that are not easily observed in respect of its agricultural influence.

Sharan et al. (2011) stated that the largest dew collectors were established in India in the semiarid area, and that they gave good results regarding the dew harvesting. The dew water accumulated during 192 days was 12.6 mm with a maximum of 0.556 mm/night.

The purpose of the new method presented in this paper is to provide the first theoretical estimation of dew potential in the UAE, as well as its detailed geospatial analysis for agriculture purposes due to Arabian Peninsula water scarcity problems and negative future climate projections regarding the climate change impact on arid environments.

Materials and methods

The study area of this research is 83,600 km^2, but the area of collected data covers 90,000 km^2. The topography of the investigated area is relatively flat in the coastal and western parts of the country. Only the northeast part of the country reaches the altitude >1,800 m on Al Hajar Mountain. This mountain belt may potentially be used for dew utilization. During the winter period, according to subtropical climate properties, it is possible to expect lapse rate or change of temperature by 0.65°C with the altitude increase by 100 m. Climate variables used in this study were obtained from the Climate Data website for the period 1980–2010. The meteorological data include average daily temperature, relative humidity, and cloud cover throughout the year (https://en.climate-data.org/; Climate-data.org 2020; Jun et al. 2014; Abrams 2000; Gas and Kusky 2006; Onderka and Pekárová 2008). The presented study covers the entire territory of the United Arab Emirates (UAE), located in the southeastern part of the Arabian Peninsula (Fig. 1). This country is bordering Saudi Arabia in the south, Oman in the east, and Persian Gulf in the north. The border with Saudi Arabia is 530 km, with Oman 450 km and with Qatar 19 km long. The country lies between 51°30 E–56°24 E and 22°39N–26°04 N (Mahmoud et al. 2019). The Arabian Peninsula, including the UAE, has dry and arid climate (Hunting 1979; Mahmoud et al. 2019). Generally, there are two distinct orographic regions in the territory of UAE: an eastern mountain region with a submontane zone of outwash plains, and a western desert region comprising a coastal belt, inland desert, and scrub (Satchell 1978). Hence, high mountains in the east cover 5% of the territory, while lower plains cover 95% of the UAE territory. This mountain system isolates the Gulf of Oman to the east from the rest of the country Baghdady and Abu-Zeid (2002). More detailed division of the landscape features is provided by Abdelfattah (2013), where the author states that the landscape of the UAE ranges from small areas of level coastal

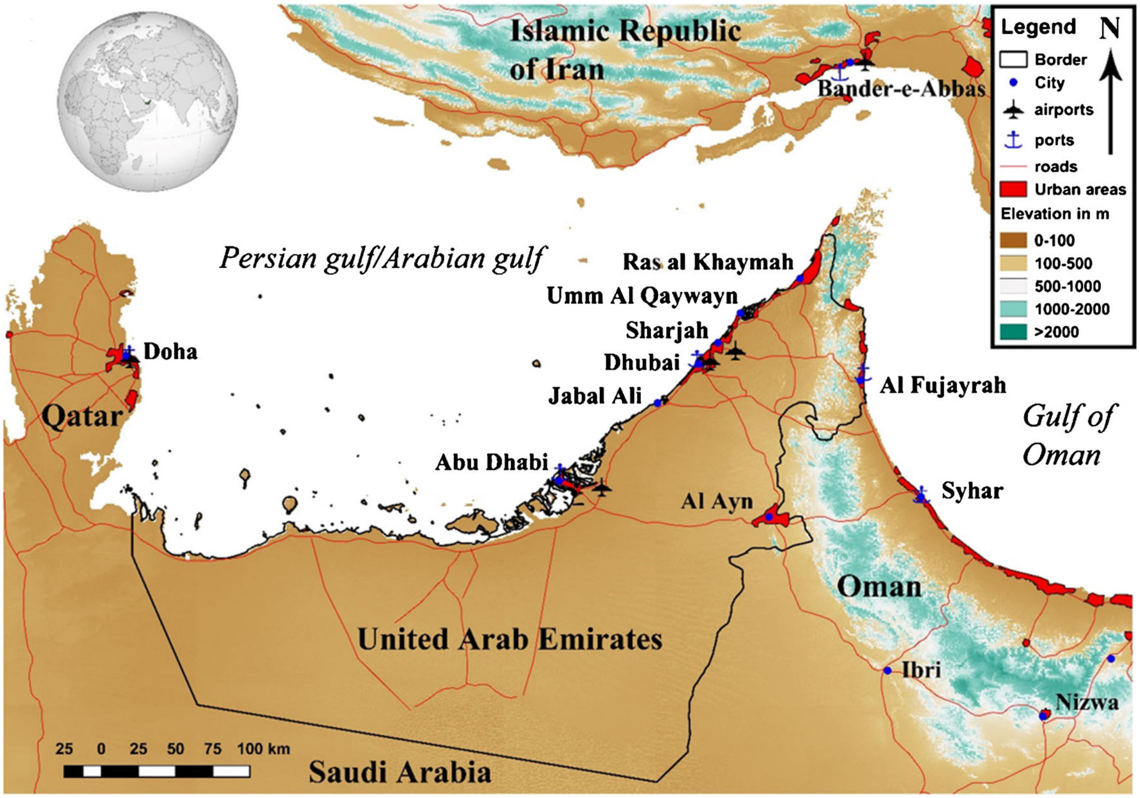

Fig. 1 Geographical position of the United Arab Emirates with elevation belts

plains and sabkha to an undulating desert sand plain, wide areas of linear and transverse dunes, wide alluvial plain, and mountainous region along the Hajar Mountains, which reach the height of 3,017 m at Jebel Akhdar in the state of Oman. In the northeast region and its western parts, linear dunes rise up to 100 m above the surrounding terrain and they are overlapping with small deflation plain areas. As discussed by Komuscu (2017), the territory of the UAE is situated in a zone which is semipermanently affected by subtropical high-pressure cells. The atmospheric circulations provide mostly dominant stable and dry weather conditions throughout the year. Semipermanent troughs of low pressure over the area of the Arabian Gulf and land-sea distribution are other important factors which control the climatic conditions of the country. The UAE is affected by land-sea breeze circulation from western and eastern sides. Also, the Oman Mountains in the east (Fig. 1) have an influence on the abovementioned local wind patterns. The dominant climate of the UAE is tropical and subtropical with warm hot summers and warm winters. The climate of the country is classified as desert climate and characterized by very low precipitation amounts, annual mean temperature >18°C, and high values of potential evapotranspiration. All these features correspond with the BWh climate within the Köppen climate classification system. Winter season lasts from November till the month of March, and represents a period when air temperatures (on rare occasion) drop below 6°C, while the summer season (from April till September) is very dry, with air temperatures reaching approximately 48°C in coastal areas of the country, accompanied with very high humidity levels (up to 90%). The southern desert regions of the UAE record air temperature values that can rise up to 50°C. Annual mean monthly temperatures in the country vary between 19 (January) and 36°C (August) (Komuscu 2017). Barbulescu and Nazzal (2020) pointed out that the hottest months in the UAE are July and August, with average maximum air temperatures above 50°C in the area of coastal planes and this temperature affects the mainland of the country. In the mountainous area, temperatures are considerably lower, as a result of the lapse rate. According to the respective authors, the average minimum temperatures are between 10 and 14°C, in the months of January and February. Humidity is not equally dispersed around the country. It is higher near coastal areas, where average minimum and maximum humidity ranges between 20.7 and 97% respectively (Climatological Data 2017).

As pointed out by Barbulescu and Nazzal (2020), the average annual rainfall varies from less than 120 mm in the coastal area of the country and up to 350 mm in mountainous areas. According to Mahmoud et al. (2019), rainy season generally occurs from the month of November and ends in April. The coastal region can experience short and intensive rainfalls during the summer months, which can induce flash floods in ordinarily dry beds. Also, this feature is observed for the mountainous regions Jabal Hafit, Jabal Malaqet and Jabal

Mundassah as well, and these regions can be considered main belts for dew harvesting in the UAE. The western part of the country is mostly comprised of dunes and merges into the Empty Quarter of Saudi Arabia (Fig. 1). The land cover is relatively uniform, being predominantly comprised and classified as bare land in the western and northwest parts of the country, and urbanized areas in the northern parts of the Persian Gulf. The most populated urban areas are in Dubai and Abu Dhabi (Fig. 1; Fig. 3)

Two types of satellite data and one astronomical and meteorological database were used in this research. The first digital elevation model (DEM) was downloaded from the free database Earthdata in 10 m of resolution. Normal difference vegetation index (NDVI) data were used from Landsat 8 satellite Mission and satellite recordings belonging to 8 OLI/TIRS C1 Level 1. DEM was used to estimate slopes and potential shaded places. NDVI was used to show the dispersion and quality of vegetation. The final data for the sun ecliptic through the year were calculated by means of open-source software Stellarium 0.20.1. The border of the UAE in vector format was inputted in the software IDRISI TerrSet 2020. To eliminate cloudiness effects on the recording, we used filtering algorithms. These data have less than 10% of haze and cloudiness effects, and they were filtered. Normal differences vegetation index was established in the IDIRISI TerrSet to show average vegetation properties.

The set of 46 satellite filtered recordings showed average state of land surface of the UAE (Wang 1990; Keuchel et al. 2003; Zhong and Zhang 2012; Atkinson 2004). Remote sensing with GIS techniques is a very powerful tool for quantifying and describing environmental data of a geospace (Valjarević et al. 2018a; Wan 2015; Young et al. 2013; Liu 2021; Milanović et al. 2017). NDVI data when downloaded from the Landsat 8 satellite are used for future precise remote sensing observation. The supervised classification is used to divide all types of vegetation and other types of land. The complete palette of classification is water, forest in common, grass, shrub, urban, and barren (desert) (Ichii et al. 2002; Melgani et al. 2000; Boegh et al. 1999). The satellite recording is obtained from channels of the visible and infrared part of spectrum (near, medium, and infrared) with a 30 m of resolution. The images were processed in color composite: 4-3-2 (4-nearinfrared channel, 3-red channel, 2-green channel) and 5-3-4 (5-mid-infrared channel, 3-red channel, 4-near-infrared channel). The purpose of the classification of images was to sort the approach or categorization of all image pixels into classes or themes. After this, downloaded data were imported into the GIS software for advanced analysis (Chaplin and Brabyn 2013). Different plants have a different reflectance ratio (Milanović et al. 2019; Valjarević et al. 2018b). The satellite recordings varied between 0.7 and 1.15 μm. From all satellite recordings, we eliminated haze and cloudiness effects, thus minimizing the average error of satellite recordings.

Classification can be done by means of two basic types of classifications: supervised and NDVI. Following classes were isolated in the process of the classification: populated, water, surface mines, forest, low vegetation, industry, and transport. The supervised pixel classification is very slow process but the results are with errors of 2%. After finishing remote sensing analysis of NDVI, supervised pixel classification was employed to estimate the percentage of vegetation and other land types, which could be useful for potential dew collecting. Upon performed NDVI analysis, red palms and low Mediterranean forests whose coefficients vary between 0.66 and 1.0 of NDVI index are considered health vegetation (Jia et al. 2011; Lu et al. 2003). This raster was digitized so we could derive the areas in square kilometer and percent of vegetation in the UAE. This classification is useful to analyze more than 100 classes and subclasses. The indexes of all classes in remote sensing varied between −1 and 0, in dependence on bend channel. The grid cells of vegetation were added together with grid cells of relative humidity and temperature in the QGIS open-source software QGIS 3.10.8. Using IDRISI terra set software, we analyzed NDVI data. To determine average humidity of land surface, we used thermal microwave filters in the same software (Valdes et al. 2006; Hain et al. 2012). After that, with the method of pixel analysis, the data were estimated on resolution of 1 km^2. In that way, it is possible to find month by month grid cells with dew potential using ideal conditions, connected with average humidity and temperatures (Valjarević et al. 2018b; Protić et al. 2012; Blake et al. 2007).

Theoretical estimation of dew utilization used in this research has the following parameters (Fig. 2). The first one is average temperature through the year, the second is average humidity through year, the third is the sun's position through the year, and the fourth is the slope of the terrain. In software QGIS and SAGA, four kinds of data are used and analyzed with the help of semi-kriging, kriging, interpolation, and zonal

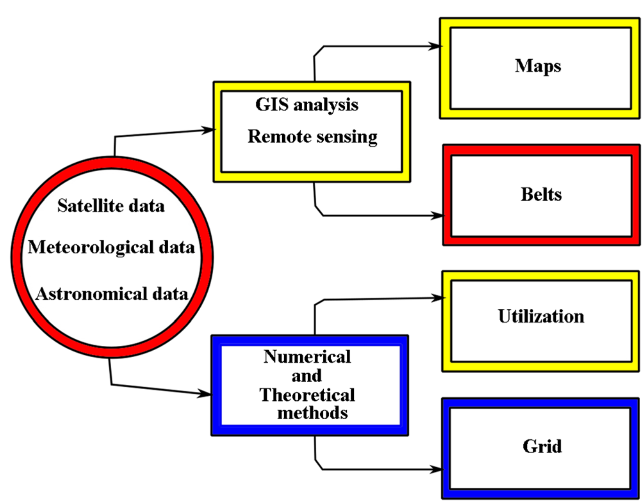

Fig. 2 Flowchart of potential dew distribution and utilization

statistics. In the following process, using two main methods, pixelization, and land cover analysis, it was possible to determine how many liters may be derived from potential dew utilization (Jacobs and Nieveen 1995; Valjarević et al. 2020). The procedures such as GIS and remote sensing analysis and numerical and theoretical calculations gave maps, grid cells, belts, and final potential distribution of areas in the UAE for dew utilization (Fig. 2; Fig. 8).

The final results were obtained by calculations of different pixels: pixels with the potential volume of dew and pixel without the potential volume of dew. The grid of all pixels has a resolution of 1 km^2.

Theoretical background of dew utilization and some limitations

For determination of dew yield, it was necessary to solve a thermal equilibrium equation between sensitive and latent heat fluxes (Eq. 1):

$$\frac{dTc}{dt}(Mc_c + MC_w) = R_i + R_{he} + R_{cond} \tag{1}$$

T_c represents the surface temperature of dew collector, M and m in kilogram represent the masses of dew collectors and condensate, respectively, c_c and $C_w(J \times kg^{-1} \times K^{-1})$ represent the specific heats of dew collectors, and $t(s)$ is the time. $R_i(W)$ represents the cooling energy and it must be less than $100Wm^{-2}$, $R_{he}(W)$ is the heat exchange with ambient air, and R_{cond} is the energy gain due to the latent heat of condensation per unit of mass $L_c(J \times kg^{-1})$. The condensation and heat exchange can be expressed as:

$$R_{cond} = L_c \frac{dm}{dt} \tag{2}$$

$$R_{he} = aS_c(T_a\text{-}T_c) \tag{3}$$

where $a(W \times K^{-1} \times m^{-1})$ represents the coefficient of convective heat transfer, $T_a(K)$ represents the temperature of the ambient air, and $S_c(m^2)$ represents the surface. The parameter a is correlated with the thickness of the thermal boundary layer and depends on the air speed $V(m \times s^{-1})$, usually higher than that of natural convection (≈ 0.6 m/s, according to Beysens et al. 2005). According to Pedro and Gillepsie (1982), the laminar flow regime is expressed as:

$$a = kf\sqrt{\frac{V}{L}} \tag{4}$$

The factor $f\left(W \times k^{-1} \times m^{-2} \times s^{\frac{1}{2}}\right)$ is empirical and varied. The equation representing the condensed mass is described by the rate of condensation.

$$\frac{dm}{dt} = \left\{\frac{wS_c(p_a(T_a)\text{-}p_{sat}(T_c)) \rightarrow if \rightarrow possitive}{0 \rightarrow if \rightarrow negative}\right\} \tag{5}$$

where $p_{sat}(T_c) \times (p_a)$ represents the saturation water vapor pressure at dew collectors temperature $T_c(K)$ and $p_a(T_a) \times (P_a)$ is the water pressure in the humid air above the dew collectors. According to Pedro and Gillepsie (1982), this is approximately:

$$w = 0.65a/(p_0 c_a) \tag{6}$$

where p_0 represents the atmospheric pressure and $c_a = (1.01 \times 10^3 J \times kg^{-1} \times k^{-1})$ is the specific heat of the air.

According to experimental measurement of these equations (Pedro and Gillepsie,1982; Nikolayev et al. 1996; Beysens 2016; Museli et al. 2002; Muselli et al. 2009; Beysens et al. 2005; Lekouch et al. 2012) T_a - T_d rarely exceeds. Finally, Eq. (3) after all calculations is:

$$R_{he} = aS_c(T_a\text{-}T_d) \tag{7}$$

Generalized average monthly temperatures and relative humidity were used, as shown in the following formulas:

$$T_{dp} = T_a\text{-}\frac{100\text{-}RH}{5} \tag{8}$$

where T_{dp} represents temperature of dew point, T_a is the average air temperature, and RH is the relative humidity expressed in %.

$$RH \approx 100\text{-}5(T\text{-}T_{dp}) \tag{9}$$

The average daily temperature, relative humidity, and overcast were used for deriving the final formula which was, later on, used for grid and geographic information system calculations. Tdp and RH relate directly as large RH (>50%) will produce small T–Tdp (Lawrence 2005).

There are many theoretical calculations which show how it is possible to estimate dew volume on regional and global scale in very similar way. With the help of data from the European Centre for medium-range weather forecasts–reanalysis, the estimation of dew volume was calculated on the territory of Iran (Atashi et al. 2019). The global potential for collecting usable water from dew on an artificial collector sheet was investigated by utilizing 34 years of meteorological reanalysis data on global scale. The main formulas for calculations of dew are (9-12):

$$L_{wi} = \frac{dm_w}{dt} = P_{rad} + P_{conv} + P_{lat} \tag{10}$$

where L_{wi} is the latent heat of fusion. According to the Eq. (10), the following formula can be written:

$$\frac{dm}{dt} = max(0, S_c k(p_{sat}(T_d)\text{-}p_c(T_c))) \tag{11}$$

m is m_i or m_w depending on whether $T_c \prec 0^\circ C$ or not; $p_{sat}(T_d)$ is the saturation pressure at the dew point temperature, $p_c(T_c)$ is the vapor pressure; k is a semi-empirical mass transfer coefficient (Pedro and Gillepsie 1982).

$$k = \frac{0.656h}{C_a p} \tag{12}$$

p is the atmospheric pressure and C_a is the specific heat of air. Irreversible condensation shows there is no evaporation or sublimation during daytime even when $Tc > Ta$.

The final formula used in this research is:

$u = \frac{\log\left(\frac{2}{Z_0}\right)}{1^n}$ (Vuollekoski et al. 2015)

Results and discussion

The results of remote sensing analysis, especially of vegetation cover, are equivalent to dew occurrence in the territory. Territory with vegetation covers 1.13%, wasteland (desert) 88.62%, excavation 0.10%, building area 2.70%, water 0.23%, and unknown (transition area) 6.91%. Forests together with orchards (oasis) cover 1.07% (see Table 1). In this area, it is possible to find dew occurrence throughout the year. Transition areas are areas between desert and oasis. In some regions with the help of artificial aquifer, the new oasis was established, thus creating some possibilities for dew collections.

Table 1 Supervised classification, pixel

United Arab Emirates land use			
	Land use	km^2	%
1.	Wasteland	74083	88.62
2.	Forest	283.84	0.03
3.	Grass	35.161	0.04
4.	Meadow	18.217	0.02
5.	Orchard	868.42	1.04
6.	Excavation	84.807	0.10
7.	Building area	2258	2.70
8.	Water	195.99	0.23
9.	Unknown	5773	6.91
10.	Total	83600 km^2	100

The northeast parts of the territory in the UAE have a better belt for potential dew use. Excluding this part, the central region with oasis also has some possibilities. Very low possibilities, according to supervised pixel classification, are situated in south and southeast regions. Northeast, coastal regions, and partly east regions of the country are densely populated. The coastal northeast region presents mostly urbanized areas. According to satellite detection, the south parts of country near Saudi Arabian border have some aquafers with surface water. The grass and meadows cover small territory, concentrated in central and northeast parts of the country (Fig. 3).

When we finished remote sensing analysis of the UAE, we got indexes for 100% of the territory of the UAE in which we may expect dew occurrences. This territory is in the northwest part of the country. Some parts of this territory partly bordered the territory of Oman near Mountain Jebel al Harim (2087 m). The other points of interest with partial vegetation are settlements Ras Al Khaimah, Ajman, Umm Al Quwain, area surrounding the city of Dubai, Al Aweer, Habsab, Al Fahlain, Dibba Al Fujairah, Dibba Al Hisn, Abu Dhabi, etc. Excluding these settlements, there are aquifers (oases), such as Al Qudra Lakes, and very large aquifer 14 km away to the west from the settlement Kizad. NDVI indexes showed a good state of vegetation in these areas (Fig. 3; Table 1).

The total sum of the UAE territory with vegetation higher than 0.6 is 0.1 % or 83.6 km^2. The territory of watering vegetation is 56 km^2. The average vegetation index of the UAE in this period was 0.6, which showed dominant areas of sand. The area comprising the complete vegetation covers 0.29% or 242.4 km^2. Within this territory, there is a transition vegetation, namely oases. The average NDVI index of vegetation showed results very similar to supervised classification. This index varied on the coast between 0.44 and 0.65 and on the mountain near Oman to 0.74 and in the middle latitudes of desert 0.56. It indicates that red palms (*Rhynchophorus ferrugineus*) and shrubs vegetation are predominant in the coastlines. In the central part of the country, there is a very large concentration of date palms (*Phoenix dactylifera*). The decoding of NDVI index showed that predominant plants in mountain areas are *Boerhavia elegans*; *Ochradenus aucheri* and *Helianthemum lippii*; *Moringa peregrina*; and *Euphorbia larica* and *Cenchrus ciliaris* (Keblawy et al. 2016: Gallacher and Hill 2006). The areas higher than 1000 m on the mountain Jebel al Harim with slope of 20° and vegetation belt 80 cm high have high possibility for dew utilization. The sum of this

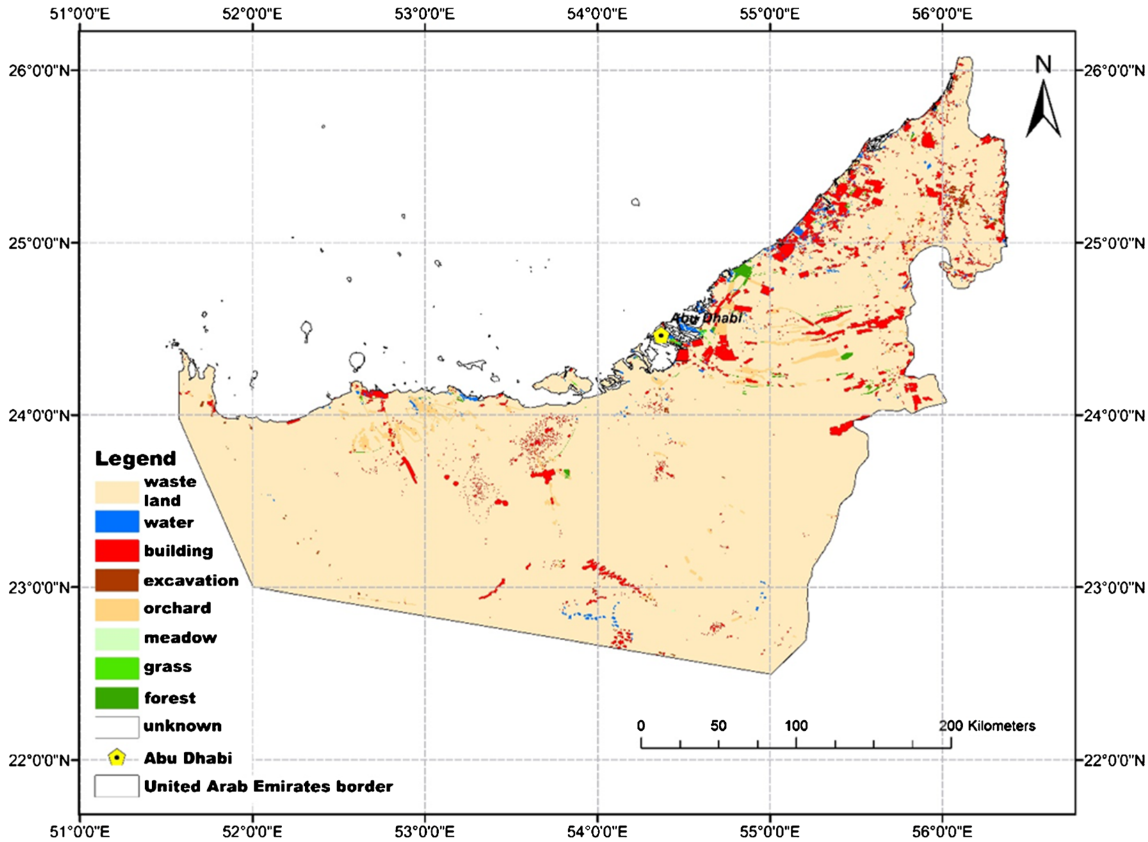

Fig. 3 Supervised satellite classification of the UAE, according to satellite data from 01.01.2020 to 01.01.2021

applicable area is 305.2 km^2 or 0.36% of the territory. In this territory, there is 98% of vegetation cover.

The areas with high NDVI index are concentrated in the northeast part of the country, north coastal zone, and very low in central as well as in western parts (Fig. 4; Table 2).

Table 2 NDVI classification of land cover with all dominating classes in the UAE

United Arab Emirates land use			
	Land use	km^2	%
1.	Wasteland	74083	88.62
2.	Forest	283.84	0.03
3.	Grass	35.161	0.04
4.	Meadow	18.217	0.02
5.	Orchard	868.42	1.04
6.	Excavation	84.807	0.10
7.	Building area	2258	2.70
8.	Water	195.99	0.23
9.	Unknown	5773	6.91
10.	Total	83600 km^2	100

IDRISI terra set and Quantum Geographical Information System (QGIS 3.16.4) were used in order to estimate the main points of potential dew occurrence in the UAE. QGIS open-source software is used to estimate the position and potential dew volume after remote sensing analysis. As mentioned before, interpolation and zonal statistics were used for better calculations of dew. Together with the potential of dew, the analysis of relief was performed. The mountainous area of the United Arab Emirates has the maximum possibility for dew collecting. The analysis of temporary drainage network over the territory of the United Arab Emirates has the area of 674,341 km. The 98% of non-perennial, intermittent, and fluctuating streams flow toward the eastern part of the country and the Gulf of Oman. .

The first screening of the landscape indicated some potential for temperature inversions. The slope has the highest values to the southwest and west side of the geographical azimuth. The area of contour lines > 800 m.a.s.l. covers 9.6 km^2. The total area of contour lines > 800 m.a.s.l., on the mountains which belong to the United Arab Emirates, encompasses 174.179 km^2. The study indicates that only in the mountain belts, there is some possibility for dew utilization and harvesting during the winter season (the main wind may blow saturated air from the sea). The topography of the

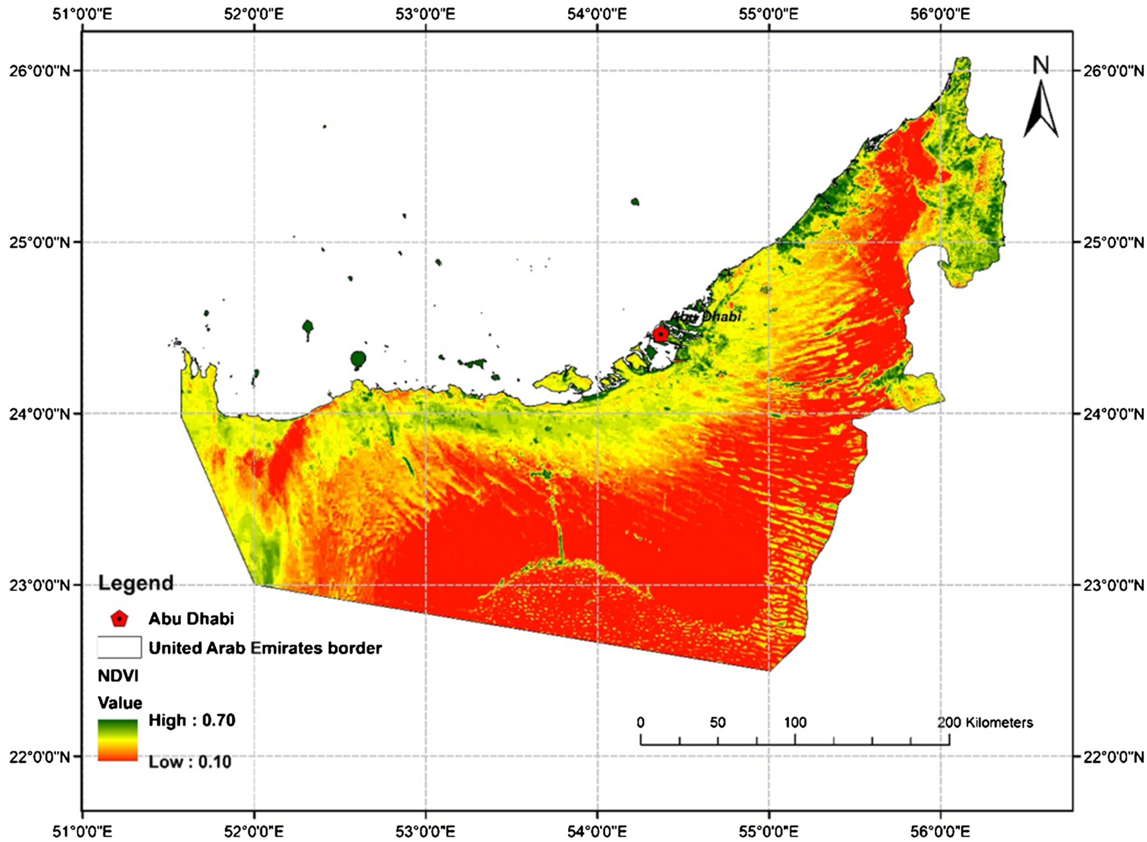

Fig. 4 NDVI index in the territory of the UAE

highest mountain in the United Arab Emirates includes very high slopes. After digital calculation of the horizontal profile, the path between the coastlines in the direction of the Arabian Gulf is 9.15 km. The lowest point on this profile is the elevation of 98 m.a.s.l., and the highest is the elevation of 1,286 m.a.s.l., where vertical differences are 1193.5 m. The average slope is 7.43°. These characteristics were estimated using GIS methods and remote sensing methods. Only the mountainous area of Al Hajar, near the border with Oman, has a slope higher than 5.0°.

The estimation of hill shades presents one of the most important characteristics for potential dew utilization. In the United Arab Emirates, the sunny days are distributed almost during the entire year. With included sun ecliptic throughout the year and relief properties, hill shade values were obtained. The areas with a high level of solar radiation and with the constant sun through the year have no chance for dew occurrences (Fig. 5).

The average value of solar constant per year is 1,367 W/m^2, but it slightly varies and depends on geographical latitude (e.g., Despotovic et al. 2015). The solar radiation can be calculated for each Julian year using the following equations (14,15):

$$I_{oyear} = 1367 \times \left[1 + 0.034cos(\beta) + 0.001sin(\beta) + 0.0007cos(2\beta) + 0.0001sin(2\beta) + 0.0001sin(2\beta) \frac{W}{m^2} \right] \tag{14}$$

$$\beta = \frac{2\pi n}{365} [radian] \tag{15}$$

The intensity of radiation can be calculated using the equation of Beer-Bouguer law (Eq. 16):

$$I_{oyear} = I_0 \times P^{\frac{1}{cos(z)}} \tag{16}$$

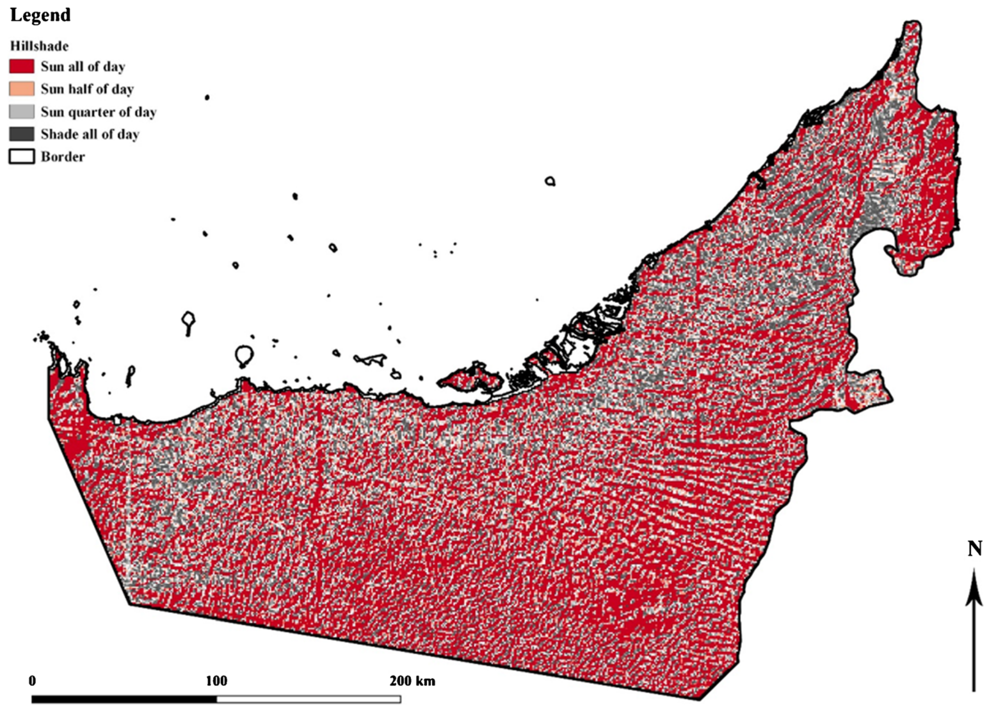

Fig. 5 Hill shade per year in the United Arab Emirates

where I_{oyear} is the radiation intensity per year on the surface in W/m^2. I_0 is the solar constant in W/m^2, P is the total transparency coefficient (-), and Z is the zenith angle.

The following equation presents the calculation of the year average daily extraterrestrial solar radiation on a horizontal surface (Eq. 17):

$$H_0 = \frac{365 I_0}{\pi}\left[1 + 0.034 cos \times \left(\frac{360 N_d}{365}\right)\right] \times \left(cos\varphi \times cos\delta \times sin\omega_{ss} + \frac{2\pi\omega_{ss}}{360} sin\varphi \times sin\delta\right) \quad (17)$$

where I_0 is the solar constant (1,367 W/m^2), φ is the latitude of the site, N_d is the day of the year starting from January 1st, and δ and ω_{ss} are the monthly mean daily solar declination and sunrise hour angle given for the calculation (Cooper 1969) (see Eq. 18):

$$\delta = 23.45 sin\left(360 \frac{284 + N_d}{365}\right) \quad (18)$$

The insolation and position of shades were calculated using digital elevation model (DEM) of 10 m of resolution. The time zone used in this research has the value of GMT+4. The difference between daylight saving mode was estimated using free and open software for astronomical calculations Stellarium 0.20.1.

Calculations were performed for Julian 2020 year which has 365.25 days. The position of the sun was used for the central point of the United Arab Emirates. These geographical coordinates are 24° 28′ 00″ N and 54° 22′ 00″ E. In the central and southeast parts of the country, the dew potential is very low or does not exist. Proposed trajectories of the sun throughout the year are calculated for the whole territory of the United Arab Emirates. Point with coordinates 25° 30′ and 56° 12′ was used, and their circle displayed sun paths throughout the year, with special view of the summer and winter solstice (Fig. 5). This calculation can help in better understanding of the position of sunny and shady sides of the mountains. The areas with highest number of sunny days throughout the year are not suitable for installation of dew collectors (Takenaka et al. 2003) (Fig. 6).

GIS and remote sensing analysis showed high potential for dew utilization only in the mountainous region near Oman border and on the south and east slopes. The first belt has higher possibilities for dew utilization than the second one, because it has 70% more areas with total shades and 30% with semi-shades. After detailed remote sensing, GIS, and numerical analysis, the areas with potential dew volume were theoretically calculated.

The first peak of dew potential is located 750 m from the city of Wadi Shaam and it has 790 m of elevation. The potential areas for dew utilization are classified as medium. Only 0.4% or 1,820 m^2 would be suitable for dew utilization. This volume of dew is closely connected with some hill shade properties of the mountain and circulation of wet air masses from the Arabian Gulf. On the Yabal Yibir mountain, at 1,527 m in winter and partly in autumn season, 2.6% of identified areas would be suitable for dew utilization. This mountain has

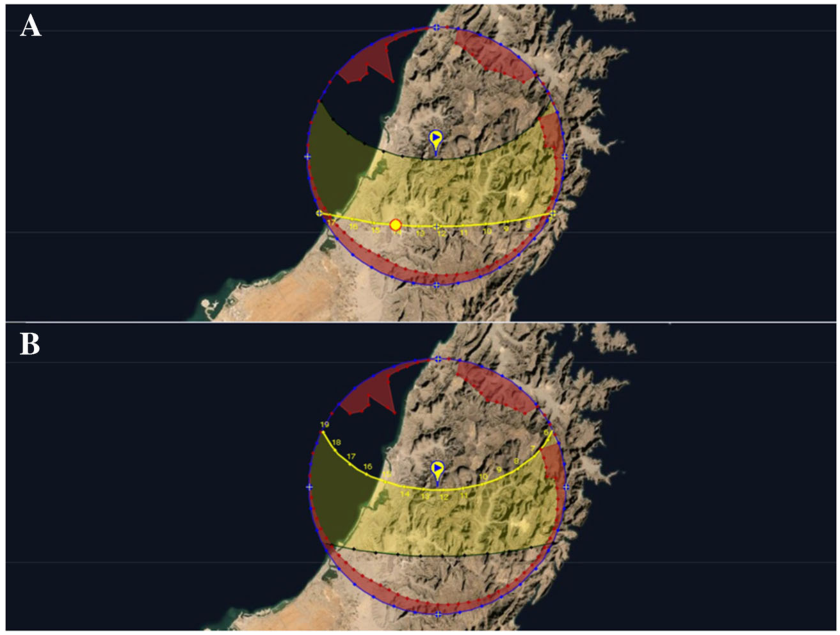

Fig. 6 **A** December solstice over mountain Jabal Yair; **B** June solstice over mountain Jabal Yair. This mountain presents the most significant landscape feature for possible dew utilization

good dew harvesting potential on the southeast slopes and northern slopes. The third area suitable for dew utilization is located on Yabal Yair border mountain with Oman. On the northern slopes, there are 1.3% of the terrains suitable for dew utilization. The total areas identified for dew utilization reach 3.94%.

In the area near Wadi Shaam, there is <10 mm a year per m^2 or 18,200 L. In the mountainous area of the Yabal Yair, the potential dew volume per year is 25 mm per m^2. This result implies that the total amount of freshwater is approximately 392,000 L. In the area of the mountain Yabal Yibir, the dew volume per year is 20 mm per m^2. This observation shows that almost 192,000 L may be derived from dew utilization. The total amount of water that could be derived and used from dew reaches 602,200 L a year. This belt stretches along the Arabian Desert with only several exceptions of dispersed oases which have possibility to generate freshwater from dew. This is possible only in autumn and winter seasons and in the periods of meteorological anomalies. Since this belt of very low possibility for dew utilization presents larger part of the territory of the United Arab Emirates, the total capacity of fresh water production is projected to 56,000 L.

As pointed out by Yilmaz and Shabib (2019), consideration of significant effects of climate change on many economic sectors is vital for defining qualitative adaptation strategies for water resources management. Elhakeem et al. (2015) point out that groundwater supplies of the UAE represent almost 51%, and are mostly used for the irrigation of crops and forestry. Desalinated water supplies occupy about 40% of the total water resources, and are used mainly for potable use (approximately 90%). The remaining 9% are products of treated wastewater that are used in urban environments. Since surface runoff represents 15% and recharge composes 10% of the hydrologic cycle, it is obvious that 75% is lost for evaporation. In a fast growing region of Middle East and with rapidly depleting fossil groundwater, possibilities for dew utilization as a limited renewable water resource (Takenaka et al. 2003) play an important role in the water management of the UAE. The first identified belt is the area with no possibility for dew utilization (covering 36.04%) and is situated between the Arabian Desert and hilly-mountainous area. The second one is characterized by medium possibility for dew utilization and covers the area of 2.66%, while the third has high possibility for dew utilization and encompasses the area of 1.3% (NE mountainous area). The fourth and the largest belt in the Arabian Desert covers the area of 60.0%, and this belt has a very small possibility for dew utilization. The total amount of water that could be derived and used from the assessed dew potential reaches 658,200 L per year in total. Although this type of water resource is not large, it is significant for utilization in agricultural and other economic sectors in arid environments of the UAE (Fig. 7A and B)

Conclusion

The arid Arabian Peninsula has few natural attributes that affect human settlements. Two key factors for building an environmentally sustainable surrounding in the country encompass climate change and water scarcity issues. The necessity for qualitative water resources management is of utmost priority to the UAE government. This is why the UAE government has recognized that renewable energy should play a more prominent role in the future, and that dew potential

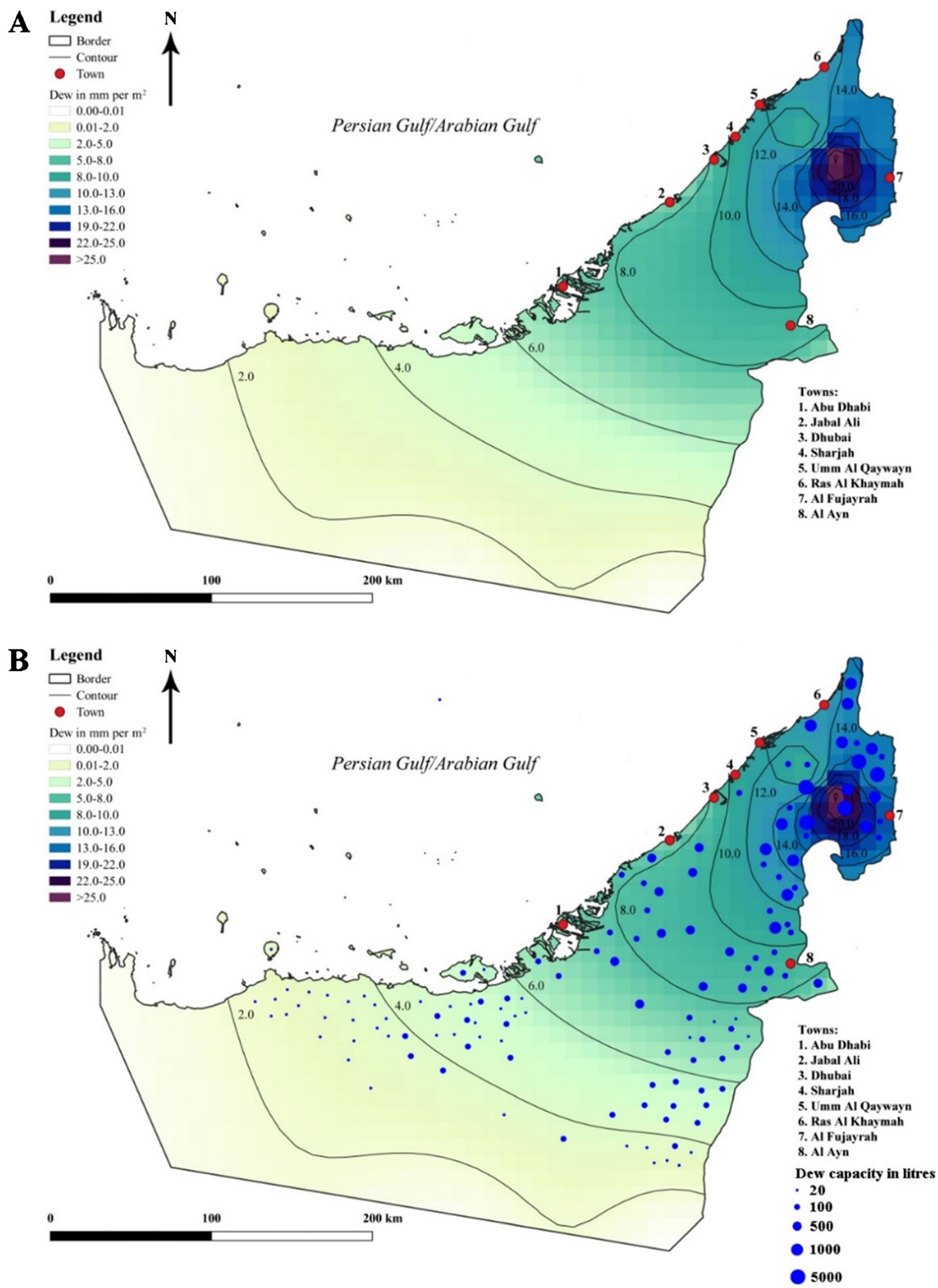

Fig. 7 **A** Dew dispersion map of the United Arab Emirates; **B** potential dew capacity in liters in the United Arab Emirates

estimation and utilization can find their place when dealing with water scarcity in arid and hyper-arid environments. The presented paper gives insight into a new approach for potential dew use estimation. Regardless this research was theoretical, it presents new insight of potential dew utilization. This relatively theoretical method, with the help of satellite detection, GIS, and numerical analysis, can give satisfying results, and it represents one of the economic approaches from the perspective of water management. The areas with a high level of solar radiation and with the constant sun through the year have no chance for dew occurrences (Fig. 5).

The investigated territory of the UAE from the standpoint of dew potential is divided into four independent parts (dew belts). The first belt is the area with no possibility for dew utilization (covering 36.04%) and is situated between the Arabian Desert and hilly-mountainous area. The second one is characterized by medium possibility for dew utilization and covers the area of 2.66%, while the third one has high possibility for dew utilization and encompasses the area of 1.3%. The fourth and the largest belt in the Arabian Desert covers the area of 60.0%, and it has a very small possibility for dew utilization. Due to the pronounced climate change and urbanization impacts, the obtained grid in this study could be very useful in future calculations and estimations for potential of dew utilization and dew harvesting which can be used in agricultural sector. The findings of this preliminary research suggest that dew potential can be used as an alternative water source in some arid, semiarid, and mountainous areas of the UAE. Future investigations should be oriented toward the experimental methods for dew harvesting and possible installment of dew collectors in the theoretically identified dew belts in this study. Adaptation to climate change impacts, including reforms of existing short- and long-term policies, is of great importance when considering the implementation of sustainable and comprehensive water management policy. The grid obtained in this study could be very useful in future calculations and estimations for the potential of dew utilization and dew harvesting which can be used in agricultural sector. One of the imperatives for mankind lies in preparedness to find the most suitable way for better use of alternative water sources such as dew, especially in semiarid and arid areas such as the UAE. In the UAE, the volume of this water will be very small but it may be used like additional water for plants, particularly in mountain areas.

Declarations

Competing interests The authors declare no competing interests.

References

Abdelfattah MA (2013) Pedogenesis, land management and soil classification in hyper-arid environments: results and implications from a case study in the United Arab Emirates. Soil Use Manag 29: 279e294–279e294. https://doi.org/10.1111/sum.12031

Abrams M (2000) The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER): data products for the high spatial resolution imager on NASA's Terra platform. Int J Remote Sens 21: 847–859. https://doi.org/10.1080/014311600210326

Ahmed I, Nazzal Y, Zaidi FK (2017) Groundwater pollution risk mapping using modified DRASTIC model in parts of Hail region of Saudi Arabia. Environmental Engineering Research 23:84–91. https://doi.org/10.4491/eer.2017.072

Atashi N, Rahimi D, Goortani BM, Duplissy J, Vuollekoski H, Kulmala M, Vesala T, Hussein T (2019) Spatial and temporal investigation of dew potential based on long-term model simulations in Iran. Water 11:2463

Atkinson PM (2004) Spatially weighted supervised classification for remote sensing. Int J Appl Earth Obs Geoinf 5(4):277–291. https://doi.org/10.1016/j.jag.2004.07.006

Baghdady AR, Abu-Zeid MM (2002). Petrography, facies and framework of sedimentation of the Upper Cretaceous–Lower Tertiary sediments in Jabal Malaqet, west of the Northern Oman Mountains, United Arab Emirates. Middle East Research Center. Earth Science Series, vol. 16. Ain Shams University, pp. 1–15

Barbulescu A, Nazzal Y (2020) Statistical analysis of dust storms in the United Arab Emirates. Atmos Res 231:104669. https://doi.org/10.1016/j.atmosres.2019.104669

Beysens D (2016) Estimating dew yield worldwide from a few meteo data. Atmos Res 167:146–155. https://doi.org/10.1016/j.atmosres.2015.07.018

Beysens D (2018) Dew water. Rivers Publisher, Gistrup

Beysens D, Milimouk I, Nikolayev V, Muselli M, Marcillat J (2003) Using radiative cooling to condense atmospheric vapor: a study to improve water yield. J Hydrol 276:1–11. https://doi.org/10.1016/S0022-1694(03)00025-8

Beysens D, Muselli M, Nikolayev V, Narhe R, Milimouk I (2005) Measurement and modelling of dew in island, coastal and alpine area. Atmos Res 73:1–22. https://doi.org/10.1016/j.atmosres.2004.05.003Get

Blake A, S J, Sinclair TM, Teles V (2007) Tourism and poverty relief. Ann Tour Res 35:107–126. https://doi.org/10.1016/j.annals.2007.14013

Boegh E, Soegaard H, Hanan N, Kabat P, Lesch L (1999) A remote sensing study of the NDVI–Ts relationship and the transpiration from sparse vegetation in the Sahel based on high-resolution satellite data. Remote Sens Environ 69(3):224–240. https://doi.org/10.1016/S0034-4257(99)00025-5

Chaplin J, Brabyn L (2013) Using remote sensing and GIS to investigate the impacts of tourism on forest cover in the Annapurna Conservation Area, Nepal. Appl Geogr 43:159–168. https://doi.org/10.1016/j.apgeog.2013.06.008

Chowdhury R, Mohamed MAM, Murad A (2016) Variability of Extreme Hydro-Climate Parameters in the North-Eastern Region of United Arab Emirates. Procedia Engineering 154:639–644

Climate-data.org (https://en.climate-data.org/). Acceded on 08.19.2020

Climatological Data (2017) (http://www.wunderground.com). Acceded on 07.09.2020

Cooper PI (1969) The absorption of radiation in solar stills. Sol Energy 12:333–346. https://doi.org/10.1016/0038-092X(69)90047-4

Despotovic M, Nedic V, Despotovic D, Cvetanovic S (2015) Review and statistical analysis of different global solar radiation sunshine models. Renew Sust Energ Rev 52:1869–1880. https://doi.org/10.1016/j.rser.2015.08.035

Dong J, Wu L, Liu X, Li Z, Gao Y, Zhang Y, Yang O (2020) Estimation of daily dew point temperature by using bat algorithm optimization based extreme learning machine. Appl Therm Eng 165:114569. https://doi.org/10.1016/j.applthermaleng.2019.114569

Elhakeem A, Elshorbagy WE, AlNaser H, Dominguez F (2015) Downscaling global circulation model projections of climate change for the United Arab Emirates. J Water Resour Plan Manag 141: 04015007. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000507

Fathollahzadeh Attar N, Khalili K, Behmanesh J, Khanmohammadi N (2018) On the reliability of soft computing methods in the estimation of dew point temperature: The case of arid regions of Iran.

Comput Electron Agric 153:334–346. https://doi.org/10.1016/j.compag.2018.08.029
Gallacher DJ, Hill JP (2006) Effects of camel grazing on the ecology of small perennial plants in the Dubai (UAE) inland desert. J Arid Environ 66(4):738–750. https://doi.org/10.1016/j.jaridenv.2005.12.007
Gas S, Kusky T (2006) Lithological mapping in the Eastern Desert of Egypt, the Barramiya area, using Landsat thematic mapper (TM). J Afr Earth Sci 44:196–202. https://doi.org/10.1016/j.jafrearsci.2005.10.014
Hain CR, Crow WT, Anderson MC, Mecikalski JR (2012) An ensemble Kalman filter dual assimilation of thermal infrared and microwave satellite observations of soil moisture into the Noah land surface model. Water Resour Res 48:W11517. https://doi.org/10.1029/2011WR011268
Hubbard KG, Mahmood R, Carlson C (2003) Estimating daily dew point temperature for the northern great plains using maximum and minimum temperature. Agron J 95:323–328. https://doi.org/10.2134/agronj2003.3230
Hunting Geology, Geophysics Limited (1979). Report on a mineral survey of the UAE, Al Ain Area, vol. 9. Ministry of Petroleum and Minerals Resources, Abu Dhabi, pp. 1–29.
Ichii K, Kawabata A, Yamaguchi Y (2002) Global correlation analysis for NDVI and climatic variables and NDVI trends: 1982-1990. Int J Remote Sens 23(18):3873–3878. https://doi.org/10.1080/01431160110119416
Jacobs AFG, Nieveen JP (1995) Formation of dew and the drying process within crop canopies. Meteorol Appl 2:249–256. https://doi.org/10.1002/met.5060020308
Jia K, Wu B, Tian Y, Zeng Y, Li Q (2011) Vegetation classification method with biochemical composition estimated from remote sensing data. Int J Remote Sens 32(24):9307–9325. https://doi.org/10.1080/01431161.2011.554454
Jun C, Ban Y, Li S (2014) China: open access to Earth land-cover map. Nature 514:434–434
Jung LW. et al. (2011). ‘Paper or plastic? Clearing misconceptions on environmental impacts of coffee cups using life cycle assessment (LCA)’, International Conference on Water, Energy and Environment 563
Keblawy AA, Khedr AHA, Khafaga TA (2016) Mountainous landscape vegetation and species composition at Wadi Helo: A protected area in Hajar Mountains, UAE. Arid Land Res Manag 30(4):389–399. https://doi.org/10.1080/15324982.2015.1136970
Keuchel J, Naumann S, Heiler M, Siegmund A (2003) Automatic land cover analysis for Tenerife by supervised classification using remotely sensed data. Remote Sens Environ 86(4):530–541. https://doi.org/10.1016/S0034-4257(03)00130-5
Komuscu AU (2017) Long-term mean monthly temperatures trends of the United Arab Emirates. International Journal of Global Warming 11:1–22. https://doi.org/10.1504/IJGW.2017.080987
Lawrence MG (2005) The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air. A Simple Conversion and Applications Bulletin of the American Physical Society 86:225–233. https://doi.org/10.1175/BAMS-86-2-225
Lekouch I, Lekouch K, Muselli M, Mongruel A, Kabbachi et al (2012) Rooftop dew, fog and rain collection in southwest Morocco and predictive dew modeling using neural networks. J Hydrol 448-449:60–72. https://doi.org/10.1016/j.jhydrol.2012.04.004
Lim XY, Foo DCY, Raymond RT (2018) Pinch analysis for the planning of power generation sector in the United Arab Emirates: A climate-energy-water nexus study. J Clean Prod 180:11–19. https://doi.org/10.1016/j.jclepro.2018.01.158
Liu P (2021) Influence of GIS technology on coastal atmospheric climate and employee’s innovation intention. Arab J Geosci 14:477. https://doi.org/10.1007/s12517-021-06788-y
Lu D, Moran E, Batistella M (2003) Linear mixture model applied to Amazonian vegetation classification. Remote Sens Environ 87(4):456–469. https://doi.org/10.1016/j.rse.2002.06.001
Maestre-Valero JF, Martínez-Alvarez V, Martin-Gorriz B, Baille A (2011) Comparative analysis of two polyethylene foil materials for dew harvesting in a semi-arid climate. J Hydrol 410:84–91. https://doi.org/10.1016/j.jhydrol.2011.09.012
Mahmoud MT, Hamouda MA, Mohamed MM (2019) Spatiotemporal evaluation of the GPM satellite precipitation products over the United Arab Emirates. Atmos Res 219:200–212. https://doi.org/10.1016/j.atmosres.2018.12.029
Melgani F, Hashemy BAR, Taha SMR (2000) An explicit fuzzy supervised classification method for multispectral remote sensing images. IEEE Trans Geosci Remote Sens 38(1):87–295. https://doi.org/10.1109/36.823921
Milanović M, Tomić M, Perović V, Radovanović M, Mukherjee S, Jakšić D, Petrović M, Radovanović D (2017) Land degradation analysis of mine-impacted zone of Kolubara in Serbia. Environ Earth Sci 76:580. https://doi.org/10.1007/s12665-017-6896-y
Milanović MM, Micić T, Lukić T, Nenadović SS, Basarin B et al (2019) Application of Landsat-Derived NDVI in Monitoring and Assessment of Vegetation Cover Changes in Central Serbia. Carpathian Journal of Earth and Environmental Sciences 14:119–129. https://doi.org/10.26471/cjees/2019/014/064
Mortuza MR, Selmi S, Khudri MM, Ankur AK, Rahman MM (2014) Evaluation of temporal and spatial trends in relative humidity and dew point temperature in Bangladesh. Arab J Geosci 7:5037–5050. https://doi.org/10.1007/s12517-013-1139-3
Murad AA (2010) An Overview of conventional and Non-conventional Water Resources in Arid Region: Assessment and Constrains of the United Arab Emirates (UAE). Journal of Water Resource and Protection 2:181–190. https://doi.org/10.4236/jwarp.2010.22020
Muselli M, Beysens D, Marcillat J, Milimouk I, Nilsson T, Louche A (2002) Dew water collector for potable water in Ajaccio (Corsica Island, France). Atmos Res 64:297–312. https://doi.org/10.1016/S0169-8095(02)00100-XGet
Muselli M, Beysens D, Mileta M, Milimouk I (2009) Dew and rain water collection in the Dalmatian Coast, Croatia. Atmos Res 92:455–463. https://doi.org/10.1016/j.atmosres.2009.01.004
Naganna SR, Deka PC, Ghorbani MA, Biazar SM, Al-Ansari N, Yaseen ZM (2019) Dew Point Temperature Estimation: Application of Artificial Intelligence Model Integrated with Nature-Inspired Optimization Algorithms. Water 11(4):742. https://doi.org/10.3390/w11040742
Nazzal Y, Barbulescu A, Howari F, Yousef A, al-Taani AA, al Aydaroos F, Naseem M (2019) New insights on sand dust storm from historical records, UAE. Arab J Geosci 12:396. https://doi.org/10.1007/s12517-019-4555-1
Nikolayev V, Beysens D, Gioda A, Milimouk I, Katiushin E. et al. (1996). Water recovery from dew. J Hydrol 182:19–35. https://doi.org/10.1016/0022-1694(95)02939-7.
Nilsson T (1996) Initial experiments on dew collection in Sweden and Tanzania. Sol Energy Mater Sol Cells 40:23–32. https://doi.org/10.1016/0927-0248(95)00076-3
Onderka M, Pekárová P (2008) Retrieval of suspended particulate matter concentrations in the Danube River from Landsat ETM data. Sci Total Environ 397:238–243. https://doi.org/10.1016/j.scitotenv.2008.02.044
Ouarda TBMJ, Charron C, Niranjan Kumar K, Marpu PR, Ghedira H et al (2014) Evolution of the rainfall regime in the United Arab Emirates. J Hydrol 514:258–270. https://doi.org/10.1016/j.jhydrol.2014.04.032
Pedro MJ, Gillepsie TJ (1982) Estimating dew duration. II. Utilising standard weather station data. Agric Meteorol 25:297–310. https://doi.org/10.1016/0002-1571(81)90082-0

Protić D, Kilibarda M, Nestorov I (2012) Super resolution mapping of agricultural parcel boundaries based on localized partial unmixing. Geodetski List 89(4):259–271

Satchell JE (1978) Ecology and environment in the United Arab Emirates. J Arid Environ 1:201–226

Sharan G, Clus O, Singh S, Muselli M, Beysens D (2011) A very large dew and rain ridge collector in the Kutch area (Gujarat, India). J Hydrol 405:171–181. https://doi.org/10.1016/j.jhydrol.2011.05.019

Sherif M, Almulla M, Shetty A, Chowdhury RK (2014) Analysis of rainfall, PMP and drought in the United Arab Emirates. Int J Climatol 34:1318–1328. https://doi.org/10.1002/joc.3768

Shiri J, Kim S, Kisi O (2014) Estimation of daily dew point temperature using genetic programming and neural networks approaches. Hydrol Res 45(2):165–181

Takenaka N, Soda H, Sato K, Terada H, Suzue T, Bandow H, Maeda Y (2003) Difference in Amounts and Composition of Dew from Different Types of Dew Collectors. Water Air Soil Pollut 147:51–60. https://doi.org/10.1023/A:1024573405792

Tomaszkiewicz M, Abou Najm M, Beysens D, Alameddine I, El-Fadel M (2015) Dew as a sustainable non-conventional water resource: a critical review. Environ Rev 23:425–442. https://doi.org/10.1139/er-2015-0035

Valdes MC, Inamura M, Valera JDR, Ly Y (2006) Multidimensional filtering approaches for pre-processing thermal images. Multidim Syst Sign Process 17:299–325. https://doi.org/10.1007/s11045-006-0001-0

Valjarević A, Srećković-Batoćanin D, Valjarević D, Matović VA (2018a) GIS-based method for analysis of a better utilization of thermal-mineral springs in the municipality of Kursumlija (Serbia). Renew Sust Energ Rev 92:948–957. https://doi.org/10.1016/j.rser.2018.05.005

Valjarević A, Djekić T, Stevanović V, Ivanović R, Jandziković B (2018b) GIS Numerical and remote sensing analyses of forest changes in the Toplica region for the period of 1953-2013. Appl Geogr 92:131–139. https://doi.org/10.1016/j.apgeog.2018.01.016

Valjarević A, Filipović D, Valjarević D, Milanović M, Milošević S, Živić N, Lukić T (2020) GIS and remote sensing techniques for the estimation of dew volume in the Republic of Serbia. Meteorol Appl 27: e1930. https://doi.org/10.1002/met.1930

Vuollekoski H, Vogt M, Sinclair VA, Duplissy J, Järvinen H, Kyrö EM, Makkonen R, Petäjä T, Prisle NL, Räisänen P, Sipilä M, Ylhäisi J, Kulmala M (2015) Estimates of global dew collection potential on artificial surfaces. Hydrol Earth Syst Sci 19:601–613. https://doi.org/10.5194/hess-19-601-2015

Wan N (2015) Pesticides exposure modeling based on GIS and remote sensing land use data. Appl Geogr 56:99–106. https://doi.org/10.1016/j.apgeog.2014.11.012

Wang F (1990) Fuzzy supervised classification of remote sensing images. IEEE Trans Geosci Remote Sens 28(2):194–201. https://doi.org/10.1109/36.46698

Wehbe Y, Ghebreyesus D, Temimi M, Milewski A, Al MA (2017) Assessment of the consistency among global precipitation products over the United Arab Emirates. Journal of Hydrology: Regional Studies 12:122–135. https://doi.org/10.1016/j.ejrh.2017.05.002

Yang X, Richter M (2020) Experimental Investigation of Surface Phenomena on Quasi Nonporous and Porous Materials Near Dew Points of Pure Fluids and Their Mixtures. Ind Eng Chem Res 59(7): 3238–3251. https://doi.org/10.1021/acs.iecr.9b06753

Yilmaz AG, Shabib AG (2019) Rainfall and air temperature projections for Sharjah City, United Arab Emirates. International Journal of Water 13:60–79

Yin YL, Wang RZ, Zhai XQ, Ishugah TF (2013) Experimental investigation on the heat transfer performance and water condensation phenomenon of radiant cooling panels. Build Environ 71:15–23. https://doi.org/10.1016/j.buildenv.2013.09.016

Young SG, Tullis JA, Cothren A (2013) A remote sensing and GIS-assisted landscape epidemiology approach to West Nile virus. Appl Geogr 45:241–249. https://doi.org/10.1016/j.apgeog.2013.09.02

Zhong Y, Zhang L (2012) An Adaptive Artificial Immune Network for Supervised Classification of Multi-/Hyperspectral Remote Sensing Imagery. IEEE Trans Geosci Remote Sens 50(3):894–909. https://doi.org/10.1109/TGRS.2011.2162589

Zhu Q, Jiang Z (2016) Using stable isotopes to determine dew formation from atmospheric water vapor in soils in semiarid regions. Arab J Geosci 9:2. https://doi.org/10.1007/s12517-015-2093-z