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Estimation of the Discharge of Sunscreens in Aquatic Environments of the Mexican Caribbean

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Abstract: Tourist growth in Quintana Roo, Mexico has brought with it an increase of pollution by sunscreens to aquatic ecosystems, which represents an environmental risk because of the chemical components of sunscreens that can negatively affect human health and aquatic ecosystems. However, the magnitude of pollution in aquatic environments is unknown. Consequently, we sought to estimate the contamination by sunscreens based on usage and tourism statistics. Our estimate indicates that the water in Quintana Roo will receive nearly 4367.25 tons of chemicals from sunscreens used by residents and tourists over a period of 18 years (2007 to 2025). On average, each tourist stays in Quintana Roo for 3.45 days, and 89.9% of these visitors apply sunscreen, although only the 83.7% engage in water activities. Additionally, 30.4% of residents engage in water activities for an average of 1.5 days/year. We considered direct sunscreen contaminant contamination, which occurs from the application of sunscreen and subsequent water activities, as well as indirect contamination, which occurs when people wash their skin with drinking water that then enters the drainage system. Our analysis indicated that the greatest contribution of sunscreen to the karst aquifer of Quintana Roo, is direct. Chemicals dissolved in water are a danger to aquatic life and human health.

Keywords: organic contaminants; personal care products; water sustainability; water quality

1. Introduction

The contamination of aquatic ecosystems via the intensive use and direct or indirect contamination of sunscreen is an environmental hazard, as the chemical components of sunscreen are a danger to biota and human health [1]. These compounds reach ecosystems primarily via the rinsing of topical sunscreen that has been applied to the skin and its eventual travel through wastewater treatment systems [2,3]. Balmer et al. [4] reported high concentrations of inorganic and organic components of sunscreens in 95% of wastewater effluents and in 86% of surface waters across the world. Sunscreen pollution in aquatic ecosystems is directly related to anthropogenic activities, especially in coastal tourist destinations, due to the intensive use and application of sunscreen by tourists. Poiger et al. [5] estimated that as much as 1.2 g of sunscreen per person is used daily. Moloney et al. [6] reported that the recommended sunscreen dosage is 2 mg/cm² of skin, translating to 30 mL/body application (3.0 g), and should be repeated every 2 h. However, in coastal areas with aquatic activities, use increases, magnifying the contamination problem [7]. In these situations, approximately 25% of the total sunscreen is washed directly into the water [8].

Therefore, the pollution by sunscreen contaminants at tourist sites with water activities and sun increases the contamination. One of the main tourist destinations that has these conditions is the state of Quintana Roo, Mexico, which contains the city of Cancun and the corridor of the Riviera Maya area. These areas have a great tourist influx with 17,146,971 tourists per year [9] with an average

stay of 3.45 ± 2.21 days. In the municipality of Benito Juárez (Cancun), the average stay for tourists is 5.0 ± 0.22 days, while the Riviera Maya (Cancun-Tulum tourist corridor) boasts average tourist stays of 6.28 ± 0.16 days [9]. The economic impact of tourism as an activity contributes to 1.6% of the gross domestic product (GDP) mainly via the cost of temporary accommodation, food, and beverage preparation services [10]. Another important aspect is that, due to this economic boom, in the last 15 years, the state's population has doubled from 875,000 people in 2000 to 1,501,000 people in 2015. Unfortunately, despite this growth, there is a significant delay in wastewater treatment services. Recent data indicate that only 84.2% of the population has piped water inside the home and that only 68% of homes have sanitation [10]. In fact, the state has only 30 work treatment plants (public and private), and these plants have an average total installed capacity of 2560 ± 140.63 L/sec. As a result, the treated water volume from 2012 to 2016 was on average $55,762 \pm 734.51$ million cubic meters.

The water pollution in Quintana Roo has increased with this increase in tourism, as 86% of visitors visit aquatic systems, whereas only 30% of the population does so [9]. Therefore, the karstic aquifer of Quintana Roo is continuously altered by contamination from chemicals and sunscreens. This contamination is a mixture of components that are used during aquatic activity, and therefore reach the water directly, and from drainage. It should be noted that the aquifer is a karst, and all the aquatic systems involved are geomorphic depressions. In this aquifer, cenotes, karst lakes, coastal coves, coastal lagoons, and mangroves are predominant and serve as reservoirs for the aquatic activities of tourists and residents. Consequently, and unfortunately, there are no real estimates of the contamination from the chemicals from sunscreens or their toxic effects on the native aquatic life and human health.

The aquatic systems have the highest biodiversity. For example, the state has six federal areas of protection of flora and fauna (381,184 ha), seven national parks (26,845 ha), four biosphere reserves (853,423 ha), one sanctuary (10 ha), four state parks (1191 ha), three reserves (309,190 ha), and three areas subject to ecological conservation (2480 ha). Of the 28 total protected natural areas of Quintana Roo, more than 50% are aquatic systems and are interconnected between the sea and the karst aquifer [10]. There is no actual inventory of the aquatic systems where aquatic activities are performed and sunscreens become contamination. At present, sunscreens are generally cataloged according to their components, presenting in two categories—biodegradable and non-biodegradable—according to a report by the Federal Office of the Consumer, Mexico (PROFECO—Procuraduría Federal del Consumidor). In Mexico (2010), the most used sunscreens in Quintana Roo were biodegradable because they are “Eco-friendly”—less harmful to the environment. Such brands include Coopertone Babe®, Hawaiian Tropic®, Nivea Sun®, and Banana Boat®. However, both types of sunscreen are highly toxic to the aquatic biota. Unfortunately, there are no current data on the magnitude of the use of sunscreens, their estimated contamination, or studies to quantify sunscreen components in the water. Thus, we sought to estimate the contamination by sunscreens based on usage and tourism statistics and to interpret the magnitude of the problem based on increases in the tourist influx and the resident population.

2. Materials and Methods

2.1. Estimation of the Contamination of Sunscreen in Aquatic Ecosystems

Based on data reported in the literature, the estimated total contamination in grams by sunscreens and their ingredients was estimated according to the following formula:

$$DTBS = \{[(TTANO * TAQ) * (TBS)] * [(TG DIA) * (TVEC)] * [TDIA]\} * 0.25$$

where DTBS is the total contamination by sunscreens or components or the maximum contamination by a component according to the maximum percentage allowed in the composition of blocker components as reported by Sánchez-Quiles and Tovar-Sánchez [7]. This DTBS value is multiplied by 0.25, which corresponds to the notion that only 25% of sunscreen applied actually reaches the water [8]. In the above equation, TTAÑO is equal to the total number of tourists per year as reported on the

portal of the national tourism statistical and geographical information system of Mexico (DATATUR: comprehensive tourism analysis). TAQ is equal to the percentage of tourists who enter an aquatic system to engage in water activities, visit recreational parks that include water activities, and visit cenotes and caverns. TBS represents the percentage of tourists using sunscreen, which according to Rodríguez-Fuentes et al., [11] was 83.7%. TDIA is equal to the average total number of days of a tourist's stay. TGDIA represents the amount of sunscreen that a tourist applies per day based on the amount in grams used by one person in a day as reported by Poiger et al. [5] and the dose recommended by the American Academy of Dermatology [12]. Thus, $(TGDIA = (1263 \text{ mg}) + (3000 \text{ mg})/\text{two})$ it is equal to 2131.5 mg or 2.1315 g. TVEC is the number of times that sunblock is applied by a tourist in a day including six hours of water activities. If one application occurs every two hours, then the TVEC is equal to three. In the sum, the calculated value indicates the number of tons of sunscreen or components of sunscreen in the water. Details of this can be found in the supplemental material.

2.2. Selection of Sunscreens

Sunscreens were selected from the data reported in the PROFECO report for 2010, the data reported by Rodríguez-Fuentes et al., [11] and a prospective survey conducted on two beaches in Cancun and a tourist cenote in this study. The surveys included structured and coded questions for better analysis. The survey is detailed in Annex 1. The prospective surveys were conducted from January to March 2018. The target audience included tourists over the age of 18 who had had contact with the services of the destination and had stayed at least 1 night at the site. The evaluation methodology was via a face-to-face survey. The probability sampling was systematic at points of influx. A total of 200 surveys were conducted.

3. Results

The total contamination by sunscreen from residents and tourists into the aquatic systems of Quintana Roo in the last 12 years (2007–2019) was 2646.43 tons with an average of 229.76 ± 51.62 tons/year (see the Supplemental material).

We observed a proportional relationship between the increase of people (both residents and tourists) and the increase in contamination by sunscreen (Figure 1). Based on this trend, the estimated contamination by sunscreen of the aquifer for the years 2020 to 2025 is 1718.82 tons. Thus, combining the observed data and the estimate, we purport that Quintana Roo's water will receive a total of 4367.25 tons of sunscreen product over a period of 18 years (2007 to 2025). Our results obtained from the 200 prospective surveys carried out in Quintana Roo identified 54 types of sunscreens, of which 12.96% were classified as biodegradable and 87.03% as non-biodegradable. The brands most used by the tourists in these three sites were Coopertone Babe®, Hawaiian Tropic®, Nivea Sun®, and Banana Boat®. Sunscreens cataloged as biodegradable that were used in Quintana Roo were the following: Kiinsun, Maya Solar, Protectyl Vegetal, and Hawaiian Tropic®.

The most used compounds in the sunscreens were xanthan, tocopherol, octocrylene, methyl paraben, glycerin, fragrance, EDTA, dimethicone, coconut glycoside, butyl methoxy dibenzoyl methane, and water. Table 1 shows the total estimated contamination over the last 12 years by each sunscreen ingredient into the aquatic ecosystems of Quintana Roo. In addition, the authors included the CAS registration number, a unique numerical identification for chemical compounds, polymers, biological sequences, and preparations. Moreover, water solubility was reported by PubChem to provide more information on the chemical and physical nature of the ingredients. Zinc oxide (181.95 tons) and titanium dioxide (165.41 tons) were the most contaminating ingredients in the state. In total, there was 410.12 tons of benzophenone contamination over the last 12 years.

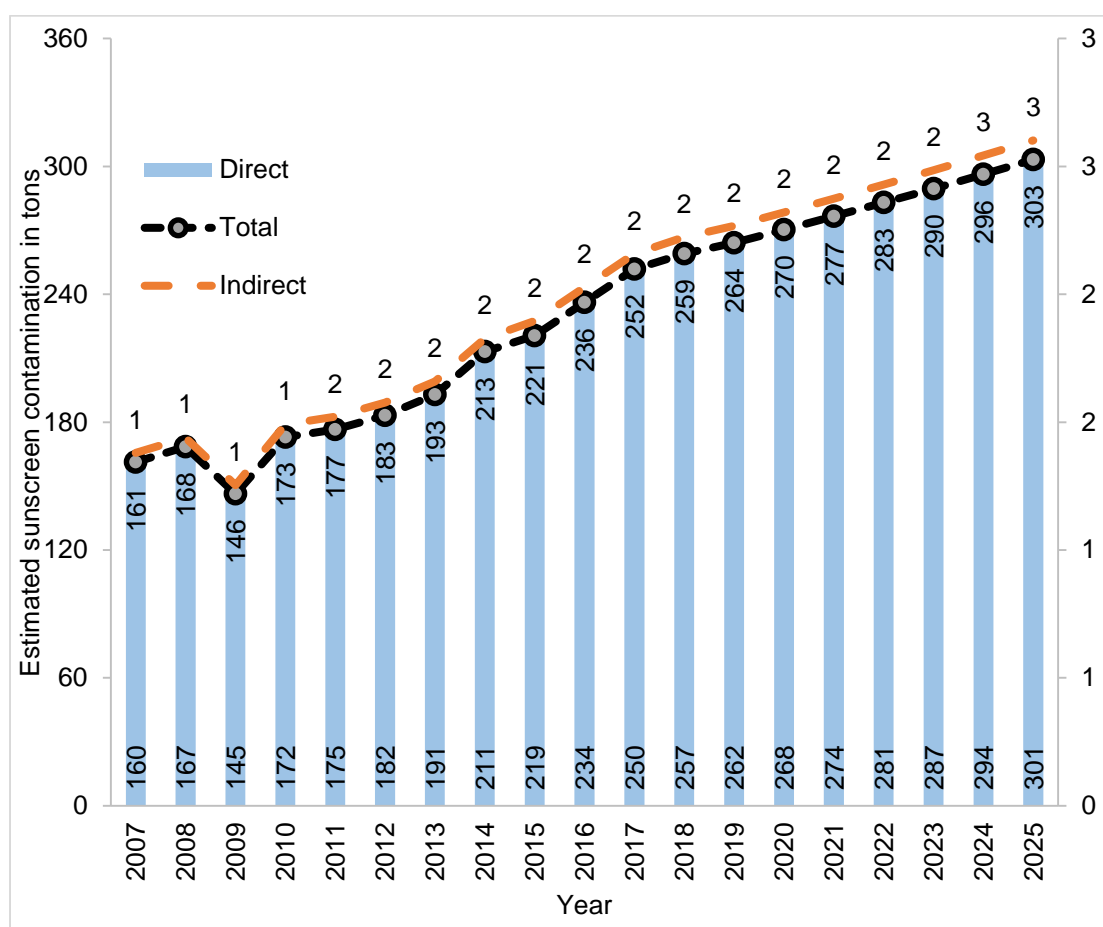


Figure 1. Direct, indirect, and total estimated sunscreen contamination of the karst aquifer in Quintana Roo, Mexico. The estimated contamination trend from 2019 to 2025 is included. Values include the direct and indirect contribution of residents and tourists.

These sunscreens entered the water from people’s bodies following application of the sunscreen to the body. The recommended dose was 2.1315 g every 2 h during sun exposure. On average, a tourist stayed in Quintana Roo for 3.45 days. According to interviews and tourism statistics [9], 89.9% of tourists applied sunscreen and 83.7% engaged in water activities. Only 30.4% of residents engaged in water activities, and these individuals only did so for an average of 1.5 days/year. Nonetheless, these residents indirectly contributed sunscreen to the water.

In general, the estimate of the total contamination by sunscreen that had been applied to the body is 25%, which represented the amount that was not absorbed and was washed into the water. Moreover, this route was the primary source of sunscreen pollution in Quintana Roo’s aquatic systems, and for the purposes of this work, this source was considered as direct contamination. Figure 1 shows the contamination by sunscreen products when people applied sunscreen and entered the water (direct), while Figure 1 illustrates the contamination by sunscreen when people applied sunscreen and then washed their skin with water that entered the drainage systems (indirect). The greatest contribution of sunscreen to the aquifer was via the direct route.

Table 1. Expected contamination by sunscreen ingredients based on the maximum allowed concentration (%) and the percentage (25%) that effectively washes off and reaches the water (Danovaro et al. 2008; Sánchez-Quiles et al., 2015).

Sunscreen Ingredients	Chemical Characteristics	Expected Contamination (Tons)
3-Benzylidene Camphor	Aromatic hydroxyketones	13.23
4-Methylbenzylidene Camphor	Aromatic hydroxyketones	28.95
Benzophenone-1	Aromatic hydroxyketones	66.16
Benzophenone-2	Aromatic hydroxyketones	66.16
Benzophenone-3	Aromatic hydroxyketones	55.34
Benzophenone-4	Aromatic hydroxyketones	50.28
Benzophenone-5	Aromatic hydroxyketones	41.17
Benzophenone-6	Aromatic hydroxyketones	66.16
Benzophenone-8	Aromatic hydroxyketones	19.85
Benzophenone-9	Aromatic hydroxyketones	44.99
Benzylidene camphor sulfonic acid	Aromatic hydroxyketones	54.82
Bis-ethylhexyloxyphenol Methoxyphenyl triazine	Oil-soluble organic compound	49.62
Butyl methoxydibenzoyl methane	Oil-soluble organic compound	39.7
Camphor benzalkonium methosulfate	Terpenoid (Isoprenoids)	39.7
Cinoxate	Aromatic hydroxyketones	25.52
Diethanolamine-4-methoxycinnamate	Oil-soluble organic compound	61.75
Diethylamino hydroxybenzoyl hexyl benzoate	Aromatic hydroxyketones	66.16
Diethylhexyl butamido triazone	Triazine-based organic compound	66.16
Digalloyltrioleate	Oil-soluble organic compound	33.08
Diisopropyl methyl cinnamate	Unsaturated carboxylic acid	66.16
Dimethoxyphenyl-[1-(3,4)-4,4-dimethyl 1,3 pentanedione	Aromatic hydroxyketones	46.31
Disodium phenyl dibenzimidazole tetrasulfonate	Disodium salt	66.16
Drometrizole	Lipophilic benzotriazole	46.31
Drometrizole trisiloxane	Lipophilic benzotriazole	99.24
Ethyl 4-[bis(2-hydroxypropyl)amino]benzoate	Para-amino benzoate	33.08
2-Ethylhexyl acetate	Acetate ester	19.85
Ferulic acid	Aromatic acid	66.16
Glyceril octanoate dimethoxy Cinnamate	Cinnamate	66.16
Glyceryl p-aminobenzoate	Cinnamate	24.26
3,3,5-Trimethylcyclohexyl salicylate	Salicylates	78.19
Isoamyl p-methoxycinnamate	Unsaturated carboxylic acid	66.16
Isopropyl salicylate	Salicylates	26.47
Methyl anthranilate	Aminobenzoic acid	33.08
Methylene bis-benzotriazolyl tetramethylbutylphenol	Micro-fine organic particles	66.16
Octocrylene	Oil-soluble organic compound	67.49
Benzoic acid	Aminobenzoic acid	54.13
Octyl salicylate	Salicylates	36.69
Octyl triazone	Para-amino benzoate	31.61
4-Aminobenzoic acid	Aromatic acid	52.27
Polyoxyethylene ethyl-4-aminobenzoate	Polymers (Ethylene oxide)	66.16
Pentyl p-(dimethylamino)benzoate	Para-amino benzoate	49.62
Phenylbenzimidazole sulfonic acid	Aromatic acid	41.68
Polyacrylamide methylbenzylidene camphor	Camphor derivates	39.7
Polysilicone-15	Polymers (Polysiloxane)	66.16
Triethanolamine salicylate	Salicylates	79.4
Terephthalylidene dicamphor Sulfonic acid	Aromatic acid	66.16
Titanium dioxide	Mineral	165.41
Zinc oxide	Mineral	181.95

4. Discussion

Sunscreen components enter ecosystems via the washing off—during washing or showering—of topical products used by tourists and the local population that reach the sewers [2,3]. The problem increases in coastal zones owing to leisure activities, as sunbathers apply sunscreens intensively. Thus, pollution from sunscreens is high in tourist destinations and may be higher than in other locations. Brausch and Rand [3] estimated the presence of four ingredients from sunscreens in wastewater treatment plants—concentrations were high for 2-ethyl-hexyl-4-trimethoxycinnamate (EHMC) with 118 g/L, while 49 g/L of 4-methylbenzylidene camphor (4MBC) were found, 69 g/L of benzophenone-3

(BP3), and 28 g/L of octocrylene [4], showing that the active ingredients are most frequently found in the effluents of wastewater treatment plants and surface water.

In the state of Quintana Roo over the last 12 years, there has been 2646.53 tons of sunscreen contamination into the aquatic systems in total, with an annual average of 229.76 ± 51.62 tons per year, according to the present study. The most contaminating ingredients in Quintana Roo were zinc oxide (181.95 tons) and titanium dioxide (165.41 tons)—mineral contamination. However, adding all the benzophenone compounds together, an expected contamination of 410.12 tons was estimated—chemical contamination. The calculation of contamination is a generally expected estimation based on statistics regarding tourist arrivals and the use and application of sunscreens. Sunscreen pollution in the state, according to our calculations and the consequences for the environment reported in the literature, is an environmental risk that presently affects the aquatic biota [1]. The toxicity of sunscreen ingredients has been documented for various aspects; for instance, the reduction of coral coverage and the death of corals, which consequentially provoke low carnivore and herbivore densities and an increase in the coverage of microalgae in coastal zones as a consequence of the reduced number of herbivores [13]. Balmer et al., [4] reported the presence of heavy concentrations of sunscreen in 95% of wastewater effluents, in 86% of surface waters, and in the tissues of aquatic biota around the world. A specific study for Cancun carried out by Rodríguez-Fuentes et al., [11] reported the use of 15 different brands of sunscreens and the authors found 2 inorganic and 13 organic compounds—titanium dioxide (inorganic compound) is an active ingredient that appears on the sunscreen labels of 21.76% of the samples, while the organic compounds oxybenzone, homosalate, octyl salicylate, octyl-dimethyl-PABA, avobenzone, octyl methoxy cinnamate, and octocrylene appear on the labels 18.23% to 56.17% of the time. Thus, in relation to our results, the most used components in sunscreens are titanium dioxide and zinc oxide. However, sunscreens are a mixture of organic and inorganic ingredients, and all of them are potentially polluting for the aquatic ecosystems. Unfortunately, the magnitude of dispersion and concentration in water and biota and their adverse effects on the native species of the state of Quintana Roo are unknown.

This increases the concern about their impact, as sunscreens are persistent pollutants and are dangerous due to their complexity as a mixture and their intensive use. In addition, for more than a decade the arrival of tourists in the state of Quintana Roo has been increasing, thereby the use and contamination of sunscreens has also increased [7]. Studies by Poiger et al. [5] and Ruszkiewicz et al., [14] estimated that an individual uses up to 1.2–1.5 g of sunscreen per day. Therefore, as a study case in the state of Quintana Roo, in 2007 17 million tourists arrived and potentially 83.75% of them used sunscreens [11].

The actual magnitude of the problem of the discharge of sunscreen ingredients into aquatic ecosystems is hard to ascertain. They are a risk because their effects are adverse and because of the evidence, in this regard, of the harm to aquatic organisms. These are mainly lethal effects, which bioaccumulate and biomagnify, and consequentially, they may have endocrine disruption effects [2,3,8,15].

For example, the water consumption of the resident population of Quintana Roo, Mexico averages 65.32 million m³ annually, whereas tourists consume an average of 114,827 m³/year. Together, the total water consumption of residents and tourists is 65.43 million m³/year. The loss of 17% of the total water consumed without treatment indicates 54.93 million m³ of contaminated wastewater go directly into the aquifer. This volume is quite large compared with the Pearl River Delta in China, where wastewater contaminations was 102 million m³ [16]. Based on the population of these areas, the average wastewater contamination is 4.45 m³/year for the inhabitants of Quintana Roo and only 2.04 m³/year for the inhabitants of the Pearl River Delta in China.

Other aspects to consider involve the components of sunscreen products and the final destination of these contaminants that reach the marine environment. An important component of sunscreen is titanium dioxide (TiO₂), which is composed of nanoparticles that are stable as colloidal suspensions in aquatic systems (Clément et al., 2013). Such nanoparticles have been found in fish and crustaceans [3].

TiO₂ has been suggested to have a worldwide production of 5000 tons/year [17] and a production and consumption in Europe of 3400 tons/year [18]. According to Johnson et al., [19] the global TiO₂ sunscreen market is approximately 1500 tons/year, and 42 tons/year of these sunscreens are potentially used in the UK. As the UK has a population of 61.4 million, 1.9 mg/day/capita of sunscreens are used on average; however, the British climate is more likely to invite the application of sunscreen during only the three summer months, yielding a sunscreen use of 7.5 mg/day/capita during this period and 0 mg/day/capita for the other nine months of the year. These calculations are based on a per-capita contamination (wastewater) of 160 L/day (58.3 m³/year), resulting in maximum effluent concentrations of approximately 47 g/L (assuming all applied nanoparticles are eliminated and none are lost en route) during this summer period. This example is important to consider, as compared to our estimation of the tons of sunscreen that have contaminated the aquatic systems of Quintana Roo, with an annual average of 229.76 ± 51.62 tons per year, contamination of sunscreen in Quintana Roo is six times less than in the UK, according to the present study. The number of residents of and visitors to Quintana Roo is, however, lower than the population of the United Kingdom—a contrast of 61.4 million (the UK population) to the tourist influx of 17 million tourists per year plus the one million population of Quintana Roo. In addition, considering that Quintana Roo has a tropical climate, this allows for longer sun exposure times, an extended season, and therefore more use of sunscreen. The scenarios are different; however, in conclusion, humans relate the contamination through the total discharge of sunscreen into aquatic systems to an increase of their use.

Another hazard of sunscreens is oxybenzone, which is considered a contributing threat to coral reef bleaching worldwide [20]. Globally, up to 14,000 tons of sunscreen are released worldwide in coral reef areas, and some of these contain up to 10% oxybenzone, posing a risk of bleaching for approximately 10% of the world's coral reefs and up to 40% of coastal reefs. This phenomenon of "bleaching" occurs when corals are put under stress and expel the algae (zooxanthellae) that live in their tissues. Coral is not necessarily dead when bleached, and they can survive, but bleaching is a clear indication that coral is under stress and is in danger [21]. In total, 410.12 tons of benzophenones have been contaminated over the last 12 years in the aquatic systems of Quintana Roo.

Raffa et al., [21] mention that worldwide 4000–6000 tons of blockers are produced annually by 78 million tourists at destinations with coral reefs. In this sense, the State of Quintana Roo received in 2018, 21 million tourists, representing 28% of the total visitors to tourist sites with corals worldwide with an average discharge of sunblock of 229.76 tons, which would represent 6% of the total discharge worldwide (4000–6000 tons) [21]. This could indicate that the estimated values could have been underestimated or that the actions taken to avoid the adverse impact of sunscreens on coral reefs and other marine/aquatic ecosystems have been carried out successfully, such as the prohibition of sunscreens and repellents containing oxybenzone in managed marine areas, such as at the theme parks of the Xcaret Group, where more than 3 million visitors are received per year.

With respect to natural aquatic ecosystems, the dramatic increase in coral bleaching around the world over the past 20 years has raised concerns about the future viability of coral reefs as well as the lifestyles that depend on them and their economic value, which is estimated at \$30–75 billion [22]. The scale of the problem is alarming. For example, in 2005, the United States lost half of its coral reefs in the Caribbean due to a massive bleaching event [23], and coral bleaching is exacerbated by the increased contamination by pollutants in coastal area [24–27] and is increased even further when coral is exposed to hazardous chemicals [21].

In the case of Quintana Roo, water contaminants pose a serious risk, as the karst aquifer has natural freshwater contamination outlets into the sea and these outlets carry contaminants directly to the coastal area, including the Mesoamerican Arrecifal System (SAM), which is located less than 10 km from the coast. SAM is the second largest coral reef system in the world and the largest coral reef system in the Atlantic Ocean due to its biodiversity and connectivity to other ecosystems located in the Gulf of Mexico. As this reef is also common to other countries, such as Belize, Guatemala, and

Honduras, the problem is not regional but international and requires greater attention in international strategies for the conservation of the hydrological and biological resources [28].

All the aquatic ecosystems of Quintana Roo experience stress from anthropogenic pollution [29], and the presence of chemicals in Quintana Roo may negatively affect the health of aquatic ecosystems. The scientific community indicated that the aquifer of Quintana Roo is vulnerable due to its geology and anthropogenic activities [29,30]. Despite this warning, the water continues to be contaminated. As it is impossible to remove aquatic ecosystems from the contaminated water, and such contamination exposes all of the organisms to the chemicals. Unfortunately, it is challenging to delineate the precise dispersion and concentrations of these chemicals due to the hydrological characteristics of the aquifer of Quintana Roo, especially due to the lack of a concerted monitoring effort with multidisciplinary participation. Thus, a specialized agency for water protection is warranted. Furthermore, we need risk analyses for the impact of these hazardous chemicals on health and biodiversity. It is time to act as a society and as research groups without institutional labels to examine the pollution of our water and to change our approach to water preservation and treatment. For example, the state of Quintana Roo has a wastewater treatment coverage of only 68%, and the remaining untreated water must re-enter the water system [31].

Finally, it is well established that exposure to Ultra Violet Radiation (UVR) causes numerous changes in the skin that can cause actinic keratoses, which are believed to be precursors of certain types of non-melanoma skin cancer (NMSC) and squamous cell carcinoma (SCC) [21]. In this regard, clinical evidence has shown that broad-spectrum sunscreens, when used properly, may decrease the rate of new precancerous lesions, which results in a significantly lower amount of actinic keratosis and less SCC [32]. Therefore, the elimination of sunscreens in tourist sites is not an option, so new alternatives should be considered, as proposed by Pandika [33] and Raffa [21], that include: zebrafish (e.g., gadusol, 3,4,5-trihydroxy-5-(hydroxymethyl)-2-methoxycyclohex-2-en-1-one) and plants (e.g., derivatives of glucolignanin from the wildflower meadowfoam).

Another side of the argument is the discharge on the coast of other substances and their effects, such as antibiotics (which produce resistance in bacteria), hormones (feminization in fish), detergents (e.g., nonylphenol ethoxylates, which produce endocrine conditions), pesticides (e.g., dichlorodiphenyltrichloroethane (DDT) which has toxic effects and persistent metabolites) and fertilizers [34]. The latter, in particular, influences the increase in the concentration of nutrients in the water, which stimulates the excessive growth of certain algae that “asphyxiate” corals and eventually destroy coastal coral reefs [35]. This shows how other practices on land, as well as contamination by sunscreens, can have important consequences for the quality of groundwater, with additional tourist attractions, such as golf courses, also contributing to contamination due to the nitrates that are applied for maintenance [36].

An average of 14.78 million people consumed water each year in the state of Quintana Roo between 2007 and 2018. In 2007, 11.8 million people consumed water and generated waste, while in 2018, 21 million people consumed water and generated waste. In addition, the trend of water consumption is related to the annual increase in the population of both residents and tourists. The data suggest that if the same trends of tourist influx and population growth are maintained (tourist influx of 7.78%/y and resident increase of 2.32%/year), in the future (2025) the contamination of sunscreens and other personal care products will increase proportionally, ultimately contaminating the karst aquifer. Only 84.2% of the population has water in the house, while 100% of tourist accommodations have an indoor water supply. Only 68% of the water supply (houses/accommodations) is treated. The use of personal care products, including sunscreens, requires water consumption and contributes to chemical water contamination.

5. Conclusions

Although the data are estimates and not predictive models, our results are baseline and may even underestimate the problem, so it is imperative to complete more in-depth studies on the use

and application of personal care products to truly estimate the level of hazard to aquatic life. Finally, we concluded that all sunscreen contamination probably produced adverse effects on biota, but it can also produce a domino effect that influences different areas, affecting the sustainability of an entire region, for example, in contravention of the Sustainable Development Goals from the United Nations: objective 1: end of poverty, objective 3: health and well-being, objective 6: clean water and sanitation, objective 14: underwater life, and Objective 8: decent work and economic growth. Because of the pollution of the water by sunscreens, marine ecosystems are at risk. Considering that the region is highly dependent on tourism, and that marine ecosystems effects natural attractions the economy is, therefore, put at risk. The contamination of water in the region also modifies its quality for consumption by the population.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2076-3298/7/2/15/s1>.

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References

1. McCoshum, S.; Schlarb, M.A.; Baum, A.K. Direct and indirect effects of sunscreen exposure for reef biota. *Hydrobiologia* **2016**, *776*, 139–146. [[CrossRef](#)]
2. Giokas, L.D.; Salvador, A.; Chisvert, A. UV filters: From sunscreens to human body and the environment. *Rev. Trends Anal. Chem.* **2007**, *26*, 360–374. [[CrossRef](#)]
3. Brausch, J.M.; Rand, G.M. A review of personal care products in the aquatic environment: Environmental concentrations and toxicity. *Chemosphere* **2011**, *82*, 1518–1532. [[CrossRef](#)]
4. Balmer, M.E.; Buser, H.R.; Muller, M.D.; Poiger, T. Occurrence of the organic UV-filter compounds BP-3, 4-MBC, EHMC, and OC in wastewater, surface waters, and in fish from Swiss lakes. *Environ. Sci. Technol.* **2004**, *39*, 953–962. [[CrossRef](#)] [[PubMed](#)]
5. Poiger, T.; Hans-Rudolf, B.; Balmer, E.M.; Per-Anders, B.; Müller, D.M. Occurrence of UV filter compounds from sunscreen in surface water: Regional mass balance in two Swiss lakess. *Chemosphere* **2004**, 951–963. [[CrossRef](#)] [[PubMed](#)]
6. Moloney, F.J.; Collins, S.; Murphy, G.M. Sunscreens, safety, efficacy and appropriate use. Review article. *Am. J. Clin. Dermatol.* **2002**, *3*, 185–191. [[CrossRef](#)] [[PubMed](#)]
7. Sanchez-Quiles, D.; Tovar-Sánchez, A. Are sunscreens a new environmental risk associated with coastal tourism? *Environ. Int.* **2015**, 158–170. [[CrossRef](#)]
8. Danovaro, R.; Bongiorno, L.; Corinaldesi, C.; Giovannelli, D.; Damiani, E.; Astolfi, P.; Greci, L.; Pusceddu, A. Sunscreens cause coral bleaching by promoting viral infections. *Environ. Health Perspect.* **2008**, *116*, 441–447. [[CrossRef](#)]
9. SECTUR. Resultados de la Actividad Turística 2018. 2018. Available online: [https://www.datatur.sectur.gob.mx/RAT/RAT-2018-12\(ES\).pdf](https://www.datatur.sectur.gob.mx/RAT/RAT-2018-12(ES).pdf) (accessed on 10 December 2019).
10. INEGI. Instituto Nacional de Estadística y Geografía. 2019. Available online: <https://www.inegi.org.mx/temas/estructura/> (accessed on 10 December 2019).
11. Rodríguez-Fuentes, G.; Luna-Ramírez, K.; Soto, M. Sunscreen Use behavior and most frequently used active ingredients among beachgoers on Cancun, Mexico. *WebmedCentral Dermatol.* **2010**, *1*, WMC001364. [[CrossRef](#)]
12. Mancuso, J.B.; Maruthi, R.; Wang, S.Q.; Lim, H.W. Sunscreens: An update. *Am. J. Clin. Dermatol.* **2017**, *18*, 643–650. [[CrossRef](#)]

13. Bozec, Y.M.; Acosta-González, G.; Núñez-Lara, E.; Arias-González, J.E. Impacts of coastal development on ecosystem structure and function of Yucatan coral reefs, Mexico. In Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, FL, USA, 7–11 July 2008; Volume 18, pp. 691–695.
14. Ruskiewicz, J.A.; Pinkas, A.; Ferrer, B.; Peres, T.V.; Tsatsakis, A.; Aschner, M. Neurotoxic effect of active ingredients in sunscreens products, a contemporary review. *Toxicol. Rep.* **2017**, *4*, 245–259. [[CrossRef](#)] [[PubMed](#)]
15. Clément, L.; Hurel, C.; Marmier, N. Toxicity of TiO₂ nanoparticles to cladocerans, algae, rotifers and plants—Effects of size and crystalline structure. *Chemosphere* **2005**, *90*, 1083–1090. [[CrossRef](#)] [[PubMed](#)]
16. Xie, H.; Hao, H.; Xu, N.; Liang, X.; Gao, D.; Xu, Y.; Gao, Y.; Tao, H.; Wong, M. Pharmaceuticals and personal care products in water, sediments, aquatic organisms, and fish feeds in the Pearl River Delta: Occurrence, distribution, potential sources, and health risk assessment. *Sci. Total Environ.* **2019**, *659*, 230–239. [[CrossRef](#)] [[PubMed](#)]
17. Mueller, N.C.; Nowack, B. Exposure modeling of engineered nanoparticles in the environment. *Environ. Sci. Technol.* **2008**, *42*, 4447–4453. [[CrossRef](#)] [[PubMed](#)]
18. Gottschalk, F.; Sonderer, T.; Scholz, R.W.; Nowack, B. Modeled environmental concentrations of engineered nanomaterials (TiO₂, ZnO, Ag, CNT, Fullerenes) for different regions. *Environ. Sci. Technol.* **2009**, *43*, 9216–9222. [[CrossRef](#)] [[PubMed](#)]
19. Johnson, A.C.; Bowes, M.J.; Crossley, A.; Jarvie, H.P.; Jurkschat, K.; Jürgens, M.D.; Lawlor, A.J.; Park, B.; Rowland, P.; Spurgeon, D.; et al. An assessment of the fate, behaviour and environmental risk associated with sunscreen TiO₂ nanoparticles in UK field scenarios. *Sci. Total Environ.* **2011**, *409*, 2503–2510. [[CrossRef](#)]
20. Schneider, S.L.; Lim, H.W. Review of environmental effects of oxybenzone and other sunscreen active ingredients. *J. Am. Acad. Dermatol.* **2019**, *80*, 266–271. [[CrossRef](#)]
21. Raffa, R.B.; Pergolizzi, J.V.; Taylor, R.; Kitzen, J.M. Sunscreen bans: Coral reefs and skin cancer. *J. Clin. Pharm. Ther.* **2019**, *44*, 134–139. [[CrossRef](#)]
22. Cesar, H.J.S.; Burke, L.; PetSoede, L. The Economics of Worldwide Coral Reef Degradation 2003. Available online: https://www.wwf.or.jp/activities/lib/pdf_marine/coral?reef/cesardegradationreport100203.pdf (accessed on 9 September 2018).
23. NOAA. What Is Coral Bleaching? Available online: https://oceanservice.noaa.gov/facts/coral_bleach.html (accessed on 9 September 2018).
24. Brown, B.E.; Dunne, R.P.; Goodson, M.S.; Douglas, A.E. Bleaching Patterns in Reef Corals. *Nature* **2000**, *404*, 142–143. [[CrossRef](#)]
25. Douglas, A.E. Coral bleaching—how and why? *Mar. Pollut. Bull.* **2003**, *46*, 385–392. [[CrossRef](#)]
26. Jones, R. More reflections on annual appraisal. *Br. J. Gen. Pract.* **2004**, *54*, 133. [[PubMed](#)]
27. Bruno, J.F.; Selig, E.R.; Casey, K.S.; Page, C.A.; Willis, L.B.; Harvell, C.D.; Sweatman, H.; Melendy, A.M. Thermal stress and coral cover as drivers of coral disease outbreaks. *PLoS Biol.* **2007**, *5*, e124. [[CrossRef](#)]
28. Carrillo, L.; Johns, E.M.; Smith, R.H.; Lamkin, J.T.; Largier, J.L. Pathways and Hydrography in the Mesoamerican Barrier Reef System Part 1: Circulation. *Cont. Shelf Res.* **2015**, *109*, 164–176. [[CrossRef](#)]
29. Melbourne-Thomas, J.; Johnson, C.R.; Perez, P.; Eustache, J.; Fulton, E.A.; Cleland, D. Coupling biophysical and socioeconomic models for coral reef systems in Quintana Roo, Mexican Caribbean. *Ecol. Soc.* **2011**, *16*, 23. [[CrossRef](#)]
30. Aguilar-Duarte, Y.; Bautista, F.; Mendoza, M.E.; Delgado, C. Vulnerabilidad y riesgo de contaminación de acuíferos kársticos. *Trop. Subtrop. Agroecosyst.* **2013**, *16*, 243–263.
31. González-Herrera, R.A.; Albornoz-Euán, B.S.I.; Sánchez-Pinto, I.A.; Osorio-Rodríguez, J.H. El acuífero yucateco, análisis del riesgo de contaminación con apoyo de un sistema de información geográfica. *Rev. Int. Contam. Ambient.* **2018**, *34*, 667–683. [[CrossRef](#)]
32. Gallagher, R.P. Sunscreens in melanoma and skin cancer prevention. *CMAJ* **2005**, *173*, 244–245. [[CrossRef](#)] [[PubMed](#)]
33. Pandika, M. Looking to nature for new sunscreens. *Chem. Eng. News* **2018**, *96*, 22–25. [[CrossRef](#)] [[PubMed](#)]
34. Elbakidze, M.; Hahn, T.; Dawson, L.; Zimmermann, N.E.; Cudlín, P.; Friberg, N.; Genovesi, P.; Guarino, R.; Helm, A.; Jonsson, B.; et al. Direct and indirect drivers of change in biodiversity and nature’s contributions to people. In *The IPBES Regional Assessment Report on Biodiversity and Ecosystem Services for Europe and Central Asia*; Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: Bonn, Germany, 2018; pp. 385–568.

35. Gormsen, E. The impact of tourism on coastal areas. *GeoJournal* **1997**, *42*, 39–54. [[CrossRef](#)]
36. Pacheco, J.; Marin, L.; Cabrera, A.; Steinich, B.; Escolero, O. Nitrate temporal and spatial patterns in 12 water-supply wells, Yucatan, Mexico. *Environ. Geol.* **2001**, *40*, 708–715. [[CrossRef](#)]



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