Maria ŚMIECHOWSKA
Gdynia Maritime University, Department of Commodity and Quality Science
ul. Morska 81-87, 81-225 Gdynia, Poland
e-mail: m.smiechowska@wpit.am.gdynia.pl

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ECOLOGICAL THREATS FOR COASTAL SYSTEMS IN THE CONTEXT OF ACQUIRING AND PROVIDING THE QUALITY OF SEA SALT. A REVIEW

Summary

Salt is a basic food commodity. Among different kinds of salt, the sea salt obtained via seawater evaporation in salterns located in the coastal zone is very important. Unfortunately, the coastal zone experiences strong anthropogenic pressure connected with leaking of pollutions from agricultural and household activities into the seawater. The aim of this paper was to present selected problems connected with sea salt acquisition and factors influencing its quality. The paper enumerates sea water pollutants, paying particular attention to the problem of novel pollutants, such as micro- and nanoplastic fibres. Additional factor influencing sea salt quality is the climate change due to its destructive activities in the coastal zones that host the salterns.
***Key words**: sea salt, coastal zone, sea salt pollutants, ecological problems*

ZAGROŻENIA EKOLOGICZNE SYSTEMÓW PRZYBRZEŻNYCH W KONTEKŚCIE POZYSKIWANIA I ZAPEWNIENIA JAKOŚCI SOLI MORSKIEJ. PRZEGLĄD BADAŃ

Streszczenie

Sól należy do podstawowych produktów spożywczych. Wśród różnych rodzajów soli duże znaczenie ma sól morska pozyskiwana w wyniku odparowania wody morskiej w salinach znajdujących się w strefie nadbrzeżnej. Niestety strefa nadbrzeżna podlega silnej antropopresji związanej z przedostawaniem się do wód morskich zanieczyszczeń z działalności rolniczej i bytowej człowieka. Celem artykułu było przedstawienie niektórych problemów związanych z pozyskiwaniem soli morskiej i czynnikami wpływającymi na kształtowanie jej jakości. W artykule przedstawiono zanieczyszczenia występujące w soli morskiej, w tym zwrócono szczególną uwagę na problem nowych zanieczyszczeń jak włókna mikro- i nanoplastików. Dodatkowym czynnikiem wpływającym na jakość soli morskiej są zmiany klimatyczne, z uwagi na niszczące działania w strefie nadbrzeżnej, w której znajdują się saliny.
***Słowa kluczowe**: sól morska, strefa przybrzeżna, zanieczyszczenia soli morskiej, problemy ekologiczne*

1. Introduction

Sea salt is composed in more than 90% from pure sodium chloride (40% Na, 60% Cl) and is an indispensable product. The name of the crystalline substance comes from combining two Greek words: *halos* (salt, sea, salty) and *lithos* (rock, stone). Once known as the "white gold", today it is referred to as "black death". The cause of the drastic change in the approach to the role and importance of salt for the human organism comes from the scientific investigations that point at a negative influence of salt on the human health due to the excessive consumption. As a consumer product, salt comes on the market in several forms: rock salt, evaporated salt, iodised salt, Dead Sea salt, Himalaya salt, sea salt. Flavoured salts and salts aromatised with herbs and vegetables also find common use. Deluxe salts are those that are utilised in regional cuisines and are becoming increasingly significant owing to culinary tourism. The present paper is devoted to the sea salt due to the increasing consumer interest in it. The aim of this work was to show the collection sites of sea salts and selected dangers resulting from environmental pollution.

2. Sea salt technology

Salt may be obtained with various methods, including deep mining, boiling and evaporation (Table 1) [25]. The current system of sea salt acquisition was most probably introduced by the Phoenicians in the Mediterranean Basin countries such as Greece, France and Italy. Later, thanks to the Roman Empire, it was transferred to Spain and Portugal [15]. Salterns are commonly situated in bays, where seawater evaporates in a series of shallow ponds located at the sea level. The proximity of the sea enables fast repletion of the pond with seawater. The production process is composed of three phases: pond filling, water evaporation, salt crystallisation. In accordance with the solubility series, initially crystallize carbonates, then sulphates and finally halite is deposited. Salt is collected from the bottom of the pan with wooden shovels and heaped up in small mounds, so that the final sun drying process could occur. The whole cycle from fresh seawater to salt acquisition lasts from several months to a few years. The works in the salterns last from spring to autumn and are intensified in summer due to weather conditions. Salt production depends mainly on high sunlight intensity, high temperature and low relative humidity, such conditions being met mainly in the summer months. In the process of evaporation the *fleur de sel* (flower of salt) appears first in the form of very delicate salt crystals [8].

Sea evaporation ponds may be considered as a special ecosystem composed of seawater, salt and organisms living in it: shellfish, molluscs, nematodes, *Artemia salina* shrimps and *Dunaliella salina* algae. All these organisms contribute to the salt productions, because apart from the colouring of salt (particularly by *D. salina*) they increase the solar energy absorption and favour water evaporation [28]. As a result the preservation of activities connected with salt production is considered necessary for the protection of these ecosystems. In order to maintain the security of salterns they were often located in remote places without agricultural or industrial activity. In this way people tried to protect this very fragile ecosystem and ensure the quality of the obtained salt. An example is the centuries old saltern Del Carmen located in the southern part of Fuerteventura at 28^{o} 22' 3" W 13^{o}52'11'' (Fig. 1).

Fig. 1. A saltern on Fuerteventura (author's photography)
Rys. 1. Salina na Fuerteventurze (fotografia autorki)

3. Properties and characteristics of sea salt

The European Commission (UE) considers hand picked seal salt as an agricultural product [20]. Such products originating from different regions of the world want to obtain the status of the protected geographical indication (PGI), since their manufacture is tied to a specific territory, and they should be protected and have their authenticity ensured. Such indication is already possessed by the grey salt from Guérande, France [19].

Sea salt has a specific taste. It is rich in nutrients such as Ca, K, Mg, Fe, Li, I and others. The work by Drake and Drake suggests that even a tiny content of some of these elements may influence the intensity of the salty taste of sea salt and may give special taste values, such as mineral and metallic notes, and sometimes stronger umami intensity and astringent feeling in the mouth [5].

Sea salt must fulfill specific microbiological requirements. It cannot contain *Escherichia coli* and *Streptococcus faecalis* bacteria. The test for the presence of the *coli* group bacteria is mandatory [8]. The count of mesophile and halophile colonies should not exceed 100 g^{-1}. Certifying institutions impose good production practices along the entire chain of production and storage of sea salt in order to protect it from contaminations. Other important quality factors that must be taken into consideration with respect to the sea salt are listed in Table 2 [32]. Depending on the country of production, minor differences in required parameters of sea salt are observed.

Table 2. Quality aspects of sea salt [32]
Tab. 2. Wymagania jakościowe dla soli morskiej [32]

Physico-chemical characteristic	**Content**
Sodium chloride (% min.)	94
Humidity (% max.)	12
Insoluble material (% max.)	0.2
NO_3^- and NO_2^- (ppm max.)	10
PO_4^{3-} (mg kg^{-1} max.)	10
Heavy metals (ppm)	
Lead (Pb)	< 1.0
Cadmium (Cd)	< 0.25
Mercury (Hg)	< 0.05
Arsenic (As)	< 0.25
Copper (Cu)	< 1.0
Pesticides (mg kg^{-1} max.)	
Organophosphates	0.5
Organochlorides	0.5
Polychlorinated biphenyls	0.5
Polycyclic aromatic hydrocarbons	0.5
Radioactivity	Natural

Table 1. Salt technology [25]
Tab. 1. Technologia soli [25]

<table>
<tr><th>Type production</th><th colspan="3">Salt technology</th></tr>
<tr><td>Collecting</td><td colspan="3">Collection of the salt naturally deposited along coast rocks, lagoons or on large-scale continental deposits.</td></tr>
<tr><td>Mining</td><td colspan="3">The mining of rock salt.</td></tr>
<tr><td>Adjustment and boiling</td><td colspan="3">Obtaining salt by heating sea water or brine in recipients made of different materials and using some type fuel to produce evaporation of the water precipitation of the salt.</td></tr>
<tr><td rowspan="6">Concentration and evaporation</td><td>Extensive salt fields</td><td colspan="2">The crystallising area is not divided. This are usually found inland, near salt spring.</td></tr>
<tr><td rowspan="5">Intensive salt fields (all of the Canary salt fields)</td><td>Natural salt fields</td><td>High tide pools found in mud flats or on rocky beds. They only have a single pool, the cocedero.</td></tr>
<tr><td rowspan="4">Artificial (comprising: intake and pumping systems, distribution and crystallisation)</td><td>Primitive salt fields on rock. They have two recipients: the cocedero and the crystalliser or condenser pool (mareto). They are circular in shape and enclosed, with walls made from stone and mud or lime mortar.</td></tr>
<tr><td>Old salt fields on mud flats. Generally located in areas of alluvial deposits. The walls of the cocederos and channels are made of stones set in lime mortar and sealed with mud or lime. The floor is made of pressed earth.</td></tr>
<tr><td>Old salt fields on lime mortar. Walls of basalt stones set in lime mortar.</td></tr>
<tr><td>New salt fields on mud with stone linings. The position of the collection pools or cocederos is now the reverse, they are inland and the water is distributed to the condensation pools which are closer to the coast. They are built from stone and earth, lime only being used for waterproofing of the insides of the pipes and channels. The bed is composed of pressed earth.</td></tr>
</table>

4. Factors causing sea salt contamination

Until recently, sea salt was considered as more valuable in terms of nutritional value and more healthy than table salt [5]. Sea salt is unrefined and contains all mineral components of sea water. Mineral components and fragments of organisms inhabiting the water influence the taste and colour of sea salt. Unfortunately, salt coming from the seas and oceans may also contain trace quantities of heavy metals and pollutants common in water reservoirs.

Currently the Himalayan salt is considered as the purest natural edible salt. Crystalline Himalayan salt is mined from deposits in Pakistan, at the foot of Himalaya, where prehistoric ocean was located millions of years ago. It has a white to light pink to deep red colour, depending on iron content. It contains many valuable minerals and trace elements that are not found in refined table salt and it is devoid of chemical additives and pollutions often found in sea salt [29].

The coastal zone has a major significance for the acquisition of sea salt. This zone is in fact a very fragile ecosystem due to the anthropocentric influence and interaction of the sea and land mass. Main dangers of pollution are connected with nutrient enrichment, increasing quantities of metals and persistent organic pollutants (POP). The coastal zone is considered a buffer zone between the land and the sea. In this context, the human activity on land, the climate change and the extreme events led to the environmental degradation in the coastal zones [16].

The coastal ecosystems are subject to the contamination with nitrogen and phosphorus compounds due to the flow of mineral fertilisers from the fields. Additionally, the quantity of nitrogen in the coastal zones increases because of the aquaculture waste. As a result, it comes to far-reaching changes in the form of eutrophication of the coastal zone [3, 4, 10]. The phenomenon of eutrophication was defined by OSPAR as "the result of excessive enrichment of water with nutrients which may result in a range of undesirable disturbances in the marine ecosystem, including a shift in the composition of the flora and fauna which affects habitats and biodiversity, and the depletion of oxygen, causing death of fish and other species." [21].

The coastal zone also experiences an increased metal pollution, including zinc (Zn), copper (Cu), chromium (Cr), lead (Pb), nickel (Ni), arsenic (As), mercury (Hg) and cadmium (Cd). The studies in this direction are, however, very fragmentary and there is a lack of detailed results on the content of these metals in the regions of salterns occurrence. From the published results it appears that the contamination of seawater with metals is diversified and comes from different sources, such as wastewater, communal waste, industrial waste and ecological disasters [16].

Thanks to the development of analytical methods we can now detect contaminations with chlorinated and fluorinated organic compounds, such as organochloride pesticides (OCP), polychlorinated biphenyls (PCB), polybrominated diphenyl ethers (PBDE), hexabromocyclododecanes (HBCD), Dechlorane Plus (DP) and perfluoroalkoxy alkanes (PFA). Monitoring of POP in coastal zones was mainly conducted in China and Europe, while it was seldom carried out in the Americas, Africa and Oceania. Sea organisms such as molluscs, fish, birds and mammals are often used as biomarkers in the studies on contamination [18, 30].

5. New threats to coastal ecosystems

The detection of microplastics in sea water and other water reservoirs was of greatest concern. Microplastic contaminants arise as a result of micronization of plastics such as polyethylene, polypropylene and polystyrene. Plastic microgranules are deposited in the coastal zone and threaten marine animals [7, 34]. Research has shown that micro- and nanogranulates of plastic have been detected in many market foods such as beer, honey, sugar, fish and fish products, mineral water, tap water and salt [1]. Yang et al. found the presence of 550–681 particles of microplastics/kg in sea salt, 43–364 particles / kg in lake salts and 7–204 particles/kg in rock salt in the samples of salt available on the market in China [33]. The presence of plastic has also been confirmed in salt from different countries. Karami et al. in 16 brands of salt from Australia, France, Iran, Japan, Malaysia, New Zealand, Portugal, and South Africa purchased from a Malaysian market detected the presence of 72 microplastics fibers [12]. In studies conducted in Spain in the sea salt obtained on the shores of the Atlantic Ocean and the Mediterranean, 50–280 microplastic particles / kg salt were found [11]. In turn, when researching salt on the US market, Koshuth et al. found a slight presence of plastic particles in the range of 46.7 to 806 particles of microplastics / kg in sea salt [14]. In studies conducted in Turkey in salt samples available on the market, 16–84 microplastic particles / kg in sea salt, 8–102 particles / kg in lake salts and 9–16 particles / kg in rock salt were found [9]. In all studies, the most commonly occurring polymers were polyethylene and polypropylene. At the present stage of knowledge, the presence of microplastics in various types of food, including salt, is firmly confirmed. However, for the time being there is no information available about the fate of microplastics in the human body. Therefore, the question arises whether microplastics can cause cancer in marine animals and humans [6]. We need more research to answer this question, but we certainly should reduce the presence of plastics in the environment.

In recent years, the impact of climate change on the coastal zone has become increasingly noticeable. Research indicates an increase in water temperature, an increase in the level of seas and oceans, the melting of glaciers and an increase in the number of violent events in nature such as hurricanes, cyclones, floods and others [2]. The impact of climate change combined with anthropogenic factors, as well as increasing eutrophication, water hypoxia and pollution can lead to coastal zone disturbance and problems in obtaining organic sea salt.

6. Threats to human health

The knowledge about the fate of micro- and nanoplastics in the human organism is at present very limited. However, the ubiquitous presence of these compound in the entire agrosystem demands further studies in this direction [17]. Is the consumption of sea salt containing micro- and nanoplastics a threat to human health? The consumption of salt should amount 5–6 g/day for an adult person. However, it is in practice much higher, due to the presence of salt in processed foods [13]. From hitherto studies it is known that micro- and nanoplastics penetrate the trophic chain. It was demonstrated in the research confirming the presence of micro- and nanoplastics in pelagic and demersal fish from the North Sea and Baltic Sea consumed by people. Higher contents of these compounds were noted in waters and fish in the coastal zones, probably resulting from the human inland activities as the major source of plastics in the marine environment [26]. In *in vitro* experiments it was shown that microplastics may disturb the metabolism of organisms and their proper functioning. These studies were conducted on the *Halomonas alkaliphila* bacteria, *Daphnia magna* and zebrafish (*Danio rerio*) [22, 24, 31]. Only one study was conducted on the human cell lines. Two different cell lines, T98G and HeLa, brain and epithelial cells, respectively, were used. The cells were exposed during 24–48 hours to different levels of contaminants from 10 ng/ml to 10 µg/ml in the same conditions. Additionally, synergistic and antagonistic relationships between fullerenes and other organic contaminants, including an organophosphate insecticide (malathion), a surfactant (sodium dodecylbenzenesulfonate) and a plasticiser (diethyl phthalate) were assessed. The obtained results confirm that oxidative stress is one of the mechanisms of cytotoxicity at cell level, which has been observed for both cell lines [27]. These results raise concerns about the cytotoxicity against the human liver cells. Substances present in the passage may interact with the liquid via the adsorption reactions facilitated by surfaces with large specific surface and charge. Large proteins may become adsorbed on the surface of plastic particles, which may lead to local inflammations [23].

It must be taken into account that micro- and nanoplastics were found not only in sea salt, but in many other foodstuffs, such as beer, honey, sugar, water and other drinks, fish and shellfish [1]. The exposure to plastics may thus be much higher considering the type of diet and the quantity of consumed products.

7. Conclusions

Salt is an important product for the human health possessing significant meaning for the food technology. Sea salt is often used for direct consumption and preparation of processed organic foodstuffs. The problems presented in this elaboration cause that sea salt, apart from the well known pollutants such as nitrates, phosphates, heavy metals, chlorooganic compounds and their derivatives, may contain micro- and nanoplastics and numerous other compounds, e.g., radioactive elements. The risk assessment connected with the consumption of contaminated sea salt is difficult and requires further studies. In order to certify sea salt as an organic product, all possible environmental dangers that may influence the quality of salt must be reduced and particular attention must be paid to the proper supervision and control of salterns.

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