Mapping palaeolakes in the Ténéré Desert of northeastern Niger using space-borne data for groundwater potential

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ABSTRACT

Groundwater resources in arid lands are crucial for supporting life. Thus, delineation of low land areas, where surface runoff accumulated during pluvial periods assists in groundwater explorations. Therefore, the drainage patterns in northeastern Niger using various sources of DEMs of optical (ASTER) and radar (SRTM) satellite data were extracted. These data reveal three palaeolakes in the Ténéré Desert. In addition, the DEMs together with the optical and radar satellite data were used to define a major watershed measuring 634,000 km². This watershed may have led to the formation of one major palaeolake as an ancestor of the three palaeolakes. The latter extend to 11,514 km², 17,571 km² and 18,453 km². The optical and radar satellites images show that the boundaries of these three lakes have been modified by extensive longitudinal and transverse sand dunes of considerable thickness. These dunes accumulated during a much later arid episode in geologic time, probably during the late Quaternary. Prior to that, the former marshlands received water from the Tibesti Mountains of northern Chad, the Ahaggar Plateau of southeastern Algeria and the Air Mountain of northern Niger. The drainage patterns clearly show the pathway of water down to the ground level. The longest drainage line is emanating from the Ahaggar Plateau and extends south west for 837 km. The water overflow of the southernmost lake led to the formation of another distinct drainage line, leading to the southwestern edge of the ancestral Megalake Chad. This drainage line begins in the vicinity of the town of Fachi and extends southward through the town of Dillia as a single tributary, and is here named the Dillia Palaeoriver. These observations, which are based on the study of satellite data require geophysical fieldwork to ascertain the interpretations, and evaluate the potential for groundwater accumulation in the region.

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1. Introduction

In arid and semi-arid regions, groundwater resources are crucial sources for life and economic development. Recent climate models predict an increase in aridity in the coming decades for most of Africa, among other regions (Dai, 2011). Thus, persistent droughts will likely cause water shortages, particularly in North Africa. Over the past forty years, Niger has experienced seven episodes of drought with dramatic consequences on agro-pastoral production, food security and socio-economic (African Development Bank, 2012). Meanwhile, the groundwater along within desert areas is considered as a good alternative resource, where the surface water is limited or totally absent. However, mining these fossil groundwater reserves should be considered in a planned manner by providing scientific information about the quantity and quality.

Meanwhile space-borne imaging using various electromagnetic wavelengths (visible, infrared and microwave) is an effective method for exploring large and inaccessible areas in a bird eye view by providing geomorphological, hydrological, and geological data. Radar remote sensing, in particular represents a valuable source of information to complement those imaged by visible and infrared sensors. Radar waves have the capability to penetrate dry sands and reveal information on the dielectric and geometric properties of the surface and near-surface. Many authors reported that space-borne SAR can penetrate the sand surface and show
hidden paleo-hydrological and tectonic structures, where the low frequency radar signal allows access to subsurface information down to a depth of a few meters (El-Baz, 1998; Paillou et al., 2003; Robinson et al., 2006; Gaber et al., 2015; Skonieczny et al., 2015; Paillou, 2017).

The land surface features of the Ténéré Desert of Niger represent an example of the vast dry eastern Sahara. It is known from previous studies that the Great Sahara hosted humid periods in the past. According to Tierney et al. (2017), the Great Sahara had 10 times the amount of rainfall as it receives nowadays. However, today rainfall in the Sahara ranges from 4 inches to less than 1 inch per year. The African humid period of the early Holocene to mid-Holocene fluctuated from abundant rainfall and rich biodiversity to dry conditions (Skinner and Poulsen, 2016). Six thousand years ago, the Great Sahara was green and covered by trees, lakes, rivers, savannah fauna, annual grasses and much rainfall (Jolly et al., 1998; Gasse, 2000; Drake et al., 2011; Boos and Korty, 2016). However, climate changes transformed the green region into dry lands (Tierney et al., 2017). This transition was related to a shift in the circulation of the tropical atmosphere (Boos and Korty, 2016).

Evidences that the Great Sahara was a wet region were presented in several studies, where researchers have discovered the existence of prehistoric megalakes and palaeorivers buried beneath the sand through the study of satellite images, including radar images (eg. Robinson et al., 2000; Ghoneim and El-Baz, 2007; Ghoneim et al., 2007; Gaber et al., 2009; Maxwell et al., 2010; Larrasoñá et al., 2013). At the present times the region has limited rainfalls and its land surface is reshaped by the prevailing wind (Fabre and Mainguet, 1991; Goudie, 2002; El-Baz, 1998; Brookfield, 2011). The wind affects the landforms in all climates, however, for significant effects, it needs to be strong enough to erode and transport sediments with the absence of vegetation cover (Shao, 2001). The region of northeastern Niger (Fig. 1) has been selected as an example of a non-vegetated and dry area of the eastern Sahara to reveal its ancient landforms using available satellite images.

The selected study region is considered one of the largest protected sanctuaries of Saharo-Sahliain wildlife areas in Africa. It covers over 7.7 million hectares, which include the Air mountains and a small Sahelian pocket (Lockwood et al., 2006). Most of the study area is covered by aeolian sand in the form of an undulating sand sheet (Warren, 1971). It comprises a vast plain of sand stretching from northeastern Niger into western Chad. The Air Mountain borders the area to the west. It is a triangular crystalline volcanic massif and sedimentary rocks ranging in age from the Precambrian to Cenozoic (Choubert et al., 1987). The Ahaggar, and the Tassili-in-Ajer Mountains bound the study area to the north. To the east, the area is bounded by the Tibesti massif of northern Chad (Fig. 1). The southeastern side of the study area is characterized by a concentration of sand sheets that were mapped by Mainguet and Callot (1978). There, the dunes are spatially oriented in longitudinal and transverse forms. The transverse sand dunes form the Erg of Bilma; which stretches southwest from Dillia and the Tibesti Mountains (Rossi and Marinangeli, 2004). Based on the study of the Niger geology by the British Geological Survey (BGS) and the U.S Geological Survey (USGS), the study area is dominated by the sedimentary Cretaceous-Tertiary-Chad Basin (Fig. 2) (Persits et al., 2002).

The northeastern part of Niger is an arid region with vast accumulations of sand. It is well known for its sand dunes and sand

![Fig. 1. SRTM topography, covering most of the eastern segment of Niger in North Africa. Study area is represented by the yellow box, while the black line is the political boundary of Niger.](image)
sheets, where at least 20% of its total surface area is covered by sand (Wilson, 1973). This condition is much like the rest of the deserts in North Africa, Arabia and Australia. These Lands lie between (15–30°N and 15–30°S), and are similar to those of mid-latitudes in central Asia, and the semi-arid great plains of North America. The formation and accumulation of sand seas and dunes are controlled by the amount of sand supply and the directions of the prevailing winds. In Niger, the wind pattern is basically from east to west, similar to the rest of the central Sahara (Mainguet and Callot, 1978). In Niger, the sand seas occur on all sides of the central uplands and move from the eastern to the central parts of the desert to form thick accumulation of sand (Mainguet and Chemin, 1983).

The purpose of this study is to utilize all available satellite images (optical, thermal, radar and DEMs) to map the surface and near-surface features in the area and define the paleodrainage patterns and their later covering by windblown sand. It is obvious that this region hosted a great amount of accumulated surface water runoff in the past, thus its geomorphology was totally different from its current situation.

2. Dataset and Methods

2.1. Characteristics of the used dataset

Satellite data were utilized in this study to extract the hydrogeological features and other water-related land surface properties. Several types of satellite-derived data were used for modeling runoff processes, locating recharge areas and predicting the water flow and accumulation regions. Satellite-derived products includes digital elevation models, landforms, geologic structures, surface lithology, rainfall distribution and rate, as well as surface temperature anomalies. The entire study area was mapped using satellite images from a variety of sensors with different spectral, spatial, and temporal characteristics.

For the optical data, the Landsat-8 and Sentinel-2 images were used. Landsat-8 was launched on February, 2013 as part of the Landsat Data Continuity Mission. It operates in two main sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI sensor uses nine spectral bands with 30 m spatial resolution and the panchromatic band with 15 m spatial resolution. While, the TIRS consist of two thermal bands, 10 and 11. These bands were collected at 100 m spatial resolution and resampled to 30 m. In addition, Sentinel-2 optical data were used for visual interpretation. The Sentinel-2 mission conducts monitoring by two satellites and provides high resolution optical imagery at 10, 20 and 60 m spatial resolutions. In the present study the bands 2, 3, 4 and 8 of Sentinel-2 with 10 m spatial resolution acquired in 2017 were used as well as the multispectral, thermal and panchromatic bands of Landsat-8 data acquired in 2016 and 2017.

In this study we used the DEMs produced by ASTER stereo images as well as by interferometric synthetic aperture radar (SAR) systems, such as the one produced by the Shuttle Radar Topography Mission (SRTM) flown in February 2000. ASTER stereo and STRM data allowed the production of seamless and consistent DEM mosaics of the entire study area at the scale 1:50,000. ASTER DEMs were produced at 15 m and averaged to 30 m. Although the original resolution of the SRTM DEM was 90 m, the data was processed at 30 m resolution. Both DEM data sets were used to extract basin morphometric parameters and evaluate their usefulness as input parameters in regional hydrologic models. For example, the
SRTM data reflect palaeotopography in the flat desert areas (Schaber et al., 1997; Robinson et al., 2006; Ghoneim and El-Baz, 2007; Elmahdy and Mohamed, 2013). The SRTM instrument consists of the Spaceborne Imagine Radar C-band (SIR-C) and has the capability to penetrate the well sorted and very dry sand sheets (Kobrick, 2006).

This data is one of the most widely used elevation product (Luedeling et al., 2007; Elmahdy, 2011). However flat regions present gaps in areas of low radar backscatter (Nikolakopoulos et al., 2006; Hirt et al., 2010). Another DEM was created from ASTER Global Terrain Model (ASTGTM), V2 (NASA JPL, 2013), to evaluate if the surface features differ from those in SRTM data. The improvements of these data include decrease in voids in areas that appear relatively flat by a new water detection algorithm, where the artifacts are mostly disappeared (ASTER, 2011).

Radar data allow mapping and characterizing surface and near-surface features such as palaeodrainage and fractures hidden by aeolian sand or fluvial deposits. It is an optimal sensor when used with multiple frequencies and polarization modes. We made ample use of the ALOS/PALSAR-1 and Sentinel-1 images with different frequencies (L- and C-band). Thus, to map the near-surface features, the L-band radar ALOS/PALSAR-1, data from Global Palsar-1/Palsar/JERS-1 mosaic with 25 m spatial resolution acquired in 2010 as well as the Sentinel-1 were used. These radar data are ortho and slope corrected for backscattering coefficient with horizontal and vertical polarization (HH and HV). Moreover, to identify the near-surface features, the Sentinel-1 radar data acquired in May 2017 with its C-band and dual polarization (VH and VV) from Copernicus (https://scihub.copernicus.eu/dhus/#/home) was utilized. Ancillary data included, geological maps, daily precipitation data from weather data from Tibesti meteorological station (in Chad) as well as the daily averages maps from Tropical Rainfall Measuring Mission (TRMM) data were used. In this work, the precipitation data were correlated with the thermal data.

Fig. 3. SRTM mosaic showing the basin and drainage patterns from the Ahaggar Mountain of southern Algeria, to the northwest and Djado plateau in the north, Tibesti Mountain to the east and the Air Mountain in the West. The three visible flat areas (A, B and C) could have been a large marsh during times of plentiful rainfall in the geological past. The total drainage may have led water to the straight segment in the bottom to the ancestral Megalake Chad. Sub-basins are marked in white lines. Yellow box shows the area of enlargement to the left, which indicates a promontory from a distinct drainage line in the Megalake Chad.
2.2. Processing

Digital elevation models (DEMs) of the SRTM and ASTER were created and transformed into the same projection, Universal Transverse Mercator (UTM), zone 32, WGS 1984 Datum to extract the surface drainages network. The models cover the study area and all of its watersheds. The elevation void fill function was applied to eliminate the voids in the data. These voids occur when no data were collected within the area represented by a pixel, mostly in flat level terrain. These voids need to be eliminated; otherwise they would affect the accuracy of the hydrological results, creating run-off interruption (Tarboton, 1997). After removing the voids, the eight directions model (D8), which was first introduced by O’Callaghan and Mark (1984), was performed. This algorithm determines the direction of flow from every cell in a given DEM assigning flow from each pixel to one of its eight neighbors, either adjacent or diagonal, in the direction with the steepest downward slope. This has been widely used to delineate drainage networks (Marks et al., 1984; Jenson and Dominque, 1988; Fairfield and Leymarie, 1991; Martz and Garbrecht, 1992; Costa-Cabral and Burges, 1994; Tarboton, 1997; Ghoneim and El-Baz, 2007; Ghoneim et al., 2002; Elmahdy and Mohamed, 2013). However using this widely used method in flat areas where gaps exist is a great challenge (Zhao et al., 2009).

Following the flow direction, the flow accumulation was calculated, which gives the flow as the accumulated weight of all cells flowing into each downslope cell. Basically, the value in each cell contains the sum of the amount of water that fell on all the raster
cells upstream from it. However, the flow accumulation performed in ArcGIS 10 presented a limitation, and did not work on both positive and negative values. This issue was resolved in the ArcGIS 10.1 version (Dilts, 2015). Streams were defined after the flow accumulation step, using a threshold of 5000 cells. These procedures were performed on both the SRTM and ASTER data. Both elevation data were chosen to compare the delineation of streams network. Drainages were slightly edited in the flat areas where streams lead to straight lines across lakes. Delineation of the borders of the palaeolakes was done where streams rimmed the edges of the palaeolakes along the same contour lines. These were manually filled at elevation of 414 and 457 m. amsl., which is the maximum elevation of the corresponding lakes. The resulting drainage network was overlaid on the other satellite data to validate the algorithm result. The main watershed was then delineated and vectorized for spatial analyses.

For visual interpretation and validation, optical and radar data were taken into consideration. In this context, Landsat-8 data provided visual details of the surface features, and thermal bands 10 and 11 were used to detect the anomalies. These bands were radiometrically calibrated using ENVI 5.3 version to obtain brightness temperatures. Several Landsat-8 scenes covering the study area were selected from January to December 2016, to examine the temperature behavior during a year and visually detect any anomaly. Moreover, Sentinel-2 optical data with 10 m spatial resolution were mosaicked to visually detect any different features and compare them with the Landsat-8 images. In addition, the radar data (ALOS/PALSAR-1 and Sentinel-1) of the entire study area were calibrated, filtered, geocoded and mosaicked for different polarization modes (HH, VV and HV). This was done to detect the near-surface features and the palaeolakes extensions, which are buried under the sand deposits and are not visible in other data.

3. Results

The generated topographic data from the DEMs (Fig. 3) show the routes of the drainage patterns from the higher (upstream) to the lower elevations (downstream). By comparing the obtained results using ASTER/DEM data with the SRTM/DEM, the SRTM data gave better hydrological results specialty in the flat areas. Previous comparisons reveal that the SRTM/DEM presented better vertical accuracy than the ASTER/DEM (Hensley et al., 2001; Fujisada et al., 2005; Slater et al., 2008; Forkuor and Maathuis, 2012). The main tributaries emanate from the Ahaggar and Tassili-in-Ajjer.
Mountains of southeastern Algeria at average elevation of 900 m, where the longest drainage line extends to the length of 837 km. Some tributaries emerge from the west at the Air Mountain, which is up to 1800 m high. Other tributaries emerge from the Tibesti Mountains of northern Chad, and Djado plateau and Murzuk basin of southern Libya. In the southernmost part of the drainage basin extends a singular drainage line, which is observed in both optical and radar satellite images. This distinct drainage line begins in the vicinity of the town of Fachi and extends southward as a single tributary. As it passes by the town of Dillia, it is here named the Dillia Palaeoriver. It further leads to the southwestern edge of the ancestral Mega Lake Chad (Fig. 4). This distinct drainage line must have been an important contributor to Lake Chad during rainy periods.

In addition, topographic data of the study area reveals the interruption of the drainage patterns in the southern part of Niger by considerably thick deposit of sand dunes. Because of the capability of radar data to penetrate the dry sand sheets, some channels were observed near the boundaries at the lower topographic areas (Fig. 5). Moreover, several drainage patterns emerge from Djado Plateau were revealed in radar data, but were not visible neither in the SRTM nor optical data (Fig. 5). Although the flat regions are covered by considerable amounts of sand, some promontories are visible in the satellite image data. For example the SRTM data show a delta deposit at the end of the drainage pattern leading to the lake (enlargement in Fig. 3).

The total watershed of the region, occupies an area of about 634,000 km², which corresponds to 25% of the entire Chad basin, which measures 2,454,081 km². It represents a major basin that must have led to the much larger sub-basin of Megalake Chad. The latter is one of the largest sedimentary basins in Africa and considered to overlay a large subsurface aquifer (Leblanc et al., 2007). The eastern boundaries of this sub-basin are dissected by the blown sand dunes deposits. These sand dunes have different shapes and thickness depending on the directions of the prevailing wind and the amount of available sands (Mainguet, 1978, 1984).

From the processed satellite images, it was possible to divide the basin into three sub-basins. The one in the northeast is pear-shaped and covers an area about 154,804 km². The basin in the north is considered the largest one and measures an area about 278,604 km² and it is also pear-shaped, but in the opposite direction. The basin in the south covers about 201,233 km² and is more irregular and not fully defined, due to sand dune accumulations. It is obvious that the sand dunes have completely masked the eastern boundaries of the three sub-basins. The flatness of the terrain at the end of the drainage patterns within the three sub-basins is clearly depicted in the satellite image data (Fig. 3). It is most appropriate to assume that these flat surfaces represent lake deposits from the drainage patterns. Therefore, it is conceivable that these flat and sand covered areas would have higher potential for groundwater accumulations, and are recommended for hydrogeophysical explorations.

In this study, a major basin of approximately 140,000 km² was defined, which today can be separated into three distinct palaeolakes. The southernmost part of these palaeolakes was the source of a single tributary (named Dillia Palaeoriver), which appears to have led to the south western edge of the former Megalake of Chad. The boundaries of these lakes have been modified by later events, particularly by the windblown deposits of thick sand dunes accumulation. The thickness of the sand dunes in the study area has been described by some researchers of the Sahara and the Sahel using the sand budget method (Mainguet and Chemin, 1983).
The study area ranges from the high altitudes of Ahaggar, Air and Djado plateau and Tibesti Mountains to flat areas, which includes the Kanem region that is characterized by sand dunes deposits in the form of transverse dunes reaching heights up to 60 m (Mainguet and Chemin, 1983). The northern side of the Kanem region is characterized by the prevalence of sand dunes and the absence of surface water (Vassolo, 2012).

4. Discussion

The obtained results clearly display the location of three distinct flat areas, which are interpreted as palaeolakes (Figs. 3 and 6). The one on the east (C) was fed from the Tibesti Maintains and the southern boundaries of Murzuk basin in Libya, and in part, from the terminal Ahaggar mountains. To the west of palaeolake C, lake (A) was fed by the major drainage patterns that emanated from the higher reaches of the Ahaggar mountains of southeastern Algeria. The southernmost lake (B) was fed by the Air Mountains of the central Niger. The eastern boundaries of the palaeolakes are not clearly visible because of the geologically younger sand deposits.

The total surface areas of these palaeolakes (A, B & C) are 11,514 km², 17,571 km² and 18,453 km², respectively. The largest is comparable to the lake Ontario in Canada, which is 18,960 Km². The generated cross sections show how relatively flat these palaeolakes are (Fig. 7). Palaeolakes A and B show a flat topography with some prominent depressions, including a straight one. The latter

Fig. 7. DEM topography showing the locations of the cross sections in red lines. Palaeolakes (A) and (B) show relatively flat areas with pronounced depression along the profile. In that major depression several villages are located close to groundwater resource. Palaeolake (C) presents relatively flat topography.
Fig. 8. SRTM data showing paleolakes A, B and C. Yellow boxes indicate the lowest areas within the flat lands. Note two main NW-SE faults dissecting Djado plateau that reach the northern part of palaeolake C.

Fig. 9. Landsat images showing sand dunes emanating from southwestern Tibesti Mountain of north Chad. Most dunes form are either longitudinal or transverse. Within areas of vast accumulation of sand crescentic dunes abound.
hosts several villages, most probably due to the accumulation of surface water in the rainy seasons. Palaeolakes B and C show a relative homogenous topography. Fig. 8 shows the palaeolakes flattest areas, with small lakes highlighted by yellow boxes. There are pronounced NW-SE faults, which extend from Djado Plateau. These have dissected the northern part of palaeolake C (Fig. 8).

Along the present study area nearly all forms of sand dunes occur, indicating multiple transport mechanisms of various amount of sand. The latter was produces by water erosion during pluvial periods of the past, when the region was closer to the equator and received greater amount of rainfall (Abdelkareem and El-Baz, 2015). When the climate changed to dry, the wind

Fig. 10. Enlargement of a Landsat image, showing the removal of sand due to occasional passage of water through the channel of the Dillia stream.

Fig. 11. Shows the connection between the identified three palaeolakes (A, B and C) and the lake of Chad through the Dillia stream.
began to transport the sand and modify the topography. The wind came from the northeast and became gradually westerly (El-Baz, 1998).

The most distinct sand field emanated from the Tibesti Mountains of northern Chad to form longitudinal dunes in parallel bundles. To the south of these linear forms, transverse dunes occur in great amounts. These dunes accumulation mask the eastern border of the three lakes, particularly C and B. In areas of flat topography, particularly at the edges of larger dune accumulations, crescentic dunes abound, some with clear barchans shapes (Fig. 9). Those in the way of drainage lines are modified or removed by the occasional water action (Fig. 10). Fig. 11 shows the connection between the identified three palaeolakes and the Mega lake of Chad through the Dillia stream.

Daily precipitation records were obtained from January to December 2016 using TRMM data as well as historical records from 2016. Fig. 12. Histogram showing the monthly average precipitation (inches) and temperature (Fahrenheit) from the Tibesti weather station in Chad (records of 2016).

![Histogram showing the monthly average precipitation (inches) and temperature (Fahrenheit) from the Tibesti weather station in Chad (records of 2016).](image)

Fig. 12. Histogram showing the monthly average precipitation (inches) and temperature (Fahrenheit) from the Tibesti weather station in Chad (records of 2016).

![Average monthly precipitation map is in inches, from TRMM, showing the dry period, which corresponds to the month of February and the wet season of the month of August (right). Temperature in Kelvin (bottom) showing the agreement with precipitation data for the months of February and August, dark blue areas (left) correspond to clouds.](image)

Fig. 13. Top: Average monthly precipitation map is in inches, from TRMM, showing the dry period, which corresponds to the month of February and the wet season of the month of August (right). Temperature in Kelvin (bottom) showing the agreement with precipitation data for the months of February and August, dark blue areas (left) correspond to clouds.
Tibesti weather station in Chad (Figs. 12 and 13). They show considerable rainfall fluctuation during the month of May, with a maximum average of 0.001290 inches, and in August, which reach 0.000645 inches. The remaining months are characterized by an absence of rain or negligible precipitation. Average temperatures show a minimum of 62°F for the month of January and a maximum average temperature of 97°F for the month of June (Fig. 12). Although the nearest climatological station to the study area was in Bilma, precipitation averages records from that station were not accurate and show higher temperatures than those recorded by Tibesti station. In contrast, precipitation averages from TRMM data show similar results to those of the Tibesti station. These indicate relative dryness during the month of February, while the most raining month is August (Fig. 12).

It is clear that the climate of Niger is variable, ranging from Saharan conditions in the northern half of the country to Sahelian climate in the south. The climate is characterized by two main seasons, the rainy period from June to September (although precipitation is relatively irregular), and the dry season from October to May. During the wet season the monsoon winds blow from the southwest to northeast dominating over most of the country. The dry season, however, is characterized by the harmattan, which is a hot and dry wind (UNICEF, 2010).

The obtained results using the thermal data show an agreement with the averages precipitation data within the study area. The hottest month is February, while May and August are the coolest months. In addition, the obtained thermal results reveal the effect of the sediments in the study area, based on their heat conductivity and thermal inertia.

5. Conclusions

The shortage of fresh water in the Great Sahara makes any contribution to the potential locations of areas for groundwater accumulation is of great importance. Several researchers continue to investigate the potential of water resources through the desert. It is assumed that groundwater must exist as accumulations from many years of wetter climate when climate of North Africa was milder.

In this study, three distinct palaeolakes were identified from satellite image data and were properly mapped. The southern boundaries of these former marshlands have been modified by thick deposits of sand dunes, which accumulated during the prevailing arid conditions. These former palaeolakes received surface water from the surrounding highland. The latter include the Tibesti Mountain of northern Chad, the Ahaggar Plateau and Tassili-in-Ajer of southeastern Algeria and the Air Mountain of northern Niger.

Water overflow of the southernmost lake led to the formation of a distinct drainage line named here Dillia Palaeoriver, which leads to the southwestern edge of the ancestral Megalake Chad. This stream would have contributed to increasing the level of water of the remnant Lake Chad during rainy seasons of the past. It must be stated, however, that these satellite images results require geophysical fieldwork to ascertain the interpretations as well as evaluate the potential of defining groundwater accumulation sites.

Precipitation and thermal data would need to be evaluated for a longer period of time to obtain more precise results; this is due to the fact that only records from one meteorological station were analyzed. Radar data revealed details in paleodrainage hidden and paleochannels in some areas. However, further analysis would have to be taken into consideration, because only C-band with two polarization direction (HH and VV) provided by sentinel-1 free data were analyzed. It is possible that longer wavelengths with different polarization would reveal more details due to the capability of radar data to penetrate sand surfaces.

This paper shows the benefits of using remote sensing data, both optical and radar, to map paleodrainage and palaeolakes over large arid and semi-arid areas. The identification of the new potential source of groundwater and near-surface water would benefit a large community that is in desperate need of water.

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