

Measurement of pre-monsoon and post-monsoon tritium activity concentrations without electrolytic enrichment in selected coastal waters of Sta. Ana, Cagayan, Philippines

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ABSTRACT

Tritium (³H) is an important environmental radionuclide because it occurs primarily as tritiated water and can be transported through hydrological and oceanographic systems. However, published measurements of tritium in Philippine coastal seawater remain limited. This study determined tritium activity concentrations in selected coastal waters of Sta. Ana, Cagayan using liquid scintillation counting (LSC), compared pre-monsoon and post-monsoon measurements, and established an initial reference dataset for future monitoring. Surface coastal water samples were collected along a 0–15 km coastal transect during five campaigns from March to December 2025.

During the pre-monsoon period, eight of twelve samples yielded concentrations above Lc, although only one exceeded the applicable MDA, with a maximum of 12.5 ± 3.6 TU. During the post-monsoon period, all eight samples were above Lc, with six exceeding MDA. The measured signals ranged from 6.2–12.5 TU pre-monsoon and 4.9–19.4 TU post-monsoon. The greater post-monsoon detection frequency and broader concentration range suggest temporal variability potentially associated with seasonal hydrological inputs and coastal mixing, although specific processes cannot be established from the present dataset. Comparison with Philippine and international measurements placed the Sta. Ana observations within the broader range reported for environmental and coastal marine waters. The study provides an initial reference

dataset for northern Luzon coastal seawater and a basis for continued monitoring.

INTRODUCTION

Tritium (³H) is an important radionuclide in environmental water monitoring because it occurs primarily as tritiated water (HTO), a chemical form that behaves similarly to ordinary water and can therefore move through hydrological and oceanographic systems. Tritium is produced naturally in the upper atmosphere through cosmic-ray interactions, but it may also enter aquatic environments from anthropogenic sources such as nuclear reactor operations, nuclear fuel-cycle activities, historical nuclear weapons testing, and accidental releases (Feng et al., 2020; Mao et al., 2024). Because tritium emits very low-energy beta radiation and is commonly present at low environmental concentrations, its measurement requires sensitive analytical techniques such as liquid scintillation counting (LSC) (Feng et al., 2020; Mao et al., 2024).

In the Philippine context, published information on tritium in coastal marine environments remains limited. Previous local studies have examined tritium mainly in freshwater systems, environmental surveillance near nuclear-related facilities, and isotope applications in hydrological or pollution studies (Castañeda et al., 2012; Garcia et al., 1986; Sugang et al., 2014). Published freshwater studies elsewhere also demonstrate that tritium concentrations can vary with hydrological conditions and the mixing of different water sources. In Goa, tritium concentrations in river water, groundwater, and rainwater were reported to vary between pre-monsoon and post-monsoon periods, with generally

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lower concentrations observed during the post-monsoon period. This seasonal variation was attributed to hydrological dynamics, including the influence of low-tritium oceanic moisture and faster circulation of the hydrological system, demonstrating the influence of seasonal processes on the distribution of tritium in the freshwater environment (Ansari et al., 2018). In Chhattisgarh, India, tritium concentrations were reported in groundwater, geothermal water, and river water, with differences among water types suggesting that mixing and differences in water sources can influence observed tritium levels (Ansari et al., 2017). A related study of tritium and other isotopes in basalt-associated water systems likewise demonstrated that variations in isotope concentrations can reflect differences in the origin and mixing of water sources (Ansari et al., 2022). These studies provide useful context for interpreting temporal and spatial variability in environmental tritium concentrations.

Tritium in freshwater systems can subsequently enter or interact with coastal and marine environments through hydrological and atmospheric processes. Consequently, measurements from different marine environments provide additional context for interpreting environmental seawater concentrations. Published studies likewise show that tritium levels in non-contaminated or weakly impacted waters are often near detection limits, requiring careful interpretation (Palomo et al., 2007). Isotopic measurements, including tritium, can also provide information useful for understanding water sources, movement, and resource management (Kumar & Ansari, 2021). For example, surface seawater concentrations in the western North Pacific have been reported at approximately 0.40–2.00 TU (Kaizer et al., 2018). Seasonal variations in environmental tritium concentrations have also been documented in precipitation samples, with fluctuations attributed to changes in atmospheric circulation (Kuwata et al., 2022).

Marine tritium concentrations, however, vary among open-ocean, marginal-sea, and coastal environments. Because tritium occurs primarily as HTO and is transported with water masses, measured concentrations may also vary with the depth and hydrodynamic characteristics of the sampled water (Cauquoin et al., 2025; IAEA, 2024; Zhao et al., 2021). Tritium concentrations of 1.34–4.87 TU in shallow waters of the East China Sea, 0.45–2.85 TU in bottom waters, and 6.64 TU in the Yangtze River estuary were measured (Zhang et al., 2023). In European coastal waters, a survey of Irish seawater reported measurable concentrations ranging from approximately 7.6 to 20.1 TU (Currivan et al., 2013). The OSPAR Commission likewise reported regional baseline concentrations of 24.8 ± 7.4 TU in the German Bight, 37.6 ± 3.4 TU in the Norwegian Coastal Current, and 29.7 ± 3.4 TU in the Barents Sea, while concentrations in the northwestern, southeastern, and central North Sea were below 6.9 TU (OSPAR Commission, 2007). These observations demonstrate the variability of tritium concentrations across different marine environments.

In the northwestern Pacific region, tritium monitoring has gained renewed scientific attention following the Fukushima Daiichi nuclear accident and Japan's subsequent discharge of ALPS-treated water. Tritium is a component of the treated water that cannot be removed by the ALPS process and is therefore diluted prior to controlled discharge. The Fukushima-related discharge has prompted extensive environmental monitoring and oceanographic studies to assess the distribution and potential transport of tritium in the Pacific Ocean (IAEA, 2024; Zhao et al., 2021; Cauquoin et al., 2025). However, marine tritium monitoring in the region is not limited to Fukushima, as routine tritium releases are also associated with nuclear power and fuel-cycle facilities in East Asia.

Environmental monitoring around nuclear facilities provides additional context for interpreting marine tritium concentrations. In the Daya Bay area of China, annual average seawater tritium concentrations of 6.8–59.3 TU have been reported (Deng et al., 2016). Long-term monitoring near the Tokai Reprocessing Plant in Japan found that 82.0% of seawater samples were below the detection limit, while 17.7% were between the detection limit <MDA–339 TU; a maximum concentration of approximately 14,407 TU was reported at a location immediately above the discharge outlet in 1979 (Kokubun et al., 2011). These observations demonstrate that measurable marine tritium can occur around nuclear facilities over a wide concentration range, although they do not establish such sources for the present study.

From a regulatory perspective, the World Health Organization guideline value for tritium in drinking water is 10,000 Bq/L, which is also adopted in the Philippine National Standards for Drinking Water (Department of Health, 2020). This value provides a general health-protection reference, although it is not directly comparable to ambient seawater concentrations. The tritium concentrations measured in the present study are substantially below this drinking-water guideline.

However, site-specific tritium data for northern Luzon coastal waters remain sparse. Sta. Ana, Cagayan is located along the northeastern margin of Luzon and is therefore a relevant location for establishing local marine tritium data within the broader western North Pacific setting. Despite the availability of tritium measurements from marine environments elsewhere in Asia and internationally, published measurements of tritium in Philippine coastal seawater remain limited. Therefore, this study aims to establish an initial reference dataset for tritium activity concentrations in selected coastal waters of Sta. Ana, Cagayan during the pre-monsoon and post-monsoon periods. Specifically, the study aims to determine tritium activity concentrations using liquid scintillation counting (LSC), compare pre-monsoon and post-monsoon values, and provide baseline data for future monitoring and assessment.

This study focuses on establishing an initial reference dataset of tritium activity concentrations in selected coastal water stations in Sta. Ana, Cagayan, using liquid scintillation counting (LSC), and on examining temporal variation between the pre-monsoon and post-monsoon periods and spatial variation among sampling locations. The study is limited to surface seawater measurements collected during the 2025 sampling campaigns and is intended to provide baseline information for future environmental radioactivity monitoring. The study does not attempt to determine the specific source or origin of the detected tritium. In particular, the measured concentrations cannot by themselves distinguish among natural background, historical atmospheric inputs, regional anthropogenic releases, or other environmental transport pathways. Interpretation is further limited by the relatively small number of sampling periods and the analytical detection limits associated with low-level LSC measurements. Differences among sampling locations or seasons should therefore be interpreted in consideration of the measurement uncertainty and batch-specific MDA. Further source attribution would require longer-term monitoring, additional depth profiles, hydrological and oceanographic data, and complementary radionuclide or tracer measurements. Because salinity and other hydrographic parameters were not measured concurrently, the study cannot exclude contributions from riverine, estuarine, groundwater, or meteoric water.

MATERIALS AND METHODS

This study employed a descriptive and analytical research design to determine the reference values for tritium activity concentrations in selected coastal waters of Sta. Ana, Cagayan. Water samples were collected along a fixed linear transect extending from the shoreline to offshore locations. The collected samples were analyzed using liquid scintillation counting (LSC) to quantify tritium activity concentration. The study was conducted over several months to capture both pre-monsoon and post-monsoon conditions and to assess possible seasonal variation in tritium levels.

Study Area and Sampling Locations

The study was conducted in the coastal waters of Sta. Ana, Cagayan, Philippines (see Figure 1). A linear transect perpendicular to the coastline was established in order to examine possible changes in tritium concentration with increasing distance from shore. Sampling points were located approximately 0 km, 5 km, 10 km, and 15 km from the shoreline as shown in Figure 1. The 0 km station represented the coastal reference point, while the offshore stations were selected to assess spatial variability across the transect. Additional comparison samples were also collected from Cavite and Manila for comparison with more urbanized coastal areas.

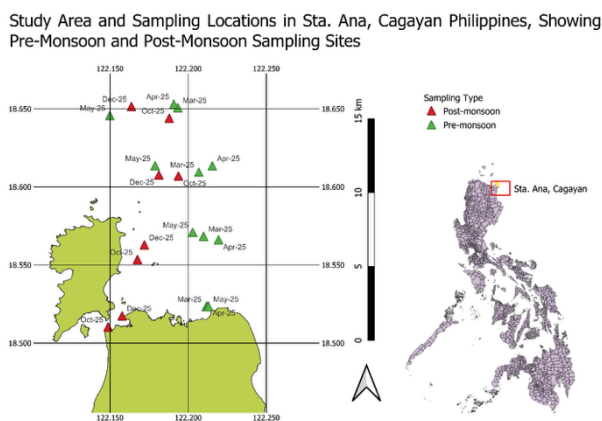


Figure 1: Study Area and Sampling Site

Sample Collection and Preparation

A total of twelve 1-L gas-tight polyethylene containers were used for seawater collection. Prior to sampling, all containers were cleaned thoroughly to minimize the risk of contamination. The cleaning procedure involved initial rinsing with tap water to remove visible residues, followed by washing with warm water and laboratory detergent. The containers were then rinsed repeatedly with distilled water and allowed to air-dry in a clean and dust-free environment. Immediately before sample collection, each container was rinsed with the water to be sampled.

Sampling was conducted in five campaigns between March and December 2025, covering both pre-monsoon and post-monsoon seasons. At each station, surface seawater samples were collected and labeled according to sampling date and location. Additional samples were collected in Manila and Cavite for near urban community comparison.

Surface seawater samples were collected at each designated station using the prepared polyethylene containers. After collection, the containers were sealed immediately and stored under dark and cool conditions during transport to the laboratory. Proper labeling was maintained throughout the collection and transport process to ensure sample traceability. Upon arrival at the laboratory, the

seawater samples were subjected to distillation prior to counting to remove dissolved salts and other potential chemical quenchers that could interfere with liquid scintillation analysis. Only the distilled fraction was used for subsequent tritium measurement.

Distillation was included as a matrix-reduction step because seawater contains dissolved salts and other constituents that may contribute to chemical or physical quenching during liquid scintillation counting. Using the distilled fraction minimized matrix-related interferences and provided consistent sample conditions for LSC analysis. Before distillation, the collected seawater was homogenized by manual agitation using porcelain chips to ensure that the aliquot was representative of the sample. An 8 mL aliquot of the distilled water was used for LSC measurement. Since environmental tritium occurs primarily as tritiated water (HTO), it was treated as part of the water phase during sample preparation.

The 8 mL distilled sample volume was selected because the liquid scintillation counting procedure used 20 mL polypropylene vials containing 8 mL of distilled sample and 12 mL of UltimaGold scintillation cocktail. Maintaining this 8:12 sample-to-cocktail ratio provided consistent sample preparation and counting conditions for samples, blanks, and standards. No electrolytic enrichment was performed in this study. Tritium measurements were conducted directly on the distilled water fraction using liquid scintillation counting.

Instrument Calibration and Quality Control

Tritium measurements were performed using a PerkinElmer Liquid Scintillation Counter (LSC) configured for low-level beta detection. All measurements were conducted using 20 mL polypropylene liquid scintillation vials, each containing a mixture of 8 mL of distilled sample and 12 mL of UltimaGold scintillation cocktail, resulting in a consistent sample-to-cocktail ratio of 8:12 across all analyses. The same vial type, sample-to-cocktail ratio, and counting conditions were used for samples, blanks, and standards to maintain consistent counting geometry and measurement conditions. Prior to sample measurement, the instrument was checked using a tritium standard solution with a known activity concentration of 1310.14 Bq/kg. This standard was prepared and counted under conditions identical to those used for the samples, including vial type, cocktail composition, and counting window, in order to ensure consistency in counting geometry and detection conditions. The standard served as the reference for determining the counting efficiency for each analytical batch.

The counting efficiency (ϵ) was determined experimentally from the measured count rate of the standard solution relative to its known activity. Batch-specific efficiency values were established to account for differences in counting response between analytical batches. These differences may arise from variations in counting conditions, including background stability and detector response. Background measurements were performed using tritium-free distilled water (dead-water blank) prepared under identical conditions as the samples. The background count rate obtained from the blank was used for background correction of the corresponding sample measurements. These background values were subtracted from the gross count rates to obtain the net count rates for all samples.

All samples, blanks, and standards were measured using a fixed counting window of channels 40–160. This window was selected based on the response of the instrument to the tritium standard and was applied consistently to the standards, blanks, and unknown samples. Since tritium is a low-energy beta emitter, the selected window was assigned as the tritium region of interest for the

specific PerkinElmer LSC setup used in this study. The channel range represents an instrument-specific pulse-height window rather than an absolute energy scale. The use of identical vial type, cocktail composition, sample-to-cocktail ratio, and counting window ensured that the tritium standard, blank, and samples were measured under comparable counting conditions.

For each analytical batch, the tritium standard provided the counting efficiency, while the dead-water blank provided the background count rate used for sample correction. This batch-specific approach accounted for variations in counting response and background conditions during the measurement period.

Possible quenching effects were controlled by using the same sample-to-cocktail ratio for all vials, distilling all seawater samples before counting, preparing blanks and standards under the same conditions as the samples, and determining batch-specific counting efficiencies. These steps minimized differences in counting response caused by sample matrix effects.

To maintain measurement reliability and consistency, all samples were prepared and analyzed using identical procedures, including vial preparation, sample-to-cocktail ratio, and counting parameters. The use of batch-specific efficiency and background values ensured that variations in instrument performance were accounted for in the calculation of activity concentrations. All measurements were performed in a single counting cycle of 1050 minutes per sample. Background measurements were performed using tritium-free (blank) water samples under identical counting conditions.

Each sample was measured for a total counting time of 1050 minutes. The gross count rate (R_g) obtained from the instrument includes contributions from both the sample and background radiation. The net count rate (R_{net}) was calculated as in Eq. (1):

$$R_{net}[CPM] = R_g[CPM] - R_b[CPM] \quad \text{Eq. (1)}$$

Where R_g represents the gross count and R_b represents the background count rate.

The detector efficiency given by the following equation:

$$\epsilon = \frac{R_{net}[CPM]}{\frac{A_{C, std}[Bq/kg]}{m_{std}[kg]} \times \frac{60[s]}{1[min]}} \quad \text{Eq. (2)}$$

Where, R_{net} is the net count of a known standard as detected by the instrument, $A_{C, std}$ is the known activity and m_{std} is the mass of the standard.

The tritium activity of each sample was calculated from the net count rate and counting efficiency. The activity of the aliquot, expressed in becquerels, was determined using the relationship:

$$A[Bq] = R_{net}[CPM] \times \frac{1}{\epsilon} \times \frac{1[min]}{60[s]} \quad \text{Eq. (3)}$$

where A is the activity in Bq, R_{net} is the net count rate in counts per minute (CPM), and ϵ is the counting efficiency. The activity calculated in Eq. (3) was divided by the sample mass to determine the activity concentration. For comparison with published literature, tritium activity concentrations were converted from Bq/kg to Tritium Units (TU) using $1 \text{ TU} = 0.118 \text{ Bq/L}$ ($1 \text{ Bq/L} \approx 8.45 \text{ TU}$). Given the approximately 1 kg/L density of seawater,

Bq/kg was treated as approximately equivalent to Bq/L for this conversion.

The critical level (L_c) was determined using the statistical approach of Currie to establish whether the measured sample signal was statistically distinguishable from background at 5% probability of false detection (Villa & Manjón, 2004). The critical level was calculated as shown in Eq. (4).

$$L_c = 1.64 \times \sqrt{\frac{2R_b}{t}} \quad \text{Eq. (4)}$$

The minimum detectable activity (MDA) was calculated to determine the lowest tritium activity concentration that could be detected under the measurement conditions used in this study. The MDA was evaluated using a Currie-type detection limit expression as shown in Eq. (5):

$$MDA[Bq/kg] = \frac{2.71 + 4.65\sqrt{R_b[CPM] \times t[min]}}{\epsilon \times t[min] \times m[kg]} \quad \text{Eq. (5)}$$

where MDA is the minimum detectable activity concentration (Bq/kg), R_b is the background count rate (CPM), t is the counting time in minutes, ϵ is the counting efficiency, and m is the mass of the analyzed sample aliquot (kg). The combined standard uncertainty associated with the activity concentration was evaluated using the law of propagation of uncertainty. The critical level L_c and the minimum detectable activity MDA were determined separately for each analytical batch using the measured background counting time, counting efficiency and sample mass.

The primary sources of uncertainty considered in this study include the gross count and net count rate as shown in Eq. (6):

$$U_{Ac} = \frac{1}{m \times \epsilon} \sqrt{\frac{R_g}{t_g} + \frac{R_b}{t_b}} \quad \text{Eq. (6)}$$

This uncertainty was calculated for each analytical batch. The reported values represent one standard deviation of the counting statistics.

RESULTS AND DISCUSSION

The measured tritium concentrations showed a clear difference in detectability between the pre-monsoon and post-monsoon sampling periods. Because low-level LSC measurements are influenced by background counting statistics, results with sample count rates that did not exceed the applicable critical level L_c were considered not statistically distinguishable from the background and were reported as $<L_c$ rather than as quantitative concentrations. For measurements exceeding L_c , tritium activity concentrations were quantified, while the batch-specific minimum detectable activity (MDA) was used to characterize the detection capability of the measurement conditions.

The measured tritium concentration showed difference in detectability as shown in Table 1. The batch-specific critical L_c values were 4.6, 4.8, 3.9 and 3.5 TU respectively, while the corresponding MDA values were 11.2, 11.6, 8.6 and 7.9 TU.

Table 1: Batch-Specific Critical Level (L_c) and Minimum Detectable Activity (MDA) for Tritium in Coastal Water Samples

Batch	L_c (TU)	MDA (TU)
March 2025 Batch	4.6	11.2
May 2025 Batch	4.8	11.6
October 2025 Batch	3.9	8.6
December 2025 Batch	3.5	7.9

Pre-monsoon measurements

During the pre-monsoon period, only one of the twelve samples exceeded its applicable MDA and was therefore reliably quantifiable. The detectable sample, collected at the 5-km station on 31 May 2025, had a tritium activity concentration of 12.5 ± 3.6 TU. Seven additional samples yielded measured activities above the critical level L_c but below the applicable MDA, indicating that the measured activities were distinguishable from background. Three samples were below L_c and were therefore reported as $<L_c$. **Table 2** summarizes the results.

Table 2: Tritium Activity Concentration Measured during Pre-Monsoon Period in Sta. Ana Cagayan

Sample ID	Tritium Activity Concentration (TU)
30-03-0KM	9.9 ± 3.6
30-03-5KM	6.2 ± 3.6
30-03-10KM	10.4 ± 3.6
30-03-15KM	9.3 ± 3.6
12-04-0KM	$<L_c$
12-04-5KM	7.2 ± 3.6
12-04-10KM	$<L_c$
12-04-15KM	$<L_c$
31-05-0KM	6.8 ± 3.6
31-05-5KM*	12.5 ± 3.6 TU
31-05-10KM	$<L_c$
31-05-15KM	8.7 ± 3.6

March Batch $L_c=4.6$ TU, MDA=11.2 TU; May Batch $L_c=4.8$, MDA=11.6
*Exceeded the MDA

The distribution of pre-monsoon tritium concentrations should be interpreted with consideration of the L_c and MDA criteria. The samples with concentrations above L_c but below the MDA indicate activities distinguishable from background; however, they did not meet the criterion for reliable quantitative detection under the measurement conditions. Consequently, only the 31 May 2025 sample from the 5-km station, which exceeded the applicable MDA, was considered a reliable quantitative detection. The available results therefore do not provide sufficient evidence for a spatial gradient in tritium concentration during the pre-monsoon period.

Post-monsoon measurements

Greater detectability was observed during the post-monsoon period. Six of the eight samples exceeded their applicable MDA and were therefore considered reliably quantifiable. The other two

samples yielded measured concentrations above L_c but below the applicable MDA, indicating activities distinguishable from background but below the criterion for reliable quantification. The measured tritium signals ranged from 4.9 to 19.4 TU, with 6 of 8 samples exceeding the applicable MDA. The highest value was measured at the 5-km station in December. **Table 3** shows the measured tritium activity concentrations.

Table 3: Tritium Activity Concentration Measured during Post-Monsoon Period in Sta. Ana, Cagayan

Sample ID	Tritium Activity Concentration (TU)
31-10-0KM	8.2 ± 2.6
31-10-5KM*	11.0 ± 2.7
31-10-10KM	4.9 ± 2.6
31-10-15KM*	10.7 ± 2.7
27-12-0KM*	10.5 ± 2.5
27-12-5KM*	19.4 ± 2.6
27-12-10KM*	9.6 ± 2.5
27-12-15KM*	17.0 ± 2.6

October Batch $L_c=3.9$ TU, MDA=8.6 TU; December Batch $L_c=3.5$ TU, MDA=7.9 TU

*Exceeded the MDA

The October sampling produced four measured concentrations above L_c , of which two exceeded the applicable MDA. All four December samples exceeded the applicable MDA. The highest concentration, 19.4 ± 2.6 TU, occurred at the 5-km sampling location. The post-monsoon results therefore show a greater proportion of measurements exceeding the MDA compared with the pre-monsoon period, as well as a broader observed signal range (4.9–19.4 TU).

Seasonal comparison

The difference between the two sampling periods is more apparent in the frequency of detectable measurements and the range of observed concentrations. During the pre-monsoon period, eight of twelve samples yielded concentrations above L_c , although only one exceeded the applicable MDA. In contrast, all eight post-monsoon samples yielded concentrations above L_c , with six exceeding the applicable MDA. The observed concentrations ranged from 6.2 to 12.5 TU during the pre-monsoon period and from 4.9 to 19.4 TU during the post-monsoon period (Figure 2).

Figure 2 summarizes the distribution of the observed tritium activity concentrations between the pre-monsoon and post-monsoon sampling periods. The post-monsoon distribution shows a higher median concentration and greater variability, with concentrations extending to 19.4 TU, compared with 12.5 TU during the pre-monsoon period.

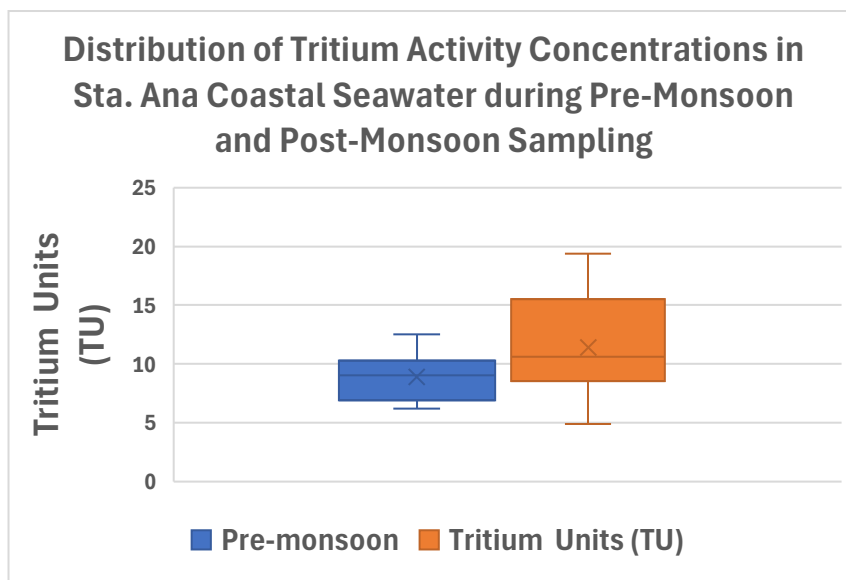


Figure 2: Comparison of Detectable Tritium Activity Concentration between Pre-monsoon and Post-monsoon Periods

The contrasting seasonal behavior observed in freshwater and coastal waters suggests possible hydrologically driven redistribution of tritium. Ansari et al. (2018) reported higher tritium concentrations in river and mine-pit waters during the pre-monsoon period and depletion during the post-monsoon period, which they attributed to the predominance of low-tritium oceanic moisture and faster hydrological circulation. In contrast, the present study showed greater post-monsoon tritium detectability in coastal water, with six of eight samples exceeding the MDA compared with one of twelve during the pre-monsoon period. The observed concentration also extended to 19.4 TU post-monsoon, compared with 12.5 TU pre-monsoon.

One possible interpretation is that monsoon-related hydrological processes may redistribute tritium between terrestrial and coastal environments. Increased rainfall and runoff during or following the monsoon could potentially transport terrestrial water containing tritium toward the coastal zone, which could contribute to the higher post-monsoon concentrations observed in Sta. Ana. Thus, the post-monsoon depletion observed in freshwater systems by Ansari et al. (2018) and the enhanced coastal signal in the present study may reflect different manifestations of seasonal water redistribution. However, this interpretation remains a hypothesis because river discharge, groundwater inputs, precipitation, salinity, and coastal circulation were not measured together in the study.

However, the observed seasonal increase in coastal water tritium does not provide direct evidence of terrestrial tritium transport to the sea. The measurements demonstrate differences in concentration and detection frequency between sampling periods but do not establish the source or transport pathway. The contribution of monsoon-related runoff therefore requires further verification through more measurements of freshwater inputs, hydrological conditions, and coastal-water tritium over successive monsoon cycles.

Comparison of Cagayan Tritium Activity with other Philippine Coastal Measurements

Sta. Ana measurements can also be compared with available measurements from other Philippine coastal locations. The results are summarized in Table 4.

Table 4: Comparison of Detectable Tritium Activity in Sta. Ana, Cagayan and Other Philippine Coastal Waters

Location	Tritium concentration (TU)
Sta. Ana, Cagayan	4.9–19.4
Cavite*	7.74 ± 2.7
Manila	14.2 ± 2.5

*Cavite measurement is less than MDA, but greater than L_c

The observed Sta. Ana measured signals (4.9–19.4 TU) overlap with the Manila measurement (14.2 ± 2.5 TU) and are within the range reported for seawater in Ireland (7.6–20.1 TU). The measured Sta. Ana signals are generally higher than the reported surface seawater range in the Western North Pacific (0.40–2.00 TU) and the shallow seawater range in the East China Sea (1.34–4.87 TU), although they remain within the broader range reported for some coastal and marginal marine environments. The Cavite measurement (7.74 ± 2.7 TU), while above L_c , was below the applicable MDA and therefore was not considered reliably quantifiable. Nevertheless, its measured value falls within the observed Sta. Ana range and is also comparable to the lower end of the Irish seawater range. These comparisons indicate that the tritium concentrations observed in Sta. Ana are within the broader range reported for some marine and coastal environments. However, the available Philippine measurements remain too limited and were not obtained through a common monitoring program, so they cannot be used to establish persistent spatial differences among the coastal locations.

Comparison of Cagayan Tritium Activity with other Select Freshwater and Marine Systems

Figure 3 shows the range of tritium concentrations reported in selected freshwater and marine environments, providing context for the detectable concentrations measured in Sta. Ana, Cagayan. Relatively low concentrations were reported in precipitation and apparently unaffected surface waters in the Philippines, as well as in freshwater systems in India. Similarly, relatively low concentrations were reported in surface and bottom waters of the western North Pacific and East China Sea. These observations provide reference values for environmental waters where no specific anthropogenic input has been identified.

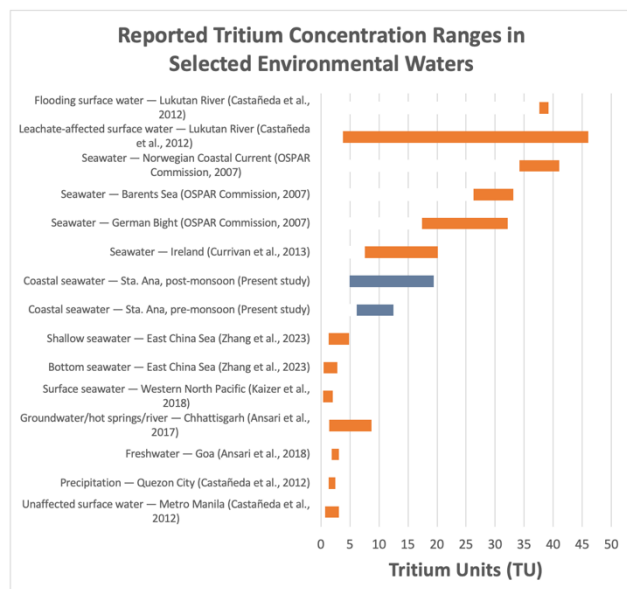


Figure 3: Range of Tritium Measurements from Various Selected Studies

These comparisons are intended to provide environmental context only, because the cited studies differ in sampling location, hydrological setting, analytical methodology, and detection capability. The measured signals in Sta. Ana, Cagayan (4.9–19.4 TU) are higher than several of the lower-concentration freshwater and open-ocean observations, but remain within the range reported for other coastal marine environments. For example, Irish seawater showed concentrations of 7.6–20.1 TU, while OSPAR monitoring reported higher concentrations of approximately 17.4–32.2 TU in the German Bight, 26.3–33.1 TU in the Barents Sea, and 34.2–41.0 TU in the Norwegian Coastal Current. Thus, the Sta. Ana concentrations fall within the broader range of environmental and coastal water measurements and are not unusually elevated relative to these observations.

The Philippine freshwater observations provide additional context for interpreting the Sta. Ana results. Castañeda et al. (2012) reported concentrations of 3.8–46 TU in leachate-affected surface waters of the Lukutan River and 38.4 ± 0.8 TU during an exceptional flooding event. The Sta. Ana concentrations are substantially below these upper freshwater values. This difference may partly reflect the different hydrological settings, as the Lukutan River observations were associated with leachate influence and exceptional flooding, whereas the present study concerns coastal water. The lower concentrations observed at Sta. Ana may therefore be consistent with a coastal environment without a similarly strong localized input, although the present data cannot establish the absence of anthropogenic influence.

Marine environments associated with nuclear facilities provide a further comparison with the Sta. Ana measurements. At Daya Bay, China, seawater concentrations near nuclear facilities were reported at 6.8–37.3 TU on an annual-average basis, with a maximum of approximately 599 TU. At the Tokai reprocessing facility in Japan, seawater measurements ranged from below the detection limit to approximately 339 TU, while an exceptional concentration of approximately 14,407 TU was reported immediately above a discharge outlet in 1979. The Sta. Ana concentrations are well below the higher concentrations reported for these facility-associated environments, particularly the localized Tokai discharge measurement. This contrast may be consistent with the absence of a strong localized anthropogenic input at Sta. Ana; however, concentration magnitude alone cannot be used to determine source or to rule out anthropogenic contributions.

Taken together, the comparison suggests that the tritium concentrations observed in Sta. Ana are within the range of reported environmental and coastal marine waters and are lower than concentrations associated with several strongly influenced or localized settings. The relatively greater post-monsoon concentrations and higher frequency of MDA exceedances may be consistent with the increased contribution of terrestrial water through rainfall, runoff, groundwater discharge, or riverine input following the monsoon, as discussed above. Coastal mixing and dilution may subsequently lower these inputs, potentially contributing to concentrations that remain below those observed in waters subject to strong inputs. However, these processes were not measured directly in the present study, and the available data cannot distinguish among natural background, hydrological transport, historical inputs, and possible anthropogenic contributions. The results therefore provide no indication of an unusually elevated environmental tritium concentration at Sta. Ana based on the literature comparison, but they should not be interpreted as definitive evidence of the absence of anthropogenic influence.

CONCLUSION AND RECOMMENDATIONS

The study assessed tritium activity concentrations in selected coastal water samples from Sta. Ana, Cagayan using liquid scintillation counting (LSC). During the pre-monsoon period, eight of the twelve samples yielded measured concentrations above the critical level L_C , although only one exceeded the applicable minimum detectable activity (MDA). The sample collected at the 5-km station on 31 May 2025 had the highest reliably quantifiable pre-monsoon concentration of 12.5 ± 3.6 TU. During the post-monsoon period, all eight samples were above L_C , with six exceeding the applicable MDA. The observed measured signals ranged from 6.2–12.5 TU during the pre-monsoon period and 4.9–19.4 TU during the post-monsoon period, indicating greater post-monsoon detectability and a broader observed concentration distribution. These results suggest temporal variability in coastal water tritium, although the specific hydrological and oceanographic processes responsible cannot be established from the present dataset.

Comparison with Philippine and international measurements showed that the observed Sta. Ana concentrations fall within the broader range reported for environmental and coastal marine waters. The concentrations were higher than several reported values for low-tritium freshwater and open-ocean environments but overlapped with concentrations reported for other coastal waters. They remained below several higher concentrations reported for strongly influenced or localized environments, including measurements associated with the Daya Bay and Tokai nuclear facilities and exceptional freshwater conditions reported in the Philippines. This comparison does not establish the absence of anthropogenic influence, but the observed concentrations do not appear unusually elevated relative to the range reported for other environmental and coastal waters.

The greater post-monsoon detectability may be associated with seasonal hydrological processes, including increased rainfall, surface runoff, freshwater discharge, groundwater contribution, and coastal mixing. The contrasting seasonal behavior reported by Ansari et al. (2018), in which lower post-monsoon tritium concentrations were observed in freshwater systems, provides a useful comparative context and raises the possibility of seasonal redistribution of tritium between terrestrial and coastal environments. However, the present study cannot confirm terrestrial transport as the source of the post-monsoon coastal signal, because freshwater discharge, groundwater inputs,

precipitation, salinity, and coastal circulation were not measured concurrently.

The study therefore provides baseline reference information on observed tritium activity concentrations in the coastal waters of Sta. Ana, Cagayan, against which future measurements can be compared. Continued seasonal monitoring is recommended to determine whether the greater post-monsoon detectability observed here represents a persistent pattern. Future studies should include repeated sampling at the existing stations, additional spatial coverage where feasible, and concurrent measurements of rainfall, riverine and groundwater inputs, salinity, temperature, freshwater discharge, and coastal circulation. Such integrated monitoring would provide a stronger basis for distinguishing seasonal hydrological effects, coastal mixing, and potential anthropogenic contributions to tritium variability.

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CONFLICT OF INTEREST

The authors declare that there are no financial, personal, or professional conflicts of interest that could have influenced the conduct, analysis, or reporting of this study. This research was carried out independently and objectively, with all findings presented without bias or external influence.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

Palisoc conducted the field sampling, performed the distillation of seawater samples, calculated the tritium activity concentrations, and prepared the original manuscript. **Madriaga** assisted in the distillation and preparation of seawater samples for analysis. **Mendoza** assisted in the calculation of tritium activity concentrations, validated the analytical results, and provided guidance on data interpretation. **Sucgang** contributed to data verification and provided recommendations on the organization, presentation, and discussion of the research findings. **Catalig** contributed to manuscript preparation and revision, conversion of tritium activity concentrations into Tritium Units (TU), and preparation of maps, graphs, and other visual representations of the results.

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