

ENVIRONMENTAL HAZARDS OF A NON-ORGANIZED “SAYHA” SOLAR SALTWORKS AT EL-RATMA, EGYPT: A SEDIMENTOLOGICAL AND GEOCHEMICAL APPROACH

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EXTENDED ABSTRACT

El-Ratma is among the largest non-organized “Sayha” solar saltworks in Egypt. Its importance rises from its position near to Damietta City, famous for its food industry. The harvested raw salt, known as “Sayha”, is used without washing and purification. The site and its concentration ponds lack the infrastructure necessary to purify the crystalline halite. Analyses of samples of salt, brines and cores indicate serious contamination, so that the quality does not meet the Egyptian quality standard for processed crude salt for food and industrial purposes. Contaminants include gypsum, heavy minerals, bitter salts and mineralized fecal pellets. The salt thus endangers human health, and the salterns cause severe soil degradation and other environmental hazards, constituting threats to the ecosystem of the area.

Keywords: solar saltworks, Egypt, Damietta City, El-Ratma, crude salt, pollution, Egyptian quality standards, gypsum, fish farms

1. INTRODUCTION AND HISTORICAL BACKGROUND

The geomorphology and soil composition of the Mediterranean coast of Egypt has been influenced throughout history by the properties of the River Nile. According to information given by Herodotus (fifth century BC) and Strabo (first century AD), the Nile Delta had seven major tributaries. The Pelusiatic and the Canopic branches respectively formed the eastern and western boundaries of the delta area during Pharaonic times [1,2]. At present only two branches remain active, namely Rosetta and Damietta, equivalent respectively to the ancient Bolbitinic and Bucolic branches [1]. The water flow through both branches has greatly changed since the Aswan and High dams were constructed, leading to a pattern of river-dominated sedimentation (sand, silt and clay with heavy minerals, including monazite, zircon, garnet, rutile as non-opaques and ilmenite, magnetite, amphiboles, pyroxenes, epidotes and spinel as opaques; some of these minerals are radioactive [3,4].

The construction of the Aswan and High dams has led to a virtually complete damming of the river near Rosetta and Damietta, and had turned the lower reaches of the Nile into tidal bodies of saline water [5]. Consequently, the shoreline has retreated along many parts of the Nile Delta coast as a result of the strong waves action as reported by Orlova and Zenkovich [6], Smith and Abd Kader [7], Stanley [8], and El-Asmar [9,10]. This has led to the distribution of heavy minerals along the Nile Delta coast, commonly concentrated in fine and very fine sand samples [10,11].

The El-Ratma area is situated to the east of Damietta City within the actively corroded region. It is located about 15 km east of the Damietta branch of the Nile, bordered from the south by the asphalt road of Damietta-Port Said and by Manzala Lake, and by the Mediterranean Sea at the north (Figs. 1A-C). Climatic characteristics of the region indicate moderate to semi-arid features. The average maximum temperature recorded in summer is 30.6°C, the minimum temperature is 11.4°C, and the relative humidity ranges from 60 to 80%. Wind speed is highest in winter (average 6.5 km/h), and the average tidal current is 14 cm/s, with a prevailing wind direction of NW-SE to NWW-SEE [12]. The El-Ratma area is approximately rectangular in shape; its dimensions are 1850 m (west), 2900 m (north), 2850 m (south) and 1200 m (east), covering an area of approximately 4.06 km² [13]. It occupies the lowest topographic position in the area. The sedimentological framework is mainly of Neolithic type (fine sand, silt and clay), rendering the area its permeable and non-porous character. Continual shore corrosion (accretion) did help accelerating the horizontal seepage of seawater (seepage-reflux and evaporative pumping mechanism as proposed by Hsü and Siegenthaler [14]), leading to the sporadic formation of salt pans along the Damietta-Rosetta coastal strip as a result of solar evaporation. The interactions of seawater and Neolithic sediments with the shoreline retreat are the main causes for the existence of "sayahas" in this area.

During the last four to five decades, economic considerations have led to the establishment of fish farms in the area (aquaculture and mariculture). Water was circulated from Manzala Lake and back via El-Ratma (the lowest topography), causing with time severe oxygen depletion, and making fish farming in the area non-profitable. The stored waters at El-Ratma turned into a saline pan by solar evaporation, especially since the water inlet and drainage routes no longer passed through the El-Ratma fish farm area. The El-Ratma area attracts the attention of many scientists as a result of its unique topographic location with respect to its surroundings: it occupies the lowest level among the fish farms. As a result of the absence of inlet and outlet channels for water from Manzala Lake and back through the fish farms, the water passes through El-Ratma due to its negative topography, whereas Manzala Lake is notorious as a dump for toxic industrial wastewaters from the surrounding factories [15].

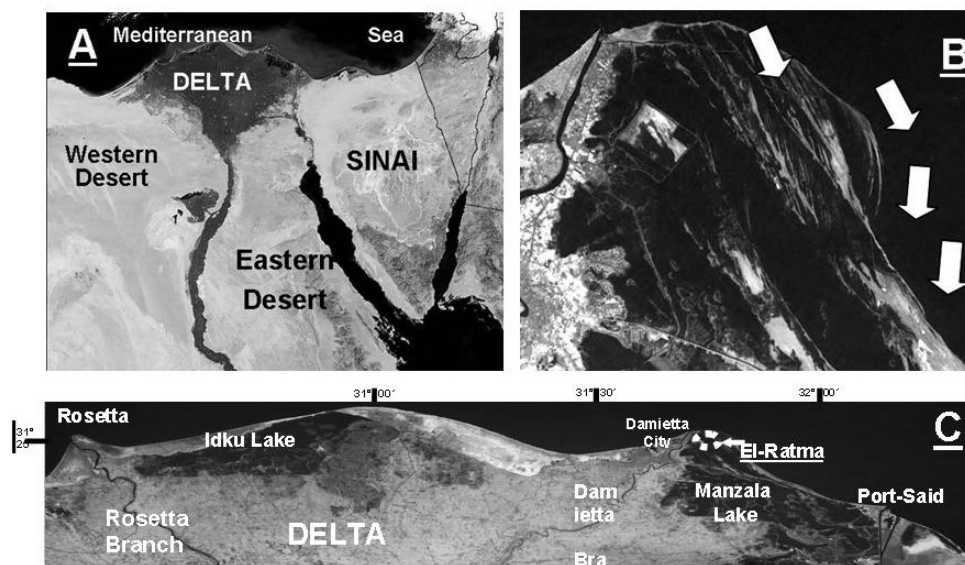


Figure 1. A: Location map of Egypt, showing the delta area, (B): The corroded shore areas (arrows) and (C): TM image, illustrating the studied area "El Ratma".

Salt extraction was introduced since then in the area as a readily available resource to serve for human consumption, and especially for food production, for which Damietta City is famous. The produced and marketed salt was not washed and refined, as the gain of financial profit was considered more important than meeting the required purity standards for crude salt to be used in such applications. Thus, crude salt is marketed without washing, refining, drying and packing. The term “Sayha” is used for such “non-organized salinas” that lack the essential infrastructure, concentration ponds, washing and refining technologies and packing units necessary to produce high-quality salt that meets the standards. Analysis result of both edible and industrial salts should satisfy the permissible Egyptian standard quality of raw salt (ESM, 273/1991 as shown in Table 1).

Table 1: Permissible qualifications of raw salt for edible and Industrial purposes in Egypt

Parameter	Edible Salt			Parameter	Industrial Salt		
	A	B	C		A*	B*	C*
Min. Dry sodium chloride (%)	98.5	97.5	98.0	Min. Dry sodium chloride (%)	99.0	98.0	97.5
Max. Humidity (%)	0.3	5.0	4.0	Max. Humidity (%)	5.0	5.0	5.0
Max. Soluble and insoluble impurities in water (%)	1.5	2.5	2	Max. Insoluble impurities in water (%)	0.3	0.25	0.4
Max. Insoluble impurities in water (%)	0.15	0.4	0.3	Max. Total dissolved salts in water (%)	0.2	2.0	2.5
Max. Iron (ppm)	0.001	0.001	0.001	Max. Sulfates (SO ₄) (%)	1.0	1.0	1.2
Max. Copper (ppm)	0.0002	0.0002	0.0002	Max. Carbonates (CO ₃) (%)	0.5	0.1	0.2
Max. Mercury (ppm)	0.0002	0.0002	0.0002	Max. Calcium (Ca) (%)	-	0.2	0.3
Max. Arsenic (ppm)	0.0001	0.0001	0.0001	Max. Magnesium (Mg) (%)	0.15	0.3	0.4
Max. Lead (ppm)	0.0002	0.0002	0.0002				

A= Coarse; B= Fine; C= Super-fine; A*= Coarse; B*= Fine; C*= Extra-Fine

The main goal of this article is to establish a scientific route as to judge the quality of the produced crude salt from non-organized solar saltworks with accurate determination of their passive effects on the environment and the ecosystem.

2. SEDIMENTOLOGICAL AND GEOCHEMICAL SPECTRUM

The El-Ratma “Sayha” as a closed basin [16] is naturally subdivided by its bottom topography into three zones (zones I, II and III), where zone I represents the shallowest area; zone II is deeper, while zone III is the deepest (Figure 2). The depth varies from 30 cm down to 2 meters in zone III. Naturally, raw salt is precipitated and harvested continuously from zone I, whereas the residual denser brines will seep into the deeper zones II and III. Sedimentologically, each zone contains an unlimited number of sub-basins, so that connections between the so-called “ponds” almost do not exist, and lateral seepage is never prevented. Consequently, the deeper zones can be expected to contain better salt, but they were never yet exploited. Also, the sub-basins themselves, which currently are used for salt exploitation, may contain bitter quality salt that is harvested together with the currently obtained crude salt. The piled crude salt is harvested manually, and collected into re-used type “flour bags”, as can be seen in Figure

3.

We have sampled surface sediments from the harvested raw salt (symbol “S”), residual brines (symbol “B”) and cores (symbol “C”) from the three zones, to judge whether or not the quality of the piled and packed salt may fit the requirements for handling and usage for domestic and industrial usages. Table 2 show the results obtained.

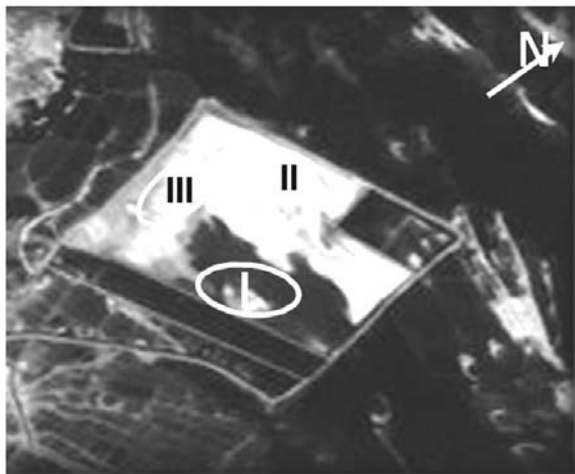


Figure 2: TM image of El-Ratma, showing the three zones



Figure 3: Piled crude salt collected manually. Arrows point to the constructed bridges

Table 2: Trace element chemistry of brines and sediments (values are in ppm).
N.D. = Not Detected

Items	Sample Detection Limit	Brine Samples					Salt Samples					
		B1	B2	B3	B4	B5	Salt 1	Salt 2	Top core (1)	Top core (3)	Top core (6)	Bottom core (6)
		Z I			Z II		Z I		Z II		Zone III	
Cu	0.015	1.08	1	0.8	0.8	0.8	1.4	1.4	1.5	0.67	1.0	0.88
Cr	0.025	0.48	0.44	0.36	0.37	0.38	0.62	0.5	0.56	0.58	0.56	0.59
Pb	0.03	N.D.	N.D.	N.D.	N.D.	N.D.	1.98	N.D.	0.59	1.5	1.15	N.D.
Sr	0.02	51.2	48.4	45.2	36	36.2	157.5	30	91.3	275.6	113.8	98
Fe	0.025	5.4	3	3.12	0.56	2.12	37.5	6.75	6.1	18.4	22.5	10.2
Ni	0.02	0.46	0.26	0.28	0.32	0.24	0.53	0.59	0.33	0.67	0.4	N.D.
Mn	0.01	4.56	4	3.6	2.64	3.3	5	5	6.3	8.4	5.5	6
Co	0.025	0.52	0.24	0.3	0.24	0.24	0.44	N.D.	0.5	1	0.5	0.44
Cd	0.005	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Zn	0.004	0.14	0.05	0.06	0.08	0.06	0.43	0.13	0.23	0.22	0.21	N.D.

Identification of major and trace minerals was based on X-ray diffraction, examination of thin-sections and scanning electron microscopy, and the data obtained were used to evaluate the incorporation of different hazardous materials into the precipitated crude salts. X-ray diffraction confirmed that halite was the main mineral present. Gypsum, glauberite, sylvite, epsomite, feldspar, kaolinite, calcite, dolomite and hematite are minor constituents. Zircon, biogenic pyrite (framboidal), tourmaline and sodium-rich clays are present as traces. This can be explained by the fact that the sediments from the Nile River contain high amounts of heavy metals incorporated within fine terrigenous materials, mainly as zircon, pyroxenes, tourmaline, iron oxide and chlorite, while quartz is a dominant light fraction. The clay minerals encountered are dominated by smectite, kaolinite, illite and chlorite, as confirmed by SEM and EDX. Whenever such contaminants are incorporated within the growing halite crystals, they will negatively influence the quality of the crude salt. Figures 4-10 illustrate examples of the different minerals incorporated within the harvested raw salt. Such types of minerals are difficult to dissolve and/or to remove by washing when they act as nuclei for the formation of halite crystals. Figure 11 shows mineralized fecal pellets encountered in the salt; these originated from washout from the surrounding fish farms that were operated in the past at the El-Ratma site.

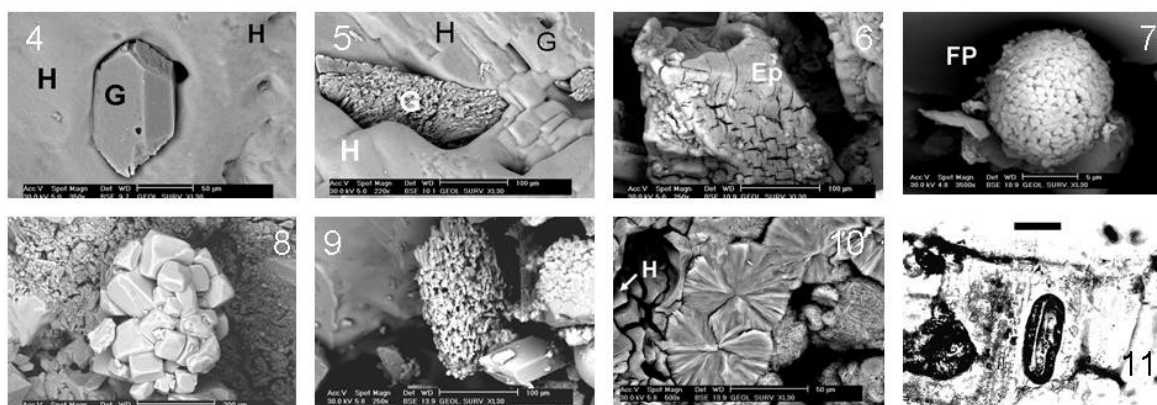


Figure 4: Crystalline gypsum in halite; **Figure 5:** Crystalline gypsum within hopper halite; **Figure 6:** Crystal of epsomite in halite; **Figures 7 and 8:** Framboidal pyrite and close-up view within halite; **Figure 9:** Tourmaline with clay aggregates; **Figure 10:** Mineralized fecal pellets; **Figure 11:** Zircon in halite; bar is 250 µm.

Adriano [17] defined trace elements as those occurring in natural and perturbed systems in small amounts, and whenever existing in sufficiently high concentrations would cause

toxicity to living organisms and microorganisms. The pollutants encountered constitute a hazard to human health, industry, soil quality, and ecosystem properties of the area. The values obtained of Mg^{2+} and K^+ increase remarkably in concentration at the greater depths of zones II and III. This explains the presence of bitter salts encountered in these two relatively deeper zones. Also, SO_4^{2-} and Cl^- display the same pattern, leading to precipitation of MgSO_4 , KCl and MgCl_2 , as verified by examining the mineralogy in zones II and III. The encountered paleotopography within zone I lead to seepage of the denser brines towards the deeper basins, causing the accumulation of polluted salt within each smaller basin as if it is a separate "Sayha" of its own. This process, together with the poor pond management at the site, is probably responsible for the relatively low NaCl content of the crude salt. Particularly in the non-harvested zones II and III, prolonged crystallization times increase the content of contaminants, especially of bitter salts, within the crude halite.

Increased concentrations of sulfur, chloride, sodium and magnesium can reach harmful levels for the soil environment as a result of human activity, and consequently these may become pollutants for the soil system [17]. This may be one of the causes for the recent acidification of the local soil.

Table 2 shows the trace elements content (in ppm) of the pollutants encountered in brine, sediments and cores. All recorded values of Cu, Cr, Pb, Sr, Fe, Ni, Mn, Co, Cd and Zn in all analyzed samples are higher than the permissible limits for both edible and industrial Egyptian salt (Table 1). Moreover, some trace elements such as Co, Sr and Cd, should be altogether absent, as they constitute serious hazards to health and soil quality.

3. PROPOSITIONS FOR SUSTAINABLE DEVELOPMENT AND CONCLUSIONS

The pollution in the studied area can be attributed to different causes: the presence of heavy minerals that are carried with the annual floods of Nile River near the Damietta branch, as well as the area's topographical conditions. The accumulation rate and the amount of the contamination with heavy metals, combined with the high content of organic matter and fine sediments, will lead to reducing conditions. The prevailing reducing character favor the accumulation of toxic heavy metals such as Pb, Cd, Cr, Cu, Hg, Ni, and Fe.

Additional sources of pollution are the drainage from the surrounding fish farms containing fish excretions of organic pellets, and the brackish water from Manzala Lake, mixed with industrial, agricultural and domestic wastewater. The main reasons for the present-day situation are:

- 1 - Improper planning when the fish farms were established, without taking the paleotopographic properties of the area into account.
- 2 - Use of improper techniques in the salt production process by insufficiently trained personnel, and use of contaminated tools and recycled packing bags.
- 3 - The absence of awareness of proper quality control, and the marketing of contaminated crude salts to food industries to obtain quick and high profits in a short time.
- 4 - The absence of applicable legislation against the greed and the private interests of part of the owners of the saltworks.

There are several possibilities for alternative uses of the accumulated salts and the saltern area:

- 1 - The contaminated raw salt can be used as a drilling mud constituent, to serve as a density balance for the viscosity control of the drilling mud, particularly for the increasing drilling activities in off-shore areas.

- 2 - The area can be converted to a mariculture farm with an open connection to the Mediterranean Sea.
- 3 - A research center can be established for aquaculture and mariculture, to support the current increase in the number of fish-farms in the area.
- 4 - The construction of a marina for tourism purposes, meeting the increasing demand for marinas on the Mediterranean Sea coast.
- 5 - The establishment of a small local distribution port for export and import, affiliated with Damietta port.

The above-mentioned plans can be executed to achieve the following targets:

- 1 - Preventing distribution of crude salt of poor quality from reaching the local markets.
- 2 - Finding economic applications for the accumulated contaminated crude salt.
- 3 - Protecting human health, food and soil from the present-day environmental threats.
- 4 - Establishing proper guidelines relating to the anticipated hazards caused by Sayha salt and its effect on human, industry and soil.
- 5 - Increasing the legalization and controls against greedy personnel in Sayha salt traders.

Application of such procedures will abolish the serious hazards of poor product quality, and will establish a safe and sustainable environment.

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