Assessment of Salt weathering in Siwa Oasis

(The Western Desert of Egypt)

By

Azza Abdallah

Department of geography
Faculty of Arts
Benha University

Bull. De la soc. De Geog. De Egypt, 2007

Assessment of Salt weathering in Siwa Oasis (The Western Desert of Egypt)

Azza Abdallah

Abstract:

Salt weathering is a negative aspect that causes marked deterioration and hazards in Siwa Oasis. Salt weathering primarily results from both mechanical and chemical deterioration of rocks. In recent years many parts of Siwa Oasis have suffered immensely from salt weathering activities such as archaeological sites, roads, cultivated and urban areas. Human activities are a main cause for secondary salinization particularly in the last decades as a result of unplanned development programs. LAND SAT- TM, SPOT, IKONOS and QUIKBIRD images in addition to GIS techniques were apply to record the varying degrees of development of salt weathering. They were used to detect, analyze and assess the negative environmental features of salt weathering. Cartographic representation of this feature was produced from multi-dates data, digital maps and field investigation. A comprehensive map of such hazards is produced and represents a contribution in this connection.

Introduction:

Siwa Oasis is located in the Western Desert of Egypt. The study area is bounded by the zero contour line, laying between latitude 29° 16′ 33″ and 25°06′ 32″ N. and longitudes 25° 48′ 15″ and 25° 17′ 36″ E. with a total area of about 408.5km^2 . Siwa Oasis has a length of about 49.9 kms and width varying between 0.6 km and 13.33 kms. (Fig.1 and Plate).

This paper is targeted to define and assess environmental deterioration consequences due to salt weathering activities. Monitoring the detected changes by applying different techniques through time, represent the main objectives in the production of the "hazard map" which identifies the overall effects of salt weathering in Siwa Oasis.

Methodology:

The following data and GIS tools were applied to achieve the overall aims of this study:

1- Maps:
  * The topographic sheets (scale 1: 25000) produced in 1933 (Egyptian Survey Authority, 1933).
  * The geological map (scale 1: 100000) (CONCO, 1998).

Both maps were used after the conversion into digital format which allowed studying the topographic and geological settings of the study area and explaining the factors lying behind salt weathering activities.

2- Remote sensing data:

* The LANDSAT – TM dated 2002 (14.5m resolution).
* SPOT dated 1998 (10m resolution).
* IKONOS dated 2005 (4m resolution).
* QUIKBIRD dated 2005 (60cm. resolution).

All the above mentioned data were applied to detect and study the recorded changes out lined in the "hazard map".

3- The Field study:

Culminated into verifying and documenting the complied data relevant to the negative side effects of salt weathering.

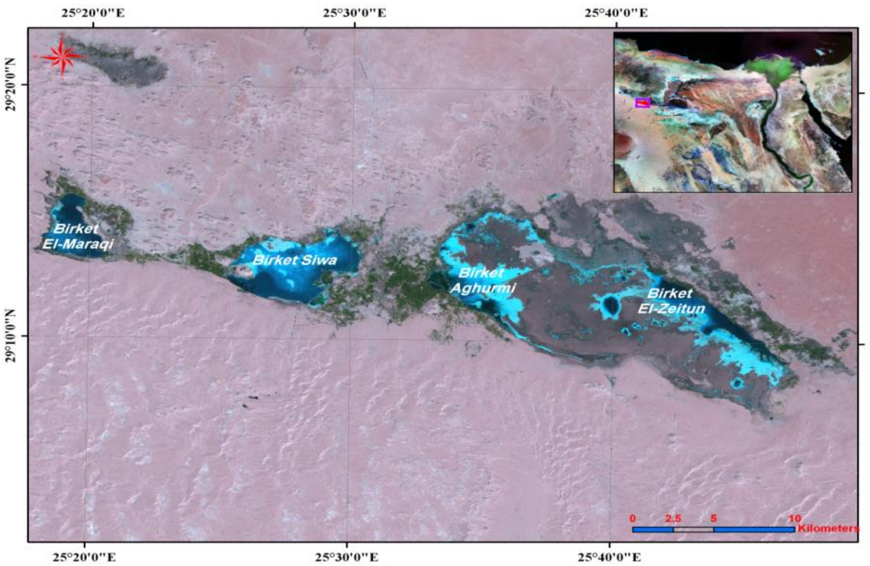

Figure (1): location of Siwa Oasis

The Data processing and techniques are used in this study are:

1. Automation of topographic and geological maps through conversion into digital format using Arc GIS V.9.1 program.
2. Digital image processing and techniques use ERDAS IMAGINE V.8.7 program in atmospheric correction, georeference with enhancement and ARCGIS V. 9.1 program to produce the "hazard map" and to assess the changes in the study area. (Burrough &McDonnell, 1998), (McCoy and Johnston, 2001).

The Interpretation of Results:

The field study and satellite images show the rapid activity of salt weathering processes and their negative effects on natural resource habitats in Siwa Oasis. The summing up of the basic elements of this scientific endeavor is as follows:

1-Physical and anthropogenic controls of salt weathering activities:

The high activity of salt weathering in Siwa Oasis are attributed to climatic conditions, geological and Geomorphological factors, the hydrogeomorphological characteristic of ground water and negative anthropogenic effects.

* Climatic conditions:

The main air temperature in January is 5.8^0c and in July is 37.8°C. The diurnal range is 32°C. The maximum mean soil temperature at 5cm depth is 32.8°C. Precipitation is precarious and variable 0.87mm/month and evaporation ranges between 4.8 to 13.5mm /day. (Fig.2). Contemporaneously, air temperature records its maximum value and rainfall drops to nothing ceases to excess and consequently evaporation becomes extreme and responsible for the formation of the salty layer in the soil profile with a marked decrease in sub-soil water level.

There are three principal directions of wind namely NW, NE and SE having general ratios of 24.4%, 18.2% and 12.4% respectively. The effect of wind (deflation and erosion) is the highest in April. Wind transport the loose sand and salt particles depositing them in sequence in the lower contour topographic areas within the Oasis. This will affect the impermeable layer by soil erosion in such a manner that the wind speed carries the soil matrix away causing decrease in the soil profile and consequently raising in the ground watertable.

Generally, high temperature, meager rainfall, high evaporation and evaspiration enhance the capillary rise of water to the surface sediments bringing about a concentration of salt crystals in soil surface causing the acceleration of salt weathering activities.

* Geological Factors:

Siwa Oasis is geologically composed of sediments belonging to both Tertraiy and Quaternary. The Tertraiy limestone outcrops belong to the middle Miocene, which is underlain by the lower cretaceous sandstone series. Quaternary deposits are characterized by the soil zone associations and consist of fluviatile sequences dominated by unconsolidated gravel, coarse to fine sands and terminated by mud and

Clay lenses. The Tertraiy rocks consist of sandy, marly, fossiliferous limestone, shale and sandstone. (El Gindy & El Askary, 1969).

According to laboratory study the limestone and sandstones are the most susceptible to attack by salt weathering. (Cooke,et al., 1982 and Pompo, 1999).

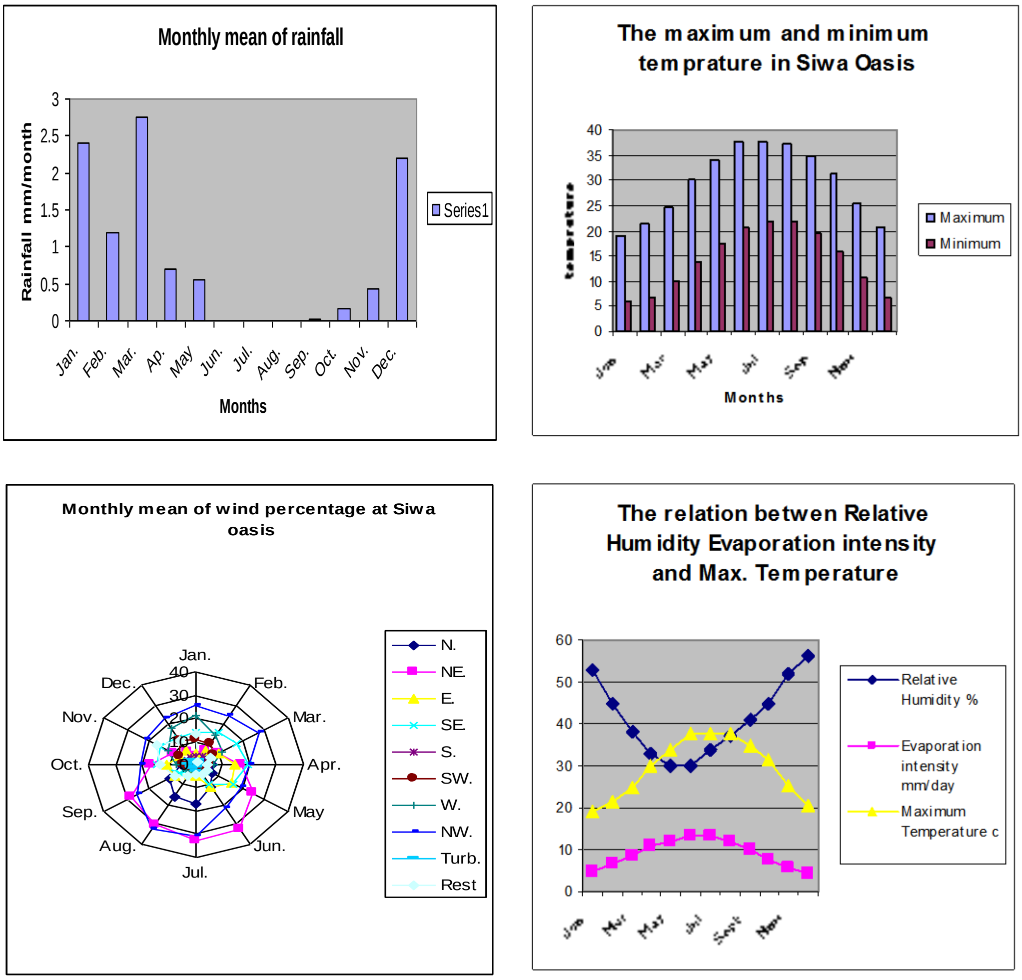

Figure (2): Climatic conditions in Siwa Oasis

* Geomorphological Factors:

The topographic map indicate that the surface level ranges between – 18m b.s.l. and zero. The Oasis is bounded in the south by a discontinuous escarpment partly hidden below a sand sheet cover, whilst the northern edge rises up to (120 m). There are some outlier scattered in Siwa Oasis such as G. Siwa (38m) , G. El kosha (Plate2) , Qaret khamsia , G. El Takrur (88m) and G. El Mota (Embabi, 2004). The Oasis is covered by a variety of aeolian sands and sabkhas. The most important landforms in Siwa Oasis are the saline lakes (Birket) e.g., Zeitun, Aghurmi, Siwa and Maraqi (Plate3). Around the saline lakes spread marshes, salinas and sabkhas (Fig. 3). The cultivated lands (Hatiat) are presents in Siwa, Aghormi, Khemisa, and Maraqi exist at variable levels from the floor of the Oasis. The difference in elevation between cultivated lands and the lakes controls the depth of the drainage water and consequently plays a vital part in the logging problem and the low lands suitable for the capillary rise of saline water and the concentration of salt crystals in the upper part of the soil profile.

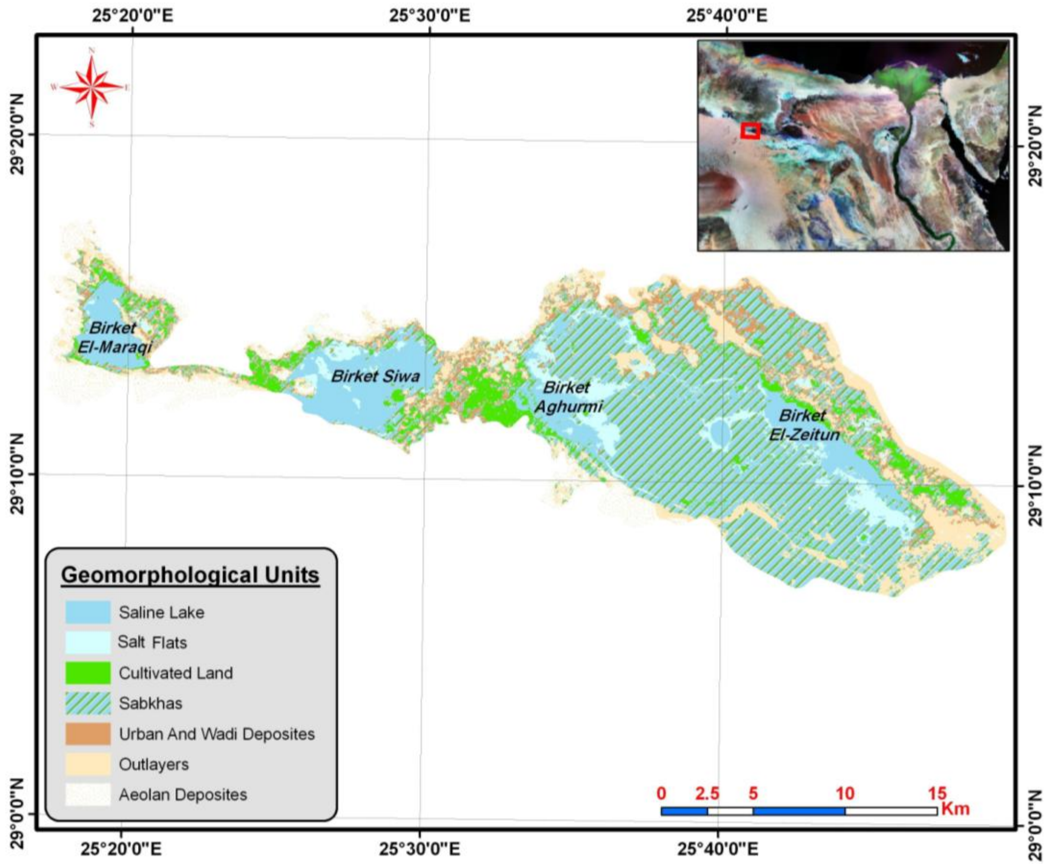

Figure (3): The Geomorphological map of Siwa Oasis

* The hydrogeomorphological characteristic of ground water:

The underground water system consists of two water bearing units. The first the deepest is the Nubia sandstone aquifer system. Salinity increases downward from 400 ppm to 55000 ppm. The second is the Middle Miocene limestone aquifer, with a salinity ranging between 1500 ppm to 7000 ppm. Uncontrolled irrigation periods cause the pooling feature of the un-seeped quantities in the soil leading to salt accumulation and salt weathering. (Abdel-Mogeeth, 1996).

The depth of soil water ranges also between 0.08 to 2.78m during winter and from 0.22 to 3.17m during the summer. The average annual rising in the soil-water of the cultivated low land areas reaches 3.6

cm/year. The general trend of soil-water movement is towards the natural drainage system from all directions and particularly from the south (Gad, 1999).

The shallow depth of soil-water leads to quick capillary rise of water in the soil profile surface and leads to the concentration of salt crystals thus forming salt flats, salinas and sabkhas due to over evaporation.

* Negative anthropogenic effects:

Water budget analysis of the saturated soil zone show that the total annual discharge from the Middle Miocene formation approaches 240 millions cubic meters and 15 millions cubic meters from the lower Cretaceous with a total annual discharge of the order of 225 million cubic meters. Over 98% of the annual discharge will be lost by evaporation and evaspiration. The annual surplus in 1997 was estimated by some 33million cubic meters mainly flowing into lakes thus expanding the expanse of saline water causing the formation of marshes, shallow water bodies, water logging and soil salinization (Gad, 1999).

Population increase in urban areas also causes a marked rise in groundwater level. This and enhances the effects of moisture lost by evaporation thus enhancing the effects of moisture lost aggravating salinization. Leakages from water pipes and sewers have also led to a substantial rise in the groundwater level and many building have been attacked by sulphate and chloride-rich water (Goudie, 2003).

2-Processes of salt weathering:

The previous studies, field and laboratory investigations define the salt weathering processes as follow:

* Growth of salt crystals:

Salt crystallization has been accepted as effective weathering process and is notably illustrated by the widespread occurrence of ground heaving associated with the development of salt polygons. (Cooke,et al., 1982). Laboratory studies have confirmed field observations pertaining to rock splitting and disintegration can be caused by salt crystal pressure growth in confined areas thus supporting the view of being the most important salt weathering process. (Plate4). Laboratory studies indicated that limestone and sandstone are the most susceptible to this form of attack (Aachen Univ. of Technology, 2005).

The effect of this process depended on climate, location, water absorption capacity, porosity and micro porosity, surface texture and the concentration and combination of salts present (Pombo , 1999). This process is effective in Siwa Oasis due to the wide diurnal temperature range and over evaporation.

*** Thermal expansion of salt crystals:**

The expansion of salt crystals when heated depends on thermal properties of the salts and the temperature range to which they are subjected. In Siwa oasis diurnal air temperature exceeds of 32°C, ground surface temperatures are higher than air temperatures during the day, for instance, a salt such as (NaCl) could expand by up to (1%) during a diurnal cycle and produce stresses which together with those created through the differential thermal expansion of the rock itself, might induce in conceivably further cracking and splitting. (Plate5).Rock flaking also attributed to thermal expansion of salt crystals in micro cracks on rock surface (Holmer, 1998).

Laboratory studies show that the effects of thermal expansion in sandstone and limestone are highly affected. The experiments also show that the amount of debris increase considerably after heating and cooling cycles with a marked increase in sandstones block which is between four and five times more debris than in limestone blocks (Smith, 2005).

*** Salt hydration:**

Disruptive stresses are generated by the hydration of anhydrous salts under day time temperature and humidity. The mechanism of hydration and dehydration is a complex process and depends on atmospheric relative humidity, temperature conditions and effect of vapor pressures on salt concentration. There conditions may lead to rock disruption by hydration:

a- The hydration process should take place for at least 12 hours.
b- The hydrated salt must be confined able to the pore which contains it.
c- Hydration pressure must exceed the tension strength of the rock. (Smith, et al., 2005).

The cyclic nature of salt hydration and dehydration causes differential stress within the rock which eventually leads to rock failure and spalling. (Mason,et al.,2004).

3-Features of rock decomposition by salt weathering processes:

The Field study has showing eight types of rock decaying due to salt weathering processes:

*** Efflorescence:**

Efflorescence formed by salt weathering when rising from groundwater containing salts moving up ward through stone fabrics. The crystallization of the salt at and near the surface can eventually result in granular disintegration of the stone (Plate 6) (Glossary of stone decay features, 2005).

*** Flowstone:**

Where water is allowed to percolate through the stonework and it often does so by following the porous network of mortared joints, where the moisture eventually leaks out of the stonework it can thus precipitating any dissolved material.

*** Granular disintegration:**

This occurs in granular sandstone, the cement holding the grains together is weakened by solution or where salts crystallizes in pores to enforce individual grains to part (Plate 6).

*** Tafoni:**

This large cave in rocks was found by salt weathering. It is formed in rock surface containing small pits, disintegrates by salt crystallization during wetting / drying cycles the amount of salt deposited at the grid nodes is evaluated and the shape of the rock surface is adjusted by removing nodes. As a result most damage will develop at these parts of the surface (Plate 6) (Huinink &kopinga, 2004).

*** Black crust:**

These form where gypsum (calcium sulphate) crystallizes on a surface in a polluted environment. As it does so it can incorporate pollution particles that give the deposit its characteristic blackness, indicating fermentation and/or oxidation of the living forms. Crusts form on limestones where the calcium carbonate can be transformed into gypsum in a sulphate-rich atmosphere.

*** Grey crust:**

These may simply represent an early stage in the development of a black gypsum crust. Some experiments have shown that these thinner crusts can form as a relatively dense surface covering the contrasts the surface with subsequent black crusts that tend to have an open structure of interlocking. (Plate 7) (Ibid, 2005).

*** Flaking:**

Thermal expansion of salt crystals in micro cracks on rock surface is the main process causing flaking (Holmer, 1998). Also flaking is associated with repeated shallow wetting and drying processes, e.g. the condensation of over night dew.

*** Rock breakdown:**

Whenever salt weathering takes place through salt crystal growth in rock pores and/or through hydration of hydrate forming salts, like sodium sulphate, the expanding salt crystals exert a pressure on the walls of the rock pores that exceeds the tensile strength of the rock (Kwaad, 2002).

4-Environmental Changes by salt weathering:

The multi data were used to detect the environmental changes in the total surface area of saline lakes and associated forms of it such as marshes salinas and sabkhas (salt flats) during the period 1933-2002 (Fig. 4).

The total surface area of saline lakes in 1933 is 62.97 Km^2, where it decreases to 52.31 Km^2 in 2002. The total surface area of marshes, salinas and sabkhas around the saline lakes increases form 30.78 Km^2 in 1933 up to 51.33Km^2 in 2002. The total surface area of the salt flats changed by 20.55Km^2 representing 5.3 % of the total surface area of the Oasis.

The results of detected changes in the study area explains the rapid increase of salt flats area, high activity of salt weathering processes and increasing its hazards, where it threatens cultivated lands, roads, archaeological sites and urban areas.

5- Salt weathering hazards:

Salt weathering activity spatially variable in Siwa Oasis. It is threatening many sites suffering damages of salt weathering and can be explain as follow:

*Buildings:

The most remarkable landscapes features in the Oasis represented in the saline lakes surrounded by marshes then by salinas and at the outer margins by sabkhas occupying the lowest parts formulating the probable source for "Korshf" which is the local building material. However, during rainy storms, this crust becomes very weak since salt is dissolved by rain water. (Embabi,2004). By this action and by salt weathering activities houses were destroyed several times during the long history of Siwa (Plate 8).

*Roads:

Surfaced roads in Siwa oasis show signs of damage as falling downs in terms of cracking, potholing, scabbing, stripping, crumbling and disintegration. This damage is apparent because saline ground water is near the surface, some roads crossing the saline lakes (Fig.5 and Plate 9) Such as the middle road crossing Lake Aghurmi, lake El Zeitun, and abundant soluble salts occur on the ground surface and in the soil. (Plate 10).

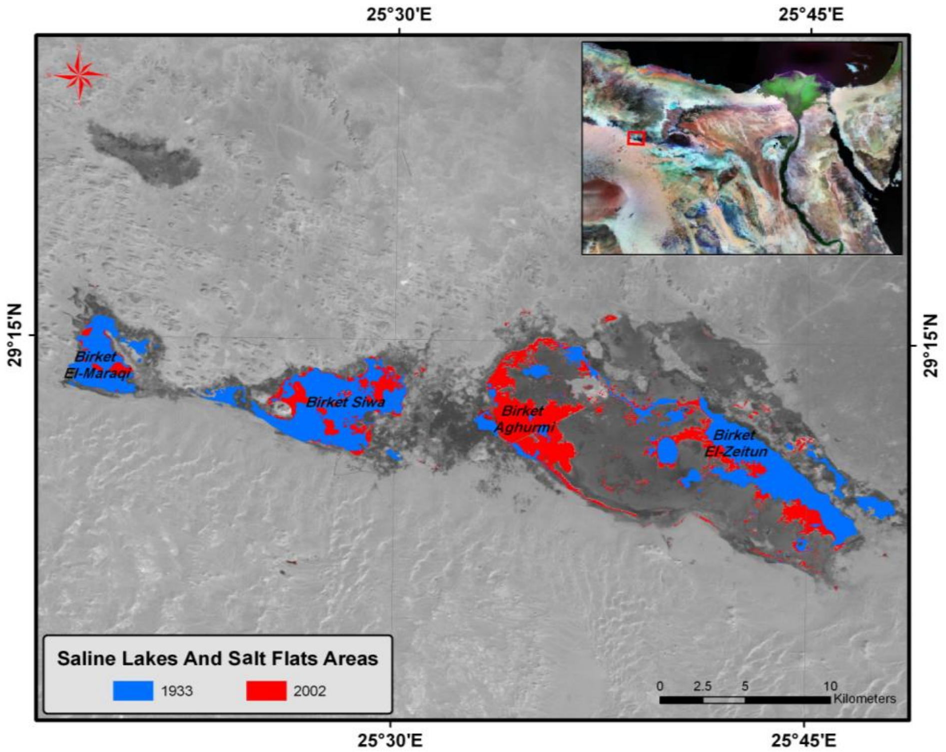

Figure (4): Environmental changes from 1933 to 2002

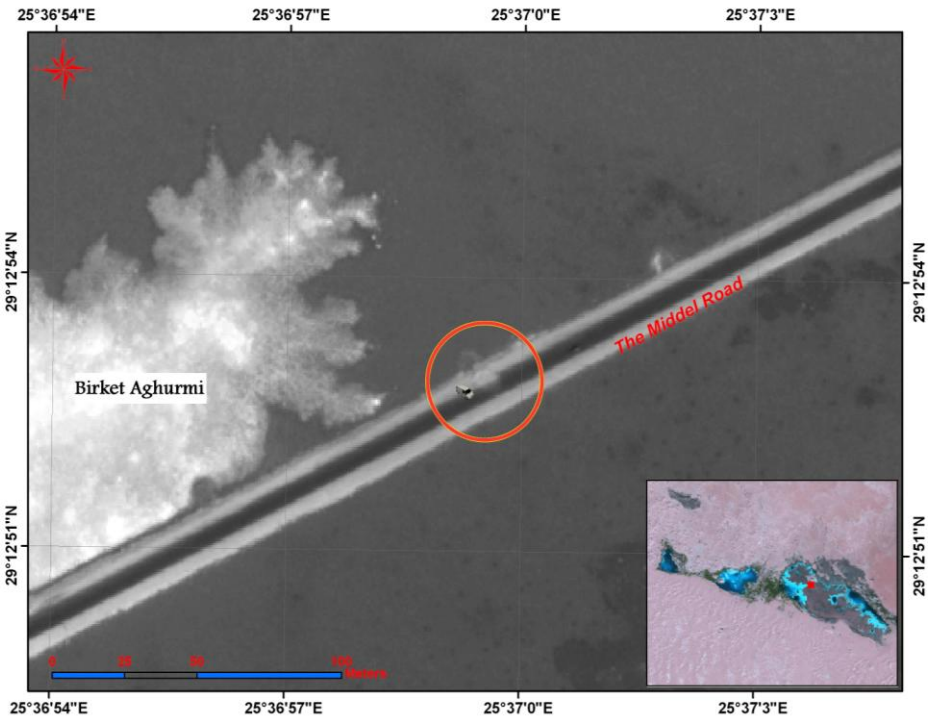

Figure (5): Location of middle road crosses Lake Aghurmi

The deterioration in the roads in Siwa Oasis is due to the use of poor coarse or fine aggregate, lack of quality control and poor workmanship. Also, break-up in roads may also be due to thermal cracking (Obika et. al., 1992).

* Soil salinization:

The cultivated lands in Siwa Oasis suffer from salinization problem (Plate11). The soil salinization is very high in low lands due to high salinity in underground water, quickly capillary rise of water in soil surface, poor workmanship of pumping water and high evaporation. Also, the high activity of salt weathering.

* Damage in archaeological sites:

The damage caused by salt weathering is high in many sites in Siwa Oasis for example Old Shalley City. Many stones show decaying features due to salt weathering e.g. efflorescence, granular disintegration, Tafoni, flaking. The result of salt weathering activity causes many cracks in dissected manner (Plate 12).

6-Hazards degrees in Siwa Oasis:

Figure 6 explains the salt weathering hazards degrees in Siwa Oasis. The highest hazards area occurs around the margins of saline lakes, within contour -15m and around sabkhas. The total surface area belongs to this degree is equal 39.1kms^2 representing 9.57% of the total surface area of the Oasis. Also, the moderately dangerous area occur around saline lakes and sabkhas equal to 41.8kms^2 representing 10.23% of the total surface area and the slightly dangerous one equal to 53.2kms^2, represent 13.02% of the total surface area of the Oasis.

Conclusion and recommendations:

Siwa Oasis with its valuable natural resources and many archaeological sites and unique habitats, represents a promising field for sustainable developed. This study explains the reasons of how salt weathering activity in Siwa varies according to its different accelerating processes. The detected changes explain that the total surface area surrounding the saline lakes (salt flats) have increased from 1933 to 2002 by some 20.55km^{s2}. The" hazard map shows that salt weathering activity vary considerably from one local to another thus manifesting a special rate of their spatial distribution. The most intense activities occur around the margins of saline lakes, in low areas, where the ground surface is affected by the capillary rise from shallow saline groundwater. The total area affected by salt weathering reaches 32.82 % of the Oasis area. The highly exposed area suffering from salt weathering, equals 39.1km^{s2} representing 9.57%of the total area of Siwa.

In this context several majors for alleviating the negative effect of salt wreathing, are recommended:

*Rationalizing water consumption.

*Using modern modes of irrigation.

* Selecting high grounds for the construction of buildings and avoiding using "Korshf".

*Avoiding soil problems such as water- logging and salinization.

*Minimizing underground salinity before utilizing for irrigation purpose.

*Emphasizing the necessity for formulating appropriate programs and a masterplan for sustainable and comprehensive development.

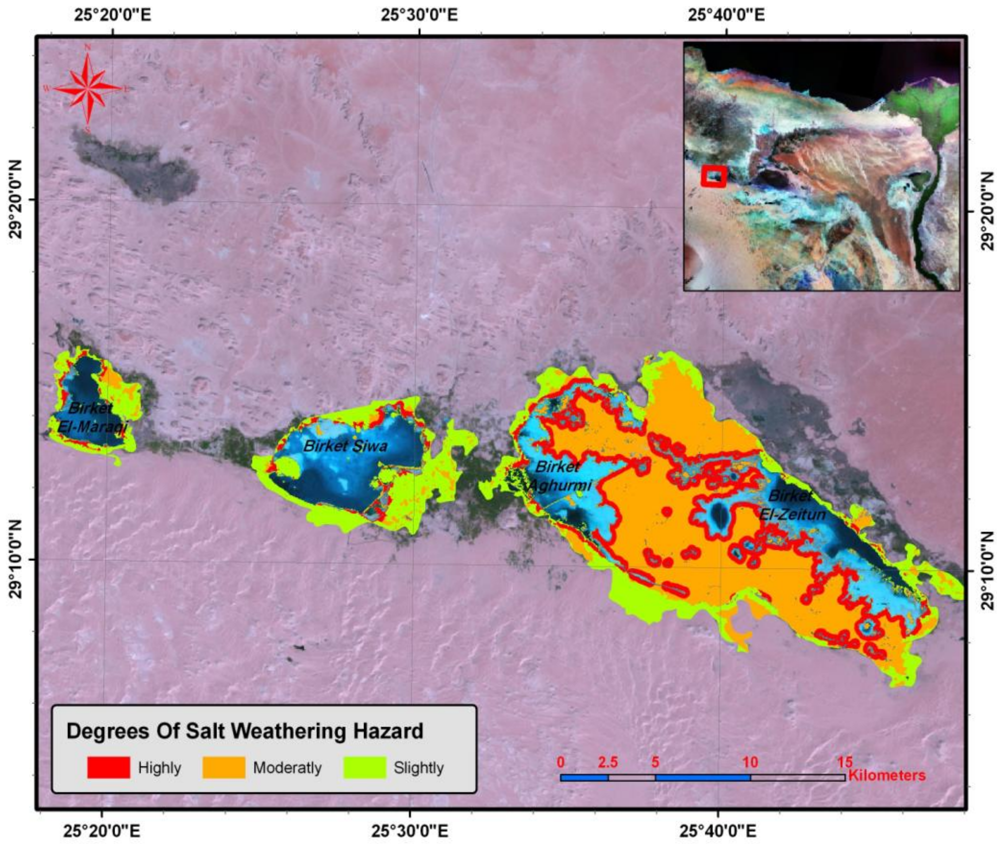

Figure (6) Difference degrees of salt weathering hazard

Plate (1): General view of Siwa Oasis

Plate (2): G. El Kosha

Plate (3): Birket El Zeitun


Plate (4): Salt crystal growth


Plate (5): Thermal expansion of salt crystal


Plate (6): Efflorences, Granular disintegration, Tafoni and Flaking in old Shalley City

Plate (7): Black and grey crust near Birket Zeitun

Plate (8): Salt weathering action   in" Korshf"

Plate (9): Road cross Birket Aghurmi

Plate (10): Damage in middle road

Plate (11): Soil Salinization

Plate (12): Stone damage in Old Shalley City

Acknowledgment:

The writer wishes to acknowledge and extend her gratitude to Prof.Dr.M.S. Abulezz president of the Egyptian geographical society for his assistance and thorough revision.

References:

1. Aachen UNIV. of Technology, (2005): "El Merdani Mosque, Cairo, Egypt", Geological Institute, Working group.
2. Abdel Mogeeth, S.M., (1996): "Ground Water Hazards in Siwa Oasis", Ground water protection, pp.113-118.
3. Atar, A., (1991): "Water Logging and Salinity Problems in Siwa Oasis", Marsa Matrouh, NOV. .
4. Burrough, P.A., & Mcdonnell, R.A., (1998): "Principles of Geographical Information System", Oxford.
5. Cooke, R.U., et al., (1982): "Urban Geomorphology in Dry lands", Oxford UNIV. presses.
6. El Gindy, A.R., & El Askary, M.A. (1969): "Stratigraphy, Structure and Origin of Siwa Depression, Western Desert of Egypt." Bull. Amer. ASSOC. Petrol. GEOL. VOL.53, NO3, pp.603-625.
7. Embabi, N.S., (2004): " The Geomorphology of Egypt: Land Forms and Evolution ", VOL.1, The Egypt GEOG. SOC. Cairo.
8. Gad, M.I., (1999): "Water Budget Analysis for the Topmost Aquifer for Some Cultivated Areas in the Central Part of Siwa Oasis, Western Desert, Egypt", PH.D. Al Azhar UNIV. FAC. Of science.
9. Goudie, A.S., (1997): "Salt Weathering Hazards." John Willy & sons.
10. Goudie, A., (2003): " Geomorphological Hazards in Arid Lands: Present and Future ", Bull .de la soci. De Geog. D' Egypte .
11. Holmer, B., (1998): "Flaking by Insulation Drying and Salt Weathering on the Swedish west Coast", Zetic. Geomor. 42, pp.39-55.
12. Huinink , H.P. , Pel , L. , & Kopinga , K. ,(2004) : " Simulating the Growth of Tafoni " , Earth surface processes and land forms 29 .
13. Kwaad, F.J., (2005): "Experiments on the Granular Disintegration of Granite by Salt Action", salt weathering. HTML.
14. Mason, L.J., et al., (2004): "Salt Weathering of Water Fall Escarpments Along the Niobrara River Near Valentine", Geological Society of America, VOL.36 NO.5 P.231.
15. McCoy , J. , & Johnston , K. , (2001) : " Using ARC GIS tm Spatial Analyst " , United states of America .

16. Mustoe, G.E., (1982): "The Origin of Honeycomb Weathering", Geog. Soc. Of America.
17. Obika , B. , Hewish , R.J. , Newill , D. , (1992) : " Physico – chemical Aspects of Soluble Salt Damage of Thin Bituminous Surfacing " , DFID , United kingdom .
18. Pombo, S., (1999): "Salt Decay of Sandstone", Masony conservation Rese. Group Aberdeen.
19. Smith, B.J., et al., (2005): " Salt Weathering Simulation under Hot Desert Conditions: Agents of Enlightenment or Perpetuators of preconceptions ", Geomorphology journal, V.67.
20. Glossary of Stone Decay Features – Alteration / Deposition, (2005): Weathering Research Group.