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Analytical Hierarchic Process in Conjunction with GIS for Identification of Suitable Sites for Water Harvesting in the Oasis Areas: Case Study of the Oasis Zone of Adrar, Northern Mauritania

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Abstract: The study area is located in the Adrar region of Northern Mauritania covering the main watersheds of Atar district (Wadi Seguelli) and Aoujeft district (Wadi Labiodh). The agricultural activities of palm trees and gardening under palm trees are the main economical activities in this region. The farmers depend directly on the water points at the Wadis alluviums for irrigation and water supply. Meanwhile, this sensitive resources are under the influences of sever natural conditions and increasing demand for agricultural use as well as for domestic use. All these have made the development of water resources one of the difficult challenges in this region. This study aims at identifying suitable sites for Water Harvesting (WH) in the arid zone of Northern Mauritania (oasis area) using Landsat imagery and GIS technology. The combinations of different thematic layers; prepared from remote sensing images and ancillary data, such as land cover, geology, slope, drainage, geomorphology and lineament, using weighted overlay technique permit an effective way for monitoring and planning natural resources. The suitability analysis results reflect the limitations of suitable areas, which are concentrated at the Wadis beds along the valley zone with 1.4% of excellent to high suitability.

Key words: Water harvesting, GIS and remote sensing, Oasis, Mauritania

INTRODUCTION

In the drier environment, most of the rainwater is lost by evaporation, therefore the rainwater productivity is extremely low (Oweis and Hachum, 2006). The efforts of development in the western African countries are mainly oriented to the semi-arid zone because of its agricultural and pastoral importance compared to the arid zone. This negligence of arid land productive areas will add more pressure on the semi arid zone and complicate its fragile environmental conditions and social problems. The study area is located in the Northern Mauritania and makes part of the north-western Africa desert, which is designated as oasis area since the agricultural activities are mainly concentrated in the oasis of palm trees along the Wadis of the region. The study area represents the most important reserve of date palm trees at the national level in terms of trees number and in terms of date fruit productions. This region has been suffering from sever droughts due to rainfall shortages and irregularity that resulted in the increase of sand dune movement and desertification. The sand dune movements are menacing the arable land of oasis and occupying large areas especially after the drought of late 1960s and 1980s. The frequencies of rainfall are varying within each 10 years by 2, 3.5 and 4 years cycles, which indicate a persistent drought in the region of Northern Mauritania (Ould Cherif Ahmed *et al*., 2006). Therefore, the need for taking counter measures for conserving and developing the endangered natural resources is urgent.

The development of water resources plays a central role in combating desertification and settling the peoples in their areas.

The usable water in the study area, in general, comes from two sources:

- The groundwater of the deep geologic layers: very much related to the tectonic accident presence mainly and its geographic placement near a source of recharge (i.e., Wadi).
- The water tables at the Wadis alluvium: the renewable resources because of its high capacity of storing the runoff after rainfall occurrences.

The groundwater quality is generally considered salty in most cases and its exploration cost is very high. In addition, in some locations water level falls down because of over pumping and the environmental problems, such as salinity, were complicated.

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The geologic structure of the Adrar region is composed of the infracambirian series in the north and North West and of the Cambro-Ordovician (cliffs series) in the East to the South. The cliffs series stand over the Infracambirian series by the intermediate of tillite. Appendix 1 explains the geological formation of the area.

Labiadh and Seguelli watersheds are mainly composed of the Cambro-Ordovician sandstone and Precambrian (limestones and sandstones) layers, respectively. The relief of the area gashes deeply by a dendritic drainage system, which are traced and oriented by tectonic accidents. The valleys are very narrow and constituted by fines alluviums more or less cemented over more coarse formations.

Conservation and development of water resources are important ways to reduce our impact on water resources and environment. Water Harvesting (WH) is a promising method for development of water resources especially in the arid environment where much pressure is exerted on the ground water. The use of suitable water harvesting techniques leads to increasing recharge of alluvium layers instead of runoff being left to cause erosion or evaporate from depressions surfaces.

Remote sensing with its spatial, spectral and temporal characteristics is a very useful tool for evaluation and monitoring the earth surface properties and its changes. In the land where the sites are inaccessible and large, the use of satellite images become a necessity and economically encouraging. The Geographical Information System (GIS) technology becomes a very important tool for monitoring and management in all fields including the environmental fields, because of its efficiency as a tool for collecting, storing, retrieving, transforming and displaying spatial and non spatial data (Padmavathy *et al*., 1993) (Appendix 1).

In this research we applied remote sensing and GIS technologies for monitoring the land surface characteristics in the watersheds of Wadi Labiadh and Seguelli in the oasis area of Northern Mauritania and we deployed the Analytical Hierarchic Process (AHP) in the attempt of identification of suitable sites for WH.

MATERIALS AND METHODS

The study area is located between 12.7° to 13.32° West and 19.88° to 21.02° North covering the two main watersheds of the Adrar region in the Northern Mauritanian arid land (Fig. 1). The Wadi Seguelli watershed of Atar district and Wadi Labiadh watershed of Aoujeft district are the most important farming areas in the Adrar region with a total surface of 455745.1 ha.

These oasis areas have been suffering from sand dune movement and water shortages as mentioned before especially after the droughts periods. Farmers depend on the shallow water tables for irrigation and drinking purposes. Therefore, the farming activities are very sensitive to the rainfall as the sole source of recharging water tables. Eighty five percent of Ardar oasis is located in this area where about 44% of the national date palm trees are being cultivated. The coverage of these trees in both watersheds was estimated to 814184 trees (Anonymous, 1993).

The Landsat images of Earth Observation System (EOS) at different periods were used in this research. EOS

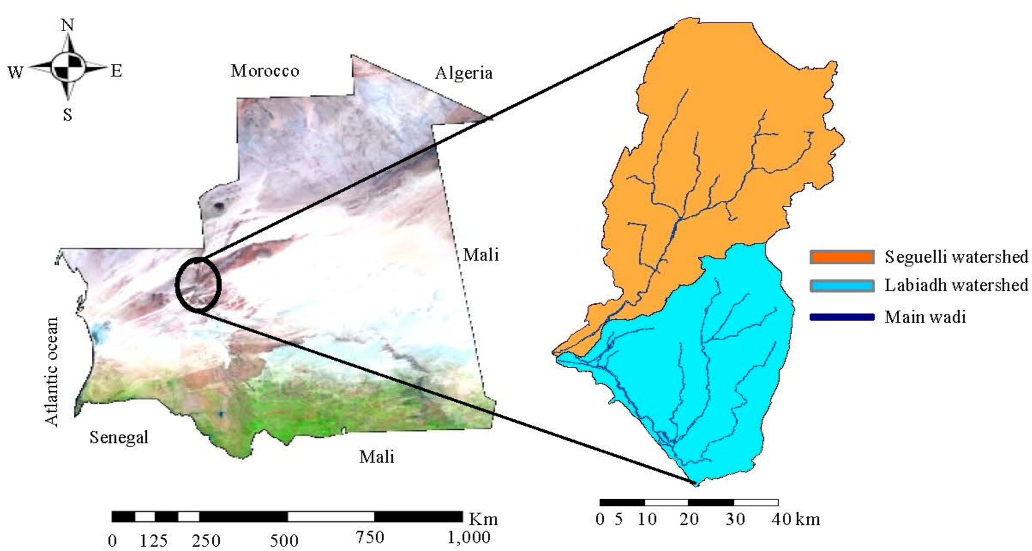

Fig. 1: Study area location map

Table 1: List of materials and data

Type of data	Details of data				Source of data
Topographic maps	Atar, Chenguetti, El Gleitat and Far Aoun sheets, 1974. (Scale 1: 200 000)				IGN (Institut Geaographique National) France.
Hydrogeologic maps	Atar and Chenguetti sheets, 1966 (Scale 1: 200 000)				IGN
	Landsat ETM+		SRTM		
	Scene	Date	Scene	Date	Earth Science Data Interface (ESDI) At GLCF (Global Land Cover Facilities) of NASA
	P203 r046	2001-12-13	p203 r046	2000	
	P204 r045	2000-12-01	p204 r046	2000	
	P204 r046	2000-12-01			
Ancillary Data	Reports of several studies in the region				Hydraulic ministry, studies Office...etc.

is one of the oldest sources of satellites images. Its data availability and the effectiveness of its spatial resolution for studying arid land area make it one of the best tools. Enhanced Thematic Mapper (ETM) of 2000-2001, was supplied by the Global Land Cover Facilities (GLCF). Also the Shutler Radar Thematic Mapper (SRTM) scenes of 90 m of 2000 mission were acquired from the same source. Other ancillary data such as topographic, hydrogeologic maps and several reports related to water resources of the study area were collected from different sources in Mauritania (Table 1).

This study was carried out during 2005-2006 on the development of arid environment.

The methodology of this study is shown schematically in the flowchart (Fig. 2) and divided into three main stages:

Stage one (data preparations): The ancillary and digital data were collected and prepared. The methodology adopted according to the available data and tools.

Stage two (data processing in erdas): Import of data to the ERDAS IMAGINE software, geometric correction (Projection: UTM, WGS84, Zone 28), mosaic of different digital images, demarcation and subset of study area images were conducted.

- Images classification.
- Digitization of the drainage network, lineament, geologic and geomorphologic maps was done using both satellite data (visual interpretation) and the cartographic maps.
- Correction of the Digital Elevation Model according to topographic maps of the study area.

Stage three: The different thematic maps were preceded in the ArcGIS software for the final analysis deploying the AHP method and weighted overlay method for WH suitable site identification.

AHP: The Analytical Hierarchical Process (AHP) developed by Saaty (1980 and 1995) allows managers to make simple comparisons of different criteria involved in a decision by producing a hierarchy. This method was selected because of its applicability in decisions involving multi-criteria. It uses both quantitative and qualitative data and the availability of ample literature describing its method.

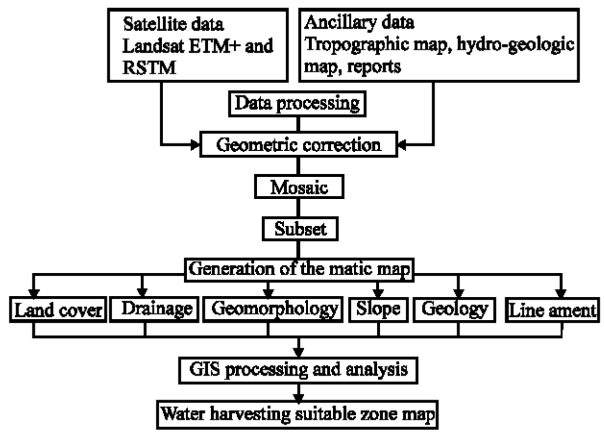

Fig. 2: Methodology flowchart

The AHP provides a system approach in conducting multi-criteria analysis and decision making and organizes the problem into smaller parts and calls for pairwise judgments to develop a hierarchy. This hierarchy is then manipulated analytically to produce a final matrix representing the overall priorities of the alternatives relative to each other using the fundamental input of the method is: The decision makers answers to a series of questions of the general form, 'how important is criterion A relative to criterion B? Questions can be easily answered using the nine-point scale and evaluating thematic layer classes in term of infiltration, perception, retention and storage for effective decision for WH. The results pair wise comparisons of the thematic layers are shown in Table 2.

Weighted overlay: Using the Saaty scale, explained above, the ranking of different parameters (thematic maps) and their classes were done based on the field knowledge and experts consultation. Table 2 shows the different

Table 2: Ranks of different layers classes

Geomorphology		Land cover		Slope		Lineament density		Drainage buffers		Geology	
R	Class	R	Class	R	Class	R	Class	R	Class	R	Class
7	Socle	5	Sand	9	0-2°	9	0.79-0.99	9	Order 6	9	Al
9	Valley	9	Vegetation	5	2°-12°	5	0.59-0.79	7	Order 5	8	i1, i3 and 19
2	Hills	3	Bare Soil	3	12°-28°	1	0.39-0.59	5	Order 4	5	i2, Co1-8 and Al Ancient
2	Cliffs	1	Urban	1	28°-57°	1	0.19-0.39	3	Order 3	3	i4,5,6,7, Sand and Socle
				1	57°-85°	1	0.00-0.19	1	Order 2	1	i8, i10, Co9-10 and Saline

R: Rank

Table 3: Weights of different composite maps

Composites	Layer	Weight*
Composite 1	Geology	0.50
	Geomorphology	0.50
Composite 2	Lineament	0.34
	Land cover	0.66
Composite 3	Drainage	0.80
	Slope	0.20
Composite 4	Composite 1	0.20
	Composite 2	0.40
	Composite 3	0.40

*Weight is the percent of the average value of the ranks gained after the pair wise combination. The values in Table 3 are normalized which mean they are divided by 100 so the total of one combination will be equal to 1

ranks assigned to different classes and Table 3 shows the weights of different combinations. In order to compute an effective weighted overlay authors Analyzed the reclassified thematic maps according to their ranks values and converted to raster type with a 28.5 m cell size.

The final map of WH (Composite 4) obtained and it reflects the zones according to their degree of suitability which vary from excellent to poor zone.

The spatial analysis tools (reclassification, conversion and overlay) vary depending on the experts decisions. However, the outputs from this method are more scientific and more reliable than the classical methods in term of time and costs.

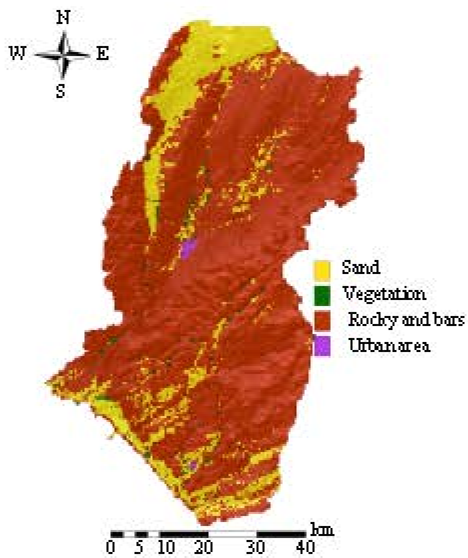

Fig. 3: Land cover map of 2000-01

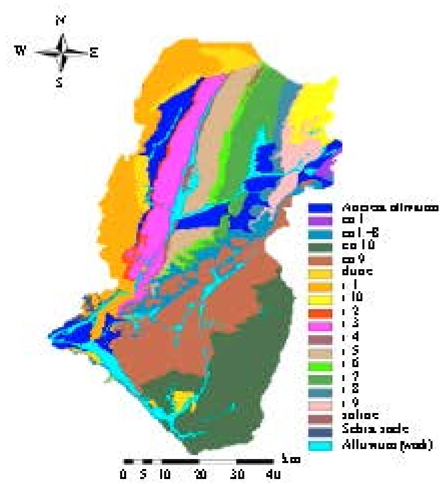

Fig. 4: Geologic map of study area

RESULTS AND DISCUSSION

Thematic layers: In such arid zone in developing countries the unavailability of adequate data usually is the most challenging point for researchers.

The economic factor also is of importance in any strategy for development in arid zones. Therefore; we tried in this research to exploit the available data, which can be found easily with minimum costs.

The delicate point in this analysis is the choices among the different layers regarding the identification of WH suitable sites. For that purposes we proceeded and analyzed each layer separately according to its suitability as shown in the Table 3. For example the land cover map of Landsat was classified; using supervised classification, into four broad classes as shown in Fig. 3 and ranked for analysis from the most suitable (vegetation) to least suitable (urban area). Prinz *et al*. (1998) proved that vegetation contributes in the increase of rainfall interception, retention and infiltration rates in the semi-arid zone of Syria. The geological formations (Fig. 4) are of importance regarding the hydraulic characteristics of the layers such as storage capacity.

The hydrological map used for the digitization of geologic layers of the study area and the ranking of their suitability carried out according to the pervious results of drilling wells and geophysical investigation in the region. The drainage network play important role for recharging the alluviums of Wadis beds and subsurface layers. The water points in this area are mostly located at the area of drains because of its geological setting and its hydraulic properties. Therefore, it is one of the most criteria for WH analysis. The topographic maps were the base map for digitizing its repartition and further modification using Landsat images to update the drains location and buffers around the drains, which were created to preserve the real widths of the streams. The system is dendritic in both watersheds and the main drains of order 6 are Wadi Sueguelli and Wadi Labiadh (Fig. 5). Higher the value of drain order indicates higher suitability for WH and here we neglected the order 1 drains to facilitate the analysis. The geomorphology helps in reducing the suitability of areas located in high altitudes (i.e., hills and cliffs) and gives the priority to the valley area, which represents the most suitable sites for harvesting runoff. By visual interpretation of satellite images in conjunction with topographic maps we divided the morphology of the study area into the following units as shown in Fig. 6:

- **The socle or peneplain:** The crystalline socle zone of Amsaga occupying small part in the West of the study area with altitudes of around 100 m.
- **The Hills (Baten zone):** With elevations of more than 100 m and is located in the Northern part.
- **The Cliffs (Dhar zone):** Located in the East of the study area with the dominant altitude from 300 to 900 m.
- **The valley:** Occupy the area between cliffs and following the tectonic accident directions making narrow drains in the area.

The lineaments were identified by a visual interpretation of Landsat images by taking the previous works into consideration as illustrated in the hydrogeologic and topographic maps. The distribution of lineaments shows a general trend of N-W direction in south (wadi Labiadh), N-S in the north (wadi Seguelli) and N-E in the east (Souiguiyat). The most important regional lineaments follow the stream courses of the main wadis (Wadi Seguelli, Labiadh and Soueguiyat). The lineaments density map (Fig. 7) prepared by ArcMap spatial analyst function shows the classified density and high density is considered of high suitability for WH. Thus, generally

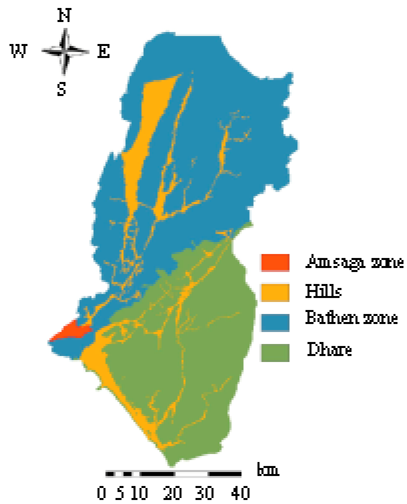

Fig. 5: Drainage map with stream order

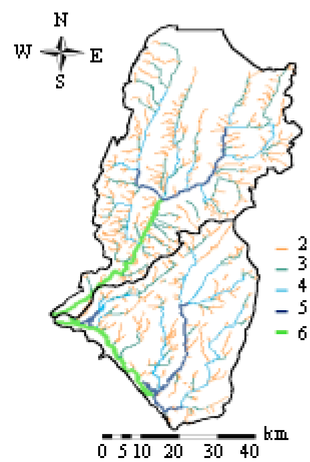

Fig. 6: Geomorphologic units map

lineaments are underlain by zones of focalized weathering and increased permeability and porosity (Gyoo-Bum *et al*., 2004).

The slope map (Fig. 8) was generated from the 90 m Digital Elevation Model (DEM) obtained by SRTM and corrected according to the topographic maps. Subsequently the slope map was classified into the following five broad classes: Level: 0-2°, Gentle: 2-12°, Moderate: 12-28°, Steep slope: 28-57° and Very steep: 57-85°. For our analysis smaller the slope value is considered as more suitable.

The drainage system, land cover and lineament distribution represent the most important factors as they serve the runoff courses and indicators for water availability. On the other hand the alluvium and other

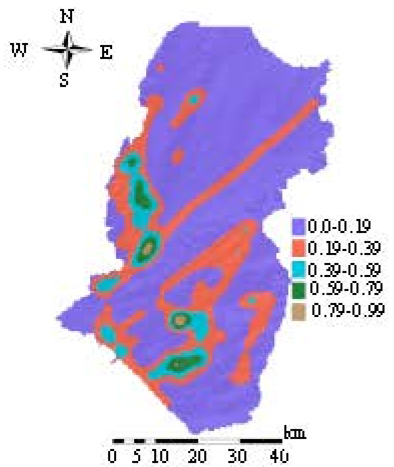

Fig. 7: Lineaments density

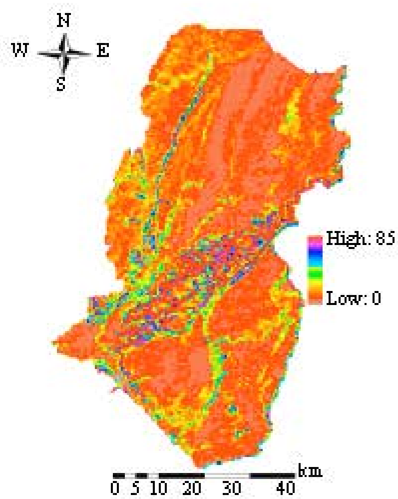

Fig. 8: Slopes degrees map

productive geologic formation serve as reservoir for water if their emplacement is located at important drain with low altitude, low slope and high lineaments density. Hopefully using a similar, easy to collect, data the planning of WH can easily carried out in the arid land areas using the described approach.

The suitable areas as shown in Fig. 9 generally located at the valley zone and following the drains courses. Therefore, the oasis farms can be developed by harvesting rainwater passing nearby.

The harvested water can be used for Supplementary Irrigation (SI) and water supply or for the preservation of vegetation in the desert area.

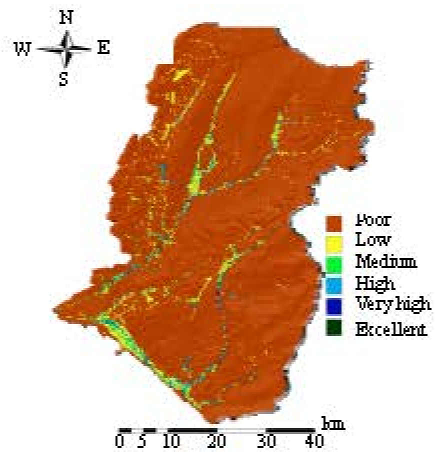

Fig. 9: Water harvesting suitability map

CONCLUSIONS AND RECOMMENDATION

In this study different thematic maps were prepared by updating existing ones while other maps, such as lineament density, drainage buffers and land cover, were created for the first time for the study area and deployed with others for analysis. The suitable sites for WH vary from excellent to poor locations according to the overlay output. The results reflect the limitation of suitable zone with a 92.8% of poor areas, 5.7% low to medium and around 1.4% of high to excellent suitability areas. These results are very logic considering the geological setting and natural conditions of the study area. The effectiveness of AHP in combination with GIS for analyzing the site suitability for WH in dry land is proved and the check dam technique seems the most suitable considering the physical characteristics of the study area and the availability of construction materials locally.

The necessity of developing and conserving water resources in such hyper arid zones with water scarcity is evident. However, the use of new techniques and introduction of scientific approach are more advantageous.

Hopefully, the presented method can help for planning and management of water resources especially when the data are limited and the area is wider or isolated.

ACKNOWLEDGMENT

We would like to thank GLCF for providing satellites images and all professors and colleagues who contributed to this research.

Appendix 1: Details of the study area geological formation

Era	Symbol	Formation's name	Characteristics
Lower Precambrian	Schist socle	Amssaga	Crystalline socle
	I1	Aguenni's Sandstone	Hard quartzite limestone with schistose basement
	I2	Azougui's Schist	Colored schist with dolomites intercalation.
	I3	Foum Chor's Sandstone	White quartzite sandstone
	I4	Ksar Torchane's Schist, Pelite, Dolomy, Limestone	Varied litholgy
	I5	Atar's Limestone	Dolometic limestones with silex and stramatolite
	I6	Tarioufet's Schist, Sandstone and Limestone	Dominated by pelites
	I7	Tawaz's Limestone	Dolometic limestones with stromatolites
	I8	Oued Terraritt's clays sandstone	Clayed layer with intercalation of thin micaceous
	I9	Toueiderguilt's Limestones	Dolometic limestones with stromatolites
	I10	Group of Assabet El Hassian siltstones.	Quartzite sandstones, fine sandstones, argillite
Cambro- Ordovician	CO1	Agmeminat's Limestones	Tillite
	CO1-8	Cambro-Ordovician basement formation	Fine sandstones, pelites, clayed sandstones and silex
	CO9	Chenguetti's sandstones	Quartzite sandstones
	CO10	Aoujeft's sandstones sandstones	Quartzite sandstones and feldspatic clayed
Quaternary	Dune	Sand	Sand and sand dune
	Ancient Al	Ancient Alluviums	Rocky, clayed, saline alluviums
	Al	Alluviums	Rocky and sandy deposits.
	Saline	Sebkha	Saline deposits

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