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A Review on Extraction Processes of Salts from Different Salt Lakes and their Environmental Impact in Industry

Hussein I. M. Metwally [1], Salman A. Salman [1], Ashraf M. El-Shamy [2,*]

[1] Geological Sciences Department, National Research Centre, Dokki, Giza, Egypt
[2] Physical Chemistry Department, Electrochemistry and Corrosion Lab., National Research Centre, El-Bohouth St. 33, Dokki, P.O. 12622, Giza, Egypt Giza, Egypt
* Correspondence: am.elshamy@nrc.sci.eg (A.M.E.S.); elshamy10@yahoo.com (A.M.E.S.);
Scopus Author ID 8585026300

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Abstract: Because of its direct and indirect penetration into numerous chemical industries, salt, also known as sodium chloride or halite, is one of the most frequent forms of salts in industrial applications. Evaporation is a typical method of extracting this chemical all around the world. Halite is also a low-cost material because it is found in concave rocks along the coast or in lakes, where saltwater is confined and subjected to evaporation, which concentrates the components in the water and deposits salt, generally by sun evaporation. Several functions of human consumption, salt manufacturing is incredibly significant. Salt is also regarded as one of the essential elements in the extraction of riches throughout history, such as oil extraction in contemporary times, as salt began to be utilized as a food additive, and thus its economic worth emerged. This is because it is common in the all-terrain and has vast origins. It is one of the five essential chemicals that make up the backbone of chemical manufacturing, alongside petroleum. It contributes significantly to the production of chlorine and sodium hydroxide, as well as being consumed by animals and humans. This study aims to describe the method of extraction of salt and its relationship to the environmental aspects so that it gives the reader a comprehensive analysis of all the problems that are related to the extraction process and what are the appropriate methods to deal with the problems associated with the extraction processes and give glimpses of the direct impact on the environment.

Keywords: Qaroun lake; extraction process; salt extraction; salt applications.

1. Introduction

The most common evaporate salt (NaCl, also known as halite). Halite is a low-cost mineral found in concave rocks along coastlines or lagoons where saltwater is trapped, and salt is deposited using sun energy. The production of salt is critical for human use. Salt is one of the most important supplies for epochs, like the importance of oil in the present eras [1]. Using salts as nutrient preservation, self-possessed with its commercial implication began to deteriorate after the manufacturing insurgency was added of 14.000 stated practices of halite, and it is lengthways with additional salts has engaged in a recreation of an exact significant starring role in human affairs [2]. Salt is a valuable monetary mineral that is widely distributed throughout all landforms and occurs in large quantities. It is one of the five primary compounds that make up the basis of chemical manufacture, including petroleum [3, 4]. It produces a serious part in the chloro-alkali industry, and it is used by collected animals and humans in their diets [5]. Separately after bedded or vestige salt vaults [6].

Beginning salt mining by disappearing seawater is the ultimate joint birthplace of the salt building (mine). The astrophysical creation of salt is the most widely used technology in many countries, notably in arid areas like Egypt, Ghana, and Saudi Arabia. The annual salt production in the ecosphere is estimated to be over 270 million tons [7]. According to measurements, around 60% of overall output in the chemical sector is monitored, followed by 30% for human feeding and 10% for extra solicitations (road de-icing, water treatment, and agriculture). Salt is used as a raw material for synthesizing chlorine, caustic soda, and soda ash for petrochemistry, carbon-based production, and goblet building by natural commerce [8]. Almost two-thirds of the world's republics have salt production conveniences ranging from traditional sun evaporation methods in salt saucepans to multi-stage evaporation in salt factories [9]. Chinese saline commerce contemplates as the major ecosphere manufacturer of salt [7].

Many additional nations (over 100) manufacture a large amount of salt, while others generate salt modestly. In 2011, China accounted for roughly 22.2 percent of the world's total salt production, followed by the United States (16.7%). India, Mexico, Australia, Canada, and Germany are other major producers. The human body requires between 5 and 7.6 grams of food each day, with around 15 million tons of food consumed annually. Salt for food is available in various forms, including bench, cooking, and manufactured salt for food preparation. Salt, on the other hand, is one of the essential fundamental materials in modern industry. Furthermore, industrialized uses account for 90 percent of the 200 million tons of NaCl consumed each year across the world. For petroleum purification, petrochemistry, organic synthesis, and glass manufacturing, salt is converted to Cl_2, caustic, and soda ash. Salt production in large quantities is a cost-effective responsibility. Manufacturing progress has increased the need for salt for continuous usage and as a raw material for creating new compounds. Seawater, lakes, and rock salt credits are the main sources of salt. Salt is extracted from the sea and lakes by desertion, but rock salt may be mined like coal or more efficiently by piercing boreholes into the salt bed, creating depressed pure water and thrusting up the soaking brine that remains. Egypt's geographic location and climatic conditions were analyzed in the presence of several salt extraction places. One of the most important salt extraction projects in Egypt is the extraction of salts from Lake Qaroun. This project has economic and environmental importance. Economically, its annual income is $ 39012376.76$/year [10].

Environmentally, when a new water lake surprises turning gradually brackish, most of the freshwater flora and fauna perish, roughly acclimatize, and survive for roughly a stretch, up to the salinity growths elsewhere their ability to adapt and these, too, perish. As a result, salt extraction has resulted in environmental protection by limiting the increase of the lake's salinity and excluding its biotic atmosphere and ordinary revenues [11]. This study aims to designate the technique of salt abstraction and its association to conservational features to provide the reader with a comprehensive investigation of all the difficulties accompanying the extraction procedure, as well as suitable methods for dealing with the complications related to the withdrawal progression and foretastes of the direct influence on the environment.

2. Materials and Methods

2.1. Salt occurrence and processing.

Salt is present in seawater, salt lakes, and Rock salt. There are 3 methods used for producing dry salt based on methods of recovery [9]. The procedure includes the conservative withdrawal of the subversive credits complete piercing; withdrawal is approved at nadirs amongst 100 m. to more than 1500 m. under the surfaces. The selected area for study is the location of salt production zones in Egypt, especially in Qaroun lake, since it represents the different locations for the occurrence of salt such as Burg El Arab, Port Said, Wadi Natrun, etc.

2.2. Salt extraction technologies.

Numerous knowhows can be used to abstract treasured internal and marketable salts and minerals from saline water. Established on the kind of parting procedure, the machinery is categorized into four groups:

2.2.1. Solar evaporation method.

Over a third of the entire worldwide once yearly salt manufacture is fashioned using this technique; in this technique, withdrawal of salt as of loads and saline water records occur by fading of aquatic in solar tarns leaving salt crystals which are then collected using machine-driven earnings.

2.2.2. Solution mixing.

Evaporated salt is a fashioned concluded explanation of fraternization of the subversive halite and eliminating the water from the saline salt water, which is ambitious to the superficial. Formerly, the water vanished after the brine with power-driven earnings, and this procedure led to the formation of a dense slurry of brine and salt crystals.

2.2.3. Thermal techniques.

These are segmented variation progressions connecting the use of thermal energy to vanish feed water to produce vapor, which is then condensed, a procedure recognized as concentration. Otherwise, saline water is ice-covered shadowed by the departure of pure ice and salts. Concentration can use any boiler basis, such as remnant fuels, nuclear energy, and solar energy.

2.2.4. Distillation.

Numerous concentration procedures are rummage-sale for salt retrieval and are categorized into conservative and marketable salt manufacture performances. Dispensation techniques supplementary to solar vanishing are rummage-sale commercially in the manufacture of salts, usually in the making of refined (table salt) and cleansing of basic salt [13]. The functioning attitude behindhand these procedures is that the vapor pressure of the provender water inside the item is dropped for boiling to happen at inferior heats deprived of supplementary hotness totaling. The solar concentration of salty water is a cost-effective salt production method that is used all over the world. It is a simple procedure that has been certified for use in narrow salt pots or pools. The sun drains the most amount of water within the light fishponds. The pools, saline originating from the sea or lake, vanish in the interior because of the sun and wind, which are accompanied by the crystallization process. After the salt deposit has become dense enough for a collection, the salt quartzes encourage an argument. Following that, the salts are washed away to reach the required levels and then stored in a channel and dewatered. The Great Salt Lake in the United States, the Dead Sea in Jordan, and the Salar de

Atacama in Chile are notable areas where the process is mostly rummage-sale for salt manufacturing on a large scale [13]. Criticizing vanishing in an uncluttered manner is a more cautious salt-making process involving applying heat to open pans. 6 m x 12 m x 1 m are the dimensions of the huge and shallow open pans or boilers. This outdated knowledge has been replaced with wood-burning heaters, which have also been proven unmaintainable in energy use [14].

The only way to get common salt (NaCl) from saltwater or natural brine is by slow evaporation and fractional separation of particles with differing densities (concentration) (Solar Salt Works). Many studies of the solar system of salt have been conducted in Egypt [12, 15-17]. Even before the chemistry of salt was understood, the method of producing (NaCl) via sunlight evaporation was widely used in Egypt. Depending on the current climatic conditions, the geographical location of the source, and the evolution of technological knowledge and its application, this approach is used to varying degrees. Solar evaporation is used to make salt, and salt of excellent quality and quantity has been produced. As the need for salt has expanded due to rising population and industrial usage, the design of solar saltworks has remained a rule of thumb for those with experience in the industry. Greater purity and production per acre have become increasingly significant. As a result, more fundamental data on brine evaporation, soil characteristics, meteorological conditions, and so on has been essential for the architecture of salt works. The following are the steps involved in establishing a salt work: Evaporation and crystallization, dependent on the solubility relationships of the elements of seawater, lagoon water, and lake water, are the key actions involved in the creation of salt. The design of a solar salt work is largely focused on completing these processes in the most effective manner possible, and it necessitates knowledge of the many engineering components of salt production.

3. Results and Discussion

3.1. Results.

3.1.1. salt uses in Egypt and the world.

In Lake Qaroun, the Na_2SO_4 unit yields two kinds of anhydrous Na_2SO_4 appropriate to glass manufacturing. Another kind is used mostly for detergent, textile dyeing, and paper pulps productions. Extra significant Na_2SO_4, which is used in soap and detergents (40 %), pulp and paper (25 %), textiles (19 %), glass making (5 %), and other uses (11 %). Na_2SO_4 has new occasions in tile engineering and in building commerce as well. NaCl unit creates iodized refined edible salt and industrialized salt with an annual assembly capability of 150,000 t/year for caustic soda, chlorine alkali industry, textile, dyes, and chemical engineering. The NaCl (edible and industrial) with high purity 99% on a dry basis. $MgSO_4$ is also used in cleaners, medicinal drives, fireproofing arrangement, gelling mediator, textile industry, and progresses the corrosion opposition of the nickelization of metals [19-22, 76-108]. There is also a chance to yield MgO for anti-caking in nitrate fertilizers. Generally, the produced sodium chloride in Egypt is used as follows: Raw Salt for export for Deicing; Food uses and table salt; Chemical industry; Chlor, alkali production; Nonfood uses.

Currently, the annual production of salt has increased to an estimated 270 million tons [7]. The chemical sector is the biggest buyer of salt, accounting for over 60% of total output. Humans are the second-largest salt consumers on the planet. Salt is used as a raw material in the chemical industry to manufacture chlorine, caustic soda, and soda ash, used in petroleum sanitizing, petrochemistry, organic compounding, and glass manufacturing [8]. Humans have bent their needs for around 30% of total salt to meet their biological functions and eating habits.

The most "forgotten" invention is salt for food, which was discovered after thousands of foundations in hundreds of items, including a table, cooking, and salt for food construction. Around 10% of salt is necessary for road de-icing, water treatment, the creation of chilled saltwater, and a variety of other reduced presentations. In any salt practice, the sodium chloride in the salt, not the froths, is required. The purer the salt, the higher its esteem [23]. Salt sodium chloride, on the other hand, has had a major position in historical times. It has been used for several things, including flavoring and preserving food, as well as functioning as a kind of cash.

This salt increases the flavor of bread and cheese and acts as a preservative in meat, dairy foods, margarine, and other items by limiting the growth of bacteria. Salt promotes the proper development of color in ham and hot dogs and boosts the sensitivity of preserved meats like ham by attracting water. In the case of iodized salt, it is an iodine mover. Thyroid hormones, which govern growth and development, require iodine to be produced. To synthesize novel compounds, chemical engineering is employed to measure vast volumes of NaCl. Cl_2 and NaOH are created electrically, starting with saline.

Chlorine chemicals are required for metal cleaners, paper bleach, polymers, and wastewater treatment. Soda ash, which contains sodium, makes glass, soaps, paper, and water softeners. Chemicals generated from NaCl reactions are used in ceramic glazes, metallurgy, hide curing, and photography. NaCl may be utilized in several different ways. It is spread on roads to melt ice by reducing the melting point of the ice. The control of body fluids relies heavily on salt. It is utilized in pharmaceuticals and animal feed. Salt caverns can also be utilized to store substances like petroleum and natural gas [27, 33, 34, 77, 87, 89, 93].

3.1.2. Worldwide supply.

World assets of salt are purely categorized as "great" due to the extensive withdrawals in the presence (Table 1&2). The oceans comprise an inexhaustible supply. Practically 2/3 of the world's nation-state has salt-creating conveniences, vacillating beginning old-fashioned solar evaporation in salt berates to progressive, multi-stage evaporation in salt refineries [9]. Over 100 countries yield a substantial quantity of salt with numerous others on a minor measure. The Chinese salt commerce is the major world maker of salt [7].

Table 1. Production of salt in several countries.

Country	Production (ton x10^6)					
	2016	2015	2014	2013	2012	2011
USA	42.000	45.000	45.300	40.300	37.200	45.000
Australia	12.000	11.000	11.000	11.000	10.800	11.700
Brazil	7.500	7.500	7.400	7.500	7.020	7.020
Canada	10.000	12.500	13.000	12.200	10.800	12.600
Chilean	11.000	11.800	8.500	6.580	8.060	9.970
China	58.000	70.000	68.000	70.000	70.000	72.000
France	6.000	6.000	6.000	6.100	6.100	6.100
Germany	12.500	12.500	12.200	11.900	11.900	18.800
India	19.000	17.000	16.000	16.000	17.000	17.000
Mexico	10.500	10.500	10.700	10.800	10.800	8.810
Poland	4.200	4.200	4.300	4.430	3.810	3.740
Spain	4.300	4.300	4.380	4.440	4.390	4.350
Ukraine	6.100	6.100	6.100	6.200	5.900	4.900
United Kingdom	5.000	5.000	6.700	6.700	6.700	5.800

Country	Production (ton x10^6)					
	2016	2015	2014	2013	2012	2011
Egypt	800.4	3.700	3.500	3.400	3.400	3.400
Other countries	100.42	43.900	42.920	44.450	45.120	54.810
Total	255.000	271.000	266.000	262.000	259.000	286.000

In 2011, it produced about 22.2 % of the world's total manufacture fathomed by the United States at 16.7 %. Other foremost producers are India, Australia, Mexico, Germany, and Canada. World production of salt has been growing by 3.3 % in the past 10 years.

Table 2. Production of salt in the Arab World.

Country	Production (ton x10^3)					
	2011	2012	2013	2014	2015	2016
Egypt	3400	3400	3400	3500	3700	4800
Saudi	1864	1611	1900	1990	2080	2150
Tunisia	1180	1131	1146	888	900	1000
Morocco	720	730	488	439	555	600
Kuwait	50	50	50	50	50	50
Jordan	32	32	32	32	32	32
Libya	20	30	30	30	30	30
Algeria	238	178	173	193	197	197
Oman	12.4	12.8	11.8	12.9	12.6	12.6
To whom	70	75	75	50	50	50
Sudan	10.8	26.3	20.8	37.3	38	38
Iraq	136	143	182	182	182	182
Lebanon	15	15	15	15	15	15
Syria	80	40	20	10	5	5
Total	9839.2	9486.1	9556.6	9443.2	9861.6	6.11177

In 2011, production augmented to 290 Mt, related with 280 Mt in 2010. China is the chief salt producer globally, accounting for approximately 22 %, followed by the United States providing about 16 % and Germany and India contributing 7 and 6 %, respectively. The Arab world contributes to the universal production of salt with about 11177.6 x 103 tons/year. Egypt and Saudi Arabia produced more than 60% of the Arab world's salt production (Table 2).

3.2. Impurities in natural salts.

The impurities brand the alteration, and the diversity of contaminations in salt (Table 3) and their comparative amounts are so mutable that every salt requirement is to be measured on its virtues. Excluding insoluble, the source of contamination is seawater. Solar sea salts, as a rule just a few months old, are somewhat like. Rock salts, lots of years old, may differ importantly, from unpolluted to dull, from white to black. Lake salts comprise constituents percolated from the pulverized of the neighboring rocks in capricious measures. Salt Lake chemistry is a science of its own. $CaSO_4$ is the most tenacious acquaintance of salt. In rock salt, $CaSO_4$ originated as anhydrite, hemihydrate, or poly-halite. Gypsum originated equally in sea salt and in lake salt. Natural seawaters are, as a rule, saturated with $CaSO_4$. Magnesium salts are continuously contemporary in sea salt, typically at a relation of approx. one and a half weight units of MgCl to one weight unit of $CaSO_4$.

In lake salts, $CaSO_4$ is usually attended by Na_2SO_4, for instance, in Sambhar Lake salts from Rajasthan in India or Azraq salts from Jordan. MgCl is also composed of $CaCl_2$, for example, in the Dead Sea brines, where KCl and NaBr are found in remarkably high concentrations. Insoluble is present-day in salts of all ancestries in greatly changeable amounts. The attendance of contaminations in salt has thoughtful monetary and conservational significance. Contamination intensification the cost of brine handling in chloral alkali plants enlarges the difficulties of polluted waste removal and requires expensive purifying of salt for human ingesting—the hydromechanical salt dispensation varieties from salt wash to counter-current cleansing with the hydro withdrawal of contaminations. The cleanliness of splashed solar salt formed in India and China reaches 99 - 99.5% (NaCl, dry bases), but solar salt produced in Australia and Mexico is 99.7 – 99.8% pure. The cleanliness of treated rock salt varies between 97 and 99%+ in the USA and Europe. Vacuity salt is typically 99.8 - 99.95% pure [8].

Table 3. Salt types and their content of impurities.

	Rock salt	Sea salt	Lake salts	Brines
$CaSO_4$	0.5 - 2%	0.5 - 1%	2%	Saturated
$MgSO_4$	Traces	0.2 - 0.6%	Traces	Traces
$MgCl_2$		0.3 - 1%	Traces	
$CaCl_2$			Traces	
Na_2SO_4			Traces	
KCl			Traces	
NaBr			Traces	
Insoluble	1 - 10%	0.1 - 1%	1 - 10%	

3.3. Factors affecting solar salt work.

Solar extract system (both non-manmade and manmade) is impacted by many natural factors [24]. These factors will be discussed in brief in the following paragraphs:

3.3.1. Selection of a suitable site.

The selection of a suitable site is the most important step in establishing solar salt work, as the project's ultimate success depends on the proper decision in this respect. This selection is influenced by the technical factors, which include the production of salt, as well as the commercial factors, which include the disposal of salt in the market. Being the cheapest commodity, a site close to the market is very desirable, as it helps minimize the cost involved in its transport. It is advantageous to locate a salt work near a salt-based industry or where shipping and rail transport is within reach.

The next step involves finding out the nature of the soil. A soil of an almost impervious nature is a major requirement. This property of soil depends on its composition. Normally the soil near the seacoast is an alluvial type and contains coarse sand:0.2 to 2.0m; fine sand 0.02 to 0.2m; silt 0.002 to 0.02 m and clay below 0.002 m [25]. The fraction coarser than coarse sand is gravel having a particle size from 2 to 75 m. Soils containing gravel and coarse sand are quite unsuitable for establishing salt work as they cause considerable percolation [26]. The percentage of fine sand, silt, and clay also varies from soil to soil, and depending on these percentages, they are broadly classified into three types of viz. Sandy, Loamy, and Clayey, and each type are further sub-classified. It is found that soils containing up to 60 % of fine sand as the largest particle size and not less than 40 % clay and silt together afford a reasonably impervious soil [27].

Therefore, soils of silty clay and clay class are the most suitable for establishing solar salt works. The presence of fine sand in soil imparts another desirable characteristic to it viz., increased bearing strength. The soils that can improve bearing strength up to 1 to 1.40 Kg per square centimeter are quite suitable [28]. This soil property makes the beds of the crystallizers sufficiently hard and does not get damaged during salt harvesting operations either manually or by mechanical means. In order of preference, after the clayey type of soils, clay loam and silty clay loam from among the loamy type are also useful for establishing the salt works.

The soil should be devoid of any vegetation as their roots in the soil cause voids through which heavy percolation occurs. The area requirement for solar salt work is very large, and sufficient land should be available close to the brine source for immediate use and any future expansion. Further, the land should preferably display a gentle gradient of about 30 to 40 cm in a kilometer and be in a depression, which gets inundated by the periodical spring tidal rise to the extent of about half to one meter. This assures a continuous adequate brine supply [29].

3.3.2. Brine density.

The brine density is a factor that links with the economics of salt manufacture. Since brine requires a large area and solar energy for concentration, which further requires exposure for a longer period, the lesser the concentration of the initial brine, the more it is uneconomical to operate the solar salt works. The normal density of seawater is in the vicinity of 3.5 ø Be'. But it varies depending on the location of the site. Brine from seacoasts about which rivers discharge their floodwaters usually gets diluted. Such dilution effect is observed immediately after the rainy season. It then slowly gains in density with the advancement of the season. It is wasteful to admit brine of the density below 1.5°Be' Specific Gravity (Density) = 145/145-°Be'.

3.3.3. Evaporation rate.

Evaporation is the chief operation involved in the manufacture of salt. Several factors are known which affect evaporation, both meteorological and physical—these sizes and shapes of water surface. Because of the complicated relationship between these various factors, it is difficult to assess the relative importance of each factor, and therefore, the combined effect of the influencing factors on the rate of evaporation is only. Quantity of Evaporation (m^3) = evaporation rate/ year × Area × Correction factor.

3.3.4. Solids in brine.

Since sodium chloride's solubility is little affected by increased temperature, it is crystallized out from Sea Water on evaporation. The evaporation rate and concentration of a liquid solution depend on the quantities of substances or substances dissolved in it. The more the quantities of dissolved substances, the lesser the rate of evaporation. Evaporation decreases by about 1% for every 1% increase in salinity under identical conditions and simultaneously decreases with increasing evaporating area.

3.3.5. Radiation.

The change in the state of water from a liquid to a gas involves the utilization of approximately 590 calories per gram of water. Solar radiation, therefore, plays a considerable part and governs the main variations in the rate of evaporation. It is now generally regarded as the most important single factor involved.

3.3.6. Temperature.

The air and water temperatures are largely dependent on solar radiation. Since the water surface temperature governs the rate at which the water molecules leave the surface and enter into overlaying air, the evaporation rate increases at higher temperatures. The ideal range of temperature is between 20°C (min).

3.3.7. Relative humidity (Rh %).

Humidity is an important factor. With an increase in relative humidity, the capacity of the atmosphere to take up more water vapor from the evaporating body decreases. The regions in which the relative humidity prevails at low value are more suitable for establishing salt works. The evaporation particularly ceases to take place when the relative humidity exceeds 80%. The relationship exists between solar energy, radiation, temperature, humidity, and evaporation.

3.3.8. Rainfall.

The progress and the net evaporation rate in a particular area depend on the total and distribution rainfall during the year. To operate a successful solar salt works, it is essential that the once-a-year rainwater must be as little as conceivable, and its delivery controlled to insufficient months sendoff longer pure climate duration for salt production.

3.3.9. Wind velocity.

Wind assistance in eliminating the air soaked through liquid-vapor after the superficial of the vanishing form and transporting in interaction with it a new unsaturated layer of the thermosphere therefore cumulative vanishing. Such an upsurge in vanishing with airstream haste is experiential up to a dangerous positive rate, and any additional upsurge in the wind speed does not further enhance the vanishing.

A wanted variety of wind speed which assistances vanishing is from 3 Km to 15 Km per hour. The way of the wind is a similarly significant deliberation as its rapidity. The wind gusting subsequently terminated the sea is usually saturated with water vapor and is incapable of taking freshwater vapor, therefore plummeting vanishing. Wind gusting from over the aquatic is dry and can take up water vapor until it reaches fullness and, therefore, vanishing.

3.3.10. Percolation (Seepage).

Brine percolation from ponds, condensers, and crystallizers is one of the major factors which should not be ignored in designing solar salt works because it affects the production and economy of the unit. Most of the soil near the seacoast is alluvial showing strong stratification. This property makes an exact measurement of percolation. This property makes the exact measurement of percolation very difficult. However, a designer with some broad guidelines should be able to design a reasonable plan [30].

3.4. Commercial distillation.

The Multi-Stage Flash development is grounded on the opinion that anywhere saline feed water is heated and vaporized by compression lessening compared to temperature augmentation. It includes recreating warming where saline water irregular in each flashy phase stretches up approximately its warmth to the salty water that successfully finished the irregular development. Impassioned water from an early-stage license to an additional stage at an inferior pressure, henceforth founding vapor which is controlled off and summarized to unadulterated water using cold brine, which feedstuffs the primary warming phase. Intensive saline is formerly approved to a second chamber at an inferior heaviness; henceforward, additional water vanishes with condensed vapor. The progression is frequent complete extra phases up to distinctive pressure. It can comprise from 4 to about 40 stages. The development is measured to be the maximum steadfast and greatest extensively cast-off.

3.4.1. Eutectic freezing crystallization.

The eutectic glacial manifestation divorces aqueous clarifications of inorganic solutions into unadulterated water and unpolluted salt [31]. The progression is branded by a process nearby the eutectic argument of the result wherever equally ice and salt develop instantaneously [32]. Equaled with the conformist vanishing and refrigeration procedures, this development is proficient in dropping energy charges by up to 70%. Nevertheless, the high outlay budgets collected with the weighbridge borders variety the manner unfavorable but can be skeptical with time [33].

3.4.2. Membrane techniques.

These processes include removing softened salts from the feedstuff water by motorized or chemical/electrical resources using a discerning membrane barricade amongst the feed water and merchandise. This attitude is practical in Reverse Osmosis (RO) and Electro-dialysis/Electro-dialysis Reversal (ED/EDR). These procedures do not include principal to a stage alteration. These procedures use a discerning artificial polymeric membrane or mastic to recuperate softened salts when exposed to a pressure incline or an electrical possible transversely the sheath surface.

3.4.3. Pressure-driven membrane processes.

These processes include removing salts from water by motorized or chemical/electrical resources using a discerning membrane barricade amongst the feed water and merchandise. This attitude is practical in Reverse Osmosis (RO) and Electro-dialysis/Electro-dialysis Reversal (ED/EDR). Osmosis is the water transmission finished by a semi-permeable membrane from a poor intense to an extremely intense resolution until an equilibrium osmotic pressure is attained. In the RO procedure, pressure superior to the osmotic pressure is functional to the extremely intense lateral of the membrane; henceforth foremost to the dissemination of water concluded the membrane to the freshwater lateral departure melted salts behindhand with an upsurge in salt attentiveness.

Advanced salt attentiveness in the feedstuff water would need advanced pressure. RO is a performance for the parting of liquefied particles on the foundation of scope, suggesting that superior particles than the membrane pore size are booked at the superficial of the membrane. Pretreatment is significant for RO procedures since the membrane is disposed to entangling due to liquefied solutes and impurities [34]. Profitable RO membranes are factory-made since contemporary malleable resources are in the arrangement of pieces or resonating fibers. Pressure ambitious sheath developments are extensively being rummage-sale for parting and retrieval of salts from water. The RO membranes were accomplished with retentive NaCl at an identical great concentration in an aqueous solution that was smooth when the concentration was near the saturation level [35].

3.4.5. Electrochemical separation processes.

Electro-dialysis/Electro-dialysis Reversing (ED/EDR) is an electro-membrane invention consisting of a cluster of ion-exchange membranes divided between an anode and a cathode. Positive and negative ions are distinguished by these membranes. Ions are forced to go in the direction of the probes by the action of a realistic electrical potential change. The cations travel through a cation membrane, while the anions pass through an anion barrier, resulting in two streams of concentrated brine and freshwater from the salty feed water. EDR, which contains a retrogressive electric current path, overcomes the fouling of ion exchange membranes by softened contaminations. The method is suitable for saline pre-concentration in arid places unsuitable for solar ponds and lack rock salt deposits [14].

The ED process, which can concentrate NaCl in seawater up to 200 g/l table salt before evaporation, is widely employed in Japan. More than 350,000 tons of table salt are generated every year using this method, needing more than 500,000 m2 of ion-exchange membranes [36]. The Middle East's salt supply has also been utilized in this technique [37]. The ED-MSF crystallization was also employed for a dual-purpose desalination-salt manufacturing system [74]. It is stated that the ED-EDR two-step ED pretreatment and pre-concentration of coal-mine brine were tried for salt production [75]. Furthermore, the combination of waste brine and mining process, discharged brine from a saltwater RO desalination plant, was used for table salt manufacture [70]. It is claimed that ED provides more cost-effective advantages than evaporation [73]. It was discovered that employing ED to produce a ton of NaCl uses roughly 151.3 kW compared to 1000 kW for evaporation. Electricity is 7-10 times more costly than steam as an energy transporter [74].

3.4.6. Chemical techniques.

In this method, chemical techniques are applied to produce salt from brine water. This method includes the application of the ion exchange principle, calcination processes, and reactive precipitation.

3.4.7. Ion exchange.

In this process, a reactive solid material was used to adsorb ions from liquid brine. The solid material may be an organic resin contained in a column where the liquid brine is passed on, leading to the exchange of ions. The dissolved Na^+, Cl, and other ions are exchanged with similarly charged ions. The ion exchange system is arranged in series. Ion exchange materials are divided into cationic and anionic. In this process, producing water and salt happened through interchange H^+ ions with positively charged ions as Na^+ on the cation material and exchange OH^- ions with negatively charged ions as Cl^- on the anion material. The advantages of this process are it is cheap, environmentally friendly, and have a long life of the exchange materials (resins). However, its disadvantage is that (a) the volume of produced desalted water is inversely proportional to the ionic concentration in the water and (b) water with high salinity requires larger ion exchange equipment, which is very expensive at this time. Finally, this technique is effective for water with low salinity [38].

3.4.8. Chemical extraction techniques.

These methods include the application of chemical techniques for extracting salts from forage water. This principle is applied in ion exchanges, reactive deposition, and lime operations. This technique includes calcination (a thermal decomposition process) and reactive precipitation. Saline water considers as a great source of common salt (NaCl) plus other important fewer amounts of salts such as Na_2SO_4, $MgCl_2$, $MgSO_4$, $CaSO_4$, etc. This technique has been used to extract and purify crude salts from saline water and prepare these salts for the package as feedstock to produce value-added products from the salts [13]. It is stated that chemical processes are applied to extract salts having the same chemical properties, which would make it difficult for high purity extraction [72].

This technique is not suitable for extracting sodium, magnesium, and potassium chlorides because they have similar chemical properties. Sodium and potassium chlorides can be extracted from the solution by the evaporation and cooling technique [2]. It was demonstrated that recovery of $Mg(OH)_2$ from samples of waste brine (bitterns) at a salt processing plant in Ghana by precipitation had been applied. Some previous studies stated that the technique used for precipitation of $MgSO_4$ from lake brine and to produce high-quality magnesia, precipitation of basic $MgCO_3$ from high sulfate content followed by calcination at 1100 ^{o}C must occur [68, 69, 71]. The recovery of KCl was demonstrated that from the Dead Sea brines occurred by precipitation and solvent extraction. Some papers concluded that a combination of chemical precipitation and evaporation-crystallization processes must occur to produce more purity of recovered salts [67].

3.4.9. Hybrid process.

These include combining the processes mentioned above into a single unit, in a sequential unit, or sequential steps. Egypt's geographic position and climatic condition were assessed in the presence of many locations for salt extraction. One of the most important salt extraction projects in Egypt is the extraction of salts from Lake Qaroun. In Lake Qaroun, the Na_2SO_4 unit yields two kinds of anhydrous Na_2SO_4 appropriate to glass manufacturing. Another kind is used mostly for detergent, textile dyeing, and paper pulps productions. Extra significant Na_2SO_4, which is used in soap and detergents (40 %), pulp and paper (25 %), textiles (19 %), glass making (5 %), and other uses (11 %). Na_2SO_4 has new occasions in tile engineering and in building commerce as well.

NaCl unit is created to create iodized refined edible salt and industrialized salt with an annual assembly capability of 150,000 t/year for caustic soda, chlorine alkali industry, textile, dyes, and chemical engineering. The NaCl (edible and industrial) with high purity 99% on a dry basis. $MgSO_4$ is also used in cleaners, medicinal drives, fireproofing arrangements, gelling mediators, textile industry, and progresses the corrosion opposition of the nickelization of metals. There is also a chance to yield MgO for anti-caking in nitrate fertilizers [21, 25, 29, 39-41; 77-108]. This process combines two or more processes from the previously mentioned techniques in single or sequential units, such as MD, MCr, RO with MSF, or MED [43]. The previous studies pointed out the cost and energy-intensive of conventional salt recovery technologies if they operate stand-alone. Accordingly, any combination between conventional techniques has been occurred to hybridize the salt recovery process to enhance system performance efficiency and reduce final disposable brine, hence maintaining zero discharge.

3.5. Comparison between extraction technologies

It is necessary for producing pure salts to select a suitable technique for a particular operation. Many factors affecting this selection are the following [43-45].

- Raw materials availability (brine, raw salt),
- Availability, reliability, and energy costs (power, steam, primary energy),
- Raw material impurities,
- Commercial readiness,
- Environment (waste products disposal, use of chemicals),
- Water situation (quantity and quality),
- Economic feasibility (financing, capital costs, operating costs). Based on the above criteria, a comparative summary of the identified salt extraction technologies and their characteristics.

3.6. Lake Qaroun.

The primary feature of Fayoum Governorate is Qaroun Lake, which is a closed lake in the north of Fayoum depression between longitudes (30.40°to30.83°E) and latitudes (29.404°to 29.537° N). It is a lake that is not open to the public. It is called a reservoir basin since it lacks an outlet and may be utilized as a release for flood control and water storage. All sorts of natural and manmade drainage water end up in the lake. It is transforming from a freshwater lake to a saltwater lake [46].

As a result of the increase in the population and the strictness of agriculture, irrigation, and other human activities, as well as evaporation, which leads to an increase in salinity, which helps to increase the rate of desertification, the salinity of Lake Qaroun climbed from 3.5 g/l in the 1890s to 34 g/l in 1992, and by 2025, it is expected to reach about 45 g/l [10]. It has a rectangle with a length of 43 kilometers and a width of 5.6 kilometers. It is a shallow lake with an average depth of 4.20 meters and a maximum depth of 9.0 meters at the horn island on the north side. In 2015, the area of Lake Qaroun was estimated to be 244.80 km^2. Previous investigations conducted since 1930 suggested that the lake had changed from fresh to salty water, with salinity exceeding that of saltwater [47].

Table 4 depicts the climate of Fayoum and Qaroun Lake. The surface of Qaroun Lake is exposed to a significant evaporation rate, nearing 2.0 m/y. Agricultural drainage water compensates for evaporation losses, allowing the lake level to remain relatively consistent at the end of the year. Lake Qaroun’s salinity increased as total dissolved solids continued to pour into the lake [48]. Because it is the lowest point in the region, roughly 350000 tons of salt are washed into the lake each year from cultivated fields (-45 m below sea level). A large amount of freshwater is lost each year due to evaporation, equivalent to the amount of inflowing water, while dissolved salts build in the lake [52]. During that time, the lakes’ evaporation rates varied from 1.9 to 8.14 mm/day [46]. In one billion cubic meters of water, the body of Qaroun Lake contains over 40 million tons of dissolved salts. Throughout the twentieth century, the lake’s salinity grew dramatically [49].

Table 4. The climate of Fayoum [46].

	Lake Qarun	Fayoum city
Mean Temperature	22.10 C°	22.00 C°
Max. Temperature	28.60 C°	26.50 C°
Min. Temperature	15.70 C°	14.50 C°
Mean relative humidity (RH)	61%	51%

	Lake Qarun	Fayoum city
Relative sunshine	82%	82%
Annual rainfall	9.20 mm	13.70 mm
Annual evaporation	1980 mm	2090 mm

3.6.1. Salinity of Lake Qaroun.

Many authors attributed the increase of Lake Qaroun salinity to intensive gradual evaporation and cultivated land drainage water [50-53]. As the lake's salinity increased gradually, the lake converted into a saline lake which led to the death of most of the freshwater fauna and flora. Also, the surrounding flora began to disappear until the whole area was dead. This led to an ecological and economic disaster where many fishers escaped from the lake, so the area became inhabitable for nature and men. Lake Qarun was freshwater in the 1890s (3.5 g/l) to rise to 26 g/l in 1950, and some researchers expected salinity to reach 50 g/l by 2005 – 2010 and 45 g/l by 2025 [10, 52]. Also, it is studied the water salinity of lake Qarun; the study concluded that evaporation from the lake is the main cause of increasing salinity [48]. The lake Qarun salinity was studied and concluded that the accumulation of salts and the drop in the lake level led to the increase of salinity of the lake Table 5 [49, 54].

Table 5. Shows the expected salinity until 2030 of Lake Qaroun.

Year	Salinity g/l	Year	Salinity g/l
1901	12	2018	34.26
1905	8.5	2019	34.62
1922	12	2020	34.98
1985	30	2021	35.34
1994	38.7	2022	35.7
2006	35.3	2023	36.06
2011	33.4	2024	36.42
2012	31.84	2025	36.78
2013	32.185	2026	37.14
2014	32.53	2027	37.5
2015	32.88	2028	37.86
2016	35.126	2029	38.22
2017	33.23	2030	38.58

3.6.2. Salt extraction from lake Qaroun.

EMISAL (The Egyptian Salts and Minerals Co.) was founded in 1984 on the southwest shore of Lake Qaroun near Fayoum to harvest salts that are collected periodically and to maintain the area’s biota and flora (Environmental and economic aspects). EMISAL relies on solar ponds to extract salts by evaporation, and changes in temperature or evaporation rate affect salt production during different months of the year, with high values from May to October compared to low values from November to April, allowing for a consistent output throughout the year. Desalination facilities come to mind, however, the cost and reject water from desalination plants are two key considerations since the rejected water (brine) is very saline and can harm the environment of Lake Qaroun and its environs. EMISAL created a three-stage process for extracting more than 300,000 tons of salts. The first stage produces 100000 tons of anhydrous Na_2SO_4 per year, followed by a second stage that produces 200000 tons of NaCl per year, and finally a third stage that produces 20000 tons of Mg-salts per year. An embankment separates a 5km2 region from the lake, which has been partitioned into evaporation ponds.

The sodium sulfate plant’s remaining mother liquor was discharged to the second set of evaporation ponds, where sodium chloride was precipitated and recovered, resulting in the stockpile. In 2001, a new factory was built with a capacity of 150,000 tons per year to convert this raw NaCl salt for commercial consumption (table and industrial sodium chloride salt). The residual liquor, bittern, was discharged to a final set of ponds after sodium chloride precipitation, whereas due to continuous production, a substantial reserve of bittern solution was accumulated, containing about 80,000 t of a mixture of magnesium sulfate and magnesium chloride, as well as other smaller quantities of other salts.

A total of 20,000 t of bittern is produced each year. In two ways, the bittern is currently a threat to the environment: First, the concentrated bittern limits all-natural development in the lagoons and serves as a source of significant groundwater pollution, which, if not regulated, might have an impact on nearby agricultural regions. Second, the lagoons' storage capacity is limited; therefore, the business must find a way to dispose of the waste if it continues performing its primary environmental duty of removing salts from Quarren Lake. The EMISAL began by producing 100,000 tons of high-quality anhydrous Na_2SO_4 per year [17]. The site's infrastructure necessitated cutting off a section of Lake Qaroun and subdividing it into four evaporation ponds (ponds 1- 4) separated by a dike.

3.6.3. Salt processing plants.

A factory assessment procedure typically has the following features: drying, screening, packaging, and palletizing devices, as well as dried palletized goods, will be situated beneath the covered area. The washing plant, the stockpile of coarse salt to be processed, the water draining tanks, and the storage of palletized bagged goods will all be in the open area.

3.6.3.1. Salt washing.

This is the most crucial stage, as it is at this stage, the salt loses specific chlorides that precipitate during salt processing. The salt is automatically deposited in a vat already filled with saturated water to be cleaned at the start. The salt is purified in the vat by removing any impure particles, which are very light and rise to the surface before falling into the drainage tanks. Furthermore, a 50 percent solution of salt and water is sent to the centrifugal unit by electro-pumps of sufficient power and pressure [55].

3.6.3.2. Salt spin-drying.

This process is carried out through continuous charge 900 rpm. Speed hydroextractors that free the salt of the water it contains to achieve approximately 4% humidity. The abovementioned water-salt solution from the washing vat is then drawn into the extractor by the electron pumps. The centrifugal force of hydro extractors provides the water separation and the salt falling with a very low relative humidity. The water retired returns to the washing vat, and the salt is ready to be triturated or ground.

3.6.3.3. Salt grinding.

This is a particular stage necessary to satisfy the market demands concerning the fine salt sector. This stage is obtained through a series of mills, which receive the salt coming from the spin-drying unit. Here, the salt is milled to considerably reduce its grain size and produce table salt for household use, salt required for Industrial applications, and leather tanning.

3.6.3.4. Salt drying.

This stage is performed by rotating or fluid bed type dryers. Both types of dryers must reduce the humidity of the salt from 4% to 0.2%. The machines dry the salt at a temperature of about 200° C using previously heated hot air.

3.6.3.5. Salt screening.

This stage is carried out through Vibrating Screens with an appropriate screening-vibrating capacity to grade different grain size ranges from the milling and drying stages.

Types of salt: Coarse dried salt; Medium dried salt; Fine dried salt; Powder.

The different types of salt with various grain sizes are stored in separate storage silos to be later bagged or packaged.

3.6.3.6. Salt sacking.

The industrial market requires the use of 50 kg or 25 kg bags.

3.6.3.7. Salt packaging.

This is one of the most important stages as the dried salt is removed from storage bins and packaged using automatic packaging machines, ready for household use. The appeal to the mark*et al*so depends on the type of packaging, aspect of the package, homogeneous grain size, the brightness of the product, and the absence of foreign matters.

3.6.3.8. Salt bags palletizing

Automatic palletizing and strapping lines, with a high degree of uniformity and speed in the process, provide efficiency in modern industry.

3.6.4. Environmental and economic future view.

The rejected water (brine) from the solar extraction system in Qaroun Lake is high saline water and can deteriorate the ecosystem in the lake or the surrounding areas. Then the proposed desalination plants in this study are reverse osmosis (RO). The addition of crystallizer and evaporator to the system of reverse osmosis desalination plants (RO) can recycle the reject water to near 100% of distilled water, in this case, the reject water is as a very condensed salt liquid, and the process is called near zero liquid discharge (NZLD). If the final product of desalination processes is dry salts and desalinated water only, then the process is called zero liquid discharge; it can be achieved by adding a dryer and package unit and the crystallizer evaporator, to the reverse osmosis desalination plant. The reduction in salinity comes from the reduction in evaporated amounts of water from the lake [10].

The salinity of Lake Qaroun has been increasing over the period. Thinking about another project of higher capacity, to extract all the salts, which can stop the increase in salinity, and perhaps reduce it slightly, is a must. Two plants with a capacity of 35 m3/day for each one are required to reduce salinity by 2.5% every year and maintain the level of salinity without changing in the lake by substituting the difference in salt balance between gained and lost salts—the locations of the proposed desalination plants.

Table 6. Total income in $/Y/T of different salts form lake water (2018) [10].

Salts	% Salts in Qarun water	International prices $/T	Ave. Prices $/T	Ave. TDS kg/m^3	Amount of each salt in t/m^3	Total income $/y
NaCl	61%	70-90	80	32.86	487654.71	39012376.76
$MgSo_4$	17.9%	100-150	125	32.86	143098.68	17887334.63
$NaSo_4$	12.4%	200-500	350	32.86	99129.81	34695433.43
$CaSo_4$	3.6%	400	400	32.86	28779.62	11511848.85
$CaCo_3$	0.2%	800	800	32.86	1598.87	1279094.32
$Ca(Hco_3)_2$	3.01%	200	200	32.86	24062.96	19250369.52
Others	1.8%	0	0	32.86	0.00	0.00
Total						123636457.5

3.7. Siwa Oasis.

Siwa Oasis was considered the virgin oasis located in the Western desert of Egypt. It contains unique geological features which can flourish geologic tourism [56]. It is one of the most promised locations for future agricultural projects in the Western Desert of Egypt because of groundwater availability. In addition, it has historical, medical, and environmental tourism importance. However, the uncontrolled abstraction and groundwater use may lead to much environmental deterioration for soil and groundwater aquifer [57]. The change in the surface area of lakes and agricultural lands in Siwa oasis was calculated from satellite images. Lake's area was duplicated from 2005 (52 km^2) to 2018 (105 km^2). Salt extraction in Siwa Oasis is natural through lagoon evaporation. This system does not need the series evaporation ponds but depends on one solar evaporation pond because the feeding brine is nearest to the saturation point of Sodium Chloride Salt.

4. Discussion

The salinity was increased from 8.5 g/l in 1905 to 38.0 g/l in 1980 owing to climate change and human activity. It is also studied the salinity of Lake Qaroun and found that the salinity was increased by about 30.9% (in 1971), 38.7‰ (in 1995), and 42.8‰ (in 1999–2000) [65, 66]. The studies expected more increase in the salinity in the 21st century, which can lead to a dead water body. It is noticed that a decrease to 32.4‰ was, however, recorded in 2003 [60, 63]. It is mentioned that the lake's salinity was 17.8–25.5 g/l in 1953– 1955; it appears that the lake salinity has strongly increased in the twentieth century. In 1906, it was 10.5 g/l but reached 18 g/l in 1919–1925 [64]. During the last 100 years, the huge changes in structure and functioning of biota in the lake due to salinity have increases. It is pointed out the intensive increase in lake salinity from 1901 (12 g/l) to approximately 34–39 g/l in 1995–2000 [49, 54, 58, 59]. Long-term studies on the lake by the previous research provided evidence for a current increase of concentrations of the major nutrients due to a growing impact of water discharge from drains [60-64].

The average salinity of Lake Qaroun from 2011 to 2017 is 32.86 g/l, as shown in Table 5; also, the analysis showed that there is an increase in salinity per year equals 0.36 g/l, the expected salinity until 2030 can be expected. In 1906, salinity was 10.5 gm/lit; it reached 18.0 gm/lit in 1925. It is reported 17.8 gm/lit in 1953, and 25.50 gm/lit in 1955 [64]. The reason behind the increased salinity rate is the high evaporation rate with no outflow of the lake [50]. Salinity increased further, to 30.9 gm/lit, 38.7 gm/lit and 42.8 gm/lit in the 1971, 1995 and 1999-2000, respectively (1973 & Ali 2002). The water was pumped from the lake to the ponds in order, from pond 1 to pond 4, when the concentration reaches 340 g/lin ponds 4. The crystallization of Glauber salt by chilling and then drying at this concentration results in an anhydrous sodium sulfate product. Company expertise aimed for modifications, which resulted in improved brine qualities and output of 108000 tons/year by 1996. The Na_2SO_4 plant's effluent brine is piped to auxiliary storage ponds until it dries up, becoming the raw material for refining and purification in the NaCl plant. Until this year (2002), the total amount of raw salt stored has reached 500000 tons, used in 20 to 30 years.

The raw brine feedstock for the third $MgSO_4.7H_2O$ plant with a capacity of 27 500 ty-1 of magnesium sulfate and an extra 5000 KCl is the leftover brine after harvesting raw NaCl salt (starting production by 2003-2004). The final phase in the commercial extraction of Lake Qaroun Salts is the production of small but useful products such as B and Br compounds. The salts which constitute more than 97% of brine solution are NaCl, $MgCl_2$, $CaCl_2$, and Na_2SO_4. For ZLD the evaporated seawater should be 100% and contains 5% of dissolved salts, and for RO plants, the recovery ratio is 35% to 45%, then the concentration of salts in brine will 0.048 ton/m3. The analysis of water of Lake Qaroun carried out by Mansour *et al*. (2000), which concluded that the percentage of salts composing the TDS in Lake Qaroun water are NaCl (61%), MgSO4 (17.9%), Na_2SO_4 (12.4%), $CaSO_4$ (3.6%), $Ca(HCO_3)_2$ (3.01%), $CaCO_3$ (0.2%), and others (1.8%). This analysis indicated the benefits of using ZLD technique income during one year for Lake Qaroun water as a solution for salinity excess. The calculations showed that the salt (NaCl) has the biggest total yearly amounts and income for one year, where the yearly income is 39012376.76$/ year. It is obvious that from Table 6, the total yearly income for all salts is 123636457.5$/year. Also, the returned income of salts NaCl, $MgSO_4$, Na_2SO_4, and $Ca(HCO_3)_2$ are more valuable than other salts.

5. Conclusions

Determination of EMISAL's water withdrawals and Qaroun Lake's evaporation is considered one of the most important issues for saving and extracting salt. Because the drainage water released into Qaroun Lake exceeds the lake's outflow and evaporation, the lake level is rising at a rate of around 4.40 cm/year. With the help of computerized elevation maps and satellite images, it was able to pick a place for the construction of evaporation ponds. According to contour lines, it is split into four basins. There are 20.48 km^2 of basin available if the earth bank of 2.30 m high is constructed between the Qaroun Lake and the Evaporation Ponds. Five years of building evaporation areas, or 12.40 cm/year of withdrawn water, raises a lake's maximum level. When the bank level hits 4.30 m, the evaporation ponds cover 27.24 km^2. Lake level lowers 17.90 cm/year because of this location. Four years after the building of evaporation ponds, a safe maximum lake level has been attained. It is predicted that Qaroun Lake can drain a huge amount of water per year with the addition of evaporation ponds.

This bodes well for future expansions and agricultural area growth. A new salt balancing equation was developed for Qaroun Lake, which considered extra evaporation ponds. After adding the minimum evaporation area of 20.48 km^2, the salinity rate increases by 0.033 g/l/year. This 27.24 km^2 region has seen a rise in salinity of 0.020 g/l/year. In the fourth and fifth scenarios, the lake's salinity has not been modified by installing evaporation ponds; thus a simulation of Qaroun Lake has been performed following the addition of new agricultural drainage water. According to the fourth scenario, there will be a salinity loss of 0.920 g/l and a 35.00 g/l salinity drop during the next six years. Each year, the lake's salinity has decreased by 1.333 g/l, and the lake's salinity was 27.92 at the end of the six years.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Russell, J.M.; Johnson, T.C. A high-resolution geochemical record from Lake Edward, Uganda Congo and the timing and causes of tropical African drought during the late Holocene. *Quaternary Science Reviews* **2005**, *24*, 1375-1389, https://doi.org/10.1016/j.quascirev.2004.10.003.
2. Kılıc, Ö.; Kılıc, A.M. Recovery of salt co-products during the salt production from brine. *Desalination* **2005**, *186*, 11-19, https://doi.org/10.1016/j.desal.2005.05.014.
3. El-Bindary, R.; El-Shamy, A.; Elhadek, M.A.; Nassef, A. Statistical Analysis of the Inhibition of Carbon Steel Corrosion in 3.5 wt.% NaCl Solution Using Lawsonia Extract. *Port-Said Engineering Research Journal* **2021**, *25*, 101-113, https://doi.org/10.21608/pserj.2020.35020.1050.
4. Baioumy, H.M.; Hassan, M.S. Authigenic halloysite from El-Gideda iron ore, Bahria Oasis, Egypt: characterization and origin. *Clay Minerals* **2004**, *39*, 207-217, https://doi.org/10.1180/0009855043920131.
5. Pérez, A.; Luzón, A.; Roc, A.C.; Soria, A.R.; Mayayo, M.J.; Sánchez, J.A. Sedimentary facies distribution and genesis of a recent carbonate-rich saline lake: Gallocanta Lake, Iberian Chain, NE Spain. *Sedimentary Geology* **2002**, *148*, 185-202, https://doi.org/10.1016/S0037-0738(01)00217-2.
6. Lückge, A.; Doose-Rolinski, H.; Khan, A.A.; Schulz, H.; von Rad, U. Monsoonal variability in the northeastern Arabian Sea during the past 5000years: geochemical evidence from laminated sediments. *Palaeogeography, Palaeoclimatology, Palaeoecology* **2001**, *167*, 273-286, https://doi.org/10.1016/S0031-0182(00)00241-8.
7. Frumkin, A.; Elitzur, Y. Historic Dead Sea Level Fluctuations Calibrated with Geological and Archaeological Evidence. *Quaternary Research* **2002**, *57*, 334-342, https://doi.org/10.1006/qres.2002.2330.
8. Yokoyama, Y.; Esat, T.M.; Lambeck, K. Coupled climate and sea-level changes deduced from Huon Peninsula coral terraces of the last ice age. *Earth and Planetary Science Letters* **2001**, *193*, 579-587, https://doi.org/10.1016/S0012-821X(01)00515-5.
9. Abu-Khader, M.M. Viable engineering options to enhance the NaCl quality from the Dead Sea in Jordan. *Journal of Cleaner Production* **2006**, *14*, 80-86, https://doi.org/10.1016/j.jclepro.2004.11.005.
10. Irino, T.; Tada, R. Quantification of aeolian dust (Kosa) contribution to the Japan Sea sediments and its variation during the last 200 ky. *Geochemical Journal* **2000**, *34*, 59-93, https://doi.org/10.2343/geochemj.34.59.
11. Madbouly, E.E.-D.I. Production of Magnesium Salts Extraction from Liquid Bittern of Emisal Accumulated in Lake Quarun. *Polymer-Plastics Technology and Engineering* **2004**, *43*, 1643-1648, https://doi.org/10.1081/PPT-200039982.
12. Russell, J.; Talbot, M.R.; Haskell, B.J. Mid-holocene climate change in Lake Bosumtwi, Ghana. *Quaternary Research* **2003**, *60*, 133-141, https://doi.org/10.1016/S0033-5894(03)00065-6.
13. Jung, S.J.A.; Davies, G.R.; Ganssen, G.M.; Kroon, D. Stepwise Holocene aridification in NE Africa deduced from dust-borne radiogenic isotope records. *Earth and Planetary Science Letters* **2004**, *221*, 27-37, https://doi.org/10.1016/S0012-821X(04)00095-0.
14. Tada, R.; Sato, S.; Irino, T.; Matsui, H.; Kennett, J.P. Millennial-scale compositional variations in late Quaternary sediments at site 1017, Southern California. In: *Proceedings of the Ocean Drilling Program: Scientific Results.* Lyle, M.; Koizumi, I.; Richter, C.; Moore Jr, T.C. (Eds.), Volume 167, **2000**; pp. 277–296, https://doi.org/10.2973/odp.proc.sr.167.222.2000.
15. von Rad, U.; Schaaf, M.; Michels, K.H.; Schulz, H.; Berger, W.H.; Sirocko, F. A 5000-yr Record of Climate Change in Varved Sediments from the Oxygen Minimum Zone off Pakistan, Northeastern Arabian Sea. *Quaternary Research* **1999**, *51*, 39-53, https://doi.org/10.1006/qres.1998.2016.
16. Herzschuh, U.; Tarasov, P.; Wünnemann, B.; Hartmann, K. Holocene vegetation and climate of the Alashan Plateau, NW China, reconstructed from pollen data. *Palaeogeography, Palaeoclimatology, Palaeoecology* **2004**, *211*, 1-17, https://doi.org/10.1016/j.palaeo.2004.04.001.

17. Verschuren, D. Sedimentation controls on the preservation and time resolution of climate-proxy records from shallow fluctuating lakes. *Quaternary Science Reviews* **1999**, *18,* 821-837, https://doi.org/10.1016/S0277-3791(98)00065-1.
18. Dardir, A.A.; Wali, A.M.A. Extraction of salts from Lake Quaroun, Egypt: environmental and economic impacts. *Global NEST Journal* **2009**, *11*, 106-113., https://doi.org/10.30955/gnj.000571.
19. Alkharafi, F.M.; El-Shamy, A.M.; Ateya, B.G. Effect of 3-aminotriazole on the Corrosion of Copper in Polluted and Unpolluted Media. *Journal of Chemistry and Chemical Engineering* **2009**, *3*, 42-50+56.
20. Ateya, B.G.; Al Kharafi, F.M.; El-Shamy, A.M.; Saad, A.Y.; Abdalla, R.M. Electrochemical desulfurization of geothermal fluids under high temperature and pressure. *Journal of Applied Electrochemistry* **2009**, *39*, 383-389, https://doi.org/10.1007/s10800-008-9683-3.
21. El-Shamy, A.M.; Alkharafi, F.M.; Abdallah, R.M.; Ghayad, I.M. Electrochemical oxidation of hydrogen sulfide in polluted brines using porous graphite electrodes under geothermal conditions. *Chemical Sciences Journal* **2010**.
22. El-Shamy, A.M.; Gaballah, S.T.; El Meleigy, A.E. Inhibition of Copper Corrosion in The Presence of Synthesized (E)-2-(4-Bromophenoxy)-N'-(2, 4-Dihydroxybenzylidene) Acetohydrazide in Polluted and Unpolluted Saltwater. *International Journal of Recent Development in Engineering and Technology* **2013**, *1*, 11-18.
23. Hamano, Y.; Odah, H.; Takaishi, Y.; Kayanne, H.; Tada, R.; Noumi, M.; Maiwa, K.; El-Qady, G.; Abouelhassan, M.; Baioumy, H.M. *Geomagnetic secular variations recorded in the sediment cores from Lake Qarun, Egypt*. **2004**; pp. 13-15.
24. Wei, K.; Gasse, F. Oxygen isotopes in lacustrine carbonates of West China revisited: implications for post glacial changes in summer monsoon circulation. *Quaternary Science Reviews* **1999**, *18*, 1315-1334, https://doi.org/10.1016/S0277-3791(98)00115-2.
25. El-Shamy, A.M.; Shehata, M.F.; Metwally, H.I.M.; Melegy, A. Chloride ions penetration and their role in sediments corrosion of buried steel structures in closed basin. *Chemical Sciences Journal* **2015**, *7*, 84-92.
26. El-Shamy, A.M.; Shehata, M.F.; Metwally, H.I.M.; Melegy, A. Corrosion and Corrosion Inhibition of Steel Pipelines in Montmorillonitic Soil Filling Material. *Silicon* **2018**, *10*, 2809-2815, https://doi.org/10.1007/s12633-018-9821-4.
27. El-Shamy, A.M.; Farag, H.K.; Saad, W. Comparative Study of Removal of Heavy Metals from Industrial Wastewater Using Clay and Activated Carbon in Batch and Continuous Flow Systems. *Egyptian Journal of Chemistry* **2017**, *60*, 1165-1175, https://doi.org/10.21608/ejchem.2017.1606.1128.
28. Ismail, A.I.M.; El-Shamy, A.M. Engineering behaviour of soil materials on the corrosion of mild steel. *Applied Clay Science* **2009**, *42*, 356-362, https://doi.org/10.1016/j.clay.2008.03.003.
29. El-Shamy, A.M.; Shehata, M.F.; Ismail, A.I.M. Effect of moisture contents of bentonitic clay on the corrosion behavior of steel pipelines. *Applied Clay Science* **2015**, *114*, 461-466, https://doi.org/10.1016/j.clay.2015.06.041.
30. Huntsman-Mapila, P.; Ringrose, S.; Mackay, A.W.; Downey, W.S.; Modisi, M.; Coetzee, S.H.; Tiercelin, J.J.; Kampunzu, A.B.; Vanderpost, C. Use of the geochemical and biological sedimentary record in establishing palaeo-environments and climate change in the Lake Ngami basin, NW Botswana. *Quaternary International* **2006**, *148*, 51-64, https://doi.org/10.1016/j.quaint.2005.11.029.
31. van der Ham, F.; Witkamp, G.J.; de Graauw, J.; van Rosmalen, G.M. Eutectic freeze crystallization simultaneous formation and separation of two solid phases. *Journal of Crystal Growth* **1999**, *198-199*, 744-748, https://doi.org/10.1016/S0022-0248(98)01003-3.
32. Vaessen, R.J.C.; Janse, B.J.H.; Seckler, M.M.; Witkamp, G.J. Evaluation of the Performance of a Newly Developed Eutectic Freeze Crystallizer: Scraped Cooled Wall CrystalIizer. *Chemical Engineering Research and Design* **2003**, *81*, 1363-1372, https://doi.org/10.1205/026387603771339573.
33. Van der Ham, F.; Witkamp, G.-J.; De Graauw, J.; Van Rosmalen, G.M. Eutectic freeze crystallization: Application to process streams and waste water purification. *Chemical Engineering and Processing: process intensification* **1998**, *37*, 207-213.
34. van Hoof, S.C.J.M.; Hashim, A.; Kordes, A.J. The effect of ultrafiltration as pretreatment to reverse osmosis in wastewater reuse and seawater desalination applications. *Desalination* **1999**, *124*, 231-242, https://doi.org/10.1016/S0011-9164(99)00108-3.
35. Karelin, F.N.; Askerniya, A.A.; Gril, M.L.; Parilova, O.F. Salt concentration and recovery from aqueous solutions using pressure-driven membrane processes. *Desalination* **1996**, *104*, 69-74, https://doi.org/10.1016/0011-9164(96)00027-6.
36. Flower, R.J.; Stickley, C.; Rose, N.L.; Peglar, S.; Fathi, A.A.; Appleby, P.G. Environmental Changes at the Desert Margin: An Assessment of Recent Paleolimnological Records in Lake Qarun, Middle Egypt. *Journal of Paleolimnology* **2006**, *35*, 1-24, https://doi.org/10.1007/s10933-005-6393-2.
37. Stein, M.; Starinsky, A.; Katz, A.; Goldstein, S.L.; Machlus, M.; Schramm, A. Strontium isotopic, chemical, and sedimentological evidence for the evolution of Lake Lisan and the Dead Sea. *Geochimica et Cosmochimica Acta* **1997**, *61*, 3975-3992, https://doi.org/10.1016/S0016-7037(97)00191-9.
38. Magny, M.; de Beaulieu, J.-L.; Drescher-Schneider, R.; Vannière, B.; Walter-Simonnet, A.-V.; Miras, Y.; Millet, L.; Bossuet, G.; Peyron, O.; Brugiapaglia, E.; Leroux, A. Holocene climate changes in the central

Mediterranean as recorded by lake-level fluctuations at Lake Accesa (Tuscany, Italy). *Quaternary Science Reviews* **2007**, *26*, 1736-1758, https://doi.org/10.1016/j.quascirev.2007.04.014.

39. El-Shamy, A.M.; Zohdy, K.M. Corrosion Resistance of Copper in Unpolluted and Sulfide Polluted Saltwater by Metronidazole. *Journal of Applied Chemical Science International* **2015**, *2*, 56-64.
40. El-Shamy, A.M.; Zohdy, K.M.; El-Dahan, H.A. Control of Corrosion and Microbial Corrosion of Steel Pipelines in Salty Environment by Polyacrylamide. *Ind Chem* **2016**, *2*, http://dx.doi.org/10.4172/2469-9764.1000120.
41. El-Shamy, A.M.; El-Hadek, M.A.; Nassef, A.E.; El-Bindary, R.A. Box-Behnken design to enhance the corrosion resistance of high strength steel alloy in 3.5 wt.% NaCl solution. *Moroccan Journal of Chemistry* **2020**, *8*, 788-800, https://doi.org/10.48317/IMIST.PRSM/morjchem-v8i4.21594.
42. El-Shamy, A.M.; El-Hadek, M.A.; Nassef, A.E.; El-Bindary, R.A. Optimization of the Influencing Variables on the Corrosion Property of Steel Alloy 4130 in 3.5 wt.% NaCl Solution. *Journal of Chemistry* **2020**, *2020*, https://doi.org/10.1155/2020/9212491.
43. Gude, V.G.; Nirmalakhandan, N.; Deng, S. Renewable and sustainable approaches for desalination. *Renewable and Sustainable Energy Reviews* **2010**, *14*, 2641-2654, https://doi.org/10.1016/j.rser.2010.06.008.
44. Wade, N.M. Technical and economic evaluation of distillation and reverse osmosis desalination processes. *Desalination* **1993**, *93*, 343-363, https://doi.org/10.1016/0011-9164(93)80113-2.
45. Abdel-Satar, A.M.; Goher, M.E.; Sayed, M.F. Recent environmental changes in water and sediment quality of Lake Qarun, Egypt. *Journal of Fisheries and Aquatic Science* **2010**, *5*, 56-69**,** https://doi.org/10.3923/jfas.2010.56.69.
46. El-Shabrawy, G.M.; Dumont, H.J. The Fayum Depression and Its Lakes. In: *The Nile: Origin, Environments, Limnology and Human Use*. Dumont, H.J. Ed.; Springer Netherlands: Dordrecht, **2009**; pp. 95-124, https://doi.org/10.1007/978-1-4020-9726-3_6.
47. Keatings, K.W.; Hawkes, I.; Holmes, J.A.; Flower, R.J.; Leng, M.J.; Abu-Zied, R.H.; Lord, A.R. Evaluation of ostracod-based palaeoenvironmental reconstruction with instrumental data from the arid Faiyum Depression, Egypt. *Journal of Paleolimnology* **2007**, *38*, 261-283, https://doi.org/10.1007/s10933-006-9074-x.
48. Vasconcelos, C.; McKenzie, J.A. Microbial mediation of modern dolomite precipitation and diagenesis under anoxic conditions (Lagoa Vermelha, Rio de Janeiro, Brazil). *Journal of sedimentary Research* **1997**, *67*, 378-390, https://doi.org/10.1306/D4268577-2B26-11D7-8648000102C1865D.
49. El-Shabrawy, G.M.; Dumont, H.J. The Fayum depression and its lakes. In: *The Nile*. Springer: **2009;** pp. 95-124.
50. Fritz, S.C. Paleolimnological records of climatic change in North America. *Limnology and Oceanography* **1996**, *41*, 882-889, https://doi.org/10.4319/lo.1996.41.5.0882.
51. Abu-Zied, R.H.; Keatings, K.W.; Flower, R.J. Environmental controls on foraminifera in Lake Qarun, Egypt. *The Journal of Foraminiferal Research* **2007**, *37*, 136-149, https://doi.org/10.2113/gsjfr.37.2.136.
52. Meshal, A.H. The problem of the salinity increase in Lake Qarun (Egypt) and a proposed solution. *ICES Journal of Marine Science* **1977**, *37*, 137-143, https://doi.org/10.1093/icesjms/37.2.137.
53. Rasmy, M.; Estefan, S.F. Geochemistry of saline minerals separated from Lake Qarun brine. *Chemical Geology* **1983**, *40*, 269-277, https://doi.org/10.1016/0009-2541(83)90033-5.
54. Baioumy, H.M.; Kayanne, H.; Tada, R. Reconstruction of lake-level and climate changes in Lake Qarun, Egypt, during the last 7000years. *Journal of Great Lakes Research* **2010**, *36*, 318-327, https://doi.org/10.1016/j.jglr.2010.03.004.
55. Rhodes, T.E.; Gasse, F.; Lin, R.; Fontes, J.-C.; Wei, K.; Bertrand, P.; Gibert, E.; Mélières, F.; Tucholka, P.; Wang, Z.; Cheng, Z.-Y. A Late Pleistocene-Holocene lacustrine record from Lake Manas, Zunggar (northern Xinjiang, western China). *Palaeogeography, Palaeoclimatology, Palaeoecology* **1996**, *120*, 105-121, https://doi.org/10.1016/0031-0182(95)00037-2.
56. Sallam, E.S.; Abd El-Aal, A.K.; Fedorov, Y.A.; Bobrysheva, O.R.; Ruban, D.A. Geological heritage as a new kind of natural resource in the Siwa Oasis, Egypt: The first assessment, comparison to the Russian South, and sustainable development issues. *Journal of African Earth Sciences* **2018**, *144*, 151-160, https://doi.org/10.1016/j.jafrearsci.2018.04.008.
57. Salman, S.; Abu El Ella, E.; Seleem, E.-M.; Elnazer, A. Groundwater quality and environmental investigations in Siwa Oasis, Egypt. *International Journal of Recent Advances in Multidisciplinary Research* **2018**, *5*, 3951-3958,
58. Abdel-Malek, S.A.; Ishak, M.M. Some ecological aspects of Lake Qarun, Fayoum, Egypt. Part II. Production of plankton and benthic organisms. *Hydrobiologia* **1980**, *75*, 201-208.
59. Abd Ellah, G.R. Physical Limnology of Fayoum Depression and Their Budget. Ph. *D. Thesis. Faculty of Sciences, South Valley University, Aswanm***1999**, *140.*
60. Ali, M. Distribution of nitrogen cycle bacteria in relation to physicochemical conditions of a closed saline lake (Lake Qarun, Egypt). *J. Egypt. Acad. Soc. Environ. Dev* **2004**, *5*, 145-167.
61. Ali, M.H.H. *Impact of agricultural and sewage effluents on the ecosystem of Lake Qarun, Egypt*. **2002**.

62. Abdel-Satar, A.M.; Goher, M.E.; Sayed, M.F. Recent environmental changes in water and sediment quality of Lake Qarun, Egypt. *Journal of Fisheries and Aquatic Science* **2010**, *5*, 56-69, https://doi.org/10.3923/jfas.2010.56.69.
63. El-Agri, M. Heavy Metal Bioaccumulation and Related Histopathological Changes in Gills, Liver and Muscle of Solea aegyptiaca Fish Inhabiting the Lake Qarun, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries* **2021**, *25*, 159-183.
64. Goher, M.E.M., Chemical studies on the precipitation and dissolution of some chemical elements in Qaroun Lake. *Ph.D. thesis. Faculty of Science, AL-Azhar University, Cairo, Egypt* **2002**, *359*.
65. El-Sayed, S.A.; Moussa, E.M.M.; El-Sabagh, M.E.I. Evaluation of heavy metal content in Qaroun Lake, El-Fayoum, Egypt. Part I: Bottom sediments. *Journal of Radiation Research and Applied Sciences* **2015**, *8*, 276-285, https://doi.org/10.1016/j.jrras.2015.02.011.
66. Zaghloul, K.H.; Omar, W.A.; Abdel-Khalek, A.A.; Abo-Hegab, S. Ecological monitoring of Mediterranean Solea aegyptiaca transplanted into Lake Qaroun, Egypt. *Aust J Basic Appl Sci* **2011**, *5*, 851-862.
67. Atashi, H.; Sarkari, M.; Zeinali, M.; Aliabadi, H.Z. Recovery of Magnesium chloride from resulting potash unit concentrate case study: Iran Great Desert Brine. *Australian Journal of Basic and Applied Sciences* **2010**, *4*, 4766-4771.
68. Estefan, S.F.; Nassif, E.H. Recovery of valuable mineral salts from Lake Qarun. *The Chemical Engineering Journal* **1976**, *11*, 239-240, https://doi.org/10.1016/0300-9467(76)80047-0.
69. Estefan, S.F.; Awadalla, F.T.; Yousef, A.A. Process technology for recovery of magnesia from brines. *Powder Technology* **1980**, *27*, 233-240, https://doi.org/10.1016/0032-5910(80)85028-5.
70. Kawahara, T. Construction and operation experience of a large-scale electrodialysis water desalination plant. *Desalination* **1994**, *96*, 341-348, https://doi.org/10.1016/0011-9164(94)85184-0.
71. Lartey, R.B. Recovery of useful chemicals from local salt bitterns. *Journal of Applied Science and Technology* **1997**, *2*, 77-84, https://doi.org/10.4314/jast.v2i1-2.47100.
72. Fishar, M.R.A.; Ali, M.H.H. Accumulation of trace metals in some benthic invertebrate and fish species revelant to their concentration in water and sediment of lake Qarun, Egypt. *J. Aquat. Res.* **2005**, *31*, 289-302.
73. Tanaka, Y. Regularity in ion-exchange membrane characteristics and concentration of sea water. *Journal of Membrane Science* **1999**, *163*, 277-287, https://doi.org/10.1016/S0376-7388(99)00169-6.
74. Turek, M.; Dydo, P. Hybrid membrane-thermal versus simple membrane systems. *Desalination* **2003**, *157*, 51-56, https://doi.org/10.1016/S0011-9164(03)00382-5.
75. Turek, M.; Dydo, P.; Klimek, R. Salt production from coal-mine brine in NF — evaporation — crystallization system. *Desalination* **2008**, *221*, 238-243, https://doi.org/10.1016/j.desal.2007.01.080.
76. Saad, A.-N.; Abass, I.M.; Badr El-Din, S.M.; Mohamed, F.H.; El-Shamy, A.M. Use of Fungal Biomass in Batch and Continuous Flow Systems for Chromium (VI) Recovery. *African Journal of Mycology and Biotechnology* **1997**, *5*, 37-47.
77. Sherif, E.-S.M.; El Shamy, A.M.; Ramla, M.M.; El Nazhawy, A.O.H. 5-(Phenyl)-4H-1,2,4-triazole-3-thiol as a corrosion inhibitor for copper in 3.5% NaCl solutions. *Materials Chemistry and Physics* **2007**, *102*, 231-239, https://doi.org/10.1016/j.matchemphys.2006.12.009.
78. Alkharafi, F.M.; El-Shamy, A.M.; Ateya, B.G. Comparative effects of tolytriazole and benzotriazole against sulfide attack on copper. *Int. J. Electrochem. Sci* **2009**, *4*, 1351-1364.
79. El-Meleigy, A.E.; Youssef, G.I.; El-Shayeb, H.A.; El-Shamy, A.M. Corrosion and corrosion protection of aluminum in hydrochloric acid by using piperidine. *Ochrona przed Korozją* **2014**, 66-71.
80. Sherif, E.-S.M.; Abbas, A.T.; Gopi, D.; El-Shamy, A.M. Corrosion and Corrosion Inhibition of High Strength Low Alloy Steel in 2.0 M Sulfuric Acid Solutions by 3-Amino-1,2,3-triazole as a Corrosion Inhibitor. *Journal of Chemistry* **2014**, *2014*, 1-8, http://dx.doi.org/10.1155/2014/538794.
81. El-Shamy, A.M.; Zakaria, K.; Abbas, M.A.; Zein El Abedin, S. Anti-bacterial and anti-corrosion effects of the ionic liquid 1-butyl-1-methylpyrrolidinium trifluoromethylsulfonate. *Journal of Molecular Liquids* **2015**, *211*, 363-369, https://doi.org/10.1016/j.molliq.2015.07.028.
82. El-Shamy, A.M.; Soror, T.Y.; El-Dahan, H.A.; Ghazy, E.A.; Eweas, A.F. Microbial corrosion inhibition of mild steel in salty water environment. *Materials Chemistry and Physics* **2009**, *114*, 156-159, https://doi.org/10.1016/j.matchemphys.2008.09.003.
83. El-Meleigy, A.E.; Youssef, G.I.; El-Shayeb, H.A.; El-Shamy, A.M. Corrosion and corrosion protection of aluminum in hydrochloric acid by using piperidine. *Ochrona przed Korozją* **2014**, 66-71.
84. El-Shamy, A.M.; Shehata, M.F.; Gaballah, S.T.; Elhefny, E.A. Synthesis And Evaluation Of Ethyl (4-(N-(Thiazol-2-Yl) Sulfamoyl) Phenyl)Carbamate (Tspc) As A Corrosion Inhibitor For Mild Steel In 0.1m Hcl. *Journal Of Advances In Chemistry* **2015**, *11*, 3441-3451, https://doi.org/10.24297/jac.v11i2.2212.
85. Farag, H.K.; El-Shamy, A.M.; Sherif, E.M.; Zein El Abedin, S. Sonochemical Synthesis of Nanostructured ZnO/Ag Composites in an Ionic Liquid. *Zeitschrift für Physikalische Chemie* **2016**, *230*, 1733-1744, https://doi.org/10.1515/zpch-2016-0777.
86. El-Shamy, A.M.; Elkarim, M.A.A.; Kalmouch, A. Mitigation of Sulfide Attach on α-Brass Surface by Using Sodium (Z)-4-Oxo-4-p-Tolyl-2-Butenoate. *J Chem Eng Process Technol* **2016**, *7*, 1-7, http://dx.doi.org/10.4172/2157-7048.1000273.

87. El-Shamy, A.M.; El-Boraey, H.A.; El-Awdan, H.F. Chemical treatment of petroleum wastewater and its effect on the corrosion behavior of steel pipelines in sewage networks. *J. Chem. Eng. Process. Technol* **2017**, *8*, https://doi.org/10.4172/2157-7048.1000324.
88. Reda, Y.; El-Shamy, A.M.; Eessaa, A.K. Effect of hydrogen embrittlement on the microstructures of electroplated steel alloy 4130. *Ain Shams Engineering Journal* **2018**, *9*, 2973-2982, https://doi.org/10.1016/j.asej.2018.08.004.
89. El-Shamy, A.M.; Abdelfattah, I.; Elshafey, O.I.; Shehata, M.F. Potential removal of organic loads from petroleum wastewater and its effect on the corrosion behavior of municipal networks. *Journal of Environmental Management* **2018**, *219*, 325-331, https://doi.org/10.1016/j.jenvman.2018.04.074.
90. El-Shamy, A.M. Fabrication of Commercial Nanoporous Alumina by Low Voltage Anodizing. *Egyptian Journal of Chemistry* **2018**, *61*, 175-185, https://doi.org/10.21608/ejchem.2017.2189.1175.
91. Abdel-Karim, A.M.; El-Shamy, A.M.; Megahed, M.M.; Kalmouch, A. Evaluation the inhibition efficiency of a new inhibitor on leaded bronze statues from Yemen. *Arct J* **2018**, *71*, 2-33.
92. Zohdy, K.M.; El-Shamy, A.M.; Kalmouch, A.; Gad, E.A.M. The corrosion inhibition of (2Z,2′Z)-4,4′-(1,2-phenylene bis(azanediyl))bis(4-oxobut-2-enoic acid) for carbon steel in acidic media using DFT. *Egyptian Journal of Petroleum* **2019**, *28*, 355-359, https://doi.org/10.1016/j.ejpe.2019.07.001.
93. Shehata, M.; El-Shafey, S.; Ammar, N.A.; El-Shamy, A.M. Reduction of Cu+2 and Ni+2 Ions from Wastewater Using Mesoporous Adsorbent: Effect of Treated Wastewater on Corrosion Behavior of Steel Pipelines. *Egyptian Journal of Chemistry* **2019**, *62*, 1587-1602, https://doi.org/10.21608/ejchem.2019.7967.1627.
94. El-Kashef, E.; El-Shamy, A.M.; Abdo, A.; Gad, E.A.M.; Gado, A.A. Effect of Magnetic Treatment of Potable Water in Looped and Dead End Water Networks. *Egyptian Journal of Chemistry* **2019**, *62*, 1467-1481, https://doi.org/10.21608/ejchem.2019.7268.1595.
95. Shehata, M.F.; El-Shamy, A.M.; Zohdy, K.M.; Sherif, E.-S.M.; Zein El Abedin, S. Studies on the Antibacterial Influence of Two Ionic Liquids and their Corrosion Inhibition Performance. *Applied Sciences* **2020**, *10*, https://doi.org/10.3390/app10041444.
96. Reda, Y.; El-Shamy, A.M.; Zohdy, K.M.; Eessaa, A.K. Instrument of chloride ions on the pitting corrosion of electroplated steel alloy 4130. *Ain Shams Engineering Journal* **2020**, *11*, 191-199, https://doi.org/10.1016/j.asej.2019.09.002.
97. Reda, Y.; Zohdy, K.M.; Eessaa, A.K.; El-Shamy, A.M. Effect of Plating Materials on the Corrosion Properties of Steel Alloy 4130. *Egyptian Journal of Chemistry* **2020**, *63*, 579-597, https://doi.org/10.21608/ejchem.2019.11023.1706.
98. Megahed, M.M.; Youssif, M.; El-Shamy, A.M. Selective Formula as A Corrosion Inhibitor to Protect the Surfaces of Antiquities Made of Leather-Composite Brass Alloy. *Egyptian Journal of Chemistry* **2020**, *63*, 5269-5287, https://doi.org/10.21608/ejchem.2020.41575.2841.
99. El-Shamy, A.M. A Review on: Biocidal Activity of Some Chemical Structures and Their Role in Mitigation of Microbial Corrosion. *Egyptian Journal of Chemistry* **2020**, *63*, 5251-5267, https://doi.org/10.21608/ejchem.2020.32160.2683.
100. Mo’men, M.; Alib, A.M.; El-Shamy, W.A. Solitary Formula for Commercial Use as Corrosion Inhibitor Related to Tubing Corrosion in Production Wells of Oil and Gas Industry. *Int. J. Scient. & Eng. Res*. **2020**, *11*, 268-279.
101. El-Shamy, A.M.;nMohamed, F.A.; Saad, W.M.A.; El-Bindary, A. Theoretical Modeling and Electrochemical Behavior of Corrosion and Microbial Corrosion of Carbon Steel Pipelines. *Int. J. Scien. & Eng. Res*. **2020**, *11*, 1599-1608.
102. Zohdy, K.M.; El-Sherif, R.M.; Ramkumar, S.; El-Shamy, A.M. Quantum and electrochemical studies of the hydrogen evolution findings in corrosion reactions of mild steel in acidic medium. *Upstream Oil and Gas Technology* **2021**, *6*, https://doi.org/10.1016/j.upstre.2020.100025.
103. Abbas, M.A.; Zakaria, K.; El-Shamy, A.M.; Abedin, S.Z.E. Utilization of 1-butylpyrrolidinium Chloride Ionic Liquid as an Eco-friendly Corrosion Inhibitor and Biocide for Oilfield Equipment: Combined Weight Loss, Electrochemical and SEM Studies. *Zeitschrift für Physikalische Chemie* **2021**, *235*, 377-406, https://doi.org/10.1515/zpch-2019-1517.
104. El-Shamy, A.M.; Abdo, A.; Gad, E.A.M.; Gado, A.A.; El-Kashef, E. The consequence of magnetic field on the parameters of brackish water in batch and continuous flow system. *Bulletin of the National Research Centre* **2021**, *45*, https://doi.org/10.1186/s42269-021-00565-3.
105. Reda, Y.; Abdelbar, M.; El-Shamy, A.M. Fortification performance of polyurethane coating in outdoor historical ironworks. *Bulletin of the National Research Centre* **2021**, *45*, https://doi.org/10.1186/s42269-021-00532-y.
106. Zohdy, K.M.; El-Sherif, R.M.; El-Shamy, A.M. Corrosion and Passivation Behaviors of Tin in Aqueous Solutions of Different pH. *Journal of Bio- and Tribo-Corrosion* **2021**, *7*, https://doi.org/10.1007/s40735-021-00515-6.
107. El-Shamy, A.M.; Abdel Bar, M.M. Ionic Liquid as Water Soluble and Potential Inhibitor for Corrosion and Microbial Corrosion for Iron Artifacts. *Egyptian Journal of Chemistry* **2021**, *64*, 1867-1876, https://doi.org/10.21608/ejchem.2021.43786.2887.

108. Megahed, M.M.; Abdel Bar, M.M.; Abouelez, E.s.M.; El-Shamy, A.M. Polyamide Coating as a Potential Protective Layer Against Corrosion of Iron Artifacts. *Egyptian Journal of Chemistry* **2021**, *64*, 3-4, https://doi.org/10.21608/ejchem.2021.70550.3555.