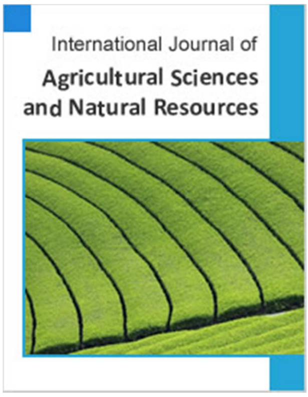
International Journal of Agricultural Sciences and Natural Resources
2017; 4(5): 32-42
http://www.aascit.org/journal/ijasnr
ISSN: 2375-3773

American Association for Science and Technology



Keywords
Agriculture Reclamation, Aquaculture, Saline-sodic Clayey Soil, Comparative Analysis

Received: September 17, 2017
Accepted: November 1, 2017
Published: November 16, 2017

Comparative Analysis of Using Aquaculture Versus Agriculture Land Reclamation in Saline-Sodic Clayey Soils in Tina Plain Area of Egypt

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Citation
Gehan Abdel Hakeem Sallam. Comparative Analysis of Using Aquaculture Versus Agriculture Land Reclamation in Saline-Sodic Clayey Soils in Tina Plain Area of Egypt. *International Journal of Agricultural Sciences and Natural Resources.* Vol. 4, No. 5, 2017, pp. 32-42.

Abstract
In Egypt, the limited water resources are the important factors that affect the decisions of the policy makers in determining the recommended reclamation strategies that would be applied in saline-sodic clayey soils in Tina plain area of Egypt. Therefore the main objective of this study is to apply a multi-criteria comparative analysis for the two strategies to help the policy makers to determine the most appropriate strategy. The evaluation was based on different criteria. Three main categories of evaluation criteria were used include: hydrology conditions, soil characteristics and socio-economic conditions. The study showed that the agriculture reclamation strategy is the most suitable for land reclamation of saline-sodic clayey soils in Tina Plain area of Egypt as compared with other reclamation strategies, without negative impacts.

1. Introduction

To relieve the pressure on the Nile Valley and Delta, the government has embarked on an ambitious programme to increase the inhabited area in Egypt by means of horizontal expansion projects in agriculture. All these developments require water. Therefore, the Ministry of Water Resources and Irrigation (MWRI) has constructed the El-Salam canal project to bring Nile water to the North Sinai region, with the primary objective of developing agricultural settlement [1]. The North Sinai developing project envisages the reclamation of an estimated area of 620,000 feddans (1 feddan = 0.42 hectare), about 400,000 feddans of this area is located in North Sinai, to the immediate east of the Suez Canal [2].

Tina plain area of North Sinai developing project is one of the three regions of the reclamation areas under El-Salam canal project and representing the first region of the project with an area of about 50,000 feddans. The soil texture in Tina Plain area varies from sand to heavy clay soil [3]. The initial soil salinity in the most area is ranged between 100 and 125 dS/m [4].

In Egypt, about 2.38 million feddans (33%) of the total irrigated lands is infested with salinity problems and belongs to salt-affected soils [5]. In Tina Plain area, soil salinity is the major soil limitation factor for agricultural production. Soil salinity is divided into two main categories: naturally occurring dry-land salinity and human-induced salinity caused by low quality water [6]. The saline-sodic clayey soils in Tina Plain area is caused by high groundwater table and high temperature that led to the salinisation of the soil profile to extremely high levels. The high salinity of the groundwater table led to the formation of salt crusts and increased the soil sodium content [7]. Increased attention has been given to reclaim, improve and manage saline-sodic clayey soils to solve salinity problems and achieve optimal crop production [8]. Salinity in clayey soils is seen as one of the most serious environmental and resource management problems. It has many environmental, economic and social impacts.

2. Problem Definition and Research Objective

Resources use conflict (land and water) and the limited water resources are the important factors that affect the decisions of the policy makers in determining the recommended leaching and reclamation strategies that would be applied in Tina plain area.

In terms of Government policy, aquaculture provides the land and water use of last resort. It is confined by law to lands which are unsuitable for any other purpose. The General Authorities for Fisheries Resources Development (GAFRD) is responsible for giving licenses to establish fish farms. Except for a very limited number of isolated instances, most aquaculture activities are located in the Nile Delta Region as shown in Figure 1 [9]. The total area of permanent fish farms (lands invalid for agricultural uses) is estimated at 180,000 feddans, which represent about 3.3% of the total area of agricultural land (8.6 million feddans). Almost an equal area is used for temporary aquaculture activities [10].

On the other hand, the development and expansion of modern aquaculture began in Egypt two decades ago [11]. Egypt is Africa's largest aquaculture producing country [12]. In 2012, Egypt was one of the top ten aquaculture producers [9]. Most of the aquaculture production is derived from semi-intensive fish farms in earthen ponds. Size of earthen ponds fish farms have increased from 1998. Fish ponds vary in size from 1 to 25 feddan [10]. The contribution of state owned farms to aquaculture production has declined, while privately managed farms production increased. The reasons for leading role of private farms are the flexibility in management and increasing private farms size [13]. Spatial planning for aquaculture zoning, site selection and the design of aquaculture management areas should consider the social, economic, environmental and governance objectives of sustainable development. This is especially relevant when aquaculture takes place in common properties such as shared water resources [14].

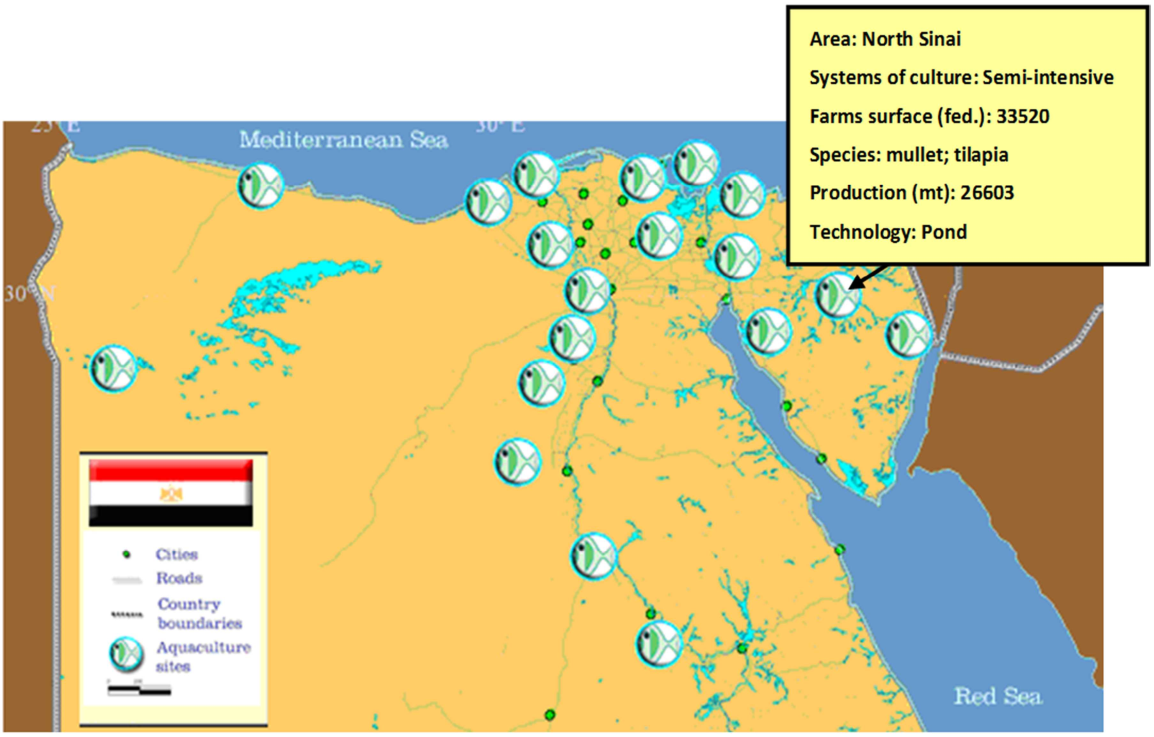

Figure 1. *Distribution of the main aquaculture production sites in Egypt [9].*

The area in the most Northern part of Tina Plain (Figure 2) is considered to be unsuitable for agriculture, and was allocated permanently for aquaculture in 1996. Several farms were leased to farmers via the Egyptian Fishing Company and GAFRD. The area has good potential for aquaculture production, but requires substantial engineering work by GAFRD to provide adequate sea water supplies and drainage [15].

In the southern part of Tina Plain (Figure 2) the MWRI leases land directly to farmers. The land is intended for agricultural production irrigated by Nile water from El-Salam canal. The farmers undertake to recover the land for this purpose, using water from the Canal to leach the soils. A grace period of four years was provided to undertake this process. It is apparent that there are several possible solutions to agricultural reclaim strategy and improvement of the problematic clayey soils. These solutions include leaching process with or without amendments and reclamation processes to improve the properties and the hydraulic conductivity of the soil [5]. The main factor in this reclamation process is drainage to drain the excess water and leach salts from the soil profile. It is clear that these solutions are dependent on each other and it is necessary to combine to improve the heavy clay soils [8].

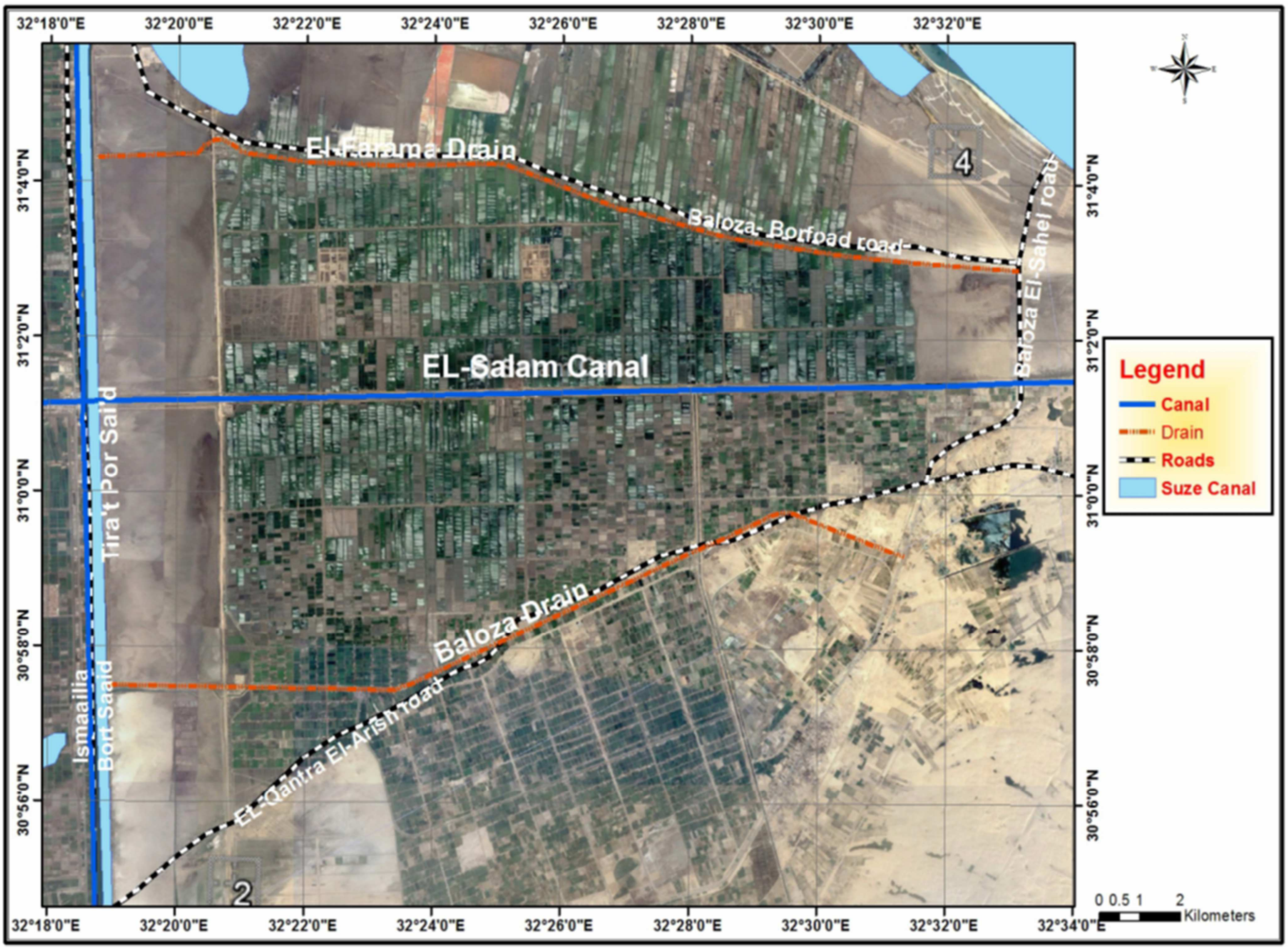

Figure 2. *Tina Plain Area of Egypt.*

However, much of the land has been sub-let and used for (unlicensed) aquaculture production, since this is one way of generating cash flow in the much shorter term. Although resisted by the farmers (who in many cases have rented small plots as fish farms from the primary lease-holder) the MWRI intends to return this land to agricultural use.

According to this conflict and given the likelihood of more limited water supplies in the future and the increasing need to grow much needed food with less water, the researches should plan to develop appropriate strategies for different types of less favored lands and irrigation water. Research aims at increasing the productivity of all crops per unit of both land and water will be vital in the future.

Therefore the main objective of this study is to apply a multi-criteria comparative analysis for the two strategies, agriculture and aquaculture, as a land leaching and reclamation strategy for saline-sodic clayey soils in Tina Plain area to help the policy makers to determine the most appropriate strategy to be applied in this area.

3. Materials and Methods

The basic principles of a multi-criteria comparative analysis are: set the evaluation criteria and give priority to each criterion, determination of scores of each criterion for each strategy, and application of the selected multi-criteria evaluation technique [16]. The overall balance of the evaluation criteria of the two strategies, agriculture and aquaculture, as a land leaching and reclamation strategy for saline-sodic clayey soils cannot be satisfactorily determined in many cases. Therefore, besides field experiments expertise in general is the best way to predict or diagnose the impacts. To achieve this approach, the study was conducted in two main steps. The first one is the experimental field work that was formulated to obtain measured data necessary to evaluate and assess the evaluation criteria of the two strategies. The second step is to design a questionnaire to evaluate the different suggested evaluation criteria through discussion with several experts and allocate a priority (weight) for each criterion. Different evaluation criteria were suggested to cover the physical, environmental and economic conditions of each alternative strategy. The main evaluation criteria that could be considered include changes in soil salinity through the soil profile, water requirements and socio-economic.

The study was conducted in an experimental field of saline-sodic clayey soil in Tina plain area of North Sinai developing project to apply the most appropriate recommended agriculture reclamation strategy, intermittent leaching and surface drainage, and compare its results with the surrounding areas that applied aquaculture reclamation strategy. The experimental field was selected to represent the saline heavy clay soil in Tina Plain area. It has an actual area of about 60 feddans. It is located in the western part of Tina Plain area. The experimental area was divided into four units (A, B, C and D). Each unit has six plots with equal areas. Total area of Unit A is (37,195 m^2), Unit B (48,816 m^2), Unit C (39,160 m^2) and Unit D (49,720 m^2). Soil properties were determined for two locations in each plot of the four units with total number of 48 samples. The main properties of the field (Table 1) indicated that it is characterised with saline heavy clay soil with average clay content (56.43%) and soil salinity (EC 380 dS/m). Due to high clay content, it has poor drainage conditions, 30 cm of surface salt crust, and shallow saline groundwater.

From the study area characteristics it was realistic that the most appropriate strategy for the first stage of agricultural reclamation in the area is to apply intermittent leaching and surface drainage to remove the salt layer [17]. The intermittent leaching was applied with irrigation water pumped from El-Salam canal (EC 1.5 dS/m). The El-Salam canal water is mixed water from reused agricultural drainage water and fresh Nile water (1:1). The required network of surface irrigation canals and surface field drains was constructed in the area as shown in Figure 3.

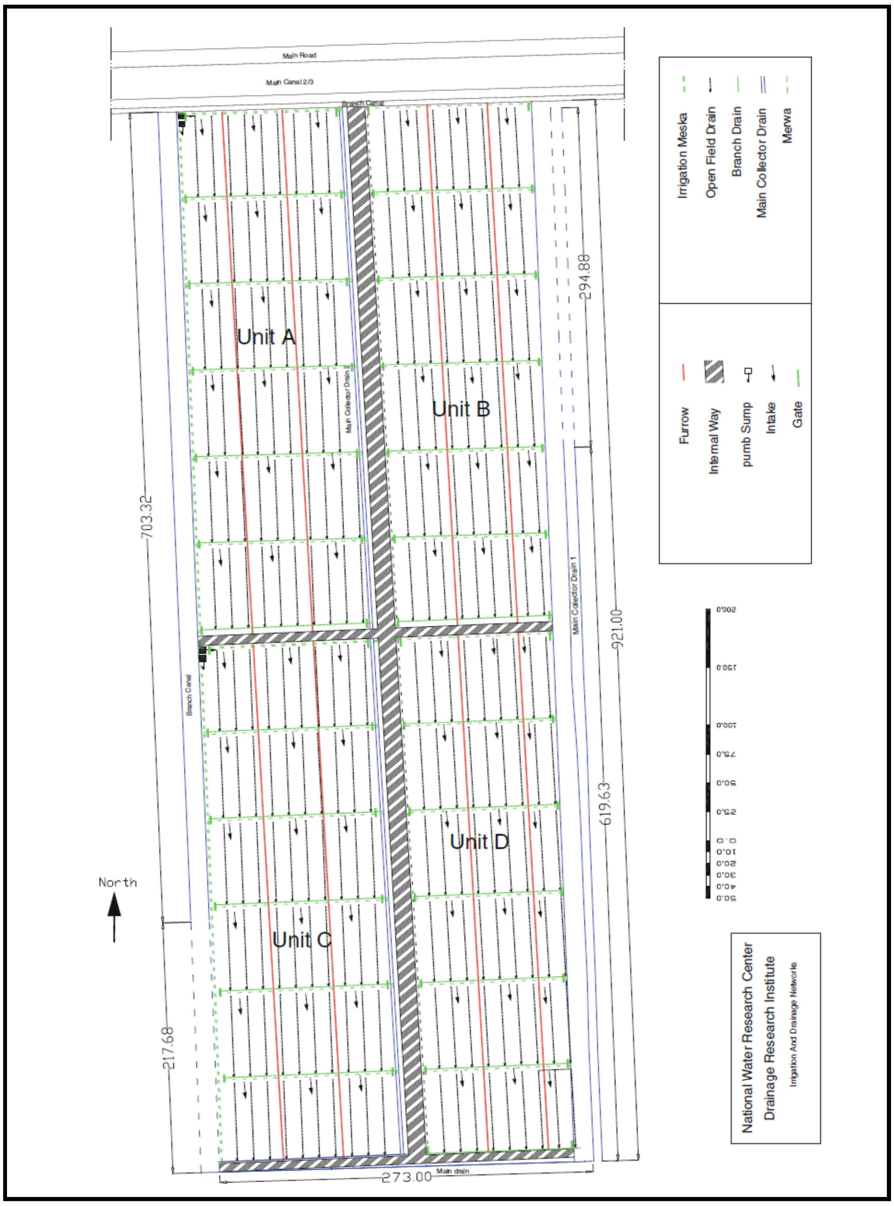

Figure 3. *Layout of the experimental field.*

Table 1. *Soil properties of the experimental area.*

Properties	Average value
ECe (Electrical conductivity of soil saturation extract in dS/m)	380
SARs (Sodium Adsorption Ratio of soil)	83
K (Soil hydraulic conductivity, m/day)	0.13
IR (Infiltration rate, cm/min)	0.02
ECiw (Salinity of irrigation water, dS/m)	1.5
WTD (Water table depth, m)	0.1
ECgw (EC of ground water, dS/m)	125

To apply the recommended reclamation strategy, each unit was provided with surface irrigation ditches and open field drains spaced at 10 m with depth of 100 cm. The leaching method was adopted to remove excess salts from the root zone or top soil layer through leaching water over the surface and applying of excess water, above that needed for evaporation, and allowing it to pass downwards to leach the soluble salts from the root zone through the field surface drains. According to the guidelines of Drainage Research Institute of leaching saline sodic clayey soils in Tina Plain Area, it was recommended to not apply gypsum amendment before the soil salinity decreased to about 16 dS/m [3]. Nevertheless, Gypsum amendment was added for one unit of the study area with amount of 4tons/feddan and mixed with the surface layer of soil (0-30 cm) to study its effect in the reclamation results. On the other hand, the Water Resources and Irrigation Sector of North Sinai recommended to not applying mechanical scrap off the top soil because of the problem of disposal of the large amounts of salt crusts results from this process unless there is a framework of large projects to benefit from these large amounts of salts [17].

4. Results and Discussion

A very important component of a multi-criteria comparative analysis is to construct an evaluation matrix where elements reflect the evaluation criteria of a given set of choice possibilities (reclamation strategies). Three main categories of evaluation criteria are used to evaluate the alternate reclamation strategies: hydrology conditions, soil characteristics and socio-economic conditions. Under each category, few most effective sub-criteria evaluation indicators are considered. Selection of the sub-criteria evaluation indicators is based on relevance, data availability, and possibility of quantification. The sub-criteria for hydrology conditions include sustainable water requirements, irrigation and drainage system condition, and water table variation. For soil characteristics, the sub-criteria include soil salinity, soil physical properties change and land reclamation. Finally, the socio-economic criteria are expressed through income (benefit cost ratio), job opportunities, resettlement, Population change, Women's role and Public awareness.

4.1. Soil Salinity

The soil salinity of the experimental area was measured after applying the recommended agriculture reclamation strategy of intermittent leaching and surface drainage and compares its results with the surrounding areas that applied aquaculture reclamation strategy.

4.1.1. Soil Salinity Change for Agriculture Reclamation Process

The leaching proceeded in the selected experimental area for about 15 months. The leaching rotation comprises the water application and the drainage. Water was applied to the experimental area to saturate sufficient depth of soil profile. The area was submerged with water for a period of about 10–15 days to permit the dissolution of salts. Then, the water is induced to flow through the soil profile, and as it does so, it leaches the excess salts away from the soil and transports it to the surface drainage system. The drainage process was extended for a period varied between 10 and 15 days. Soil samples from each unit were collected after each rotation of leaching at 25-cm intervals to 150-cm depth. Soil samples were analyzed to follow up the changes in soil salinity through the soil profile during leaching process.

The average variations in soil salinity for Units A, B, C and D of the area for the three soil depths 0-50, 50-100 and 100-150 cm are shown in Figures 4, 5 and 6 respectively. The soil salinity before leaching for the surface soil layer (0–50 cm) ranged from 360 to 560 dS/m with an average value of about 400 dS/m. On the other hand, the soil salinity for the other layer (50–100 cm) was ranged from 260 to 330 dS/m with an average value of 290 dS/m. For the last layer (100-150 cm), the soil salinity was ranged from 250 to 270 dS/m with an average value of 260 dS/m. After leaching process, which extended for 15 months (due to the limited time of the experiment), it was found that the soil salinity for surface layers is decreased to an average value of about 50 dS/m with leaching efficiency of 87%. In case of applying gypsum, it helps to increase the leaching efficiency of the surface layer with a percentage of 5%. For the other two layers, it was decreased to an average value of about 130 dS/m and 120 dS/m respectively with an average leaching efficiency of 60% with no effect of gypsum application.

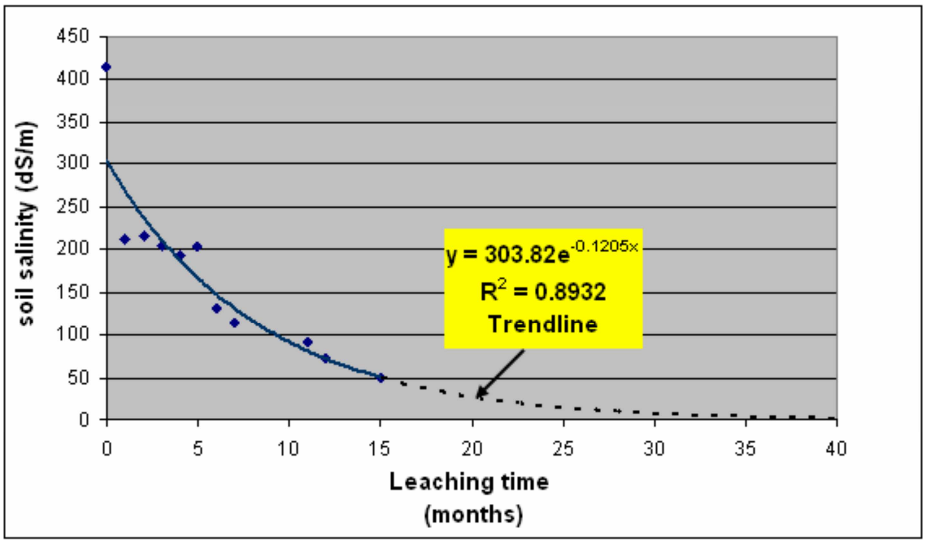

Figure 4. *Variation of soil salinity for soil surface layer (0–50 cm).*

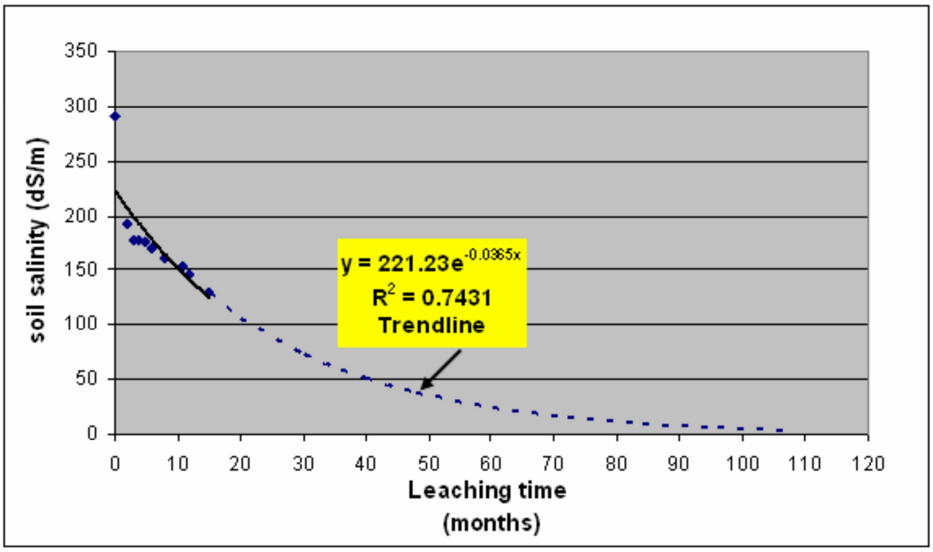

Figure 5. *Variation of soil salinity for soil surface layer (50–100 cm).*

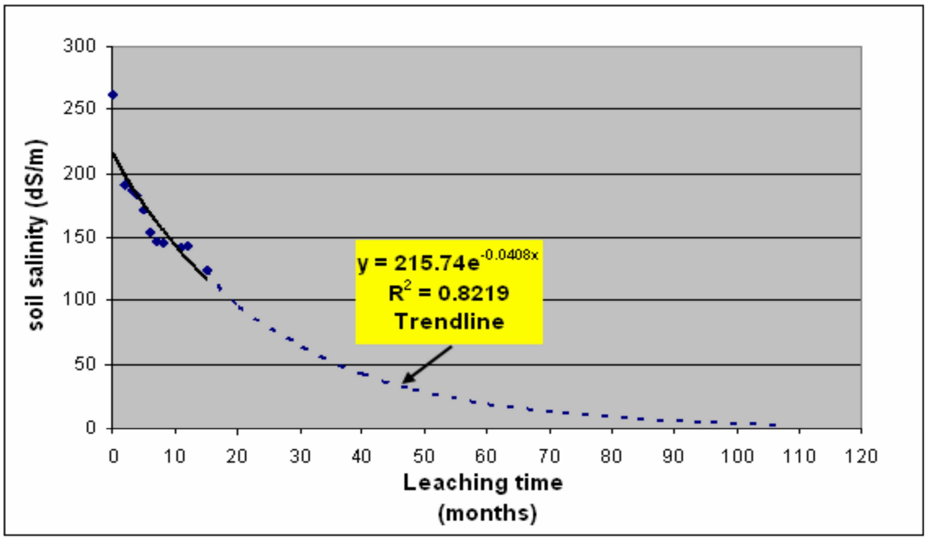

Figure 6. *Variation of soil salinity for soil surface layer (100–150 cm).*

Taking into account all factors which could together enhance soil ripening, structuring and leaching of the heavy clays soils it seems worthwhile to distinguish several stages in the planting process, going from a saline to a less saline production system. In the first stage, it should be concentrated on improvement of the first 10-20 cm of the profile so using of true halophytes (like amshout). After that, in the second stage ripening and structuring soil should be increased to 50- 60 cm. In this stage using of salt resistant/tolerant plants which improve the structure of the soil and soil fertility by nitrogen fixation is recommended. These plants like barely, alfalfa, rice, and grass species have strong root system making pores to improve leaching and stimulate biological activity and organic matter [17]. This stage could be applied after 24 months of leaching at which the soil salinity of the surface layer reached to about 16 dS/m as shown in Figure 4. After that, growth of less tolerant and more profitable crops like sugar beet, cotton and wheat is recommended. Development of sustainable cropping systems (crop rotations) is considered taking into account nutrient balances and organic matter input. From the trend line of Figure 4, it is predicted for soil salinity to reach the most appropriate value of 4 dS/m within 36 months of leaching. For the others two layers of 50-100 cm and 100-150 cm, from Figure 5 and Figure 6 respectively, it is clear that it could take about 65 months of leaching to achieve the soil salinity of 16 dS/m and 100 months to reach 4 dS/m.

4.1.2. Soil Salinity Change for Aquaculture Reclamation Process

Village 6 with an area of 600 feddans was investigated to measure the effect of aquaculture process in soil salinity. It is located in the surrounding areas of the experimental field. It was sub-let and used for (unlicensed) aquaculture production, nearly for 10 years, and then left fallow without any reclamation for about one year. Soil samples were collected from 60 locations (with grid system of 200 m) for two depths of 0-50 cm and 50-100 cm. Soil samples were analyzed to follow up the changes in soil salinity through the soil profile. It was found that the soil salinity before aquaculture production for the surface layer of 0-50 cm was ranged from 75 to 100 dS/m with an average value of 87 dS/m [2]. After aquaculture production, the soil salinity was ranged from 30 to 150 dS/m with increasing percentage of about 20% as shown in Figure 7. However, for the other soil layer of 50-100 cm, the soil salinity was changed from an average value of 112 dS/m to an average value of 220 dS/m with increasing percentage of about 95%.

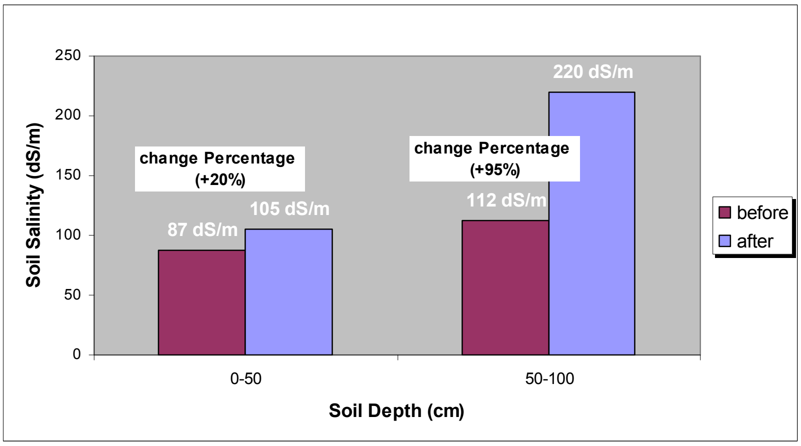

Figure 7. *Variation of soil salinity for aquaculture production.*

4.2. Water Requirements

The water requirements for each reclamation process were calculated in the base of the consumption quantity of water in cubic meter per feddan.

4.2.1. Water Requirements for Agriculture Reclamation Process

For agriculture reclamation, the leaching procedure with its two stages, submergence and drainage, was repeated for thirteenth times (rotations) in the four units of the experimental area over the period time of leaching (The area was submerged with water for a period of about 10–15 days and drained for a period varied between 10 and 15 days). The quantity of irrigation water that was pumped to each unit of the area was measured according to the discharge of the irrigation pumps in the area. The irrigation pumps in the area were calibrated to know its actual discharge. The discharge of each pump was equal to about 155m^3/hr.

The results revealed that the total quantities of water used for the thirteenth leaching rotations equal to about 42,500 m^3/feddan to achieve the leaching efficiency of 87% for soil surface layer (0-50 cm) and 60% for the other soil layers (50-150 cm). According to that, the first two years would take about 68,000 m^3/feddan for the leaching process with cultivating true halophytes. For the next two years, it would take about 22,880 m^3/feddan to cultivate plants which improve the structure of the soil and apply leaching during fallow periods between crops. Consequently, it would take about 90,880 m^3/feddan (65 m^3/day/feddan) through the four years of reclamation to achieve the target of agriculture reclamation and improve, ripening and structuring of the soil profile to the level of growing any type of crops.

4.2.2. Water Requirements for Aquaculture Reclamation Process

For aquaculture reclamation, the pond systems depend on constructed earthen ponds with size of about one feddan with higher dykes allowing water depths to reach 1.5–1.75 meters. Ponds have a higher rate of water renewal between 2–10 percent per day with an average of 6 percent per day for reused mixed water [18]. The total water requirements for aquaculture reclamation process included the water required to fill the total pond, the renewal water, the evaporation water from the free surface of the pond and finally the quantity of seepage water from the soil surface.

One rotation of fish production takes about 9 months (270 days) to complete. The rate of water renewal is taken as an average of 6 percent per day for reused mixed water. The evaporation rate in the semiarid region; like Tina Plain area; range between 0.4 to 0.8 cm/day, so the evaporation water quantity was calculated in the base of 0.6 cm/day. Finally, the seepage water depends on the soil type and the compaction of the side bank of the pond. Therefore, the seepage rate for the area as a heavy clay soil was assumed equal to 0.5 cm/day [19]. The total quantity of water consumption for one feddan in one rotation is equal to summation of quantity of water to fill the total pond, the quantity of renewal water, the quantity of evaporation water and finally the quantity of seepage water. This equal to about 120834 m^3/feddan (447.5 m^3/day/feddan). It is clear that the required water for aquaculture reclamation process take about 7 times of required water for agriculture reclamation.

4.3. Benefit Cost Analysis

The benefit cost analysis is considered as one of the main aspects of impact assessment. The benefit cost ratio (B/C) for the two reclamation strategies was measured to predict their returns within a reasonable period of time. In finance, net present value (NPV) analysis also is one of the most recommended methods of valuing a project. It is a measurement of profit calculated by subtracting the present values of cash outflows from the present values of cash inflows over a period of time. Incoming and outgoing cash flows can also be described as benefit and cost cash flows respectively [20]. NPV is calculated as following:

$$NPV = R_t / (1+i)^t \tag{1}$$

where: [t] is the time of the cash flow, [i] is the discount rate, [R_t] is the net cash flow

A benefit cost analysis was made along the grace period of the four years that was provided to farmers to undertake the reclamation process of the land. This was made through administration of structured questionnaire to the farmers to be able to get facts and figures on the input and output data. Table 2 shows the details of the cost, the net recovery and NPV of agriculture reclamation process. It was taking into consideration that only leaching process was applying in the first year with no cultivation. After that in the second year, to improve the structure of the soil and soil fertility, the area would be cultivated with true halophytes (like amshout). In the third year, a sustainable cropping system (crop rotations) is considered, so Barely as winter crop and Rice as summer crop would be cultivated. Finally, in the fourth year the area could be cultivated with Sugar Beet as winter crop and Rice as summer crop. The agricultural cost for crops includes many things such as the prices of seeds, land preparation, fertilizers, harvesting and transportation. The net recovery or the benefit is considered as the price of selling the crop yield. The net recovery or the benefit is calculated according to the average price of the cultivated crops yield as following:

$$B = q_{avg} \times p_{avg} \tag{2}$$

where: [B] is benefit, [q_{avg}] is average crop yield, and p_{avg} is average crop price

The average yield of rice crop in the area is equal to about 2 ton/fed with average price of 2000 LE/ton. For barley crop, the average yield equals to about 10 ardeb/fed (where 1 ardeb = 120 Kg) with average price of 400 LE/ardeb. Finally for sugar beet crop, the average yield equal about 15 ton/fed with average price of 400 LE/ton.

Finally the B/C ratio is calculated according to following equation:

$$B/C = TotalBenefit / TotalCost \tag{3}$$

Table 2. *Detailed Benefit Cost Analysis of Agriculture Reclamation Process.*

Reclamation year	Activities cost	Net Recovery	Cash flow	B/C	Present value
1st year Applying leaching process	4000 LE/fed (construction cost of infrastructure systems of irrigation and drainage) 1200 LE/fed (operation and maintenance cost of irrigation)	0	-5200	0	-5200
2nd year Continue leaching with amshout cultivation	1700 LE/fed (agricultural cost of amshout) 1200 LE/fed (operation and maintenance cost of irrigation)	500 LE/fed	-2400	0.17	-2285
3rd year Cultivate rice and barley	4330 LE/fed (agricultural cost of 2210 LE/fed for rice and 2120 LE/fed for barley) 600 LE/fed (operation and maintenance cost of irrigation)	8000 LE/fed	+3070	1.6	+2784
4th year Cultivate rice and sugar beet	5670 LE/fed (agricultural cost of 2210 LE/fed for rice and 3460 LE/fed for sugar beet) 500 LE/fed (operation and maintenance cost of irrigation)	10000 LE/fed	+3730	1.62	+3222

On the other hand, the production cost of aquaculture process includes many things such as construction cost of ponds, the prices of young fish species, feed cost, fertilizers, and extra cost (includes labor, fishery and transportation). The net recovery or the benefit is considered as the sales price of the fish yield. For Tilapia, the average yield equals to about 5 ton/fed with average price of 14000 LE/ton. For Mullet, the average yield equals to about 0.350 ton/fed with average price of 25000 LE/ton. Table 3 shows the details of the cost and the net recovery or the benefit of aquaculture reclamation process.

It is clear that the B/C ratio for the agriculture process is increasing gradually through the grace period of the four years from zero to about 1.6. However, for the aquaculture process, the B/C ratio is equal to about 2. The discounted cash flow results also indicated that, the NPV of agriculture process equals to -1479 LE/fed while the NPV of aquaculture process is equal to +147359 LE/fed.

Table 3. *Detailed Benefit Cost Analysis of Aquaculture Reclamation Process.*

Production process elements	Cost of element	Net Recovery	Cash flow	B/C	Present value
1st year - construction cost - prices of young fish species - feed cost - fertilizers - extra cost	2500 LE/fed 4000 LE/fed (Tilapia & Mullet) 30,000 LE/fed 500 LE/fed 4000 LE/fed (maintenance & operation cost of irrigation)	78750 LE/fed	+37750	1.9	37750
2nd year (same costs except construction cost)	38500 LE/fed	78750 LE/fed	+40250	2	38333
3rd year	38500 LE/fed	78750 LE/fed	+40250	2	36507
4th year	38500 LE/fed	78750 LE/fed	+40250	2	34769

Multi-Criteria Comparative Analysis

Multi-criteria comparative analysis provides the decision-makers with the best solution of a problem or with a ranked list of alternative solutions. The Multi-Criteria Analysis (MCA) does not necessarily require exact and accurate numbers and values for representing the criteria considered, but rather indicate the relative preference. The basic principles of a multi-criteria comparative analysis are: set the evaluation criteria and give priority to each criterion, determination of scores of each criterion for each strategy, and application of the selected multi-criteria evaluation technique. Weighted Average Method (WAM) is probably the easiest and most commonly used technique for the comparative evaluation of alternatives [21]. The basic component of WAM is called "simple multi-attribute procedures". The utility of each alternative U_j is determined by the summation of the weighted numerical values of each criterion as following:

$$U_j = \sum_{i=1}^{m} W_i S_{ij} \quad (4)$$

where: S_{ij} is standardized value of the score of each criterion in the evaluation matrix. The alternative which has the greatest utility is the best alternative. The standardization formula used in this study was described by Voogd, 1983 [21] as:

$$S_{ij} = \frac{(r_{ij}) - \min(r_{ij})}{\max(r_{ij}) - \min(r_{ij})} \quad (5)$$

where: r_{ij} is the score of each criterion for each alternative. This standardization method yields results where the highest level is equal to 1 and the lowest level is equal to 0.

A questionnaire was designed to evaluate the different suggested evaluation criteria through discussion with several specialists. A total 13 participants have been selected to allocate a priority (weight) for each criterion and to predict or diagnose the qualitative scores of the evaluation criteria that cannot be satisfactorily determined. Some interviews were arranged with the specialists to discuss with them the questions of the questionnaire and clear some points to help them to fill the questionnaire completely according to their expertise and make it effective to our comparative analysis. The participants were classified from different fields of professionalism that involved in this process to ensure various disciplines including: Sector of Water Resources; Irrigation and National infrastructure in North Sinai (MWRI), Central Directorate for Water Distribution (MWRI), Ground Water Research Institute (NWRC), Coastal Research Institute (NWRC), Drainage Research Institute (NWRC), Soil; Water & Environment Research Institute (MOA), Agricultural Economics Research Institute (AERI), Agricultural Economics Department of Faculty of Agriculture, Desert Research Institute, Central Laboratory for Aquaculture Research (CLAR) and Agriculture Applications; Soils and Marine Division of National Authority for Remote Sensing and Space Sciences (NARSS). Two more copies of the questionnaire were investigated with local farmers from the area as specialists to consider the social element of the public debates on ways and means to reclaim saline-sodic soils in Tina Plain area.

Priorities of the presented criteria were determined based on seven points scale method, and were found sufficient to allow people to express their preference adequately. In order to give this scale a meaning to the respondent, the principle of semantic differentia was used; one end of the scale has a score (7), which expresses the most important criterion and other end has a score (1) which expresses the unimportant criterion [21].

It was noticed from the weights recommended by specialists that the highest priorities were given to sustainable water requirements (ensure demand matches continuous supply), change in soil salinity and income. Statistical analysis was carried out using the average and the standardization technique of the different weights suggested to calculate the weights presented in Table 4.

Table 4. *Ranking Weights for Evaluation Criteria.*

Criteria	Sub-Criteria	Weight
Hydrology	Sustainable water requirements	7
	Irrigation and drainage system	5
	Water table variation	3
Soil Characteristics	Soil salinity	7
	Soil physical properties change	5
	Land reclamation	6
Socio-Economic Criteria	Income (benefit cost ratio B/C)	7
	Job opportunities	4
	Resettlement	6
	Population change	3
	Women's role	3
	Public awareness	5

Then qualitative scores for the different evaluation criteria are expressed in the form of expressions as *G* for good, *F* for fair and *P* for poor to reflect the evaluation of each criterion for the different alternatives. To convert the qualitative scores into quantitative scores, a scale range from 1-10 is given as basis for evaluating the different techniques [22]. Levels 10 and 1 represent the Good and Poor measurements respectively while for Fair measurements the score is 5.

The main hydrology parameter considered in the evaluation matrix is sustainable water requirements for each reclamation process which was equal to about 90,880 m^3/feddan (65 m^3/day/feddan) for agriculture reclamation and 120834 m^3/feddan (447.5 m^3/day/feddan) for aquaculture reclamation which equal to about 7 times of the required water for agriculture reclamation. So for agriculture reclamation, it has score *G* and for aquaculture reclamation, it has score *P*. Moreover for irrigation and drainage system in the area, in the case of aquaculture reclamation, it would require redesign and reconstruct to face the increasing water requirements and drainage recharge. This means that it has negative impact and consequently score *P*.

For soil characteristics, it was found that after leaching process of agriculture reclamation which extended for 15 months, the soil salinity for surface layers was decreased with percentage of about 87% and for the other two layers decreased with percentage of about 55%. On the other hand, the soil physical properties represented by hydraulic conductivity and infiltration rate are improved so it has score *G*. The hydraulic conductivity increased from 0.13 m/day to about 0.16 m/day and the infiltration rate increased also from 0.02 cm/min to about 0.06 cm/min. For the aquaculture reclamation, it was found that soil salinity of the surface layer was increased with a percentage of about 20%. For the other layers it was increased with a percentage of about 95%. The soil also continues to be saturated that leads to decrease the soil physical properties. So, it has negative impact and score *P*.

The B/C ratio for the agriculture process is increasing gradually through the grace period of the four years from zero to about 1.6 and has NPV equal to -1479 LE/fed so, it has score *F*. However, for the aquaculture process, the B/C equal to 2 and has NPV equal to +147359 LE/fed so, it has score *G*. The score for each reclamation strategy is presented in the evaluation matrix shown in Table 5 as a scale range from 1-10.

Finally, the utility of each alternative U_j is determined by applying equation 1 and equation 2 to develop the appraisal matrix. Summing all the scores for each reclamation strategy, the one with the maximum score is considered the best strategy as shown in the following equation:

$$[W]_{1*j}\,[S]_{i*j} = [U]_{1*i} \qquad (6)$$

where: $[W]_{1*j}$ is the Weighing vector,
$[S]_{i*j}$ is the Standardization matrix, and
$[U]_{1*i}$ is the Appraisal matrix

$$\left[7\&5\&3 \quad 7 \quad 5 \quad 6 \quad 7 \quad 4 \quad 6 \quad 3 \quad ■(3\&5] \right] \begin{bmatrix} 1.0 & 0 \\ 1.0 & 0 \\ 0.7 & 0 \\ 1.0 & 0 \\ 0.7 & 0 \\ 1.0 & 0 \\ 0.4 & 1.0 \\ 0.7 & 0.7 \\ 1.0 & 0.4 \\ 0.7 & 0.4 \\ 0.7 & 0 \\ 1.0 & 0.4 \end{bmatrix} = [51.4 \quad 15.4]$$

The results of the appraisal matrix approved that the agriculture reclamation strategy is the best with scores of 51.4 versus scores of 15.4 for aquaculture reclamation strategy for Saline-Sodic Clayey Soils.

Table 5. *Evaluation Scores Matrix.*

Evaluation Criteria	Agriculture Reclamation	Aquaculture Reclamation
Sustainable water requirements	10	1
Irrigation and drainage system	10	1
Water table variation	7	1
Soil salinity	10	1
Soil physical properties change	7	1
Land reclamation	10	1
Income (benefit cost ratio B/C)	7	10
Job opportunities	7	7
Resettlement	10	5
Population change	7	5
Women's role	7	1
Public awareness	10	5

5. Conclusion

The study showed that the agriculture reclamation strategy is the most suitable for land reclamation in saline-sodic clayey soils in Tina Plain area of Egypt with scores of 53.5 without negative impact on soil and infrastructure of the area. It could decrease the soil salinity to about 4 dS/m within 36 months of leaching with a quantity of water equal to 65 m^3/day/feddan. On the other hand, the aquaculture reclamation strategy has scores of 15.4 with negative impacts on soil, water availability, infrastructure of the area and resettlement which is the main political objective of the reclamation process in the area.

This gives major indicator that agriculture reclamation process have high positive impact on environmental and aquaculture reclamation process have low value comparing with the positive value of agriculture reclamation process in the case of saline-sodic clayey soils.

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