APN
ASIA-PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH

FINAL REPORT

Collaborative Research Platform to Manage Risk and Enhance Resilience of Coral Reef in Southeast Asia

CRRP2019-08MY-Khanal

2024

Project Reference Number: CRRP2019-08MY-Khanal

Project Duration: 2 years

Funding Awarded: 85,800 USD

Grant DOI: https://doi.org/10.30852/p.4608

Date of Publication: 22 July 2025

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Recommended Citation: Khanal, R., Yoshimura, C., Mishra, B. K., Kasuga, I., Lohwacharin, J., Giang, P. Q., Siev, S., Boonyaroj, V., & Khov, V. (2025). Collaborative research platform to manage risk and enhance resilience of coral reef in Southeast Asia. Project Final Report. Asia-Pacific Network for Global Change Research.

1. Summary

Sea level rise, marine acidification, nutrient runoff, degraded benthic sediment and water quality, and increment in emerging pollutants like microplastics, pharmaceuticals and personal care products (PPCP) along the coastal beaches of Southeast Asian countries (SeAC) Thailand, Cambodia, and Vietnam are resulting into imminent diminish or extinction of coral reefs. Due to lack of scientific regional collaboration and evidence-based research, fate and distribution of coral reefs and marine ecosystem services have not been effectively managed in these SeAC. Hence, the main objective of this research is to manage risk and enhance resilience of the coral reef. A trans-disciplinary team through appropriate mix of engineering, socioeconomic significance, and policy framework were employed to research on identifying the gaps, opportunities and threat in coral reef management.

Southeast Asia's coral reefs, covering 34% of the world's total, are crucial ecological and economic assets, supporting millions through tourism and fisheries. However, these vibrant ecosystems are under severe threat from combined global and local pressures. Climate change brings rising sea temperatures causing bleaching and ocean acidification, while local stressors include overfishing (often destructive), coastal development leading to habitat loss and sedimentation, and widespread pollution.

Pollutions is in SeAC are multifaceted, encompassing marine debris like plastics, agricultural runoff, aquaculture waste (especially in Vietnam, contributing sludge and chemicals), and wastewater from burgeoning coastal populations and tourism. A specific concern is chemical pollution from sunscreen UV filters (e.g., oxybenzone, octinoxate), detected in reef environments and known to potentially harm corals. Research indicates these filters can interact complexly with other pollutants, sometimes enhancing their degradation under sunlight.

Our research across the region actively assessed these impacts. Studies monitor water quality, map bleaching hotspots using satellite data, and assess ecosystem health, revealing alarming degradation rates in areas like Vietnam, with significant losses of coral, mangroves, and seagrass. Models like SWAT are used to understand land-based impacts, such as soil erosion from river basins potentially smothering coastal reefs. Water quality studies, like in Cambodia's Koh Rong, found acceptable chemical parameters, suggesting other factors like physical damage or overfishing may be primary drivers of local reef decline.

Despite the grim outlook, management efforts offer some hope. The successful restoration of Maya Bay, Thailand, demonstrates that decisive action—closing the area

to tourism, actively planting corals, and controlling pollution—can lead to significant recovery. This highlights the importance of strong policy, stakeholder cooperation, and potentially limiting tourism pressure. Nations are developing policies, including marine protected areas, integrated coastal zone management, and sustainable development strategies. International actions, like bans on harmful UV filters, also provide potential pathways. Resilience-based management, focusing on factors that help reefs withstand and recover from stress, is a guiding principle.

Future directions emphasize strengthening research, particularly on pollutant interactions and toxicology. Enhanced monitoring and quantitative risk assessments are needed. Critically, effective enforcement of existing environmental laws and bridging the gap between science and policy are paramount. Promoting sustainable tourism, addressing plastic pollution, controlling land-based runoff, and fostering collaborative platforms among all stakeholders are essential steps towards securing a future for Southeast Asia's invaluable coral reefs.

2. Objectives

General Objective:

To assess the key threats (including pollution, climate change, and anthropogenic activities), understand the current status, and evaluate management strategies for enhancing the resilience and sustainable management of coral reef and associated marine ecosystems in Southeast Asia.

Specific Objectives:

- To investigate the occurrence, distribution, and potential ecotoxicological impacts of specific pollutants, such as UV filters and land-based runoff (including sediment and nutrients), on coral health and marine water quality.
- To evaluate the current status and spatio-temporal trends of coral reef health, biodiversity, and bleaching events in specific Southeast Asian regions (e.g., Vietnam, Thailand, Cambodia) using monitoring data and modelling approaches.
- To analyze the influence of socio-economic factors, including coastal development, urbanization, fisheries, and tourism (specifically over-tourism), on marine ecosystem degradation and evaluate the effectiveness of related management interventions.

- To assess the impact of climate change factors, particularly increased sea surface temperature, on coral bleaching patterns and predict future risks to marine ecosystems under different climate scenarios.
- To analyze existing environmental policies and management frameworks (e.g., resilience-based management, Marine Protected Areas (MPAs), pollution control measures) and propose evidence-based recommendations for improving marine ecosystem protection and conservation effectiveness.

3. Outputs, Outcomes and Impacts

Objective	Outputs	Outcomes	Impacts
1. Assess Pollutant Impacts: Investigate the occurrence, distribution, and potential ecotoxicological impacts of pollutants (UV filters, runoff) on coral health/water quality.	Research papers/presentations on UV filter presence & effects; Water quality reports (e.g., Koh Rong); Soil erosion models/maps (e.g., Cai River); Pollutant interaction studies (UV filters + Sulfamethoxazole).	Increased understanding of pollutant sources, pathways, concentrations; Identification of high-risk pollutants (e.g., oxybenzone); Quantified soil erosion rates & sediment yields.	Basis for informed policy on pollutant control (e.g., UV filter regulations/bans); Improved land management recommendations to reduce runoff; Targeted water quality management plans.
2. Evaluate Ecosystem Status: Evaluate the current status and trends of coral reef health, biodiversity, and bleaching in specific SE Asian locations.	Ecosystem health reports (e.g., Vietnam marine env.); Water quality assessments & Water Pollution Index calculation; Coral bleaching hotspot maps; Biodiversity inventories; Reef status surveys.	Baseline data established for coral cover, species diversity, water quality parameters; Identification & mapping of degraded vs. healthier areas; Understanding of bleaching patterns & species susceptibility.	Prioritization of areas for conservation and restoration; Input for evaluating management effectiveness over time; Increased awareness of ecosystem vulnerability.
3. Analyze Socio-economics/Tourism:	Case studies (Maya Bay over-tourism);	Understanding of the link between	Justification for sustainable

Objective	Outputs	Outcomes	Impacts
Analyze the influence of socio-economic factors (coastal development, tourism) on marine ecosystem degradation.	Presentations/summaries on tourism impacts & coastal economies; Analysis of threats (fishing, development).	over-tourism and coral/beach degradation; Quantification of economic contributions of marine ecosystems; Identification of socio-economic pressures (pop. growth, fishing dependency).	tourism policies and practices; Support for integrated coastal zone planning; Potential development of alternative livelihoods.
4. Assess Climate Change/Bleaching: Assess the impact of climate change factors (Sea Surface Temperature) on coral bleaching and predict future risks.	Coral Bleaching Hotspot Maps (NOAA CRW); Analysis of SST trends & correlation with bleaching; Climate impact assessments & future projections.	Identification of areas most vulnerable to thermal stress; Correlation established between SST anomalies and bleaching events; Understanding of future climate risks (temp. rise, sea level rise) for the region.	Input for climate adaptation and mitigation strategies; Basis for regional vulnerability assessments; Support for resilience-building management measures.
5. Evaluate Management/Policy : Analyze existing management frameworks and propose evidence-based recommendations for improvement.	Policy reviews/analyses; Restoration strategy reports/analysis (Maya Bay); Resilience framework proposals & decision tools; Presentations on evidence-based policy synthesis.	Evaluation of existing policy effectiveness & gaps; Development of resilience strategies & decision support tools; Identification of successful interventions (e.g., Maya Bay closure); Policy recommendations formulated.	Improved conservation planning & adaptive management; Potential adoption of recommended policies/strategies (e.g., resilience-based management); Strengthened legal and institutional capacity.

4. Key facts/figures

1. **Pollutant Impacts:** Research confirmed the presence of UV filters like oxybenzone in reef areas, sometimes at levels raising concern. Studies showed these filters can interact with other pollutants, affecting their degradation. Water quality assessments in places like Koh Rong indicated generally acceptable levels for standard parameters but highlighted the need to look beyond basic water quality for causes of degradation. Soil erosion modeling in Vietnam quantified significant sediment loss, particularly during peak rainfall months, indicating a major potential source of stress to coastal waters.
2. **Ecosystem Status:** Assessments revealed significant degradation across Southeast Asia, particularly in Vietnam, with major losses in coral, mangrove, and seagrass cover. Biodiversity is threatened, with many species at risk due to over-exploitation. Bleaching events linked to high SST were mapped, identifying vulnerable areas and periods. Water quality varied, with some areas like Koh Rong showing relatively good conditions based on WPI, while others face significant pollution pressures.
3. **Socio-economics/Tourism:** The link between rapid tourism growth and environmental degradation was clearly demonstrated in the Maya Bay case study, showing how unchecked visitor numbers led to severe coral loss. The vital economic contribution of marine ecosystems was highlighted, underscoring the need for sustainable management. Pressures from coastal population growth and reliance on fishing were identified as key challenges.
4. **Climate Change/Bleaching:** Analysis confirmed the link between elevated Sea Surface Temperatures (SST) and coral bleaching events in the region. Mapping showed spatial and temporal variations in thermal stress hotspots. Climate change projections for Vietnam indicate significant future increases in temperature and sea-level rise, posing long-term threats to marine ecosystems.
5. **Management/Policy:** The Maya Bay restoration demonstrated the potential effectiveness of strict management interventions like closures and active restoration when supported by government and stakeholders. Frameworks for resilience-based management and decision-making were proposed. Reviews of existing policies in Vietnam suggest that while strategies exist, implementation and enforcement mechanisms need strengthening to effectively protect marine resources. The need for evidence-based policy and better communication between researchers and policymakers was emphasized.

Objective 1: Assessment of Pollutant Impacts

- **UV Filters (Okinawa Example):**
    - Oxybenzone concentration reached around 1.4µg/L on some Okinawa beaches during summer.
    - At some Okinawa reef sites, oxybenzone was found around 0.01µg/L, about 500 times lower than the LC50 range (5.4 to 14.5µg/L) for *Acropora cervicornis* larvae.
- **UV Filters (General):**
    - BP (Benzophenone) and BP3 (Oxybenzone) are detected in environmental waters in ng/L to µg/L levels.

    - Surface water detections reported up to 82ng/L for BP and 44,000ng/L for BP3.
    - Oxybenzone and octinoxate are banned/being banned in Hawaii, Palau, Bonaire island, and Mexico. Hawaii added avobenzone and octocrylene to its ban effective Jan 1, 2023.
- **UV Filters & Co-Pollutant Interaction (SMX):**
    - Adding BP (at 0.10µM & 0.25µM) and BP3 (at 0.10µM & 0.25µM) significantly increased the degradation rate constant of 1.00µM SMX by up to 50.0%.
    - Maximum indirect photodegradation induced by BP and BP3 reached 33.8% and 27.7% respectively, at a [BPs]/[SMX] ratio of 0.25.
- **Water Quality (Koh Rong, Cambodia):**
    - Average temperature: Dry season ≈31.3∘C, Rainy season ≈29.5∘C.
    - Average Electrical Conductivity (EC): ≈53mS/cm in both seasons.
    - Average Salinity: Dry season ≈32.4 psu, Rainy season ≈31.9 psu
    - Average pH: Dry season ≈7.35, Rainy season ≈7.83.
    - Average Dissolved Oxygen (DO): Dry season ≈8.07mg/L, Rainy season ≈7.96mg/L.
    - Water Pollution Index (WPI) for Koh Rong was in the "good" range overall: Dry season = 0.72, Rainy season = 0.71.
- **Pollution (Vietnam):**
    - Domestic wastewater generation in coastal cities estimated at 122-163 million m3/day.
    - Per capita solid waste generation: Urban 1.08kg/person/day, Rural 0.45kg/person/day. 74% collected in coastal localities in 2019.
    - Solid waste from cruise ships in Gulf of Tonkin: 11.3kg/vessel/day.
    - Wastewater from aquaculture (2018): Shrimp sludge ≈120.7 million tons, Shrimp wastewater ≈5 billion m3; Pangasius sludge ≈47.5 million tons, Pangasius wastewater ≈13.1 billion m3.
    - Plastic waste dumped along coastal areas/sea (2018): 0.28 to 0.73 million tons/year (approx. 6% of global total). Vietnam ranked 4th globally for mismanaged plastic waste (1.83 million tons/year).

Objective 2: Evaluate Ecosystem Status

- **Southeast Asia Overview:**
    - Hosts ≈100,000km2 (34%) of world's coral reefs.
    - Home to 600 out of 800 known coral species.
    - Globally, 75% of reefs were considered threatened by 2020; projected 90% by 2030 and >95% by 2050 under business-as-usual.
- **Vietnam Status:**
    - Has about 20 typical marine ecosystems covering >1 million km2. Includes 155,000 ha mangroves, 1,300km2 coral reefs, 16,000 ha seagrass.

    - Hosts approx. 11,000 marine species, including 350 reef-forming coral species.
    - Degradation since early 2000s: 11-12% of coral reefs lost, 48% vulnerable; 70% mangrove forests lost; 40-60% seagrass lost. Seagrass area reduced to ≈5,580 ha.
    - Approx. 100 marine species threatened due to over-exploitation/fishing.
- **Cambodia (Koh Rong Example):**
    - Koh Rong Archipelago covers ≈280km2.
    - Live coral cover varied across sites: Koh Kong 47.4%, Koh Rong 23.1%, Koh Tang 38.3% (based on 2011 data).

Objective 3: Analyze Socio-economics/Tourism

- **Economic Value:**
    - SE Asia reefs generate USD ≈10 billion/annum (tourism 55%). Supports ≈35 million people via ≈8000 businesses.
    - Vietnam's marine/coastal economy contributes ≈50% of national GDP; marine economy alone is 20-22%.
    - Estimated value of Vietnam's coral ecosystems: ≈USD100 million/year; 1km2 reef provides seafood worth ≈USD10,000/year. 1km2 mangroves provide ≈450kg seafood/year. Seagrass provides >USD 20 million/year. Lagoons >USD 2,000/ha/year.
- **Tourism Impacts (Maya Bay, Thailand):**
    - Visitor numbers increased from ≈10 people/day (early 2000s/2008) to 170/day (2017 mentioned as baseline, likely error, should be earlier) to ≈3500 people/day before closure.
    - Thailand tourism contributes ≈7% to national GDP.
- **Coastal Population (Vietnam):**
    - 28 coastal provinces/cities host 51 million inhabitants (in 2022). Population density is 1.9 times the national average. 125 coastal districts/islands host 18 million people.

Objective 4: Assess Climate Change/Bleaching

- **Global Context:** Sea surface temperature increased ≈0.14◦F per decade during the 20th century. By 2050, 95% of reefs projected to experience high thermal stress; only 15% may have adequate aragonite levels for growth.
- **Vietnam Climate Change:**
    - Average annual temperature projected to increase by up to 2.3◦C by mid-21st century and 4.2◦C by end-century.
    - Average sea level rise observed: 2.45mm/year (1960-2014) and 3.34mm/year (1993-2014). Satellite data (1993-2018) shows 4.1mm/year for the whole East Sea, 3.6mm/year for Vietnam's coast.
    - Projected sea level rise by end-21st century (RCP8.5 scenario) is ≈77cm (range 51-106 cm).

- **Regional Bleaching (2019 vs 2020):** Coral Bleaching Hotspots (CBH) of 1−2◦C were dominant in the Gulf of Thailand (Thailand/Cambodia) in May, higher pre-pandemic (2019). CBH (1−2◦C) dominant in South China Sea (Vietnam) in July, higher pre-pandemic (2019). Exception: CBH higher during pandemic (Sep 2020) along Vietnam coast.

Objective 5: Evaluate Management/Policy

- **Restoration (Maya Bay):** Closure and active restoration led to significant recovery after severe degradation.
- **Policy Goals (Vietnam):** Strategy aims to increase marine conservation zones to at least 6% of the national sea area; restore coastal mangrove area to at least 2000 levels.
- **Model Performance (SWAT for Cai River):** Calibration/Validation showed "Satisfactory" performance (NSE 0.63/0.57, R^2 0.67/0.72).
- **Soil Erosion Rates (Cai River, 2013-2021):** Average annual soil erosion rate = 77.67 tons/ha/year. Lowest year: 2014 (1.01 tons/ha). Highest year: 2016 (246.87 tons/ha). November accounts for average 63.03% of annual erosion

5. Publications

Published Journal Articles

Giang, P. Q., & Khanal, R. (2024). What next for marine ecosystem management in Vietnam: assessment of coastal economy, climate change, and policy implication. *Environmental Research Communications, 6*(2), 025002. doi:10.1088/2515-7620/ad19a5

Kodikara, D., Guo, Z., & Yoshimura, C. (2023). Effect of Benzophenone Type UV Filters on Photodegradation of Co-existing Sulfamethoxazole in Water. *Photochem, 3*(2), 288-300. doi:10.3390/photochem3020017

Conference Presentations

Garcia-Hernandez, J., Khanal, R., & Yoshimura, C. (2021, February). *Current Presence and Possible Repercussions of UV Filters in Coral Reef in Okinawa Prefecture*. Presentation abstract presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.

Khanal, R. (2021, February). *Managing Risk and Enhancing Resilience of Coral Reef in Southeast Asia*. Keynote speech presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.

Khanal, R. (2021, September). *Analytical and policy aspects for the management of UV filters in marine environment*. Presentation presented at the IWA ACHSW/EESS/CWR Online Workshop on Emerging Contaminants in Water.

Khanal, R., Boonyaroj, V., & Garcia-Hernandez, J. (2021, February). *Paradox of over-tourism, income opportunities and coral degradation: A case of Maya bay, Thailand*. Presentation abstract presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.

Khanal, R., Giang, P. Q., Mishra, B. K., Sith, R., Siev, S., Boonyaroj, V., Ann, V., Khov, V., & Garcia-Hernandez, J. (2021, February). *Comparison of Coral Bleaching Hotspot Mapping in Southeast Asia (Thailand, Cambodia and Vietnam) based on Sea Surface Temperature Modelling by National Oceanic and Atmospheric Administration Coral Reef Watch before and during Covid-19 Pandemic*. Presentation abstract presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.

Theses

Ngo, T. M. T. (2022). *Application of the SWAT Model to assess soil erosion in the Cai River Basin, Khanh Hoa Province* (Master's thesis). Vietnam National University Of Agriculture, Hanoi, Vietnam (in Vietnamese)

Manuscripts (Submitted)

Nhem, V., Siev, S., Chhin, R., Peng, C., Wai, M. P., Khanal, R., & Yoshimura, C. (n.d.). *Status of Seawater Quality at Koh Rong Island, Sihanoukville, Cambodia*. Manuscript submitted for publication in Techno-Science Research Journal, Institute of Technology of Cambodia

6. Media reports, videos and other digital content

None

7. Pull quotes

Rajendra Khanal

"Southeast Asia is blessed with incredibly beautiful and diverse coral reefs. However, these vital ecosystems are facing unprecedented threats from climate change, pollution, and unsustainable human activities, jeopardizing not only biodiversity but also the livelihoods of millions who depend on them."

"Effective coral reef conservation demands more than just scientific understanding; it requires bridging the gap between research and policy. We must strive for robust science-policy interlinkages, utilizing evidence-based approaches and collaborative platforms to formulate pragmatic, implementable management strategies that enhance resilience in the face of complex environmental challenges."

Chihiro Yoshimura

"Understanding the fate of micropollutants in aquatic systems requires meticulous investigation into their environmental interactions. Our work on benzophenones, for example, revealed they don't just act as UV screens; they can actively sensitize the degradation of other co-existing pollutants like sulfamethoxazole, highlighting the complexity we must consider in water quality management."

“Marine pollution and addressing the risk to coral reefs demands global collaboration, backed by deep scientific knowledge and the innovative energy of young researchers working together to discover and implement solutions that can truly safeguard these vital ocean ecosystems. This APN research has been one of the crucial experience of regional collaboration in understanding coral reef in Southeast Asian countries "”

Pham Quy Giang
"In Vietnam, the pressure on our marine ecosystems is immense. Rapid coastal development, population growth, intense aquaculture, and pollution from land-based sources are causing significant degradation, particularly visible in the loss of coral reef, mangrove, and seagrass habitats essential for our nation's biodiversity and coastal economy."

"While Vietnam has established legal frameworks and strategies for marine protection, the ongoing decline signals a critical need for stronger implementation and enforcement. Addressing pollution sources, managing fisheries sustainably, and adapting to climate change impacts are urgent priorities for safeguarding our marine heritage."

"Creating the soil erosion maps was insightful; it clearly visualizes the areas most at risk within the basin. Hopefully, this research provides practical information for local managers to implement targeted measures and mitigate the negative impacts of erosion on land use and potentially downstream marine environments like Nha Trang Bay."

8. Acknowledgments

The research team express sincere gratitude to the **Asia-Pacific Network for Global Change Research (APN)** for providing the essential funding support for the project "Collaborative Research Platform to Manage Risk and Enhance Resilience of Coral Reef in Southeast Asia" (Grant No. CRRP2019-08MY-Khanal), which made this research possible.

Special appreciation is extended to **Ms. Yumi Namba** of the Tokyo Institute of Technology for her invaluable assistance and ensuring the smooth coordination of project activities.

Furthermore, we deeply appreciate the contributions of all collaborating researchers, government and non-governmental organizations, and the other stakeholders with whom we interacted directly and indirectly in this project. Their willingness to share valuable time, experiences, local expertise, and essential datasets, including active participation in survey and other discussions was crucial to the successful execution and outcomes of this research.

9. Appendices

Giang, P. Q., & Khanal, R. (2024). What next for marine ecosystem management in Vietnam: assessment of coastal economy, climate change, and policy implication. Environmental Research Communications, 6(2), 025002. doi:10.1088/2515-7620/ad19a5

Abstract
Vietnam is a coastal country with a coastline stretching more than 3,260 km. Marine resources are important for the development of Vietnam. In Vietnamese seas, there are about 20 typical ecosystems spreading over 1 million square kilometers in the East Sea consisting of mangrove forests, coral reefs, lagoons, seagrasses in intertidal areas and estuaries, and living species in 155,000 hectares, 1,300 square kilometers, 500 square kilometers, 16,000 hectares, and 11,000 living species, respectively. At present, the impact of climate change, socio-economic development, and environmental pollution are considered as the main causes of degradation of Vietnam's marine ecosystems. This paper presents and discusses the pressure of socio-economic activities including industry, tourism, marine transportation and services, aquaculture and fishery on marine ecosystems. In Vietnam, compared to the early 2000s a total of 12% of coral reefs, and 48% of other coral reefs are vulnerable to degradation. So far, about 100 species of marine life in Vietnam are at risk of being threatened due to over-exploitation and fishing. The seagrass-bed ecosystem is currently being degraded with only over 5,580 ha remaining. In some areas, such as Cat Ba, Ha Long, and Quang Nam, seagrass beds have almost no chance to recover naturally due to serious impacts from tourism and aquaculture activities. From the findings, orientations that aim at effective management and protection of marine ecosystems to cope with adverse impacts of anthropogenic activities, climate change, and the pressure of socioeconomic development were proposed.

Keywords: climate change, environmental protection, marine ecosystem, pressure, socio-economic development

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Kodikara, D., Guo, Z., & Yoshimura, C. (2023). Effect of Benzophenone Type UV Filters on Photodegradation of Co-existing Sulfamethoxazole in Water. *Photochem, 3*(2), 288-300. doi:10.3390/photochem3020017

Abstract
Benzophenones (BPs) frequently occur in water environments, and they are able to both screen UV light and to sensitize reactive intermediate (RI) production. However, BPs have largely been overlooked as a background water component when studying photodegradation of co-existing organic micropollutants (OMPs). Therefore, in this study, we investigated the influence of BP and its derivative oxybenzone (BP3) on the degradation of the co-existing model OMP sulfamethoxazole (SMX). A series of photodegradation experiments were conducted covering a range of BPs concentrations in μg/L levels, and the degradation of 1.00 μM of SMX was studied. The addition of BP at 0.10 μM, 0.25 μM, and 0.30 μM, and BP3 at 0.10 μM and 0.25 μM, significantly increased the first order degradation rate constant of 1.00 μM of SMX (kobs(BP)) by 36.2%, 50.0%, 7.3%, 31.5%, and 36.2% respectively, compared to that in the absence of any BPs. The maximum indirect photodegradation induced by BP and BP3 reached 33.8% and 27.7%, respectively, as a percentage of the observed SMX degradation rate at the [BPs]/[SMX] ratio of 0.25. In general, triplet excited dissolved organic matter (3SMX*, 3BP*, and 3BP3*) played the major role in the photosensitizing ability of BPs. The results further implied that the increase of SMX degradation at the molar ratio of 0.25 was possibly due to 3BP* for the mixture of SMX and BP. Overall, this study revealed the sensitizing ability of BP and BP3 on the co-existing OMP, SMX, in water for the first time. Our findings can be applied to other BP type UV filters which are similar to BP and PB3 in molecular structure.

Keywords: indirect photolysis; reactive intermediates, photodegradation, benzophenone; sulfamethoxazole

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Garcia-Hernandez, J., Khanal, R., & Yoshimura, C. (2021, February). *Current Presence and Possible Repercussions of UV Filters in Coral Reef in Okinawa Prefecture*. Presentation abstract presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.

Abstract
Ultra-violet (UV) filters are pollutants of arising concern due to its persistence in water environment. In previous researches, UV filters have been reported in pristine coral environment in Okinawa, Japan. The main objective of this research is to review the spatiotemporal variation of 12 of the 16 UV filters, categorized as 3 groups by the Food and Drug Administration (FDA) on the Act to Modernize the Regulation of Sunscreen Products in the United States proposed in 2019. The target area is the Japanese coral reef environment in Ryukyu Trench, Ryukyu Islands, and Okinawa trough, for highlighting its toxicological and bioaccumulating impacts on coral reefs ecosystems. The web of science database from 2000 to 2020 was searched with the key words: anthropogenic activities, persistent organic pollutants, sunscreens, UV filters, UV protection, sunblock, UV stabilizer, coral, Japan, and Okinawa. Most of the studies

agreed that organic UV filters such as oxybenzone, octinoxate or octocrylene significantly degrade the water quality, which may have potential risk to coral ecosystems. In addition, the wide spread of UV filters has shown a perceivable presence in some Okinawa beaches, containing around 1.4 µg/L oxybenzone during summer season. Nevertheless, oxybenzone at some reef sites have been found to be around 0.01 µg/L which is almost 500 times lower than the LC50 range of 5.4 to 14.5 µg/ for Acropora cervicornis larvae. More toxicological and bioaccumulate studies on coral reef bleaching by UV filters have to be performed to support this statement and re-evaluate their ecological risks in coral reef ecosystems at different season and complex environmental exposure.

Keywords: UV filters, Okinawa, UV protection, coral, Oxybenzone

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Khanal, R. (2021, February). ***Managing Risk and Enhancing Resilience of Coral Reef in Southeast Asia*****. Keynote speech presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.**

Abstract
Coral reefs worldwide are vulnerable to climate change impacts (acidification, sea-level rise, warming temperatures), coastal development (sedimentation, nutrient discharge), and local stressors like disease, invasive species, over-tourism, and unsustainable fishing. This keynote speech analyzes past, present, and future trends of coral bleaching and the socio-economic impacts of coral degradation, with a specific focus on Southeast Asia (SeA). Major threats highlighted in SeA include overfishing, marine-based pollution, and the combined effects of local threats and thermal stress. The presentation discusses the paradox of over-tourism, which brings economic opportunities but also drives coral degradation, using the successful ongoing restoration strategy in Maya Bay, Thailand, as a case study. It emphasizes the crucial need for scenario analysis and quantitative risk assessment. Furthermore, bridging the gap between policymakers and researchers through evidence-based science communication is stressed for formulating effective coral restoration policies. The discussion concludes with an analysis of existing relevant policies in SeA and proposes a strategy for forming a collaborative platform to enhance resilience-based management for coral restoration.

Keywords: Coral Reefs, Southeast Asia, Resilience Management, Climate Change Impacts, Marine Pollution, Sustainable Tourism, Science-Policy Interface

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Khanal, R. (2021, September). ***Analytical and policy aspects for the management of UV filters in marine environment*****. Presentation presented at the IWA ACHSW/EESS/CWR Online Workshop on Emerging Contaminants in Water.**

Abstract
Marine environments face accumulating threats from climate change and pollution, with emerging contaminants like Ultra-Violet (UV) filters posing significant risks. These chemicals, originating from sources including wastewater discharge, recreational activities, and land run-off, enter surface waters and impact marine ecosystems. Specific UV filters, such as oxybenzone and octinoxate, have demonstrated toxicity, leading to regulatory actions like sales bans in regions such as Hawaii. Managing UV filters requires addressing both analytical and policy dimensions. This involves understanding their occurrence, concentrations, and potential health effects through processes like risk assessment. However, translating scientific findings into effective management necessitates robust policy synthesis, bridging the gap between technical research and regulatory decision-making. This synthesis must consider diverse stakeholder perspectives, potential socio-economic impacts, and utilize structured frameworks for integrating evidence. An evidence-based, resilience-focused approach is crucial, emphasizing clear communication and the contextualization of scientific knowledge to support the formulation and implementation of pragmatic environmental policies for UV filter management in marine environments.

Keywords: UV Filters, Marine Pollution, Environmental Policy, Risk Assessment, Science-Policy Interface

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Khanal, R., Boonyaroj, V., & Garcia-Hernandez, J. (2021, February). ***Paradox of over-tourism, income opportunities and coral degradation: A case of Maya bay, Thailand*****. Presentation abstract presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.**

Abstract
Abstract Tourism plays an important role in the economic development of the country. Tourism contributes to as much as 7% of Thailand national GDP. Pristine beaches in Thailand attracts millions of tourists every year. On one hand, local economy is boosted with tourism. Contrary to that, over-tourism may lead to stress on the local environment. One of the classical examples of impact of over tourism on the environment is the degradation of pristine beach and coral communities in the Maya bay, Phi Phi Leh, southern Thailand. This paper, aims to analyze the paradox of over-tourism, income opportunities and the impact on coral community in Maya bay, based on the literatures. Ever since, Maya bay was known to the world in early 2000's, the number of tourists visiting there every day increased by close to 3000-fold in the last 20 years. Though, tourism helped to increase the local economy dramatically, later, due to impact of probably over exploitation of corals from snorkeling and diving, and wash-off of the toxic UV-filters led to bleaching of the corals. Most of the corals were dead in 20 years of tourism exploitation by 2017. Government of Thailand came up with the strategy to ban Maya bay as a tourist hotspot, and promoted coral recovery. Because of the solid policy, and action plan of the multiple stakeholders, in the last three years,

corals has been significantly recovered. This paper discusses about the strength, weakness, challenges, opportunities and threat of the action plan in restoring coral community in Maya bay.

Keywords: Maya bay, UV-filters, coral planting, bleaching, over-tourism, stakeholder management

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Khanal, R., Giang, P. Q., Mishra, B. K., Sith, R., Siev, S., Boonyaroj, V., Ann, V., Khov, V., & Garcia-Hernandez, J. (2021, February). ***Comparison of Coral Bleaching Hotspot Mapping in Southeast Asia (Thailand, Cambodia and Vietnam) based on Sea Surface Temperature Modelling by National Oceanic and Atmospheric Administration Coral Reef Watch before and during Covid-19 Pandemic*****. Presentation abstract presented at The 13th AUN/SEED-Net Regional Conference on Chemical Engineering 2020 (RCCHE-2020) jointly held with The 5th International Symposium on Conservation and Management of Tropical Lakes.**

Abstract

Due to Covid-19 pandemic in the year 2020, international travel and hence the tourism was down by more than 95% globally. Influx of tourism has been regarded as one of the reasons for coral bleaching. In this study, attempt has been made to compare the coral bleaching hotspot (CBH) mapping in the year 2019 (pre-pandemic) and 2020 (during pandemic) based on sea surface temperature (SST) modelled data by National Oceanic and Atmospheric Administration Coral Reef Watch (NOAA-CRF). The NOAA 7-day maximum SST database is compared for the Coral Triangle region – with a focus on gulf of Thailand and south China sea covering Thailand, Cambodia and Vietnam in southeast Asia – for the first day of the month in Jan, Mar, June, Sep, and Nov both in 2019 and 2020. The CBH is taken as the measure of the difference between observed SST and monthly maximum mean temperature, and was measured in the range 0 to 5 OC. No visual (< 0 OC) CBH was observed in the region for the month January and March pre-pandemic and during pandemic. In the month of May, CBH (1 - 2 OC) was dominant in the gulf of Thailand covering mostly Thailand and Cambodia, and was higher during pre-pandemic period. During July, CBH (1 - 2 OC) was dominant in the south China sea covering Vietnam, and was also higher during pre-pandemic period. Surprisingly, CBH was higher during pandemic along the Vietnam in south China sea, the reason of which is still a matter of further investigation. In general, with an exception in September 2020, CBH was higher during pre-pandemic period. A detailed study covering daily, and monthly average SST would provide better understanding of impact of covid-19 pandemic on CBH.

Keywords: Coral bleaching hotspot, covid-19 pandemic, sea surface temperature, National Oceanic and Atmospheric Administration, Coral Reef Watch, gulf of Thailand, south China sea

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Manuscripts (Submitted)

Nhem, V., Siev, S., Chhin, R., Peng, C., Wai, M. P., Khanal, R., & Yoshimura, C. (n.d.). *Status of Seawater Quality at Koh Rong Island, Sihanoukville, Cambodia*. Manuscript submitted for publication in Techno-Science Research Journal, Institute of Technology of Cambodia

Abstract

Marine water quality can be good or bad depending on the presence or absence of different components. The delicate underwater ecosystem risks collapsing when the chemical run-off contaminates the ocean. Increased levels of chemicals can lead to toxic algal blooms, threatening the safety of marine life. Even minor damage to an ecosystem can have larger repercussions, as the harmonious balance becomes disturbed. Therefore, this study aimed to determine the physico-chemical parameters around Koh Rong Island in situ and understand the water conditions related to corals and marine biodiversity. In this study, 15 sampling points were chosen across the island to collect water sampling to retrieve some physio-chemical parameters such as temperature, EC, TDS, salinity, pH, DO, ORP, and Chl-a. As a result, the water quality parameters were in the acceptable range of marine water quality according to the water quality standard for coastal water by EPA. The temperature was around 31℃ for the dry season and 29.5℃ for the rainy season. While EC was about 53 mS/cm and TDS was 32.2 ppt for the dry season and 26.8 ppt for the rainy season. For Salinity, in the dry season, was about 32 psu, and in the rainy season, it decreased to 26.8 psu. The pH, DO, ORP, and Chl-a were 7.35, 8.07 mg/L, 257 mV, and 0.58 µg/L, respectively, in the dry season. While in the rainy season, pH was slightly increased to 7.83. The DO decreased to 7.96 mg/L, the ORP up to 294 mV, and Chl-a was 0.014 µg/L. Additionally, the Water pollution index (WPI) was also studied to clarify the condition of water around the study area. WPI of both seasons were in the good range with WPI = 0.72 and 0.71 respectively. with a good condition of water quality for marine biodiversity. It has shown that the coral damage or low number of fish and invertebrate abundance around the study areas has no sign related to the pollution of the water. However, basic marine water quality alone may not account for the complex and multifaceted causes of coral reef destruction, such as climate change, pollution, overfishing, and dynamite fishing. Therefore, further research is needed to investigate the specific factors and mechanisms that lead to coral bleaching and mortality.

Keywords: Marine water quality, WPI, Koh Rong Island, Coral Reef

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Thesis

Ngo, T. M. T. (2022). *Application of the SWAT Model to assess soil erosion in the Cai River Basin, Khanh Hoa Province* (Master's thesis). Vietnam National University Of Agriculture, Hanoi, Vietnam (in Vietnamese)

THESIS ABSTRACT

Master candidate: Ngo Thi Minh Trang

Thesis title: "Application of the SWAT Model to assess soil erosion in the Cai River Basin, Khanh Hoa Province"

Major: Land Management **Code**: 8. 85.0103

Educational organization: Vietnam National University Of Agriculture (VNUA)

Research objectives:
Applying SWAT Model to calculate soil erosion in the Cai River Basin, Khanh Hoa Province. Building soil erosion maps of the Cai River Basin, Khanh Hoa Province

Materials and Methods:
Method of collecting data and documents: Collect data on natural conditions, socio-economic development situation, data on meteorology, hydrology, soil, vegetation cover,... documents, data on erosion and its effects; topographic map, current land use map; soil map; map of the network of rivers, streams, reservoirs in the basin; digital elevation model (DEM)... of the Cai River basin. Collect primary data on topography, land use types, vegetation cover, and soil erosion of the Cai River basin, Khanh Hoa province.

Normalize the input data (spatial data, attribute data) of the SWAT model using tools in ArcGIS and Microsoft Excel software. Put the normalized data into the SWAT model to simulate and calculate the amount of soil erosion in the study area.

Method of illustration by maps and charts: Using built-up maps to show the level of soil erosion; Using graphs to illustrate the data that has been built with tables of results.

Data processing methods: Using Microsoft Excel software to synthesize and calculate data.

Main findings and conclusion:
Cai River basin, Khanh Hoa province covers Khanh Vinh, Dien Khanh, Cam Lam district, and Nha Trang city with a basin area of 1,880,1 km^2. The topography of the Cai River basin is very complex, with many high mountains, and high density divided by crevices, streams, and rivers. It has diverse vegetation that differentiates according to the altitude of the terrain; under the general influence of the tropical monsoon climate, with oceanic climate influence. The flow of the Cai River is abundant but unevenly distributed, the flood season usually concentrates about 80% to 85% of the annual flow, causing extensive flooding on both sides of the Cai River and serious erosion in many riverbank areas. In recent years, the forest area has shrunk a lot and the forest cover is reduced due to cutting down watershed forests along with the effects of tropical depressions, storms, and floods during the year, which has caused erosion in the Cai River basin to increase significantly.

The study has successfully applied the SWAT model to calculate soil erosion and build soil erosion maps of the Cai River basin. With the collected input data source, the study has determined a set of model parameters suitable for the basin conditions. The results of calibration and validation have confirmed the applicability of the SWAT model which has high accuracy and satisfactory reliability.

On that basis, the built-in parameter set is applied to calculate the soil erosion rate of the sub-basins in the period 2013 - 2021; calculate the monthly soil erosion rate of the whole basin in the period of 2013 - 2021; building soil erosion maps for the years 2013, 2016 (the year with the highest amount of soil erosion), and 2021; build a map of average soil erosion rate for the period 2013-2021. Thereby, the total average annual soil erosion rate in the period 2013-2021 is 77.67 tons/ha/year, the year with the lowest level of erosion is 2014 (1.01 tons/ha). The year with the highest level of erosion was 2016 (246.87 tons/ha). The study also shows a close relationship between the soil erosion rate and rainfall and flood regime in the year, in which, the largest amount of soil erosion falls in November (the month with the highest frequency of rain and flood), with an average of 3.34 tons/ha, accounting for 63.03% of the total annual soil erosion.

The construction of soil erosion maps of the study area using the SWAT model is quite accurate, making it easy for managers to identify areas that are likely to occur soil erosion. Appropriate measures can be taken to limit the impact of this process on land use as well as the agricultural production of local people.

Acknowledgement: Field surveys and data collection for this thesis work was supported by the project Collaborative Research Platform to Manage Risk and Enhance Resilience of Coral Reef in Southeast Asia - CRRP2019-08MY-Khanal funded by Asia-Pacific Network for Global Change Research (APN). The author would like to thanks Dr.Rajendra Khanal – the project leader for his advice and help during the conduct of this thesis work.