Chapter VI

Role of Artemia in salt quality and quantity enhancement
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ROLE OF ARTEMIA IN SALT QUALITY AND QUANTITY ENHANCEMENT

6.1. Introduction

Solar salt works are widely known chemical plants, mainly because of their product called sodium chloride (NaCl), the chemical substance which is most related to the history of civilization. Producing salt from sea water involves the selective recovery of pure sodium chloride, free of other soluble and insoluble salts and other substances. For this purpose, sea water is concentrated through natural evaporation which leads to fractional crystallization of all the salt present, a process based on their varying solubility. The evaporation of brine is achieved by exposure to solar radiation and with the help of the prevailing micro climate in the area, especially the wind, rainfall, air temperature, humidity and the duration of sunshine. As a result, an increasing salinity gradient is created with the simultaneous and continuous reduction of the volume of sea water. This is the physico-chemical process of salt production. The evaporation of an open surface of water is a complex phenomenon of simultaneous transfer of mass, energy and momentum.

However, apart from the physico-chemical process described above, the biological process within the ponds also influences the evaporation and crystallization processes during salt production. Surprisingly enough, despite the rising salinity, life in the basins of the salt works does not stop. Sea water organisms gradually disappear as they move from the initial pan to the hostile
environment of the others. However, other organisms develop in this place and in parallel to the physico-chemical process; a chain of micro organisms is developed in the evaporating pond system, constituting the biological process and is vital to the production of salt\textsuperscript{21}. Biological process of salt works is a sensitive process which depends on the prevailing conditions in the salt works. A biological system maintained at a desired condition allows continuous production of high quality salt at designed capacities quite economically\textsuperscript{162}.

With the enormous increase in size and value of modern salt works, the importance of organisms in salt production has proved much greater than that revealed by earlier records\textsuperscript{163-165}. The biological system is in such an admirable harmony with the production that it produces the appropriate amount of organic matter. This serves as a source of energy for various organisms and reduces the permeability of the bottom of the ponds, thus minimizing brine losses, especially at low concentrations. Moreover, it colours the brine red in the crystallizers and thus maximizes the evaporation rate, by maximizing the rate of solar energy absorption and eliminating the solar radiation reflection from the while salt bed. Finally, it creates and maintains appropriate conditions in the evaporation ponds and crystallizers, for the continuous and the maximum production of high quality salt, which is characterized by clear, compact and mainly thick granules\textsuperscript{166}.

6.1.1. *Artemia* in salt production

Records attributed to ancient Chinese and Romans\textsuperscript{32,167} refer to events related to organisms in brine ponds during salt production. As the manufacturing process improved, the presence and the value of *Artemia*, the small anostrac crustacean in clearing brine and in preventing salt from
becoming contaminated with the bottom mud, have been already mentioned by many salt producers\textsuperscript{168,169}

The small crustacean \textit{Artemia}, also called brine shrimp is the organism referred as clearer worm and is the key organism involved in the biological process that takes place in solar salt works. The active brine shrimp population ingests and oxidizes much of the plankton and organic particulates in brine, releases waste products in faecal pellets, decreases the organic content of the water and finally clears the brine\textsuperscript{170}. Several biological and physical management procedures exist to improve the quality and the quantity of salt. Of them, the important are the creation of conditions conducive to large \textit{Artemia} population and the use of crystallizers only for the deposition of salt\textsuperscript{171}.

During salt production, excess extra cellular polysaccharide has been known to reduce or shut down salt harvesting in solar salt works\textsuperscript{172,173}. The increase in excess extracellular polysaccharide production increases the dissolved organic carbon concentration and viscosity of brine and can affect the salt crystal quality by creating small, hollow and fragile crystals that may have brine inclusions\textsuperscript{174}. Moreover, brine bacteria, dissolved organic carbon and other impurities may be incorporated within this inclusion. These conditions result in reduced salt quality as well as increased transport costs and also washer losses. The floors of the crystallizers are also weakened causing damage to the ponds\textsuperscript{175}. The small and hollow salt crystals that retain liquids are characteristic of sodium chloride crystallized, from brines containing high concentration of organic matter\textsuperscript{171}. When the biological system of salt works is upset, an excessive quantity of organic matter is produced, and the salt works become downgraded with the reduction of the surface of the
ponds and increased viscosity of the brine, resulting in the production of bad and sometimes even potentially unmarketable quality salt\textsuperscript{170}. 

6.1.2. \textit{Artemia} in salt works

In salt works, \textit{Artemia} is found in the evaporation ponds only at intermediate salinity levels from about 10 to 20\textdegree Be. The hydro biological activity in a solar salt operation largely determines the quality and the quantity of salt produced\textsuperscript{176,177}. The presence of brine shrimp \textit{Artemia} in sufficient numbers is essential not only for controlling the algal blooms but also for providing essential nutrients for the development of \textit{Halobacterium} in the crystallization ponds\textsuperscript{164}. High concentrations of red halophilic bacteria promote heat absorption, accelerate evaporation and reduce concentration of dissolved organics. Low viscosity levels promote the formation of larger salt crystals and improve salt quality\textsuperscript{177,178}.

In many salt operations natural recruitment of \textit{Artemia} from cysts dispersed by wind and water birds assures the presence and development of sufficient numbers of brine shrimp for optimal salt production. \textit{Artemia} does not occur naturally in S.E-Asia, although thousands of hectares of saltpans are in operation during the dry season. Brine shrimps of the genus \textit{Artemia}, are not natives of Australia but have been introduced to help maintain salt quality in the salt harvesting industry\textsuperscript{179}. As solar salt works are distributed along the coasts, most of the \textit{Artemia} population is coastal in distribution in Australia\textsuperscript{180}. The absence of a migration route of water birds probably explains why the very large 20,000 hectares of Salinas in Rio Grande do Norte along the northeast coast of Brazil contained no brine shrimp until \textit{Artemia franciscana} was introduced in 1977 in one saltern in Macau, which then spread to a distance of 1000 km within a few years\textsuperscript{181,182}. 

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Though in many salt works, natural recruitment of *Artemia* from cysts dispersed by wind and water birds assures the presence of brine shrimp for optimal salt production, the salt producer should not rely on this opportunistic dispersion of *Artemia*. Since, more and more salt operators are convinced of the critical role of the hydrobiological activity in their salt ponds nowadays, they introduce freshly hatched nauplii in natural sea water, directly into salt ponds at 10°Be salinity and these nauplii grow into adults within a period of two weeks 183-185.

In the saltpans of Kanyakumari District, Tamilnadu, South India, the recruitment of *Artemia*, the key organism involved in enhancing the quality and the quantity of salt is not witnessed in all the salt works and is not continuous due to dilution by heavy rainfall during the monsoon seasons. Also, though *Artemia* is said to improve the salt quality in solar salt works, enough data in the literature is not available regarding the same. Hence the present study was undertaken as a preliminary work to confirm that the small crustacean *Artemia* can be employed in solar salt works to enhance the quality and the quantity of salt.
6.2. Materials and Methods

Salt works which use sea water, underground water and estuarine water independently for salt production were chosen for this study. In each salt work, three ponds each such as primary, secondary, tertiary condensers and crystallizers were selected and modified for *Artemia* inoculation. The area of the condenser and the crystallizer ponds were 400 and 100 m² with the depth of 35 and 15 cm respectively. The height of water in the ponds was maintained at 30 and 12 cm respectively. In addition to the experimental ponds, control ponds in triplicates were also maintained (Fig 6.2.1 – 6.2.3).

*Artemia franciscana* cysts imported from USA were allowed to hatch in sea water at a salinity of 3°Be in the laboratory and the nauplii were fed using rice bran extract and the salinity was raised to 8°Be gradually, which was then introduced into the experimental primary condensers of almost same salinity. After seven days, water was let into the secondary condensers when the salinity rose to 12 to 13°Be. After staying in the secondary condenser for another five days, water was made to enter into the tertiary condensers.

*Artemia franciscana* cysts imported from USA
Fig : 6.2.1 Control and *Artemia* inoculated experimental ponds of SP1 Kovalam (Sea water source)

CP - Control Pond
PC - Primary Condenser
SC - Secondary Condenser
TC - Tertiary Condenser
CR - Crystalliser
EP - Experimental Pond
Fig: 6.2.2 Control and *Artemia* inoculated experimental ponds of SP7 Puthalam (Underground water source)

CP - Control Pond
PC - Primary Condenser
SC - Secondary Condenser
CP-CR
EP-PC
CP-SC
EP-SC
CP-TM
EP-TC
CP-CR
EP-CR

EP - Experimental Pond
TC - Tertiary Condenser
CR - Crystalliser
Fig: 6.2.3 Control and *Artemia* inoculated experimental ponds of SP8 Puthalam (Estuary water source)

CP - Control Pond
PC - Primary Condenser
SC - Secondary Condenser
CR - Crystalliser

EP - Experimental Pond
TC - Tertiary Condenser
In the tertiary condenser, water was retained for four to six days where the salinity crossed 20°Be. By that time the *Artemia* had attained the adult stage. The adult *Artemia* was not allowed to enter into the crystallizer pond, but the concentrated brine solution was let into the crystallizers. Sodium chloride crystallized within five days and was scraped after one or two days. The process continued thereafter.

The salt samples were collected monthly from the three salt works and packed in air tight polythene containers for salt quality analysis. The monthly values obtained in each case were segregated for season I, (May, June and July), season II (August, September and October), and season IV (February, March and April). The third season (November, December and January) failed to have salt samples due to the northeast monsoon. During the period of investigation evaporation rate was calculated monthly in the condensers (primary, secondary and tertiary) and crystallizers of both the experimental and the control ponds of the three salt works in the field itself. Monthly salt production in the control and the experimental crystallizers was also monitored. The different salt quality parameters like moisture content, insoluble impurities, calcium sulphate, magnesium sulphate, magnesium chloride and sodium chloride content were determined. Moreover, heavy metals like chromium, lead, manganese, zinc, copper, iron, cobalt and nickel were estimated both in the control and the experimental samples using standard procedures.

6.2.1. Statistical Analysis

The results obtained were subjected to the student’s ‘t’ test by following the procedure described by Zar\textsuperscript{56}.
6.3. Results

6.3.1. Evaporation rate

The rate of evaporation calculated in the control and the experimental ponds (primary, secondary, tertiary condensers and crystallizers) of the tested salt works SP1, SP7 and SP8 during the three seasons is presented in Table 6.3.1 to 6.3.3 respectively.

6.3.1.1 SP1 (Sea water- source)

In SP1, the mean percentage increase in evaporation of the primary condensers was $2.2 \pm 0.20$, $6.7 \pm 0.23$ and $3.6 \pm 0.18\%$ in season I, II and IV respectively. In the secondary condensers its values were $3.1 \pm 0.20$, $4.4 \pm 0.36$ and $8.8 \pm 0.42\%$ in the respective seasons. Likewise, in the tertiary condensers, the increase in evaporation rate calculated was $5.9 \pm 0.31$, $6.8 \pm 0.4$ and $2.8 \pm 0.22\%$ in season I, II and IV respectively. Similarly, the percentage increase in evaporation observed in the crystallizer pond was $16.5 \pm 0.51\%$ during season I, $17.1 \pm 0.24\%$ in season II and $19.8 \pm 0.38\%$ in season IV (Table 6.3.1 and Fig 6.3.1).

6.3.1.2. SP7 (Underground water- source)

The percentage increase in evaporation calculated in the primary condensers of SP7 was $5.1 \pm 0.23$, $4.1 \pm 0.14$ and $3.0 \pm 0.15\%$, in season I, II and IV respectively. Similarly, in the secondary condensers, their values were $10.0 \pm 0.35$ during season I, $9.4 \pm 0.25$ in season II and $2.7 \pm 0.20$ in season IV. Likewise, the percentage increase in evaporation calculated in the tertiary condensers was $11.7 \pm 0.68$, $4.5 \pm 0.33$ and $8.1 \pm 0.42\%$ in season I, II and IV respectively. In the case of crystallizer ponds, the values observed were
21.2 ± 0.90% in season I, 15.3 ± 0.73% in season II and 17.4 ± 0.97% during season IV (Table 6.3.2 and Fig 6.3.2).

6.3.1.3. SP8 (Estuary water-source)

The primary condensers of the control and the experimental ponds of SP8, witnessed a difference in evaporation rate of 4.1 ± 0.18, 3.8 ± 0.12 and 6.8 ± 0.29% in season I, II and IV respectively. Similarly, in the secondary condensers, the value in the respective seasons was 7.4 ± 0.24, 6.7 ± 0.41 and 4.25 ± 0.23%. Likewise, in the tertiary condensers the values calculated were 9.7 ± 0.36, 10.8 ± 0.48 and 5.5 ± 0.18 % in season I, II and IV respectively. In the case of crystallizer ponds, the percentage increase in evaporation monitored was 17 ± 0.81% in season I, 20 ± 0.66% in season II and 17.0 ± 0.59 % in season IV (Table 6.3.3. and Fig 6.3.3)

6.3.2 Salt quality parameters

6.3.2.1 SP1 (Sea water source)

The result of the salt quality parameters estimated in the SP1 salt samples is presented in Table 6.3.4 and the comparison table of the statistical analysis (student’s ‘t’ test) on different salt quality parameters between the control and the experimental salt samples during different seasons is given in Table 6.3.4a.

6.3.2.1.1 Moisture content

In SP1, the moisture content of the salt samples decreased from the control to the experimental ponds in all the three seasons. During season I, the mean moisture content of the salt samples in the control pond was 7.8 ± 0.33 %, whereas in the experimental pond it was 6.0 ± 0.25%. The percentage decrease in moisture content was 22.6 ± 0.41%. Similarly, in season II the
mean moisture content of the salt samples in the control and the experimental ponds was 7.1 ± 0.32 and 6.3 ± 0.37% respectively and the percentage decrease was 11.8 ± 0.68 %. Likewise, during season IV the samples from the control ponds recorded the mean moisture content of 7.3 ± 0.27% but, the experimental ponds registered the mean moisture content of 5.8 ± 0.41%. The percentage decrease in moisture content with respect to the control pond was 20.9 ± 1.4 % (Table 6.3.4).

Statistical student’s ‘t’ test for the data on the variation in moisture content of the control and the experimental salt samples observed in all the three seasons were statistically significant (t = 10.41 to 21.67; P < 0.0001 to 0.001) (Table 6.3.4a).

6.3.2.1.2 Insoluble impurities

The mean insoluble impurities of the salt samples recorded during season I in the control and experimental ponds was 0.52 ± 0.06% and 0.50 ± 0.05% respectively with the percentage difference of 3.8 ± 0.18%. In season II, the insoluble impurities recorded in the control pond was 0.67 ± 0.08% and in the experimental pond it was 0.62 ± 0.11%. The percentage difference calculated was 7.8 ± 1.2%. Similarly, season IV recorded insoluble impurities, 0.59 ± 0.06% in the control pond and 0.49 ± 0.07% in the experimental pond. The percentage difference calculated was 16.4 ± 1.2% (Table 6.3.4).

Statistical student’s ‘t’ test for the data on the variation in the insoluble impurities of the control and the experimental salt samples observed in all the three seasons were statistically not significant (t = 0.541 to 1.69; P > 0.05) (Table 6.3.4a).
6.3.2.1.3 Calcium sulphate

During season I, the mean calcium sulphate content in the control and the experimental samples was 0.327 ± 0.03 and 0.309 ± 0.03% respectively with the decrease in percentage of 5.5 ± 0.52%. In season II, the mean calcium sulphate content estimated was 0.338 ± 0.06% in the control pond, and in the experimental pond it was 0.327 ± 0.04%. The decrease in percentage calculated was 3.2 ± 0.18%. Likewise, in season IV the mean calcium sulphate content was 0.377 ± 0.06% and 0.36 ± 0.03% in the control and the experimental ponds respectively and the percentage difference estimated was 4.5 ± 0.20 % (Table 6.3.4).

Statistical student’s ‘t’ test for the data on the variation in the calcium sulphate content of the control and the experimental salt samples observed in season I and IV were statistically significant (t = 0.484 to 2.2 ; P < 0.05), whereas in season II it was statistically not significant (t = 1.34 ; P > 0.05) (Table 6.3.4a).

6.3.2.1.4 Magnesium sulphate

In season I, the mean magnesium sulphate content in the control pond was 1.3 ± 0.04% and in the experimental pond it was 1.03 ± 0.21%. The percentage difference between the two values was 20.7 ± 2.3%. Similarly, during season II, the mean magnesium sulphate content estimated was 1.12 ± 0.16% and 0.96 ± 0.04 in the control and experimental ponds respectively with the percentage decrease of 13.3 ± 1.4%. Likewise, during season IV the mean magnesium sulphate content of the control and the experimental samples was 1.2 ± 0.04 and 0.86 ± 0.21% respectively and the percentage difference calculated was 28.3 ± 2.3% (Table 6.3.4).
Statistical student’s ‘t’ test for the data on the variation in magnesium sulphate content of the control and the experimental salt samples observed during season I and IV were statistically significant ($t = 2.08$ to $4.87$, $P < 0.01$ to $0.05$), whereas in season II, it was statistically not significant ($t = 1.95$; $P > 0.05$) (Table 6.3.4a).

6.3.2.1.5. Magnesium chloride

Data on the mean magnesium chloride content in the salt samples of the control and the experimental ponds recorded during the study period revealed that, in season I, the magnesium chloride content in the salt samples of the control pond was $1.09 \pm 1.1\%$, whereas in the experimental pond it was $0.89 \pm 0.07\%$. The percentage decrease in magnesium chloride content observed was $18.3 \pm 1.2\%$. In season II, the recorded values were $0.98 \pm 0.02$ and $0.90 \pm 0.09 \%$ in the control and the experimental ponds respectively. The percentage decrease in magnesium chloride content was $8.1 \pm 0.6\%$. Likewise, in season IV, the magnesium chloride content of the control and the experimental samples was $1.0 \pm 0.02\%$ and $0.80 \pm 0.10 \%$ respectively and the percentage decrease calculated was $20 \pm 1.2\%$ (Table 6.3.4).

Statistical student’s ‘$t$’ test for the data on the variation in the magnesium chloride content of the control and the experimental salt samples observed in season I and II were statistically not significant ($t = 1.58$ to $1.59$; $P > 0.05$), whereas in season IV it was statistically significant ($t = 2.44$, $P < 0.05$)(Table 6.3.4a ).
6.3.2.1.6. Sodium chloride

The mean sodium chloride content recorded in the salt samples of the control and the experimental pond during the three seasons of the study period showed that during season I, the mean sodium chloride content in the control and the experimental samples was 88.5 ± 2.2% and 91.4 ± 2.8% respectively with the percentage increase of 3.3 ± 0.07%. Likewise, season II had sodium chloride content in the control sample as 88.1 ± 2.1% and in the experimental sample as 90.8 ± 2.9% with the percentage increase of 3.0 ± 0.12%. Similarly, the mean sodium chloride content in season IV was 88.9 ± 2.3% in the control and 92.0 ± 3.7% in the experimental samples. In this season, the percentage increase in sodium chloride content observed was 3.6 ± 0.19% (Table 6.3.4).

Statistical student’s ‘t’ test for the data on the variation in the sodium chloride content of the control and the experimental salt samples observed in all the three seasons were statistically significant (t = 3.42 to 3.91; P < 0.01) (Table 6.3.4a).

6.3.2.2 SP7 (Underground water source)

The result of the salt quality parameters estimated in the salt samples of SP7 is presented in Table 6.3.5 and the comparison table of the statistical analysis (student’s ‘t’ test) on different salt quality parameters between the control and the experimental salt samples of SP7 during different seasons is given in table 6.3.5a.

6.3.2.2.1 Moisture content

In SP7, the mean moisture content of the salt samples showed decreased level from the control to the experimental ponds in all the three seasons. The values decreased from 10.6 ± 1.3% to 8.5 ± 0.36% in season I, 10.2 ± 1.1 to
7.9 ± 0.68% in season II and 9.5 ± 0.62 to 8.0 ± 1.2% in season IV. The percentage decrease in moisture content observed with respect to the control pond was 19.8 ± 1.3, 22.5 ± 1.2 and 16.2 ± 1.2% in season I, II and IV respectively (Table 6.3.5).

Statistical student’s ‘t’ test for the data on the moisture content of the control and the experimental salt samples observed in season I was statistically not significant (t = 0.290, P > 0.05), whereas in season II and IV it was statistically significant (t= 4.98 to 14.08; P < 0.0001 to 0.01) (Table 6.3.5a).

6.3.2.2.2. Insoluble impurities

The mean insoluble impurities observed during season I in the control and the experimental pond was 1.07 ± 0.04% and 1.04 ± 0.02% respectively and the percentage difference estimated was 2.8 ± 0.23%. In season II, the insoluble impurities recorded in the control sample was 1.08 ± 0.03% and that in the experimental sample was 1.0 ± 0.01%. The percentage difference in insoluble impurities calculated was 7.4 ± 0.63%. During season IV, the mean insoluble impurities recorded in the control sample was 0.9 ± 0.06%, whereas in the experimental sample it was 0.76 ± 0.02% with the percentage difference of 22.2 ± 0.23% (Table 6.3.5).

Statistical student’s ‘t’ test for the data on the variation in insoluble impurities of the control and the experimental salt samples observed in all the three seasons were statistically not significant (t = 0.857 to 1.92, P> 0.05) (Table 6.3.5).
6.3.2.2.3 Calcium sulphate

The mean calcium sulphate content in the control ponds was 0.331 ± 0.07, 0.315 ± 0.02, and 0.358 ± 0.07% during season I, II and IV respectively. The corresponding values in the experimental ponds were 0.315 ± 0.03, 0.295 ± 0.03 and 0.320 ± 0.04%. The decrease in percentage of calcium sulphate calculated with respect to the control sample was 3.3 ± 0.29, 6.3 ± 0.65, 10.6 ± 0.78% during season I, II and IV respectively (Table 6.3.5).

Statistical student’s ‘t’ test for the data on the variation in calcium sulphate content of the control and the experimental salt samples observed in season I was statistically not significant (t = 0.852; P > 0.05), whereas in season II and IV it was statistically significant (t = 2.24 to 2.94; P < 0.05) (Table 6.3.5a).

6.3.2.2.4 Magnesium sulphate

During season I, the mean magnesium sulphate content in the control pond was 1.58 ± 0.19% and in the experimental pond it was 0.96 ± 0.10% with the percentage decrease of 39.2 ± 2.6%. During season II, the magnesium sulphate content in the control and the experimental samples was 1.52 ± 0.03 and 1.08 ± 0.04% respectively. The percentage decrease calculated was 21.2 ± 1.1%. Similarly, during season IV the magnesium sulphate content of the control and the experimental samples was 1.39 ± 0.08 and 1.14 ± 0.08% respectively. The percentage decrease calculated was 17.9 ± 0.98% (Table 6.3.5).

Statistical student’s ‘t’ test for the data on the variation in the magnesium sulphate content of the control and the experimental salt samples observed in all the three seasons were statistically significant (t = 3.54 to 10.53; P < 0.0001 to 0.05) (Table 6.3.5a).
6.3.2.2.5 Magnesium chloride

The mean magnesium chloride content of the salt samples of the control ponds in season I was 1.01 ± 0.08%, whereas in the experimental ponds it was 0.86 ± 0.13%. The percentage decrease calculated was 14.8 ± 0.98%. In season II, the recorded values were 0.98 ± 0.08% and 0.79 ± 0.03% in the control and the experimental samples respectively with the percentage decrease of 28.5 ± 1.2%. Likewise, in season IV the mean magnesium chloride content of the control and the experimental samples was 0.89 ± 0.65% and 0.83 ± 0.08% respectively. The decrease in percentage calculated was 7.7 ± 0.38% (Table 6.3.5).

Statistical student's 't' test for the data on the variation in the magnesium chloride content of the control and the experimental salt samples observed in season I and II were statistically significant (t = 2.54 to 3.51; P < 0.05), whereas in season IV it was statistically not significant (t = 0.66; P > 0.05) (Table 6.3.5a).

6.3.2.2.6 Sodium chloride

The mean sodium chloride content recorded in the salt samples of SP7 in the control samples was 84.5 ± 1.4, 85.7 ± 1.1 and 85.4 ± 1.3% in the respective seasons I, II and IV. Similarly, the sodium chloride content in the experimental samples was 87.3 ± 1.2, 88.9 ± 0.99 and 88.5 ± 1.8% in the respective seasons. The corresponding increase in percentage of sodium chloride content was 3.3 ± 0.32%, 3.7 ± 0.40% and 3.6 ± 0.17% (Table 6.3.5).

Statistical student's 't' test for the data on the variation in the sodium chloride content of the control and the experimental salt samples observed in all the three seasons were statistically significant (t = 3.42 to 3.91; P < 0.01 to 0.01) (Table 6.3.5a).
6.3.2.3. SP8 Estuarine water source

The result of the salt quality parameters estimated in the SP8 salt samples is presented in Table 6.3.6 and the comparison table of the statistical analysis (students' t' test) on different salt quality parameters between the control and the experimental salt samples of SP8 during different seasons is given in Table 6.3.6a.

6.3.2.3.1. Moisture content

In season I, the mean moisture content of the salt samples in the control pond was 10.7 ± 1.2%, whereas in the experimental pond it was 8.6 ± 0.72%. The percentage difference in moisture content observed was 19.8 ± 1.0%. In season II, the mean moisture content of the salt samples in the control and the experimental ponds was 10.6 ± 1.2 and 8.1 ± 0.51 % respectively and the percentage difference was 23.5 ± 0.94%. Similarly, during season IV the control samples recorded the mean moisture content of 10.3 ± 1.6%, whereas the samples of the experimental pond registered the mean moisture content of 7.0 ± 0.61% with the percentage difference of 22.3 ± 1.1 % (Table 6.3.6).

Statistical student’s ‘t’ test for the data on the variation in the moisture content of the control and the experimental salt samples observed in season I and II were statistically significant (t = 8.04 to16.49, P < 0.0001 to 0.001), whereas in season IV it was statistically not significant (t = 0.171, P > 0.05) (Table 6.3.6a).

6.3.2.3.2 Insoluble impurities

The mean insoluble impurities during season I in the control and the experimental samples was 1.99 ± 0.58% and 1.68 ± 0.63% respectively and the percentage difference with respect to the control sample was found to be 15.5 ± 2.5%. In season II, the insoluble impurities recorded in the control
sample was 1.45 ± 0.22% and in the experimental pond it was 1.1 ± 0.03%. The percentage difference calculated was 24.1 ± 1.6%. During season IV, the mean insoluble impurities recorded in the control sample was 1.09 ± 0.04%, whereas in the experimental sample it was 1.0 ± 0.05%, with the decrease in percentage of 8.2 ± 1.4% (Table 6.3.6).

Statistical student’s ‘t’ test for the data on the insoluble impurities of the control and the experimental salt samples observed in season I and II were statistically significant (t = 2.17 to 2.57, P < 0.05), whereas in season IV it was statistically not significant (t = 0.788; P > 0.05) (Table 6.3.6a).

### 6.3.2.3.3 Calcium sulphate

The mean calcium sulphate content in the control and the experimental samples was 0.422 ± 0.04 and 0.313 ± 0.06% in season I, 0.379 ± 0.08 and 0.316 ± 0.03% in season II and 0.352 ± 0.07% and 0.307 ± 0.09% in season IV. The decrease in percentage calculated in the respective seasons was 25.8 ± 2.7%, 16.6 ± 1.5% and 12.7 ± 0.9% (Table 6.3.6).

Statistical student’s ‘t’ test for the data on the calcium sulphate content of the control and the experimental salt samples observed in all the three seasons were statistically significant (t = 5.1 to 13.34, P < 0.0001 to 0.01) (Table 6.3.6a).

### 6.3.2.3.4 Magnesium sulphate

In season I, the mean magnesium sulphate content in the salt samples of the control pond was 1.62 ± 0.27% and in the experimental ponds it was 1.18 ± 0.12% and the decrease in percentage with respect to the control sample was 27.1 ± 1.3%. During season II, the magnesium sulphate content in the control and in the experimental samples was 1.53 ± 0.20 and 1.32 ±
0.08% respectively with the percentage decrease of 12.7 ± 2.9%. Similarly during season IV, the magnesium sulphate content of the control and the experimental samples was 1.6 ± 0.04 and 1.4 ± 0.19% respectively. The percentage decrease in magnesium sulphate content observed was 12.5 ± 1.1% (Table 6.3.6).

Statistical students ‘t’ test for the data on the magnesium sulphate content of the control and the experimental salt samples observed in season I was statistically not significant (t = 0.431, P > 0.05), whereas in season II and IV it was statistically significant (t = 2.44 to 2.59, P < 0.05) (Table 6.3.6a).

6.3.2.3.5 Magnesium chloride

The mean magnesium chloride content in the salt samples of the control and experimental ponds in season I was 1.36 ± 0.23% and 1.1 ± 0.07% respectively. The percentage decrease in magnesium chloride content was 19.1 ± 0.99%. In season II, the recorded values were 1.09 ± 0.18 and 0.91 ± 0.1% in the control and the experimental samples respectively with the percentage decrease of 16.5 ± 1.3%. Likewise, in season IV the magnesium chloride content of the control and experimental samples was 1.11 ± 0.04% and 0.88 ± 0.29 % respectively. The percentage decrease in magnesium chloride content observed was 20.7 ±1.2% (Table 6.3.6).

Statistical student’s ‘t’ test for the data on the variation in the magnesium chloride content of the control and the experimental salt samples observed in all the three seasons were statistically significant (t = 2.81 to 5.26; P < 0.01 to 0.05) (Table 6.3.6a).
6.3.2.3.6. Sodium chloride

The mean sodium chloride content recorded in the salt samples during season I in the control and the experimental ponds was 83.6 ± 0.8% and 87.4 ± 1.2% respectively. Likewise, in season II the mean sodium chloride content in the control sample was 84.8 ± 1.6 % and in the experimental sample it was 88.4 ± 1.9%. Similarly, in season IV the mean sodium chloride content in the control and experimental samples was 85.9 ± 1.1 and 89.7 ± 1.0% respectively. The percentage increase in sodium chloride content in the respective seasons was 4.5 ± 0.4%, 4.2 ± 0.30 % and 4.3 ± 0.21% (Table 6.3.6).

Statistical student’s ‘t’ test for the data on the variation in the sodium chloride content of the control and the experimental salt samples observed in all the three seasons were statistically significant (t = 2.92 to 7.98; P < 0.001 to 0.05) (Table 6.3.6a).

6.3.3 Heavy metals

The result of the heavy metals estimated in the salt samples of the control and the experimental ponds of SP1, SP7 and SP8 during the study period is presented in Table 6.3.7 and their percentage difference in accumulation in Fig 6.3.7. Table 6.3.7a is the comparison table for the heavy metal accumulation in the control and in the experimental salt samples of SP1, SP7 and SP8.

6.3.3.1 Chromium

In the case of salt from the sea water source SP1, the control and the experimental samples recorded the mean chromium content of 2.8 ± 0.54 and 2.3 ± 0.52 ppm with a decrease in percentage of 18.7 ± 1.6%. The mean
chromium content recorded in the salt samples of underground water (SP7) was 0.84 ± 0.03 ppm in the control and 0.71 ± 0.02 ppm in the experimental samples and the percentage decrease was 14.9 ± 1.5%. Similarly, the salt samples from estuarine water (SP8) recorded the mean chromium content as 0.73 ± 0.03 ppm in the control sample and 0.61 ± 0.03 ppm in the experimental sample with a decrease in percentage of 17.1 ± 0.76% (Table 6.3.7).

Statistical student’s ‘t’ test for the data on the variation in the chromium content of the control and the experimental salt samples observed in all the three saltpans were statistically significant (t = 6.5 to 83.5, P < 0.001 to 0.05) (Table 6.3.7a).

6.3.3.2 Lead

The mean lead content in the salt samples of the control ponds of SP1 was 1.32 ± 0.15 ppm and in the experimental samples it was 1.27 ± 0.11 ppm with a decrease in percentage of 3.6 ± 0.21%. The salt sample from underground water (SP7) was found to contain 0.08 ± 0.00 ppm of lead in both the control and the experimental salt samples. The same element in the control and in the experimental salt samples of SP8 was 0.36 ± 0.03 and 0.34 ± 0.03 ppm respectively with a percentage decrease of 5.8 ± 0.3% (Table 6.3.7).

Statistical student’s ‘t’ test for the data on the variation in the lead content of the control and the experimental salt samples observed in SP1 was statistically significant (t = 8.66, P< 0.01) whereas in SP7 and SP8 it was statistically not significant (t = 0 to 0.692, P > 0.05) (Table 6.3.7a).
6.3.3.3 Nickel

The mean nickel content in the control and in the experimental salt samples of SP1 was 0.14 ± 0.04 ppm each. The SP7 samples recorded 0.12 ± 0.0 ppm in the control sample and 0.11 ± 0.01 ppm in the experimental sample. The decrease in percentage accumulation of this element was 9.09 ± 1.0%. Similarly, the accumulation of nickel in SP8 salt samples of the control and experimental pond was 0.091 ± 00 and 0.089 ± 00 ppm respectively with a decrease in percentage accumulation of 2.1 ± 0.06 % (Table 6.3.7).

Statistical student’s ‘t’ test for the data on the variation in the nickel content of the control and the experimental salt samples observed in SP1 and SP7 were statistically not significant (t = 0 to1.73, P > 0.05), whereas in SP8 it was statistically highly significant ( t = 5, P > 0.05) (Table 6.3.7a).

6.3.3.4 Iron

Iron accumulation in the SP1 salt sample amounted to 38 ± 2.8 ppb in the control pond and 25 ± 1.2 ppb in the experimental pond. The decrease in percentage of iron accumulated was 36.1 ± 2.2%. In the salt sample from SP7, the iron content in the control and experimental pond was 47.3 ± 2.8 and 31 ± 2.7 ppb respectively with a decrease in percentage accumulation of 39.5 ± 3.1%. Similarly, the salt sample from SP8 recorded 25.3 ± 2.2 ppb iron in the control pond and 16.0 ±1.2 ppb in the experimental pond. The decrease in percentage of iron accumulated was 30.7± 2.8% (Table 6.3.7).

Statistical student’s ‘t’ test for the data on the variation in iron content of the control and the experimental salt samples observed in all the three saltpans (SP1, SP7, SP8) were statistically significant (t = 3.7 to 27.7; P < 0.01 to 0.05) (Table 6.3.7a).
6.3.3.5. Cobalt

Accumulation of cobalt in the control and experimental samples of SP1 was 1.1 ± 0.03 and 1.0 ± 0.02 ppm respectively and the percentage decrease was 5.9 ± 0.20%. In the SP7 salt samples, the value in the control and the experimental sample was 1.6 ± 0.01 and 1.1 ± 0.01 ppm respectively with the decrease in percentage of 24.5 ± 1.3%. Similarly, the salt samples from SP8 recorded 0.70 ± 0.05 ppm cobalt in the control sample and 0.61 ± 0.00 ppm in the experimental sample and the decrease in percentage accumulation was 12.1 ± 1.6 % (Table 6.3.7).

Statistical student’s ‘t’ test for the data on the variation in the cobalt content of the control and the experimental salt samples in SP7 and SP8 were statistically significant (t = 3 to 3.11; P < 0.05), whereas in SP1 it was statistically not significant t = 1.36; P > 0.05) (Table 6.3.7a).

6.3.3.6 Copper

The mean copper content in the control and the experimental samples of SP1 was 0.014 ± 0.01 and 0.011 ± 0.00 ppm respectively with a decrease in percentage accumulation of 20 ± 1.5%. The salt sample from SP7 recorded 0.030 ± 0.00 ppm copper in the control and 0.023 ± 0.00 ppm in the experimental samples and the percentage difference calculated was 22.5 ± 0.88%. Similarly, in SP8 salt samples the mean copper content recorded was 0.035 ± 0.00 ppm in the control and 0.025 ± 0.00 ppm in the experimental samples. The decrease in percentage accumulation of this element was 23.0 ± 1.8% (Table 6.3.7).

Statistical student’s ‘t’ test for the data on the variation in the copper content of the control and the experimental salt samples in SP1 and SP8 were statistically significant (t = 4.3 to 5.19; P < 0.05), whereas in SP7 it was statistically not significant (t = 2.33; P > 0.05) (Table 6.3.7a).
6.3.3.7. Zinc

Zinc accumulation in the SP1 salt sample amounted to 0.037 ± 0.00 ppm in the control pond and 0.029 ± 0.00 ppm in the experimental pond with the decrease in percentage of 20.5 ± 1.4%. In the SP7 salt sample, zinc content in the control and the experimental salt samples was 0.060 ± 0.00 and 0.052 ± 0.00 ppm respectively. The decrease in percentage accumulated was 12.9 ± 1.3 %. Similarly, the salt sample from SP8 recorded 0.13 ± 0.01 ppm in the control pond and 0.11 ± 0.01 ppm in the experimental pond. The decrease in percentage accumulation was 14.8 ± 0.25% (Table 6.3.7).

Statistical student’s ‘t’ test for the data on the variation in zinc content of the control and the experimental salt samples from SP1 and SP8 were statistically significant (t = 6.92 to 12.3 ; P < 0.01), whereas in SP7 it was statistically not significant (t = 2.77 ; P > 0.05) (Table 6.3.7a).

6.3.3.8. Manganese

The mean manganese content in the SP1 salt samples of the control and experimental pond was 0.10 ± 0.01 and 0.09 ± 0.02 ppm respectively and the percentage decrease was 10.2 ± 0.51%. In SP7, the manganese content recorded was 0.20 ± 0.03 ppm both in the control and in the experimental samples. The amount of manganese in SP8 samples of the control and the experimental pond was 0.065 ± 0.00 ppm and 0.059 ± 0.00 ppm respectively. The decrease in percentage of manganese accumulated was 8.6 ± 0.24% (Table 6.3.7).

Statistical students ‘t’ test for the data on the variation in the manganese content of the control and the experimental salt samples of all the saltpans (SP1, SP7 and SP8) were statistically not significant (t = 0 to 0.866; P > 0.05) (Table 6.3.7a).
Table 6.3.1. Evaporation rate (L/m² day⁻¹) recorded in the control and the experimental ponds of SP1

<table>
<thead>
<tr>
<th>Stages</th>
<th>Season I</th>
<th>% diff</th>
<th>Season II</th>
<th>% diff</th>
<th>Season IV</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E</td>
<td></td>
<td>C</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Primary condenser</td>
<td>17.6 ± 1.1</td>
<td>18.1 ± 0.65</td>
<td>2.2 ± 0.2</td>
<td>13.9 ± 3.2</td>
<td>14.8 ± 1.2</td>
<td>6.7 ± 0.23</td>
</tr>
<tr>
<td>Secondary condenser</td>
<td>11.0 ± 0.96</td>
<td>12.1 ± 0.34</td>
<td>3.1 ± 0.2</td>
<td>9.7 ± 1.6</td>
<td>10.1 ± 0.45</td>
<td>4.4 ± 0.36</td>
</tr>
<tr>
<td>Tertiary condenser</td>
<td>7.1 ± 0.65</td>
<td>7.39 ± 0.52</td>
<td>4.1 ± 0.1</td>
<td>5.9 ± 0.31</td>
<td>5.3 ± 0.38</td>
<td>6.8 ± 0.4</td>
</tr>
<tr>
<td>Crystallizer</td>
<td>9.7 ± 0.88</td>
<td>11.3 ± 0.22</td>
<td>16.5 ± 0.51</td>
<td>7.2 ± 0.47</td>
<td>8.4 ± 1.33</td>
<td>17.1 ± 0.24</td>
</tr>
</tbody>
</table>

Table 6.3.2. Evaporation rate (L/m² day⁻¹) recorded in the control and the experimental ponds of SP7

<table>
<thead>
<tr>
<th>Stages</th>
<th>Season I</th>
<th>% diff</th>
<th>Season II</th>
<th>% diff</th>
<th>Season IV</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E</td>
<td></td>
<td>C</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Primary condenser</td>
<td>15.6 ± 2.3</td>
<td>16.4 ± 1.7</td>
<td>5.1 ± 0.23</td>
<td>13.4 ± 1.1</td>
<td>14.0 ± 1.7</td>
<td>4.0 ± 0.14</td>
</tr>
<tr>
<td>Secondary condenser</td>
<td>7.9 ± 0.68</td>
<td>8.7 ± 1.1</td>
<td>10.0 ± 0.35</td>
<td>6.6 ± 0.32</td>
<td>7.2 ± 0.45</td>
<td>9.4 ± 0.25</td>
</tr>
<tr>
<td>Tertiary condenser</td>
<td>5.2 ± 0.88</td>
<td>5.8 ± 0.46</td>
<td>11.7 ± 0.68</td>
<td>4.4 ± 0.74</td>
<td>4.6 ± 0.35</td>
<td>4.5 ± 0.33</td>
</tr>
<tr>
<td>Crystallizer</td>
<td>6.4 ± 0.42</td>
<td>7.7 ± 0.43</td>
<td>21.2 ± 0.90</td>
<td>5.7 ± 0.69</td>
<td>6.6 ± 0.34</td>
<td>15.3 ± 0.73</td>
</tr>
</tbody>
</table>

Table 6.3.3. Evaporation rate (L/m² day⁻¹) recorded in the control and the experimental ponds of SP8

<table>
<thead>
<tr>
<th>Stages</th>
<th>Season I</th>
<th>% diff</th>
<th>Season II</th>
<th>% diff</th>
<th>Season IV</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E</td>
<td></td>
<td>C</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Primary condenser</td>
<td>14.5 ± 1.2</td>
<td>15.1 ± 0.98</td>
<td>4.1 ± 0.18</td>
<td>12.9 ± 1.4</td>
<td>13.4 ± 1.5</td>
<td>3.8 ± 0.12</td>
</tr>
<tr>
<td>Secondary condenser</td>
<td>6.7 ± 0.98</td>
<td>7.2 ± 1.1</td>
<td>7.4 ± 024</td>
<td>7.6 ± 0.97</td>
<td>7.9 ± 0.90</td>
<td>6.7 ± 0.41</td>
</tr>
<tr>
<td>Tertiary condenser</td>
<td>4.4 ± 0.63</td>
<td>4.8 ± 0.45</td>
<td>9.7 ± 0.36</td>
<td>3.7 ± 0.45</td>
<td>4.1 ± 0.41</td>
<td>10.8 ± 0.48</td>
</tr>
<tr>
<td>Crystallizer</td>
<td>6.4 ± 0.72</td>
<td>7.5 ± 1.2</td>
<td>17 ± 0.81</td>
<td>6.0 ± 0.62</td>
<td>7.2 ± 0.73</td>
<td>20 ± 0.66</td>
</tr>
</tbody>
</table>

C- Control ; E-Experimental
Table 6.3.4. Salt quality parameters in the control and experimental salt samples of SP1

<table>
<thead>
<tr>
<th>Salt quality parameters</th>
<th>Season I</th>
<th>Season II</th>
<th>Season IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C (±)</td>
<td>E (±)</td>
<td>% diff</td>
</tr>
<tr>
<td>Moisture content</td>
<td>7.8 ± 0.33</td>
<td>6.0 ± 0.25</td>
<td>22.6 ± 0.41</td>
</tr>
<tr>
<td>Insoluble impurities</td>
<td>0.52 ± 0.06</td>
<td>0.50 ± 0.05</td>
<td>3.8 ± 0.18</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>0.327 ± 0.03</td>
<td>0.309 ± 0.03</td>
<td>5.50 ± 0.52</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>1.3 ± 0.04</td>
<td>1.03 ± 0.21</td>
<td>20.7 ± 2.3</td>
</tr>
<tr>
<td>MgCl₂</td>
<td>1.09 ± 1.1</td>
<td>0.89 ± 0.07</td>
<td>18.3 ± 1.20</td>
</tr>
<tr>
<td>NaCl</td>
<td>88.5 ± 2.2</td>
<td>91.4 ± 2.8</td>
<td>3.3 ± 0.07</td>
</tr>
</tbody>
</table>

C- Control; E-Experimental

Table 6.3.4a. Comparison table of the statistical analysis (students 't' test) on different salt quality parameters between the control and the experimental salt samples of SP1 during different seasons

<table>
<thead>
<tr>
<th>S.Q.P (Control vs experimental)</th>
<th>Season I t-value</th>
<th>P-value</th>
<th>Season II t-value</th>
<th>P-value</th>
<th>Season IV t-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>21.67</td>
<td>&lt;0.0001*</td>
<td>10.41</td>
<td>&lt;0.001*</td>
<td>15.64</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Insoluble impurities</td>
<td>0.541</td>
<td>&gt;0.05**</td>
<td>0.844</td>
<td>&gt;0.05**</td>
<td>1.69</td>
<td>&gt;0.05**</td>
</tr>
<tr>
<td>Calcium sulphate</td>
<td>2.20</td>
<td>&lt;0.05*</td>
<td>1.34</td>
<td>&gt;0.05**</td>
<td>0.484</td>
<td>&lt;0.05**</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>2.08</td>
<td>&lt;0.05*</td>
<td>1.95</td>
<td>&gt;0.05**</td>
<td>4.87</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>1.58</td>
<td>&gt;0.05**</td>
<td>1.59</td>
<td>&gt;0.05**</td>
<td>2.44</td>
<td>&lt;0.05*</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>3.42</td>
<td>&lt;0.01*</td>
<td>3.91</td>
<td>&lt;0.01*</td>
<td>3.79</td>
<td>&lt;0.01*</td>
</tr>
</tbody>
</table>

* Statistically significant; ** Statistically non significant
Table 6.3.5. Salt quality parameters in the control and the experimental salt samples of SP7

<table>
<thead>
<tr>
<th>Salt quality parameters</th>
<th>Season I</th>
<th>Season II</th>
<th>Season IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E</td>
<td>% diff</td>
</tr>
<tr>
<td>Moisture content</td>
<td>10.6 ± 1.3</td>
<td>8.5 ± 0.36</td>
<td>19.8 ± 1.3</td>
</tr>
<tr>
<td>Insoluble impurities</td>
<td>1.07 ± 0.04</td>
<td>1.04 ± 0.02</td>
<td>2.8 ± 0.23</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>0.331 ± 0.07</td>
<td>0.315 ± 0.03</td>
<td>3.3 ± 0.29</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>1.58 ± 0.19</td>
<td>0.96 ± 0.10</td>
<td>39.2 ± 1.6</td>
</tr>
<tr>
<td>MgCl₂</td>
<td>1.01 ± 0.08</td>
<td>0.86 ± 0.13</td>
<td>14.8 ± 0.98</td>
</tr>
<tr>
<td>NaCl</td>
<td>84.5 ± 1.4</td>
<td>87.3 ± 1.2</td>
<td>3.3 ± 0.32</td>
</tr>
</tbody>
</table>

C- Control ; E-Experimental

Table 6.3.5a. Comparison table of the statistical analysis (students’t’ test) on different salt quality parameters between the control and the experimental salt samples of SP7 during different seasons

<table>
<thead>
<tr>
<th>S.Q.P (Control vs experimental)</th>
<th>Season I</th>
<th>Season II</th>
<th>Season IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t-value</td>
<td>P-value</td>
<td>t-value</td>
</tr>
<tr>
<td>Moisture content</td>
<td>0.290</td>
<td>&gt; 0.05**</td>
<td>14.08</td>
</tr>
<tr>
<td>Insoluble impurities</td>
<td>0.964</td>
<td>&gt; 0.05**</td>
<td>0.857</td>
</tr>
<tr>
<td>Calcium sulphate</td>
<td>0.852</td>
<td>&gt; 0.05**</td>
<td>2.44</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>10.53</td>
<td>&lt; 0.001*</td>
<td>7.47</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>2.54</td>
<td>&lt; 0.05*</td>
<td>3.21</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>3.42</td>
<td>&lt; 0.05*</td>
<td>3.91</td>
</tr>
</tbody>
</table>

* Statistically significant     ** Statistically non significant
### Table 6.3.6. Salt quality parameters in the control and the experimental salt samples of SP8

<table>
<thead>
<tr>
<th>Salt quality parameters</th>
<th>Season I</th>
<th>Season II</th>
<th>Season IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E</td>
<td>% diff</td>
</tr>
<tr>
<td>Moisture content</td>
<td>10.7 ± 1.2</td>
<td>8.6 ± 0.72</td>
<td>19.8 ± 1.0</td>
</tr>
<tr>
<td>Insoluble impurities</td>
<td>1.99 ± 0.58</td>
<td>1.68 ± 0.63</td>
<td>15.5 ± 2.5</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>0.422 ± 0.04</td>
<td>0.313 ± 0.06</td>
<td>25.8 ± 2.7</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>1.62 ± 0.27</td>
<td>1.18 ± 0.12</td>
<td>27.1 ± 1.3</td>
</tr>
<tr>
<td>MgCl₂</td>
<td>1.36 ± 0.23</td>
<td>1.1 ± 0.07</td>
<td>19.1 ± 0.99</td>
</tr>
<tr>
<td>NaCl</td>
<td>83.6 ± 0.8</td>
<td>87.4 ± 1.2</td>
<td>4.5 ± 0.40</td>
</tr>
</tbody>
</table>

C - Control; E - Experimental

### Table 6.3.6a. Comparison table of the statistical analysis (students' t' test) on different salt quality parameters between the control and the experimental salt samples of SP8 during different seasons

<table>
<thead>
<tr>
<th>S.Q.P (Control vs experimental)</th>
<th>Season I</th>
<th>Season II</th>
<th>Season IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t-value</td>
<td>P-value</td>
<td>t-value</td>
</tr>
<tr>
<td>Moisture content</td>
<td>16.49</td>
<td>&lt; 0.0001*</td>
<td>8.04</td>
</tr>
<tr>
<td>Insoluble impurities</td>
<td>2.57</td>
<td>&lt; 0.05*</td>
<td>2.17</td>
</tr>
<tr>
<td>Calcium sulphate</td>
<td>13.34</td>
<td>&lt; 0.0001*</td>
<td>7.44</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>0.431</td>
<td>&gt; 0.05**</td>
<td>2.59</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>3.18</td>
<td>&lt; 0.05*</td>
<td>5.26</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>7.98</td>
<td>&lt; 0.001*</td>
<td>7</td>
</tr>
</tbody>
</table>

* Statistically significant ; ** Statistically non-significant
Table 6.3.7. Heavy metal accumulation in the control and the experimental salt samples of SP1, SP7 and SP8

<table>
<thead>
<tr>
<th>Heavy metals</th>
<th>Sample I - SP1 (Sea water source) ppm</th>
<th>Sample II - SP7 (Underground water source) ppm</th>
<th>Sample III - SP8 (Estuary water source) ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E</td>
<td>% diff</td>
</tr>
<tr>
<td>Cr</td>
<td>2.8 ± 0.14</td>
<td>2.3 ± 0.12</td>
<td>18.7 ± 1.6</td>
</tr>
<tr>
<td>Pb</td>
<td>1.32 ± 0.15</td>
<td>1.27 ± 0.11</td>
<td>3.6 ± 0.21</td>
</tr>
<tr>
<td>Ni</td>
<td>0.14 ± 0.04</td>
<td>0.14 ± 0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>Fe</td>
<td>38 ± 2.8</td>
<td>25 ± 1.2</td>
<td>36.1 ± 2.2</td>
</tr>
<tr>
<td>Co</td>
<td>1.1 ± 0.03</td>
<td>1.0 ± 0.02</td>
<td>5.9 ± 0.20</td>
</tr>
<tr>
<td>Cu</td>
<td>0.014 ± 0.01</td>
<td>0.011 ± 0.02</td>
<td>20 ± 1.5</td>
</tr>
<tr>
<td>Zn</td>
<td>0.037 ± 0.00</td>
<td>0.029 ± 0.00</td>
<td>20.5 ± 1.4</td>
</tr>
<tr>
<td>Mn</td>
<td>0.10 ± 0.01</td>
<td>0.09 ± 0.02</td>
<td>10.2 ± 0.51</td>
</tr>
</tbody>
</table>

*ppb ;  C - Control ; E - Experimental
Table 6.3.7a. Comparison table of the statistical analysis (students' t' test) on heavy metal content between the control and experimental salt samples of SP1, SP7 and SP8

<table>
<thead>
<tr>
<th>Heavy metals (Control vs experimental)</th>
<th>SP1</th>
<th>SP7</th>
<th>SP8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t-value</td>
<td>P-value</td>
<td>t-value</td>
</tr>
<tr>
<td>Cr</td>
<td>83.5</td>
<td>&lt; 0.0001*</td>
<td>6.5</td>
</tr>
<tr>
<td>*Pb</td>
<td>8.66</td>
<td>&lt; 0.01*</td>
<td>0</td>
</tr>
<tr>
<td>Ni</td>
<td>0</td>
<td>&gt; 0.05**</td>
<td>1.73</td>
</tr>
<tr>
<td>Fe</td>
<td>5.5</td>
<td>&lt; 0.05*</td>
<td>27.7</td>
</tr>
<tr>
<td>Co</td>
<td>1.36</td>
<td>&gt; 0.05**</td>
<td>3.11</td>
</tr>
<tr>
<td>Cu</td>
<td>5.19</td>
<td>&lt; 0.05*</td>
<td>2.33</td>
</tr>
<tr>
<td>Zn</td>
<td>6.92</td>
<td>&lt; 0.01*</td>
<td>2.77</td>
</tr>
<tr>
<td>Mn</td>
<td>0.866</td>
<td>&gt; 0.05**</td>
<td>0</td>
</tr>
</tbody>
</table>

* Statistically significant; ** Statistically non significant
Fig. 6.3.1. Percentage difference in evaporation rate (Lm^{-2} day^{-1}) at different seasons in the control and the experimental ponds of SP1

![Graph showing percentage difference in evaporation rate at different seasons in SP1](image)

Fig. 6.3.2. Percentage difference in evaporation rate (Lm^{-2} day^{-1}) at different seasons in the control and the experimental ponds of SP7

![Graph showing percentage difference in evaporation rate at different seasons in SP7](image)

Fig. 6.3.3. Percentage difference in evaporation rate (Lm^{-2} day^{-1}) at different seasons in the control and the experimental ponds of SP8

![Graph showing percentage difference in evaporation rate at different seasons in SP8](image)
Fig. 6.3.4. Percentage difference in the salt quality parameters at different seasons in the control and experimental salt samples of SP1

Fig. 6.3.5. Percentage difference in the salt quality parameters at different seasons in the control and experimental salt samples of SP7

Fig. 6.3.6. Percentage difference in the salt quality parameters at different seasons in the control and experimental salt samples of SP8
Fig. 6.3.7. Percentage difference in heavy metal accumulation between the control and experimental salt samples of SP1, SP7 and SP8
6.4. Discussion

The salt work ecosystem has an influence on salt production. Problems in salt making can arise when algal blooms develop in the evaporation ponds. It is accepted that salt works function best where there is adequate biological productivity. The enhancement of both the quality and the quantity of common salt during solar salt manufacture through biological management was acknowledged by many biologists in most of the salt works, all over the world. At the same time, quantitative correlation regarding the quality and quantity improvement lacked except with the algal mat culturing in a Chinese salt work. In the present one year study, *Artemia* inoculation in the salt works resulted in both quality and quantity improvement.

6.4.1 Evaporation rate

Evaporation is the chief process involved in the concentration of weak brine to saturation followed by crystallization in solar salt manufacture, which is affected by a number of physical factors like vapour pressure, temperature, wind velocity, humidity, the extent of the surface exposed and salinity. The evaporation rate decreased from the primary to tertiary condensers in both the control and the experimental samples of all the three salt works SP1, SP7 and SP8 in all the seasons. The decrease in evaporation rate observed was due to the increase in salinity as the brine passes successively from the primary to the tertiary condensers. According to the earlier report evaporation proceeds with great difficulty with rise in salinity. But in the crystallizers, the evaporation rate measured was higher than in the tertiary condenser, which is due to the reduction in the depth of the condenser from 35cm to 15cm in the crystallizer. As the depth decreases, the rate of
evaporation increases, despite, rise in salinity where light can penetrate easily into the bottom brine accelerating evaporation\textsuperscript{192}. In the case of primary condensers of the three salt works the increase in evaporation rate observed was 2 to 6\%, whereas in the secondary condensers, the value recorded was 2 to 10\%. Similarly, in the tertiary condensers the value increased by 4 to 11\%. In the case of crystallizers, the increase in evaporation rate monitored ranged from 15 to 21\% during the different seasons. The decrease in evaporation rate witnessed in the primary to the tertiary condenser samples is in agreement with the earlier report\textsuperscript{193} in the salt pans of Tuticorin District and with the reports\textsuperscript{75,107} in the salt pans of Kanyakumari District.

6.4.2. Evaporation rate and production

Normally solar salt works are designated on the basis of their output. They range in size from 500 tonnes to 6 million tonnes per annum\textsuperscript{194}. The yield potential of an area depends on the net brine evaporation, intake brine salinity and seepage losses\textsuperscript{192}. It is observed that in solar salt works the production will be from 10 to 250 tonnes per hectare per annum. In temperate climate, annually the salt works can yield from 50 to 150 tonnes per hectare. The Indian sub-continent enjoys tropical climate and hence the production is expected to be more. India produces approximately 15 million tonnes of salt per year in 2 lakh hectares of salt pans\textsuperscript{18}. Thus the mean production of salt in India works out to be 75 tonnes per hectare per annum. Salt production is directly related to the evaporation rate and the present investigation has witnessed the same.

In SP1, season IV recorded the maximum percentage increase in production of $15.1 \pm 0.68 \%$ and the increase in rate of evaporation monitored in the same season was $19.8 \pm 1.3 \%$. In SP7, the maximum evaporation rate
observed was 21.2% in season I, with the maximum increase in production of 14.9 ± 1.2% during the same season. In the case of SP8, the maximum increase in production recorded was 16.9 ± 0.84% during season IV and the corresponding evaporation rate was 17.0 ± 1.2 (Table 6.4.1 and Fig 6.4.1).

The difference in the evaporation rate and hence the increase in salt production observed is due to the inoculation of *Artemia franciscana* in the experimental ponds. *Artemia*, a filter feeder\(^9\) feeds on particulate matter of any origin and filters minute particles, (< 50 \(\mu\)m) dispersed and suspended in salt water\(^9\). Filtering of this minute particulate matter reduces the viscosity of brine thus increasing light penetration into the water. According to the earlier report *Artemia franciscana* had filtered better than *Artemia parthenogenetica*\(^1\). The increase in light penetration accelerates the evaporation rate and hence an increase in salt production.

In addition, *Artemia* presence in the condensers causes a good density of halobacteria to develop in the crystallizer brine. The C\(_50\) terpenoid (carotenoid) present in the chloroplast of these halobacteria imparts a beautiful pleasing pink colour to the brine which traps more solar radiation and thus the brine temperature is increased\(^2\). The increase in brine temperature is greater than the temperature of the air above and hence the rate of evaporation is accelerated leading to an increase in production. In the present study, the increase in salt production ranged from 12.2 to 16.9 %. According to the earlier report the increase in evaporation rate due to artificial colouring resulted in 15-20% increase in production. Natural colouring of the brine due to halophilic bacteria is as effective as the chemical dye which too can increase the production at the same rate\(^3\). It is interesting to note that the
Table 6.4.1. Salt harvested from the control and the experimental ponds of SP1, SP7 and SP8 (tonnes /ha/month)

<table>
<thead>
<tr>
<th>Saltpans</th>
<th>Season I</th>
<th></th>
<th></th>
<th></th>
<th>Season II</th>
<th></th>
<th></th>
<th></th>
<th>Season IV</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E</td>
<td>% diff</td>
<td>C</td>
<td>E</td>
<td>% diff</td>
<td>C</td>
<td>E</td>
<td>% diff</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP1</td>
<td>27 ± 1.5</td>
<td>30 ± 1.8</td>
<td>12.2 ± 1.1</td>
<td>31 ± 1.6</td>
<td>35 ± 1.8</td>
<td>13.8 ± 0.84</td>
<td>37.5 ± 2.3</td>
<td>43 ± 2.0</td>
<td>15.1 ± 0.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP7</td>
<td>21 ± 2.3</td>
<td>24 ± 1.1</td>
<td>14.9 ± 1.6</td>
<td>25.5 ± 2.0</td>
<td>28 ± 1.2</td>
<td>13.5 ± 0.65</td>
<td>34.5 ± 1.7</td>
<td>39 ± 0.97</td>
<td>14.2 ± 0.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SP8</td>
<td>25.5 ± 2.1</td>
<td>29 ± 1.4</td>
<td>14.3 ± 0.96</td>
<td>27.5 ± 1.2</td>
<td>32 ± 1.7</td>
<td>15.5 ± 0.88</td>
<td>33.5 ± 1.9</td>
<td>39 ± 1.05</td>
<td>16.9 ± 0.84</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 6.4.1. Percentage difference in salt harvested from the control and the experimental ponds of SP1, SP7 and SP8 (tonnes/ha/month)
increase in production witnessed in the present investigation (15-20%) is comparable with the earlier reports.\footnote{164}

6.4.3. Salt quality enhancement

The salt quality parameters like moisture content, insoluble impurities, calcium sulphate, magnesium sulphate and magnesium chloride content decreased from the control to the experimental samples in all the seasons in all the three salt works. As expected, the sodium chloride content increased from the control to the experimental samples.

The reduction in moisture content was greater for the estuarine salt sample (19.8 ± 1.2 to 23.5 ± 1.4%) than for the other two salt woks, SP1 (11.8 ± 1.2 to 20.9 ± 1.4%), and SP7 (16.2 ± 1.2 to 22.5 ± 2.2). In the case of insoluble impurities, both the control and the experimental samples witnessed only marginal differences. The percentage decrease ranged from 3.8 ± 0.18 to 16.4 ± 1.2% in the case of SP1, which is similar to the value obtained for the salt sample from underground water (SP7). But the percentage difference in the case of estuarine sample ranged from 8.2 ± 1.4 to 24.1 ± 1.6%. The greater variation in SP8 may be due to the abandoning of the salt work for a few years from salt cultivation.

The decrease in the calcium sulphate, magnesium sulphate and magnesium chloride content of the salt samples from the control to the experimental samples showed variations. Compared to SP1 and SP7, calcium sulphate decreased to a greater percentage in the case of SP8. The decrease in magnesium sulphate and magnesium chloride content is similar in all the three salt works.

The increase in sodium chloride content ranged from 3.5 ± 0.02 to 3.6 ± 0.19% in the case of SP1, 3.3 ± 0.32 to 3.7 ± 0.04% in the case of SP7 and 4.2 ± 0.30 to 4.5 ± 0.40% in the case of SP8 during the different seasons.
Among the three, the increase in sodium chloride content was higher in the estuarine salt than in the other two. Similar increase in sodium chloride content (2.02%) and greater decrease in other salt quality parameters were proved in the Chinese salt works by artificially culturing algal mats in the evaporation ponds\textsuperscript{30}. The difference in the chemical composition of the control and the experimental salt samples and the percentage difference with respect to the control pond are given below (Table 6.4.2).

Table 6.4.2. Salt quality parameters before and after artificially culturing algal mats (%)

<table>
<thead>
<tr>
<th>Salt quality parameters</th>
<th>Control pond %</th>
<th>Experimental pond %</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium chloride</td>
<td>94.1</td>
<td>96</td>
<td>2.02</td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>1.6</td>
<td>1.4</td>
<td>12.5</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>1.8</td>
<td>1.0</td>
<td>44.4</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>2</td>
<td>1.3</td>
<td>35.0</td>
</tr>
<tr>
<td>Others</td>
<td>0.5</td>
<td>0.3</td>
<td>40.0</td>
</tr>
</tbody>
</table>

6.4.4. Heavy metals

The content of heavy metals (lead, chromium, nickel, zinc, copper, iron cobalt and manganese) decreased from the control to the experimental samples except nickel in SP1 and lead and manganese in SP7. This is in accordance with the earlier report which has detected high levels of heavy metals in the Anemia biomass and the cysts in a condition where heavy metals exist in the habitat\textsuperscript{47}. The decrease in the heavy metal content in the experimental samples may be due to the bio-accumulation of these metals by Artemia or due to the tendency of Artemia in transferring these metals to the bottom mud or to the other organisms that inhabit the evaporation ponds of the salt works, which needs further study.