



# Study of the salinity and pH dilution pattern of discharged brine of the Konarak desalination plant into the Chabahar bay: a case study

Farahnaz Noori<sup>1</sup> · Mir Mahdi Zahedi<sup>1</sup> · Atefe Bayati-Comitaki<sup>1</sup> · Morteza Ziyaadini<sup>1</sup>

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## Abstract

This research aims to study the salinity and pH dilution pattern of discharged brine of the Konarak desalination plant into the Chabahar bay, their relation on coastal environment, and type of its brine discharge. Due to the shallow water depth of the coast and type of brine discharge, evaluating the salinity and pH was done with a sampling of surface seawater. The type of brine disposal is a direct surface discharge of negatively buoyant flow in the coastal environment of Chabahar bay. The brine discharge mechanism is a shore-attached surface jet, which is most likely influenced by the cross-flow deflection, dynamic shoreline interaction, and more minor by bottom attachment factors. The laboratory simulations using actual brine and seawater and either satellite pictures support the finding dilution pattern. The zone of initial dilution is under 50 m which, in the long run, can affect the quality of water of intake seawater pool of the plant.

**Keywords** Konarak RO desalination plant · Brine disposal · Chabahar bay · Salinity · pH · Surface discharge

## Introduction

Now, due to the current lifestyle, the scarcity of freshwater resources has emerged as a global crisis, and for overcoming it, desalination of seawater is a suitable solution (El-Emam et al. 2014, Yusefi et al. 2021). The global climate changes, earth warming, reducing rainfall, and increasing water consumption are the main reasons for water scarcity (Mehdizadeh 2006). Like other countries in the Middle East, Iran suffers a lack of access to conventional freshwater supplies that have added to the severity of the water scarcity and its related problems (Marcovecchio et al. 2005; Farhoudi et al. 1992). The central and southeast regions of Iran have little rainfall and are considered dry and semiarid climates (Daneshmand et al. 2017; Rezaee et al. 2014). To solve the problems of water shortage, the move is toward the construction of desalination systems with the majority of reverse osmosis (RO) desalination plants (Van der Bruggen et al. 2002). Here, it is needed to pay attention to suitable pre- and

post-treatments procedures (Brandt et al. 2017; Zahedi et al. 2017; Pourmortazavi et al. 2017).

Selecting the most suitable and inexpensive method for the management of plant discharge is one of the most significant challenges of desalination plants (Mavukkandy et al. 2019; Kress et al. 2020; Wood et al. 2020). The concentrate water (brine water containing the rejected salts), pretreatment filter backwash water, membrane cleaning solutions, and other treatment by-products are the main content of the discharge brine. The suggested methods for concentrate management in order of their importance are surface water discharge, sewer disposal, deep-well injection, land application, and evaporation ponds (Mickley 2009; Panagopoulos et al. 2019). Surface water discharge is the most common brine disposal method. It involves the disposal of brine from the desalination plant to an open water body such as a bay, tidal lake, brackish canal, or ocean. Surface water discharge methods with imposing related limitations and potential environmental impacts are classified as: (1) direct surface discharge, (2) discharge through existing wastewater treatment plant outfall, and (3) co-disposal with cooling water of existing power plant (Hoepner 1999; Hoepner et al. 1996; Rhodes 2006; Mavukkandy et al. 2019). The most appropriate location for a desalination plant's surface outfall discharge is included: an area devoid of endangered species and stressed aquatic habitats, having powerful underwater

✉ Mir Mahdi Zahedi  
idm.m.zahedi@gmail.com

<sup>1</sup> Department of Marine Chemistry, Faculty of Marine Sciences, Chabahar Maritime University, P.O. 99717-56499, Chabahar, Iran

currents for quick and effective dissipation of the concentrate discharge, avoiding areas with frequent naval vessel traffic, and being in relatively shallow waters to minimize outfall construction expenditures.

Salinity changes of aquatic species inhabiting the discharge area, water constituent increase to harmful levels, discoloration, and reduction in oxygen content, are essential environmental impacts accompanied by concentrate (brine) disposal to surface seawaters (Frank et al. 2017). The typical range of natural salinity fluctuation in open ocean waters is at least  $\pm 10$  percent of the average annual ambient seawater salinity concentration (Cotruvo et al. 2010). Seawater desalination plants usually produce a concentrate with salinity approximately 1.5 to 2 times higher than that of the ambient seawater, generally in the range of 50 to 70 ppt. While many marine organisms can adapt to this salinity range, some species are less tolerant to elevated salinity concentrations than others (Bleninger et al. 2010).

Since reverse osmosis (RO) desalination is one of the important desalination methods which could produce a massive amount of brine water with environmental impact, investigation into brine disposal and its effects is necessary. This research aims to study the salinity and pH dilution pattern of discharged brine of the Konarak desalination plant into the Chabahar bay. To do this, surface seawater near the brine discharge canal was sampled and determined in terms of salt content and pH, and the brine dilution pattern is estimated. Finding a dilution pattern can help us assess some environmental impacts and the future performance of the desalination plant.

## Experimental

### Konarak RO desalination plant description and case study

Noor Vijeh Co. (NVCO), an Iranian company active in reverse osmosis and freshwater production and distribution industry, operates the Konarak RO desalination plant in  $X = 247,276$  and  $Y = 2,816,084$ , on the north Oman Sea coast and Chabahar bay (Fig. 1). This current reverse osmosis desalination plant has been replaced with the previous thermal one. NVCO is the executor of the freshwater supply project of Chabahar and Konarak cities with a capacity of  $18,750 \text{ m}^3/\text{day}$  in two phases during 2010 and 2019. To do this, it uses seven series of reverse osmosis desalination water (SWRO) with a capacity of  $3,000 \text{ m}^3/\text{day}$ . The raw intake water is provided through direct seawater from the Chabahar bay using an intake pool, suitable facilities, and equipment. Then, through the pipeline, after adding the coagulants, it passes through gravel sand filters. After being stored in the initial raw water tank, it is transferred through the pumping station to the cartridge filters and then to the reverse osmosis series. After suitable post-treatment is pumped to the reserving tank, the produced freshwater is papered for pumping into the distribution network of the Chabahar and Konarak cities. Figure 2 shows the location and facilities of the Konarak RO desalination plant.

**Fig. 1** Location of Konarak RO desalination plant

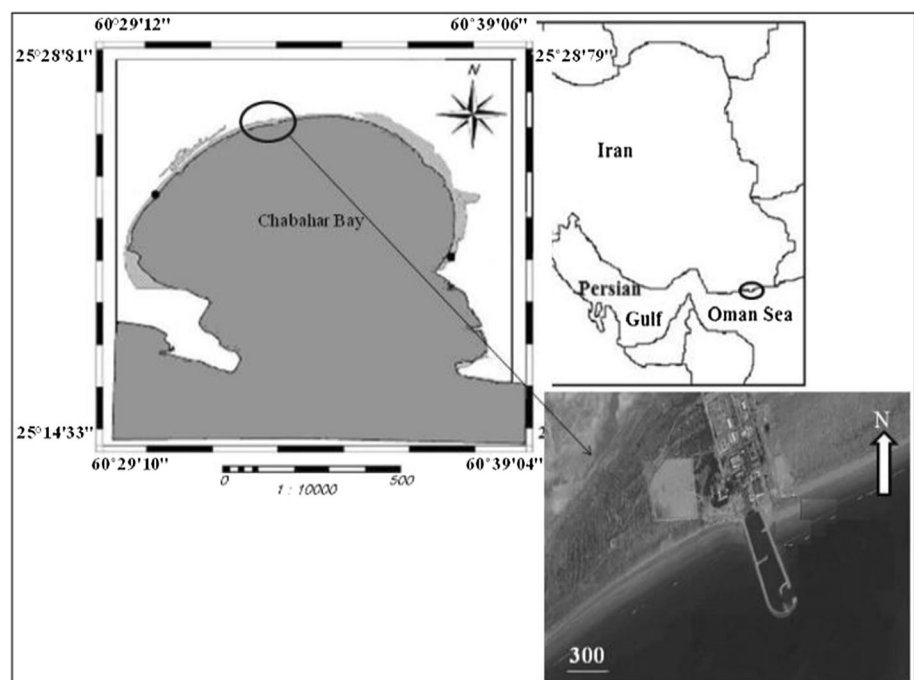
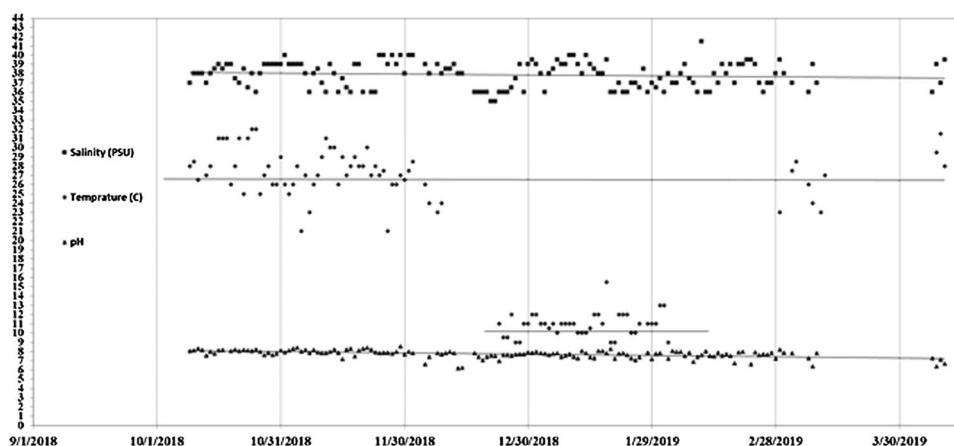




Fig. 2 Konarak RO desalination plant

The brine of the plant, contains the plant’s source water treatment by-products, concentrate water, spent pretreatment filter backwash water, and membrane cleaning solutions flow to the discharge concrete canal with a width of about 2.5 m, and transport to the shore zone for direct surface shoreline disposal (Fig. 2). The distance between the brine discharge canal and the intake seawater for the RO desalination plant is 300 m.

Fig. 3 Monitoring of salinity, pH and temperature in Chabhar bay



### Sampling and monitoring of disposal brine

To investigate the changes in salinity, pH, and temperature of seawater as a result of the released brine into the Chabhar bay, surface seawater samples were collected using 250-mL sample polyethylene containers, from 5-, 10-, and 12-m intervals left and right of the brine discharge canal over several periods in November, February, and March 2018 with different atmospheric tidal conditions (Fig. 3). Temperature measurements were performed at the sampling site using a Thermo Model TA-288 digital rod thermometer with a precision of 0.1 °C. The pH of samples was analyzed using a portable pH meter of TRANS, in the sampling site and benchtop pH meter of TPS model wp-80 (Brisbane, Australia) after transporting the concentrate brine seawater to the laboratory. The salinity of brine water sample was determined conductometry (Metrohm 712) and gravimetrically. The samples in the laboratory first were filtered using Whatman filter paper mesh 40 to remove suspended matter, and then the salinity of seawater was determined gravimetrically after evaporation of water content using an oven of 105 °C and cooling to the laboratory temperature using a desiccator.

To study the brine dilution overall pattern more accurately, saline water flow was simulated in the laboratory. To do this, a glass aquarium equipped with coastal area soil (replacing shore rocks), colored brine water of RO plant, and artificial waves were used. The shape of the seashore and the discharge canal flow were simulated at the same deviation angle (under 7°) and the peristaltic pump with a flow rate of 2 mL/min.

### Results and discussion

#### Study of general conditions of Chabhar bay in terms of temperature, salinity, and pH

Monitoring any environmental changes requires an understanding of the general conditions of the target environment

away from the influencing factor. To achieve this goal, the team monitored a site near the Chabahar Maritime University (CMU) for relatively long periods to record changes in salinity, pH, and temperature of seawater. The results of this monitoring are shown in Fig. 3, which shows the general water conditions from 2018 until 2019, as well as the synchronous investigation of the brine disposal method of the Konarak RO desalination plant. The results show that the mean salinity and pH are  $37.9 \pm 1.3$  and  $7.8 \pm 0.4$ , respectively. The issue is slightly different for seawater temperature; during this monitoring period, the temperature can be divided into two hot and relatively cold periods with a mean temperature of  $27.4 \pm 2.3$  °C and  $11 \pm 1.3$  °C, respectively.

### Intake seawater of Konarak RO desalination plant as major element component

This desalination plant selects onshore intakes to prepare consuming seawater as feed which, as we know, have found application mainly for huge seawater desalination plants with the lowest cost as its key advantage. As clearly shown in Fig. 1, to prevent the negative effects of water turbidity caused by sea waves, seawater is fed through a relaxation pool equipped with several wave breakers. After screening, and then the disinfection, feed seawater at the bottom of the relaxation pool is pumped into the planned pretreatment route.

### Impact of brine temperature on inshore zone

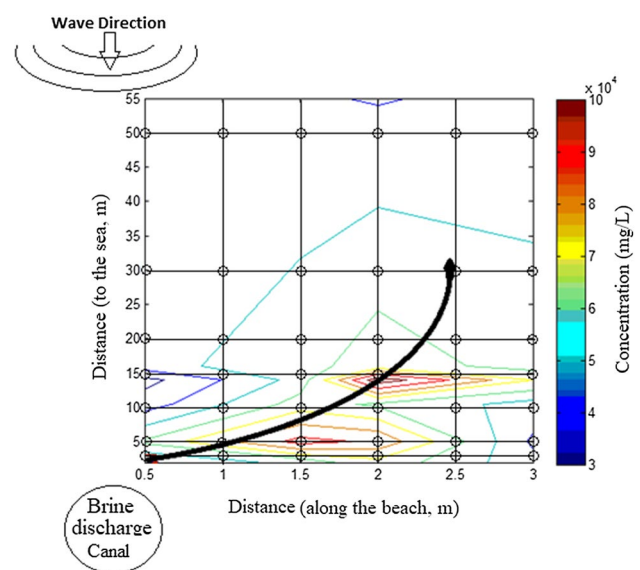
Releasing heat from the cooling agent of industries such as thermal power plants in the aquatic environment, especially in coastal and intertidal sensitive areas, can lead to thermal pollution (Di Pippo 2016). Due to the importance of this case, the temperature distribution was studied. However, since the Konarak desalination plant is currently reverse osmotic, its feed is supplied directly from the seawater pond; there is little thermal difference between the brine discharge to the sea rather than the feed seawater temperature. Mainly since its used power is directly supplied by city electricity, no thermal power unit is used. The measured temperature difference between the discharge brine and seawater varies by about  $2 \pm 0.2$  °C depending on the season (Fig. 3). Therefore, thermal pollution in the case of an RO desalination plant of Konarak can be considered low.

### Impact of brine salinity on inshore zone and laboratory simulation to study the dilution mechanism

Direct surface discharges, in the form of the open canal near or parallel to the free surface of the receiving water,

are a common and costly method for the disposal of large volumes of effluent into the sea (Doneker et al. 1997; Jones et al. 2007; Abessi et al. 2012a). In these cases, the mixed effluent could be positively, neutrally, or negatively buoyant that forms discharge with complex hydrodynamics. To investigate the brine disposal pattern and effectiveness in the Konarak RO desalination plant, the surface seawater has been sampled and measured along the outlet canal. The results of the salinity analysis of the surface water in the brine disposal coastal zone as a three-dimensional diagram are shown in Fig. 4, where its zero points are the location of the brine discharge canal of the Konarak desalination plant. The first axis of the chart shows the distance from the brine discharge canal along the shore, and the second axis shows the distance of the canal to the sea. The diagrams include the left-side profile relative to the brine disposal canal. This measurement (Fig. 4) is performed when the seawater reaches the brine discharge canal at the shore. However, seawater flows back about 150 m away in tide conditions rather than the brine discharge canal. (The sea bed slope at this location is approximately about 7° relative to the horizon.) The sea waves are from the south-east of the Chabahar bay with a range of height about 20 to max 70 cm and a period of 5–10 s in the usual climate.

As can be seen in Fig. 4, brine salinity dilution is such that most saline points are on either side of the brine canal, thus reducing the salinity of the outflow to the sea. The black arrow curve shows the coastal seawater locations with high salinity. Based on previous studies (Abessi et al. 2012b), it can be stated about the Konarak desalination plant that the changes of initial fluxes as surface discharge is negatively



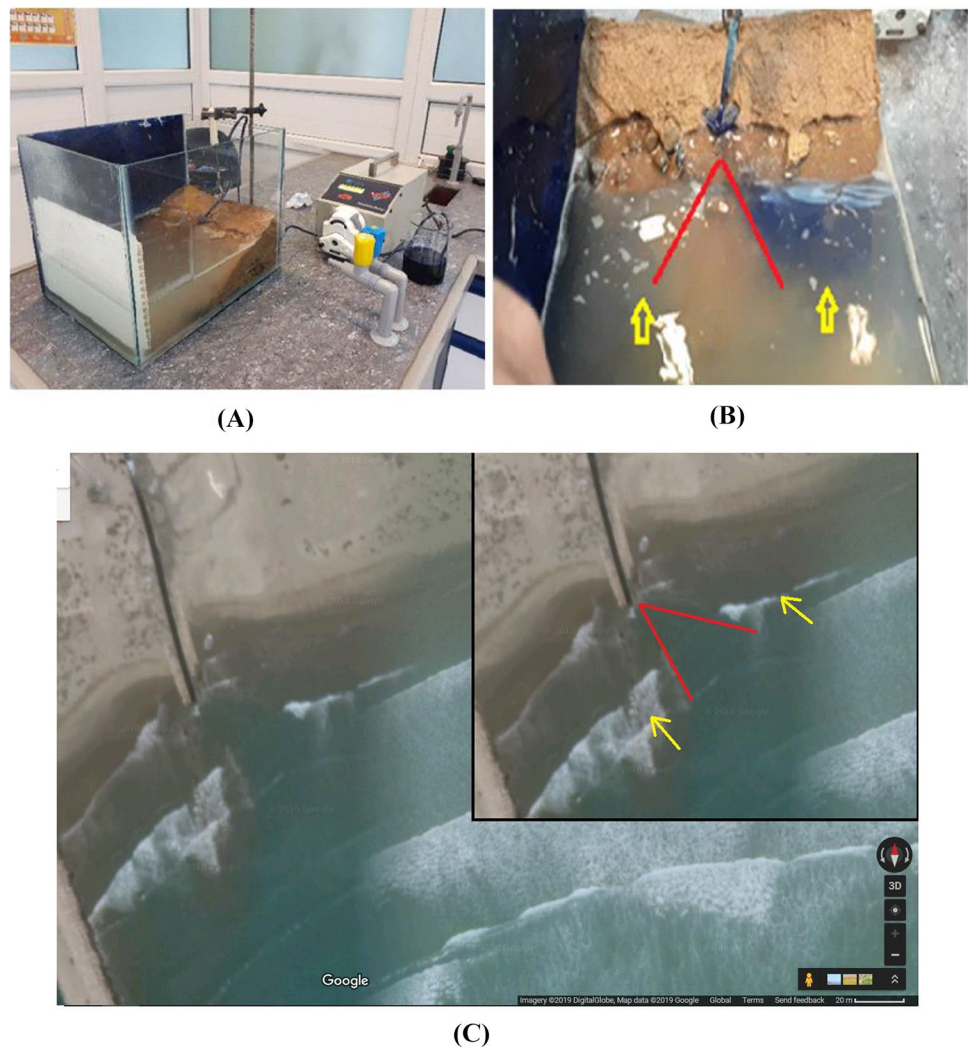
**Fig. 4** 3D surface seawater brine concentration dilution profile. The zero point of the graph shows the location of the brine discharge canal. Open circles are shown sampling zone

buoyant flow in ambient current. This type of brine flow pattern in Konarak desalination plant discharge forms within the receiving water with impacting cross-flow deflection, dynamic shoreline interaction, and less bottom attachment. These interactions can dramatically alter the initial mixing and configuration of the flow. In this regard, Abessi et al. (2012b) identified three flow regimes for negatively buoyant surface discharges as the free surface jet, the shore-attached surface jet, and the plunging plume, which in about Konarak desalination plant, the shore-attached surface jet is in good agreement.

To further test this issue, laboratory simulations were performed as follows. According to Fig. 5, a glass aquarium of  $50 \times 40 \times 40$  cm and sand were obtained from the Konarak brine discharge sea bed and a sloping bed was constructed on the one side. The water used in the aquarium is from the Chabahar bay, and the brine used in the simulation process is from the Konarak desalination drainage canal, which

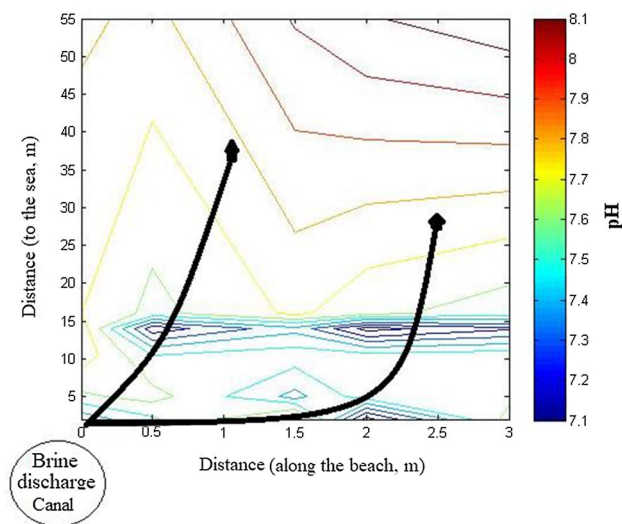
is added with methylene blue to make it visible. There is a plastic plate on the opposite side of the aquarium used to create the simulated waves manually (with a period of 5 s), and the brine flows in it with a constant rate of 2 mL/min using a peristaltic pump. The simulation was recorded nonstop at the start of the interring the colored concentrate water to the aquarium, and the result is shown in Fig. 5. As the result of the simulation, the mechanism of the shore-attached surface jet is strongly confirmed, and contrary to popular belief, there are zones with lower salinity than the brine canal, directly in front of it. There are several empirical experiments in this regard, and most are related to computational estimations (Bashitialshaaer et al. 2013). As can be seen from the satellite picture, that was accidentally spotted while monitoring the output of the Konarak desalination plant when discharging the backwash filters. The predicted discharge pattern is fully confirmed.

**Fig. 5** Photographs of laboratory simulation which shows the mechanism of brine dilution. **a** Tools used to simulate and how to connect, **b** saline dilution mechanism, **c** satellite picture (source Google Earth)



## Impact of brine pH on inshore zone

The crucial importance of acid–base status and regulation in whole-organism functional maintenance and enantiosis shows the significance of the threat of ocean acidification for marine life. pH values play a key role in maintaining physiological function or their limitation under functional or environmental stress and affect protein function in metabolism and oxygen transport. Seawater typically has a pH ranging between 7.9 and 8.4, and for surface water, the average value is near 8.2; therefore, it is alkaline (Riebesell et al. 2010). Due to the importance of this parameter in the marine environment, the study of the pH changes and distribution in the location of the Konarak desalination drainage canal has been carried out. The result of the pH measurement of these sampling is presented as a three-dimensional diagram in Fig. 6. The brine pH at the canal location is 7.1, while the pH of the surrounding seawater is about 8.1 and has about one-unit difference. One can see the results of the pH experiment, the distribution pattern, and the way of the acidity pollution elimination of brine in the marine environment, similar to the mechanism described for salinity. The pH of the feed seawater is generally lowered by poly-acids as antiscalants before being presented to reverse osmosis membranes. Thus, the RO desalination plants are required to neutralize its acidity. However, as already mentioned, seawater is naturally alkaline! When seawater is titrated with acid, the pH drops at first slowly and then more rapidly. The major species that react with hydrogen ions are  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ , and  $\text{B}(\text{OH})_4^-$ ;



**Fig. 6** 3D surface seawater brine pH profile. The zero point of the graph shows the location of the brine discharge canal

accordingly, the complex cycles of chemical species in the water will change.

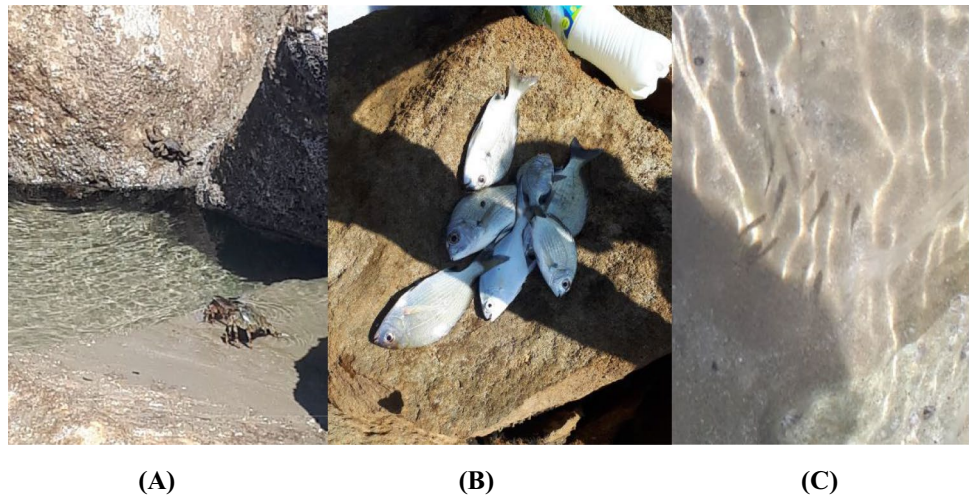
## Environmental aspect and the typology of indicator organisms near the brine discharge canal

The potential environmental impacts of concentrate disposal have been discussed in some publications (Cambridge et al. 2019; Lattemann et al. 2008), including short-term and longer-term effects of brine discharge. The concentrate and chemical discharges of desalination plants to the marine environment may have adverse effects on water and sediment quality, impair marine life, and the functioning and intactness of coastal ecosystems. Most marine organisms can adapt themselves to salinity and temperature tolerance but not continuous exposure to unfavorable conditions. The concentrate of RO plants with a higher density than seawater will spread over the seafloor in shallow coastal waters unless a diffuser system dissipates it. Benthic communities, such as seagrass beds, may thus be affected by high salinity and chemical residues (Missimer et al. 2015). To estimate the extent of short-term environmental impacts on the Konarak RO desalination site, biological species near the brine canal are monitored. We can see some of these species in Fig. 7, which were a few meters away from the brine canal. These species include several fish from the family of *Sparidae*, *Ocyrodidae* crab, and some juvenile fishes. These predominantly carnivorous species in this environment, some of which are even known as environmentally sensitive species, indicate their resilience in brine stress. On the other hand, at least the benthic communities in this area can be confirmed.

## Conclusions

Consequently, we can say that the type of brine disposal in Konarak RO desalination plant is the surface discharge of negatively buoyant flow in the inshore environment of Chabahar bay. Mechanism of brine dissemination is a shore-attached surface jet, which is most likely influenced by the cross-flow deflection, dynamic shoreline interaction, and minor bottom attachment factors. The laboratory simulations have confirmed this trend well. Currently, the selected brine disposal method for concentrate water dilution is suitable, with an estimated ZID under 50 m in normal governing climate conditions. But, if we want to increase the site's capacity, we definitely need to rethink about the method of brine discharge. Control and chemical treatment of discharge brine to regulate it in the alkaline range can significantly impact reducing environmental stresses afterward in seawater, which can be costly. In the current work capacity of the

**Fig. 7** Some active organisms near the brine discharge canal: **a** Ocypodidae crab, **b** Sparidae fishes, **c** some juvenile fishes



plant, short-term environmental damage cannot be verified and long-term environmental impacts cannot be commented on and require long-term monitoring of environmental conditions and parameters.

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## Declarations

**Conflict of interest** The authors declare that there is no conflict of interest, and no other funding was received to assist with the preparation of this manuscript.

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