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Alarming the impacts of the organic and inorganic UV blockers on endangered coral's species in the Persian Gulf: A scientific concern for coral protection

Hamidreza Sharifan

Department of Civil and Environmental Engineering, Colorado State University, 1320 Campus Delivery, Fort Collins, CO 80523, USA

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ABSTRACT

Coral reefs provide many benefits to the society, including ecological nest for aquatic species, medicine ingredient, and protection of coastlines from flooding and storms. Organic and inorganic UV filters (UVfs) are key ingredients in a variety of sunscreen and personal care products, which are massively released to natural waters by marine tourism. Reports are alarming UVfs cause fast bleaching of coral reefs in the Persian Gulf at a tiny concentration (less than 10 µl L^{-1}). Here, for the first time, the evidence pertaining to the impacts of UVfs on corals in the Persian Gulf is highlighted. Based on the existing field reports, laboratory experiments and increasing trend f tourism, corals of Kish Island in Iran are seriously threatened. Here, Kish is a study model that highlights the alarming impacts of UVfs on the endangered population of corals in all Gulf countries. This study found a positive relation between the number of visitors to the island and the bleaching rate of stony coral.

1. Introduction

Coral reefs are unique living structures providing a habitat for a variety of marine organisms in the tropical and subtropical areas [27,51]. Corals offer tremendous benefits to humans, directly through providing essential molecules for pharmaceutical (i.e., medicine for cancer and AIDS) and indirectly via tourism attraction [3,36,51]. For example, in 96 countries and regions, the tourism revenue of corals attraction significantly contributes to the gross domestic income [20]. In addition, corals protect over 150,000 km of coastlines in at least 100 countries against storms and marine erosion, including the Gulf countries [20].

In 2001, the existence of more than 35 coral species was reported in the Persian Gulf [34,48]. The number of recorded coral species was raised to 60 species in 2017 [39], most likely due to the advancement of the underwater footage technologies. The Persian Gulf is a relatively shallow and semi-enclosed system connected to the subtropical northwest part of the Indian Ocean [19]. Corals in some large areas of the Gulf are severely threatened and in some cases, completely vanished. Recently, about 70% of corals in the Gulf were reported dead, which has led to a subsequent annual loss of $94 billion [46]. In a particular area, the extremely vulnerable community of *Acropora sp.* was vanished by approximately 90% [13,35]. The significant loss of the corals in the area is highly alarming and calls for an urgent identification of the causes of these phenomena and the ongoing environmental stresses.

Most of the recent studies on the Gulf's corals are focused on the impacts of temperature anomalies, high salinity/sedimentation, and oil spills [1,14,17]. Reduced diversity of species and a variety of environmental stresses (i.e., diseases) put Iran's coral populations in endangered status [1,30]. Among all anthropogenic impacts, tourism activities are considered a crucial affecting factor on corals' health in the whole Gulf area that has not been studied yet. In a global view, marine tourism is developing into different classes including fishing, snorkeling, swimming and sunbathing. Recently, it was reported that approximately 90% of tourism is concentrated in about 10% of the total reef area, which triggers the potential impacts on corals' health [43]. Increasing numbers of marine tourism are associated with a progressive increase of ultraviolet filters (UVfs) -sunscreen on the human body- concentrations in seawater through being washed-off from the skin [44]. Both organic and inorganic (i.e., TiO_2, CeO_2) UVfs are the active ingredients in sunscreen formulation and many other cosmetic products (i.e., shampoos, hair sprays) to protect human health against UV rays and support the product integrity [38,42,53]. The formulated levels of UVfs are variable upon their application purpose and commercial factory protocol [32,42].

Due to hot weather and extreme sun UV radiation on the coastline of the Persian Gulf, the tendency of people to apply sunscreen lotions and other related cosmetics naturally increases. [9] reported that the release of UVfs in tropical areas might reach up to 25,000 tons per year. However, this number seems to be overestimated, but environmentally it is extremely alarming. Based on the recent scientific evidence, a trace concentration of organic UVfs (10 µL L^{-1}) can bleach the hard corals in a matter of hours [9]. Coral bleaching is defined as the loss of color for corals due to partial to the total elimination of the symbiotic algae

E-mail address: hsharifan@tamu.edu

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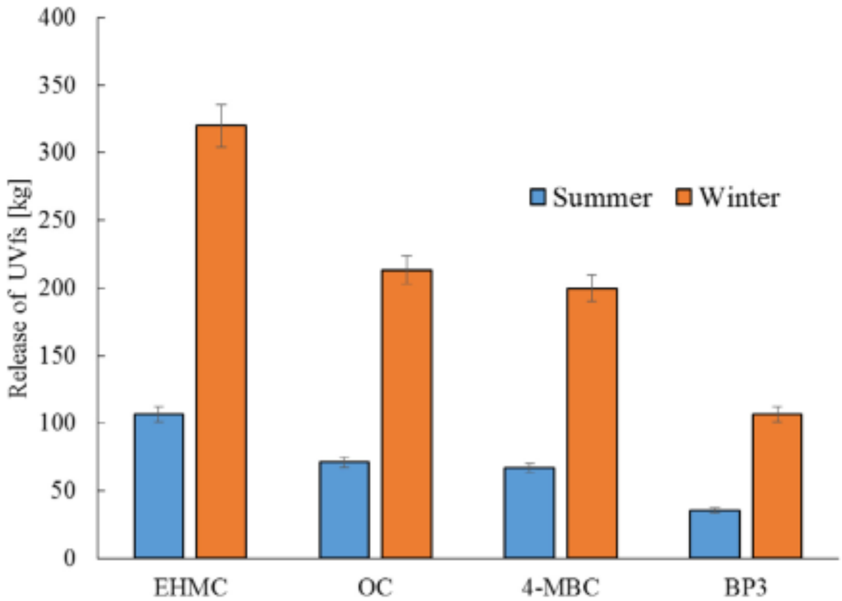

Fig. 1. The estimate of the average release of the four frequently used UV filters [kg] in the Persian Gulf from Kish Island by tourism activities during summertime and wintertime. The data was calculated based on the experimental model developed by Sharifan et al. [42,43]. The error bars indicate %5 of the standard errors.

(e.g., *Symbiodinium*) or algal pigments [10]. Therefore, bleaching can be triggered by the unlimited increasing number of marine tourism [40].

According to scientific evidence, complete bleaching of certain coral species occurs within 96 h of exposure to certain organic UVfs and 48 h of inorganic UVfs [8,9]. Organic UVfs are capable of inducing the lytic viral cycle in symbiotic zooxanthellae(intracellular photosynthetic) with latent infections [15,26]. Also, exposure to certain organic UVfs is associated with genotoxic impacts on corals and further bleaching [11]. Additionally, with the positive temperature anomalies in the Gulf region [1,27], the progressive release of UVfs exposes synergistic stresses and mediates the bleaching of the coral communities [8].

The Persian Gulf is known for the historic oil spills events, and the increasing trend of oil extractions, production, and transportation make Gulf'marine ecosystem highly susceptible to anthropogenic stresses. In November 2015, the Department of Environment in Iran reported 43% of corals around Kish Island, and 70% in Qeshm Island in the Persian Gulf were bleached [28]. Qeshm Island is about 16 times larger than the Kish Island and corals in both islands are threatened by the oil spills from petroleum activities in the Gulf [18]. Therefore, the amount of bleaching in Kish in relation to the area and higher number of visitors appeared to be a significant loss.

Kish is a coral reef visiting site with a fast-developing trend that receives over 700,000 annual domestic tourists [22] and nominated as the fourth most visited destination in the Middle East [25]. Due to its importance, Kish was selected as a representative case for the potential impacts of UVfs that provides a baseline for the protection of coral in the other Gulf countries. To the best knowledge of the author, the effects of UVfs in the Gulf area have not been studied yet. This article attempts to highlight the critical threats of UVfs, aiming to protect the corals towards a sustainable future and to increase public awareness around the world.

2. Methods

2.1. Study model area and field observations

Kish is a small flat coral island located in the northern belt of the Persian Gulf, and with 91 km^2 surface area and 35 km of coastal lines [23], it represents the highest coverage and biodiversity of stony corals (28 species) of the Gulf [13].

Data of the coral bleaching in Kish that were interpreted and retrieved in this study were collected through a survey conducted by the National Research Institute of the Persian Gulf and Oman Sea during a 12 months monitoring in 2008–2009 [2].

Briefly, the coral health was assessed on the densest population of corals at the Bird Garden Site through the scuba diving along the six transects (60 m length) with triplicates [16]. The underwater camera used for the photography was the Sonny 12 MP Ikelite housing [29]. Transects were surveyed between 1 and 6 m depth, where coral communities were most abundant. To monitor coral health, the established method of the Coral Health Chart was applied in this survey [6,47].

2.2. Estimation of UV filters release

Currently, more than 20 organic and three inorganic UVfs are authorized in the USA and Europe [21,37]. Kish Island is a free zone and receives remarkable numbers of international tourists without visa procedure, which allegedly is the primary vector for introducing a variety of sunscreen (UVfs) from all over the world into the Gulf. To predict the amount of the UVfs released to the coral sites, four frequently used organic UVfs which are known for high bleaching effects on local coral species, were selected: benzophenone-3 (BP3); 4-methylbenzylidene camphor (4MBC); Octocrylene (OC) and Ethylhexyl methoxycinnamate (EHMC). Also, briefly, the impacts of inorganic UVfs on coral health will be discussed.

Due to the lack of data monitoring on tourism entry, harsh summer seasons, and to consider the worst-case scenario, it was assumed Kish would receive 75% of tourists in winter and the remainder in summer. The detail of estimation of UVfs release in relation to the number of visitors and application rate of sunscreen were previously reported [43], briefly the method follows Eqs. (1) and 2. In the empirical formula shown in Eq. (1), the $c_{j,\,rel}$ indicates an estimation of the UVfs released from the skin surface of an adult swimmer (1.94 m^2) [12].

$$c_{j,rel} = c_{j,av} \times \alpha \times \beta \times A \tag{1}$$

where, $c_{j,av}$ is the average content of UVfs in typical sunscreen products [33], α is the average reported amount of sunscreen/cm^2 of skin(α = 2), β is the frequency of the application rate ($\beta = 1.5$), S represents the average surface area of the body reported by EPA and A is the expected body percentage covered by UVfs (A = 87%) [33,42,54]. To estimate the amount of UVfs enters the Gulf from Kish Island, Eq. (2) was used [42]. In this estimation, only the number of annual domestic visitors was included.

$$c_{j,rel} = c_{j,rel} \times \emptyset \times P \tag{2}$$

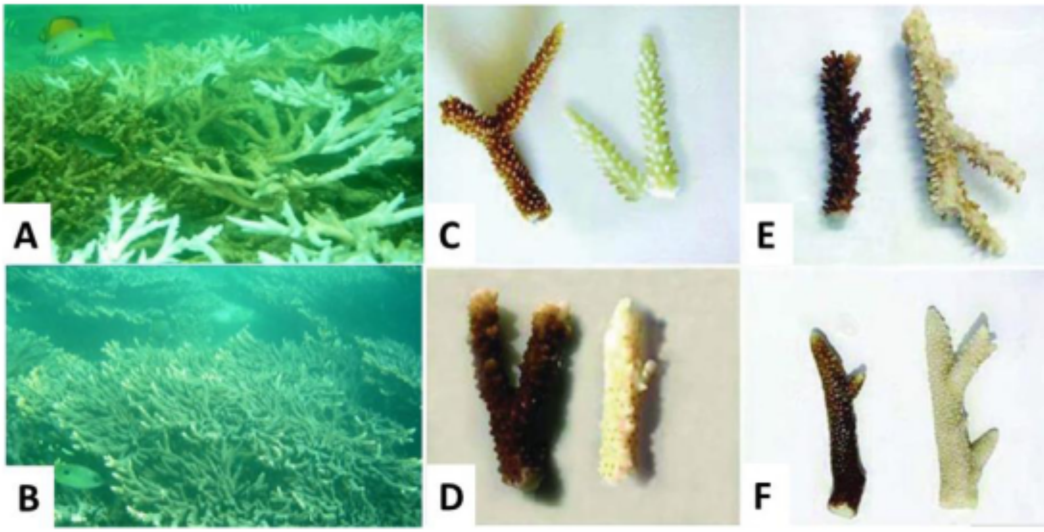

Fig. 2. (A) The bleaching of the corals in Kish Island during the winter (stony corals with lighter color) and (B) corals in summer with less bleached coverage (darker due to coverage of alga pigments). Both A&B pictures have been taken by S. Behzadi (C) *Acropora cervicomis*; (E) *Acropora divaricata*; (D) *Acropora sp.*; and (F) *Acropora intermedia*. Pictures (C-F) were taken after 62 h of exposure to UVfs, in which left is the control species and right indicates the exposed species to the organic UVfs [modified from Danovaro et al. [9].

Ø is the lipophilic UVfs wash-off rate from the human skins. P represents the number of swimmers or bathers in Kish Island (P = 0.7 million, Ø=0.5).

3. Results and discussion

3.1. Organic UV filters

Fig. 1 illustrates the estimated amounts of organic UVfs released to the seawater from the Kish throughout the year. The estimated amount of EHMC exhibit higher contamination compared to three other UVfs by 106 kg release in summer and 320 kg in winter. The released amount of OC was approximately in the range of 71–213 kg, respectively, during the summer and winter. 4-MBC showed a potential release rate of 67 kg in summer and 200 kg in winter. BP3 was minimal due to the lower dose in the formulation of the typical sunscreen products. These values reflect the total potential input of UVfs to the coral sites around the Kish. Although this is just an estimation, but it is indicative of an alarming level of UVfs in the Gulf area.

For example, a trace concentration of EHMC (33 µl L^{-1}) in 24 h can bleach as high as 90% of *Acropora sp* by 86% expulsion of zooxanthellae [9]. At slightly higher concentrations (50 µl L^{-1}), 4-MBC, BP3, EHMC, and butylparaben cause bleaching up to 90% in 96 h [9].

Available studies affirmed that certain UVFs in the order of 10 µL L^{-1} are sufficient to induce the lytic cycle in lysogenic viral toxification of the zooxanthellae and kill the stony corals [9]. As can be seen in Fig. 2(A), the corals are massively bleached in winter, coinciding the time when the high release of UVfs was predicted. In this regard, less bleaching was observed in summer when less tourist population is expected in the study area (Fig. 2(B)). The remainder images(C-F) demonstrates the ex-situ effects of UVfs after 62 h of exposure to a variety of *Acropora* species.

To better understand the magnitude of UVfs impacts, assume if in a cubic meter of the Gulf, 35 µg L^{-1} UVfs are sufficient to bleach 1 m^2 of the reef, the estimated quantities of EHMC can threat the area over 5 km of the coastal line by 5 m depth and 0.5 m width. In a worst-case scenario, the cumulative of the UVfs can massively kill the corals in the Persian Gulf. Of course, this scenario excluded the complex matrices of the sea (i.e., dilution factor) but it is worth to mention the kinetic reaction of the UVfs with the corals is fast enough to kill the corals [43].

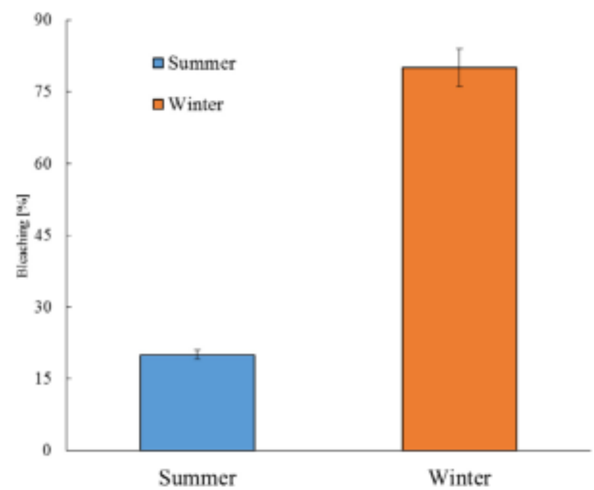

Fig. 3. The percentage of the coral bleaching in Kish Island (Bird Garden site) obtained by a 12-month coral health survey (2008–2009). Data were retrieved and processed from a national report in Persian [2]. The bleaching rate significantly differs between seasons ($p < 0.05$).

The data analysis in this study further confirmed that the higher estimation of the UVfs in winter is consistent with the high bleaching rate of corals in Kish Island. The data shown in Fig. 3 was retrieved from surveyed data reported by Behzadi et al. [2]. As above mentioned, a significantly high winter bleaching of corals ($P < 0.05$) can be linked to the estimated amounts of UVfs. This pattern of relation between the rate of bleaching and the increasing quantity of UVfs was in good agreement with recent studies in China and Japan [50,52].

3.2. Inorganic UV filters

Three inorganic UVfs nanoparticles are generally formulated in sunscreen products including, cerium oxide (CeO_2), titanium oxide (TiO_2), and zinc oxide (ZnO) nanoparticles [44]. Studies on the toxicological impacts of inorganic UVfs-NPs on the bleaching of corals are very limited. For example, Jovanovic et al. 2014 revealed that short-term exposure (a week) to 0.1–10 mg/L TiO_2 could cause acute stress on expul-

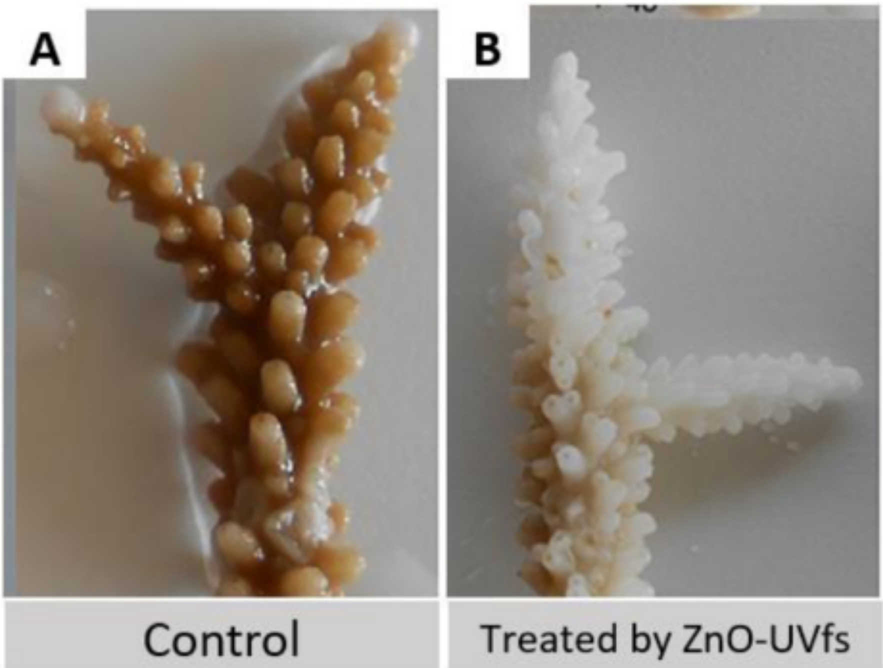

Fig. 4. Illustration of the ZnO-UVfs bleaching effects on *Acropora spp*. (A) is showing the control after 48 h with no chemical exposure, and (B) shows the results of the exposure to zinc oxide after 48 h. Pictures were slightly modified from the original [8].

sion zooxanthellae leading to coral death. In another study, Tang et al. [49] highlighted the impacts of ZnO-UVfs-NPs on coral health as a consequence of raising the snorkeling activities in Taiwan coastal areas. The impacts ZnO-UVfs on stony corals (*Seriatopora caliendrum*) are associated with the deformation of cellular membrane and disruption on lipid metabolism [49].

Recent studies on the exposure of ZnO-UVfs with the predominant stony corals of the Persian Gulf (*Acropora spp*.) showed the loss of zooxanthellae, which resulted in rapid bleaching of 67% the corals' surface within 24 h of exposure [8].

Similarly, CeO_2 disrupt the cellular membrane by generating the reactive oxygen species (ROS) [38,56], which induce oxidative stress on corals including DNA and RNA dysfunctioning, oxidizing lipids and proteins in coral cells [24,31].

Among all the inorganic UVfs, the formulation of the uncoated ZnO-UVfs in sunscreen found to result in serious threats on the life of the stony corals in the Persian Gulf due to active chemical kinetics [8]. The studies suggested the release of the uncoated ZnO-UVfs in water bodies could lead to an entirely irreversible stony coral bleaching that indirectly stimulates the enrichment of the microbial communities of seawater in coral zone area [8]. Respectively, Fig. 4 illustrates the bleaching impacts of the uncoated ZnO-UVfs in exposure to stony corals within 48 h.

Despite the direct impacts of UVfs-NPs on the zooxanthellae, they can also change the fatty acid composition, and reduce the membrane fluidity in other living cells of a coral species [24,55]. Therefore, coral tissues can become susceptible to infection by the accumulation of hazardous heavy metals.

In addition, UVfs-NPs demonstrated a high adsorption capacity for hazardous heavy metals including As, Cr, Pb and Cd [4,7,38], that led deeper penetration of the heavy metals into the biological tissues of corals [5,41]. Further, it was shown that the UVfs-NPs could disrupt the dynamic of the essential minerals for the photosynthetic tissues and cause the deformation of the living hard core structures [45].

4. Conclusion

Both types of UVfs expose extreme bleaching and damaging effects on corals population in the Persian Gulf. Considering all associated destructive impacts are co-occurring; oil spills, construction activities, and progressive marine tourism development in the Persian Gulf, in the near future, there would not be any corals left in this area. Above all, it is needed to monitor the application and restriction of the type and amounts of sunscreen and other cosmetic products that enter the coastal areas of the Persian Gulf.

Declaration of Competing Interest

None.

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