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Seasonal Heavy Metal Analysis Through Gill, Skin, Muscle, and Intestine of Selected Aquatic Organism *Scomberomorus guttatus* from Nizampatnam Harbor, and Kothapalem Beach; Bapatla (District), Andhra Pradesh

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Abstract

The present study was undertaken to evaluate the seasonal variation and bioaccumulation of heavy metals in different tissues of the marine fish *Scomberomorus guttatus* collected from Nizampatnam Bay, Palnadu District, Andhra Pradesh. Fish samples were collected seasonally from selected stations in the bay during the study period from June 2022 to July 2023. The tissues selected for analysis included gill, skin, muscle, and intestine, as these organs play a significant role in metal accumulation and human consumption. Heavy metals such as lead (Pb), manganese (Mn), zinc (Zn), nickel (Ni), cadmium (Cd), chromium (Cr), and copper (Cu), were analyzed using standard analytical procedures. The sediment samples collected from all sampling locations showed variations in heavy metal concentrations. Among the analyzed metals, chromium (Cr) had the highest concentration, followed by copper (Cu), lead (Pb), and manganese (Mn). In contrast, zinc (Zn) and cadmium (Cd) were found at comparatively lower concentrations. The study also explored the correlation between the presences of trace elements in different tissues namely the gills, skin, muscle, and intestine of *Scomberomorus guttatus* of the examined tissues, the intestine exhibited the highest accumulation of heavy metals compared to the gills, skin, and muscle, indicating its greater capacity for metal bioaccumulation and metabolic activity. The present study is highly useful in understanding the seasonal distribution and bioaccumulation of heavy metals in marine ecosystems, particularly in commercially important fish species such as *Scomberomorus guttatus* from Nizampatnam Bay, Palnadu District, Andhra Pradesh. The investigation provides valuable baseline data on the concentration of heavy metals in different fish tissues, including gill, skin, muscle, and intestine, which can be used for future environmental monitoring and comparative studies.

***Key words*:** Heavy metal, Nizampatnam bay, *Scomberomorus guttatus* bioaccumulation

The global issue of heavy metal pollution in the marine ecosystem has escalated in recent years. Toxic heavy metal pollutants are generated through air deposition, geologic weathering, or the discharge of industrial waste effluents. Due to their hazardous nature and ability to accumulate in marine settings, there has been a recent surge in public awareness regarding the extent and distribution of heavy metal contamination in the vulnerable coastal region [1]. The aquatic ecosystem serves as a repository for various pollutants, including pesticides used in agriculture and heavy metals released from human activities such as industrial metal processing and mining waste disposal. Naturally, water and sediments contain tiny amounts of heavy metals.

However, human activity significantly increases the usual concentration of these metals from parts per billion (ppb) to fewer than 10 parts per million (ppm) [2]. The presence and toxicity of trace metal elements and heavy metals in the aquatic environment, including fishes, have been extensively studied and recognized [3]. In aquatic ecosystems, metals are typically introduced by the weathering of soils and rocks, volcanic eruptions, and human activities such as mining the use of metal-containing compounds that contain contaminants. The contamination of water bodies, specifically due to industrial waste and home sewage, has experienced a significant or moderate rise at present [4]. The majority of researchers have elucidated that the presence of heavy metals in both water and sediment is primarily in the form of physicochemical compounds. The presence of both inorganic and organic pollutants of heavy metals is particularly significant due to their resistance to biological degradation. These metals tend to accumulate in the lower levels of living organisms, resulting in high concentrations throughout the food chain. This has been

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extensively discussed by Bini *et al.* [5], Chao *et al.* [6]. According to Manju Mahurpawar [7] the harmful impact is not limited to aquatic organisms but also affects human beings. The primary factor is the significant stability of heavy metals, which hinders their easy disposal through oxidation or precipitation processes. Therefore, even at low levels of concentration, heavy metals persist in aquatic environments for extended periods, allowing them to accumulate in aquatic creatures through the process of bioaccumulation.

However, metals are found in the environment due to both natural processes and pollution caused by human activity. Fish, a vital dietary resource for humans, also plays a crucial role in numerous ecological food chains. Fish is a source of fats, fat-soluble vitamins, and protein. The protein derived from fish is of superior quality in terms of its impact on human health compared to that found in meat and fowl. Fish contains protein ranging from 15% to 24%, carbohydrates ranging from 1% to 3%, lipids ranging from 0.1% to 22%, inorganic compounds ranging from 0.8% to 2%, and water ranging from 66% to 84%.

Monitoring heavy metal pollution is a significant field of research in Andhra Pradesh, India. This is because the concentrations of heavy metals in aquatic ecosystems have a direct impact on the fish industry, which is a crucial source of livelihood [8]. Squadrone *et al.* [9] found that fish absorb metals by many mechanisms, including the ingestion of suspended particulate elements in water, the ingestion of food, the exchange of dissolved metals across lipophilic membranes (such as the gills), and the adsorption of metals on tissue and membrane surfaces. *Scomberomorus guttatus* (vanjaram) Parvez and Vijaya [10] highlighted that in Nellore, cadmium levels in fish muscles exceeded European Commission (EC) 2005 limits, and zinc concentrations surpassed World Health Organization (WHO) [11] guidelines, raising significant concerns about food safety. These findings emphasize the need for continuous monitoring of heavy metal contamination in aquatic environments, particularly in areas impacted by industrial activities and agricultural runoff.

MATERIALS AND METHODS

Study area

Two stations were selected in the Nizampatnam Bay: Station I (Nizampatnam Fish Harbor; Latitude 15°54′N, Longitude 80°40′E) and Station II (Kothapalem; Latitude 10.8851°N, Longitude 78.5791°E). Station I is located in the Bapatla district of the Indian state of Andhra Pradesh. The Bapatla district is characterized by industrial activities, including cement and dye manufacturing industries. Station II is situated approximately 16 km away from Station I.

Sample collection

The study was carried out over a period of 12 months, from June 2022 to July 2023. Monthly water samples were collected throughout the study period, covering three different seasons. Water samples were collected from harbour areas at a depth of 1–1.5 m. The samples were collected in clean, dried plastic cans with a capacity of 2 liters and transported immediately to the laboratory for analysis. Sampling was conducted during the morning hours between 7:00 a.m. and 9:30 a.m. Monthly sampling was performed continuously throughout the study period from June 2022 to July 2023 (Fig 1).

Seasonal variation and accumulation of heavy metals in water and in selected fish organs

The study was carried out for the seasonal variation; in which accumulation of heavy metals in water in selected fish organs, determination of heavy metals in water determination of heavy metals in soil and Risk assessment of heavy metal contamination in stations 1 and 2 for the study.

Fig 1 Selected Aquatic species *Scomberomorus guttatus* (vanjaram)

RESULTS AND DISCUSSION

The accumulation of heavy metals in the gills of *Scomberomorus guttatus* fish at station-1 (Nizampatnum Harbour)) will take place from June 2022 to July 2023 to explore metal concentrations in three seasons. In the pre-monsoon season, chromium (Cr) was shown to be the concentrated metal at 2.05 µg/g, followed by copper (Cu) at 1.75 µg/g. Lead (Pb) at 1.59 and manganese (Mn) at 1.35 also showed moderate levels. At the same time, nickel (Ni) at 1.19 and zinc (Zn) at 0.18 had relatively low concentrations, with cadmium (Cd) being the least prevalent at 0.14 µg/g and ranking in lowest to highest concentrated (Cd < Zn < Ni < Mn < Pb < Cu < Cr).

Table 1 Accumulation of heavy metals (µg/g) in gills of *Scomberomorus guttatus* in station 1 during study period of June 2022 - July 2023 (Mean ± S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	1.59	1.35	0.185	1.19	0.14	2.05	1.75
	Std. Er	0.03	0.02	0.09	0.19	0.25	0.27	0.19
	Range	0.14	0.04	0.03	0.03	0.02	0.3	0.3
	Min	1.52	1.33	0.17	1.17	0.13	1.9	1.6
	Max	1.66	1.37	0.20	1.21	0.15	2.2	1.9
Monsoon	Mean	2.9	1.5	0.31	1.53	0.26	3.15	2.55
	Std. Er	0.02	0.02	0.09	0.19	0.27	0.27	0.02
	Range	0.5	0.2	0.07	0.33	0.04	0.6	0.6
	Min	2.7	1.4	0.28	1.42	0.24	2.9	2.2
	Max	3.1	1.6	0.35	1.65	0.28	3.4	2.9
Post monsoon	Mean	2.6	1.36	0.245	1.34	0.14	2.65	2.4
	Std. Er	0.03	0.02	0.09	0.18	0.23	0.27	0.20
	Range	0.4	0.06	0.09	0.07	0.3	0.5	0.2
	Min	2.4	1.33	0.20	1.31	0.13	2.4	2.3
	Max	2.8	1.39	0.29	1.38	0.16	2.9	2.5
One-way	F-value	1.1	1.3	1.06	0.42	0.25	0.1	0.3
ANOVA	*p-value*	0.00*	0.00*	0.32	0.66	0.86	0.1	0.80

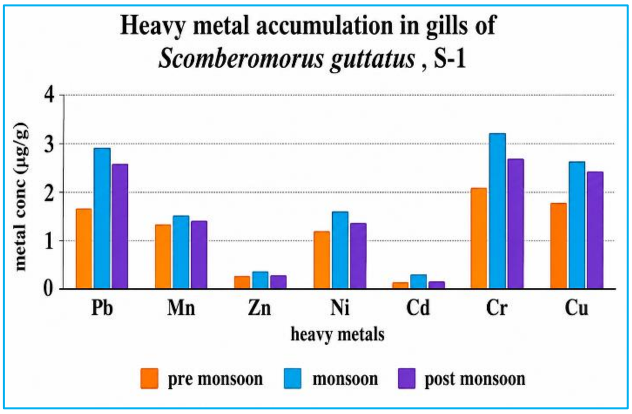

Fig 2 Analysis of heavy metal accumulation in gills of *Scomberomorus guttatus* S-1(Nizampatnum Harbour)

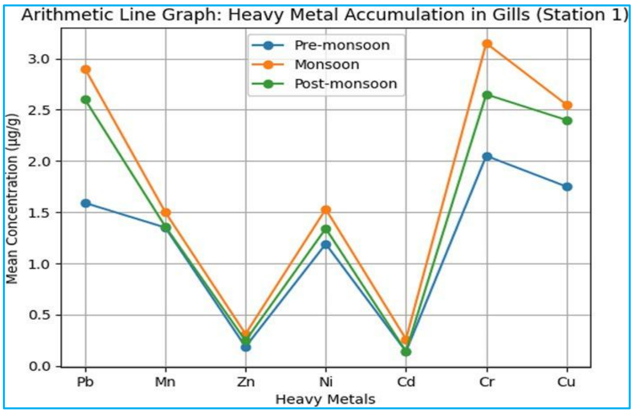

Fig 3 Graph- Heavy metal accumulation in Gills (Station-1)

In monsoon season an increase in chromium concentrations reaches a peak level of 3.15 µg/g, along with significant elevations in copper (2.55 µg/g) and lead (2.9 µg/g). This shift indicates a possible increase in metal bioavailability or environmental runoff during this period. Post-monsoon data reflected a slight decrease in chromium to 2.65 µg/g, while copper and lead remained elevated, suggesting persistent contamination risks. The ranking of metals (Cd < Zn < Ni < Mn < Pb < Cu < Cr,) again indicates cadmium's predominance in terms of reactivity and toxicity, reinforcing the need for careful monitoring of this metal in aquatic ecosystems (Table 1-2, Fig 2-3).

Table 2 Accumulation of heavy metals (µg/g) in gills of *Scomberomorus guttatus* fish in station 2 during study period of June 2022-July 2023 (Mean ± S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	1.71	1.4	0.255	1.27	0.18	2.4	2.15
	Std. Er	0.02	0.02	0.09	0.19	0.25	0.27	0.19
	Range	0.1	0.07	0.07	0.03	0.02	0.2	0.5
	Min	1.66	1.36	0.22	1.23	0.16	2.3	1.9
	Max	1.76	1.43	0.29	1.31	0.21	2.5	2.4
Monsoon	Mean	3.3	1.6	0.365	1.64	0.22	4	2.85
	Std. Er	0.02	0.02	0.09	0.19	0.27	0.27	0.12
	Range	0.6	0.3	0.11	0.33	0.2	0.6	0.5
	Min	3.1	1.5	0.31	1.53	0.19	3.6	2.6
	Max	3.5	1.7	0.42	1.75	0.25	4.4	3.1
Post monsoon	Mean	2.7	1.39	0.47	1.37	0.21	3.1	2.55
	Std. Er	0.03	0.02	0.09	0.18	0.23	0.27	0.20
	Range	0.4	0.06	0.12	0.07	0.1	0.3	0.3
	Min	2.5	1.36	0.41	1.33	0.18	2.9	2.4
	Max	2.9	1.42	0.53	1.41	0.24	3.3	2.7
One-way	F-value	1.0	1.1	1.0	0.22	0.25	0.1	0.1
ANOVA	*p-value*	0.00*	0.00*	0.32	0.00	0.86	0.94	0.00

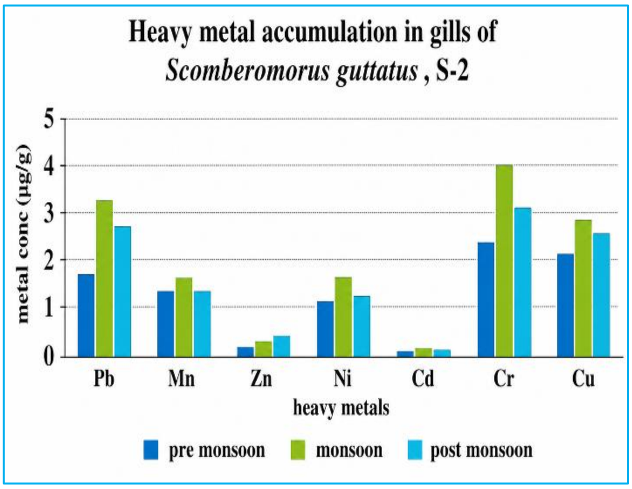

Fig 4 Analysis of heavy metal accumulation in gills of *Scomberomorus guttatus* S-2(Kothapalem Beach)

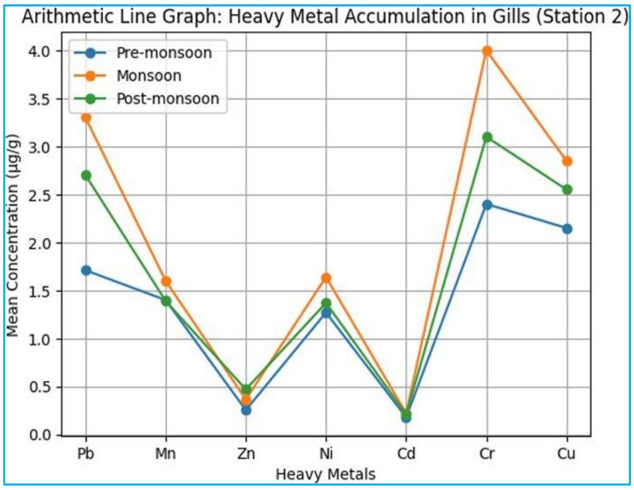

Fig 5 Graph heavy metal accumulation in Gills (S-2)

The heavy metals analysis of the gills of *Scomberomorus guttatus* fish (Kothapalem sea shore) provides insight into environmental contamination trends from June 2022 to July 2023. In the pre-monsoon period, chromium (Cr) was the most concentrated metal at 2.4 µg/g, indicating its prominence in the aquatic environment. Copper (Cu) followed at 2.15 µg/g, suggesting considerable uptake by the fish. Moderate levels of lead (Pb) and manganese (Mn) were recorded at 1.71 µg/g and 1.4 µg/g, respectively, reflecting ongoing environmental contamination. Zinc (Zn) and cadmium (Cd) showed lower concentrations of 0.255 µg/g and 0.18 µg/g. The hierarchy of heavy metals in terms of concentration (Cd< Zn < Ni < Mn < Pb < Cu < Cr) indicates that while cadmium levels were low, they still pose potential toxicity risks in aquatic environments [13].

The monsoon season marked a significant increase in heavy metal concentrations, particularly chromium, which peaked at 4.0 µg/g. This rise is likely attributable to increased runoff, which enhances the bioavailability of metals [12]. Lead concentrations surged to 3.3 µg/g, alongside an increase in copper to 2.85 µg/g. Manganese and nickel remained moderate at 1.6 µg/g and 1.64 µg/g, respectively. The slight increases in zinc (0.365 µg/g) and cadmium (0.22 µg/g) suggest altered conditions for metal uptake during this season. The order of heavy metal concentrations (Cd< Zn <Ni < Mn < Pb < Cu < Cr) reflects the complexity of environmental dynamics during this period.

In the post-monsoon period, chromium remained a significant contaminant at 3.1 µg/g, highlighting the persistence of environmental influences. Lead concentrations decreased slightly to 2.7 µg/g, while copper was stable at 2.55 µg/g. Manganese showed a slight decline to 1.39 µg/g, and nickel remained consistent at 1.37 µg/g. Zinc levels rose to 0.47 µg/g, while cadmium decreased marginally to 0.21 µg/g (Table 3-4, Fig 4-5). The hierarchy of concentrations (Cd< Zn < Ni < Mn < Pb < Cu < Cr) indicates ongoing variability in accumulation patterns [14].

Heavy metal exposure can cause severe histopathological damage to fish organs. For instance, mercury can induce nerve tissue necrosis, while copper can lead to gill epithelial necrosis [14]. Bioaccumulation patterns vary among organs, with the liver typically showing the highest concentrations, followed by gills and muscles [15].

Table 3 Accumulation of heavy metals (µg/g) in skin of *Scomberomorus guttatus* fish in station 1 during study period of June 2022-July 2023 (Mean ±S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	1.80	2.05	0.27	1.21	0.26	3.7	3.4
	Std. Er	0.01	0.02	0.09	0.01	0.25	0.27	0.19
	Range	0.24	0.3	0.3	0.03	0.02	0.2	0.3
	Min	1.76	1.7	0.22	1.18	0.25	3.6	3.2
	Max	1.85	2.4	0.25	1.24	0.28	3.8	3.6
Monsoon	Mean	3.2	2.35	0.38	1.74	0.37	4.95	4.8
	Std. Er	0.02	0.02	0.09	0.19	0.27	0.27	0.19
	Range	0.6	0.4	0.07	0.33	0.03	0.3	0.2
	Min	2.8	1.9	0.35	1.58		4.8	4.7
	Max	3.6	2.8	0.42	1.91		5.1	4.9
Post monsoon	Mean	3	1.95	0.265	1.38		4.3	4.25
	Std. Er	0.03	0.02	0.09	0.18	0.23	0.2	0.20
	Range	0.3	0.2	0.04	0.7		0.2	0.2
	Min	2.6	1.7	0.24	1.35		4.2	4.1
	Max	3.4	2.2	0.29	1.42	0.30	4.4	4.4
One-way	F-value	1.1	1.3	1.0	0.34	0.1	0.10	0.11
ANOVA	*p-value*	0.00*	0.00*	0.32	0.66	0.6	0.94	0.80

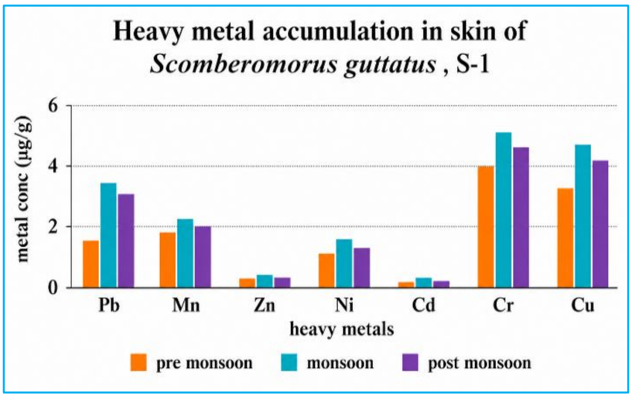

Fig 6 Heavy metal analysis in skin of *Scomberomorus guttatus* Station-1

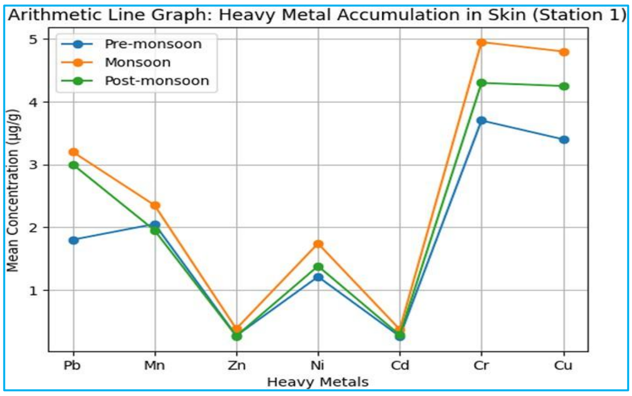

Fig 7 Graph heavy metal accumulation in S-1

This study investigates the seasonal variations in heavy metal concentrations in the skin of *Scomberomorus guttatus* fish at Station 1 from June 2022 to July 2023. During the pre-monsoon period, the concentrations of heavy metals were as follows: Zn (0.27 µg/g) < Cd (0.26 µg/g) < Ni (1.21 µg/g) < Pb (1.80 µg/g) < Mn (2.05 µg/g) < Cu (3.4 µg/g) < Cr (3.7 µg/g). The low levels of Zn and Cd suggest minimal bio-accumulation, while the higher concentrations of Cu and Cr may indicate localized sources of contamination, possibly related to agricultural runoff and industrial discharge [16].

Monsoon season exhibited heightened concentrations, particularly for Pb (3.2 µg/g) and Cr (4.95 µg/g). The overall ranking during this period was Cd (0.37 µg/g) < Zn (0.38 µg/g) < Ni (1.74 µg/g) < Pb (3.2 µg/g) < Mn (2.35 µg/g) < Cu (4.8 µg/g) < Cr (4.95 µg/g). The significant increase in Pb and Cr can be attributed to enhanced runoff that mobilizes heavy metals into aquatic systems, increasing their bio availability [17]. Post-monsoon concentrations indicated a slight decrease in most metals, with Zn (0.265 µg/g) and Cd (0.28 µg/g) remaining the lowest (Table 5-6, Fig 6-7). The order of concentrations was Zn < Cd < Ni (1.38 µg/g) < Mn (1.95 µg/g) < Pb (3.0 µg/g) < Cu (4.25 µg/g) < Cr (4.3 µg/g). Safety limits established by regulatory bodies suggest that Cr levels in seafood should not exceed 2.0 mg/kg [16], [18].

Table 4 Accumulation of heavy metals (µg/g) in skin of *Scomberomorus guttatus* fish in station 2 during study period of June 2022-July 2023 (Mean ±S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	1.9	2.9	0.29	1.28	0.31	3.9	3.45
	Std. Er	0.01	0.02	0.09	0.01	0.25	0.27	0.19
	Range	0.24	0.3	0.05	0.03	0.02	0.2	0.3
	Min	1.85	2.5	0.27	1.25	0.29	3.8	3.5
	Max	1.94	3.3	0.32	1.32	0.33	4.0	3.8
Monsoon	Mean	4.65	3.35	0.49	2.09	0.42	5.35	5.2
	Std. Er	0.02	0.02	0.09	0.19	0.27	0.27	0.19
	Range	0.6	0.4	0.05	0.33	0.06	0.3	0.2
	Min	4.2	2.9	0.45	1.92	0.39	5.2	5.1
	Max	5.1	3.8	0.53	2.27	0.45	5.5	5.3
Post monsoon	Mean	3.8	2.55	0.32	1.5	0.32	4.7	4.5
	Std. Er	0.03	0.02	0.09	0.18	0.23	0.2	0.20
	Range	0.5	0.2	0.04	0.7	0.3	0.2	0.3
	Min	3.5	2.3	0.30	1.45	0.30	4.6	4.4
	Max	4.1	2.8	0.35	1.55	0.34	4.8	4.7
One-way ANOVA	F-value	1.27	1.5	1.02	0.44	0.1	0.11	0.22
	p-value	0.00*	0.00*	0.32	0.66	0.6	0.94	0.80

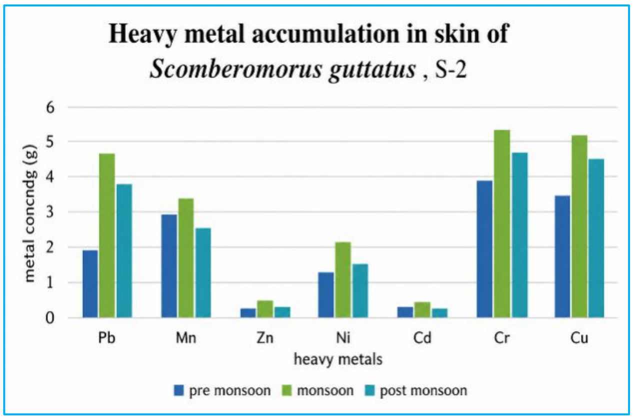

Fig 8 Heavy metal analysis in skin of *Scomberomorus guttatus* Station-2

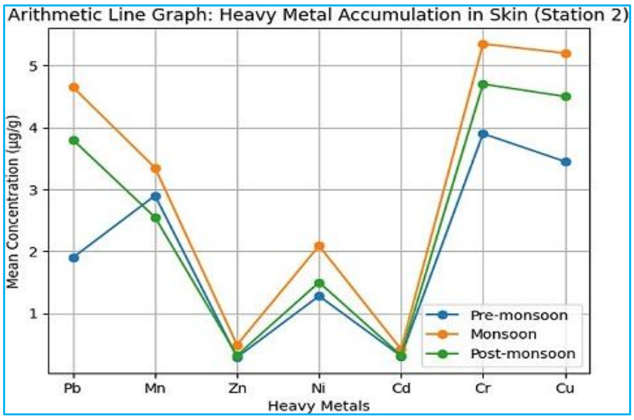

Fig 9 Heavy metal accumulation in ski station-2

Table 5 Accumulation of heavy metals(µg/g) in muscle of *Scomberomorus guttatus* fish in station 1 during study period of June 2022 - July 2023 (Mean ±S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	2.6	2.2	0.275	1.37	0.31	3.5	2.7
	Std. Er	0.01	0.02	0.01	0.11	0.2	0.27	0.11
	Range	0.6	0.3	0.1	0.04	0.02	0.6	0.2
	Min	2.3	1.9	0.27	1.35	0.22	3.2	2.6
	Max	2.9	2.1	0.28	1.39	0.24	3.8	2.8
Monsoon	Mean	3.8	2.9	0.53	1.98	0.38	5.35	4.9
	Std. Er	0.02	0.02	0.02	0.10	0.2	0.27	0.19
	Range	0.2	0.4	0.05	0.27	0.04	0.3	0.2
	Min	3.7	2.7	0.51	1.85	0.36	5.2	4.8
	Max	3.9	3.1	0.56	2.12	0.40	5.5	5.0
Post monsoon	Mean	3.25	2.26	0.4	1.64	0.25	4.7	4.5
	Std. Er	0.01	0.01	0.02	0.11	0.11	0.11	0.10
	Range	0.3	0.22	0.04	0.07	0.04	0.2	0.2
	Min	3.1	2.1	0.38	1.61	0.23	4.6	4.4
	Max	3.4	2.42	0.42	1.68	0.28	4.8	4.6
One-way	F-value	1.27	1.13	1.0	0.44	0.25	0.13	0.33
ANOVA	*p-value*	0.00*	0.00*	0.32	0.66	0.86	0.94	0.80

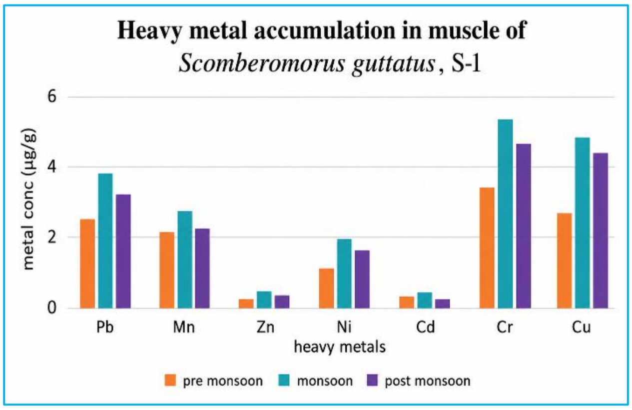

Fig 10 Heavy metal analysis in muscle of *Scomberomorus guttatus* Station-1 (Nizampatnum Harbour)

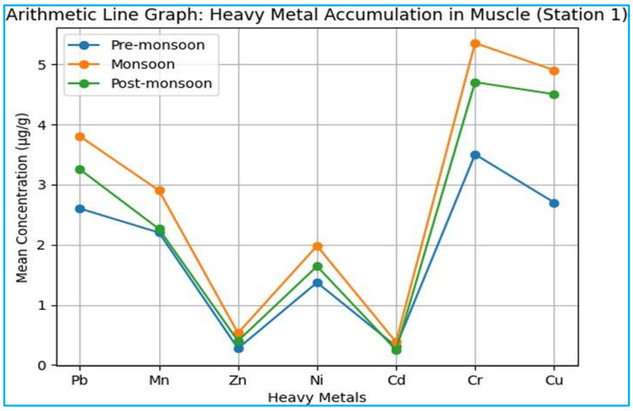

Fig 11 Heavy metal analysis in muscle of *Scomberomorus guttatus* Station-1 (Nizampatnum Harbour)

The seasonal accumulation of heavy metals in the muscle of *Scomberomorus guttatus* fish collected from Station 1 over the period from June 2022 to July 2023. In pre-monsoon season, the concentrations of heavy metals were observed as follows: Zn (0.275 µg/g) < Cd (0.31 µg/g) < Ni (1.37 µg/g) < Mn (2.2 µg/g) < Pb (2.6 µg/g) < Cu (2.7 µg/g) < Cr (3.5 µg/g). The results show that zinc and cadmium levels were comparatively low, while chromium and copper exhibited higher concentrations.

In the monsoon, to increase in heavy metal concentrations was observed: Zn (0.53 µg/g), Cd (0.38 µg/g), Ni (1.98 µg/g), Mn (2.9 µg/g), Pb (3.8 µg/g), Cu (4.9 µg/g), and Cr (5.35 µg/g). The marked rise in Pb and Cr concentrations suggests a direct correlation with increased rainfall and runoff, leading to higher metal bio availability in the aquatic environment [19-20].

In post-monsoon, concentrations were recorded as follows: Zn (0.4 µg/g), Cd (0.25 µg/g), Ni (1.64 µg/g), Mn (2.26 µg/g), Pb (3.25 µg/g), Cu (4.5 µg/g), and Cr (4.7 µg/g); While zinc and cadmium levels showed a decrease, lead and chromium remained elevated, suggesting lingering contamination effects post-monsoon (Table 7-8, Fig 8-9). The elevated concentrations of lead (Pb) and chromium (Cr) pose serious concerns regarding the health of aquatic ecosystems and the safety of fish consumption. Chronic exposure to heavy metals can lead to detrimental effects on fish health, impacting growth, reproduction, and survival [21]. The lower growth coefficient (0.23) and higher asymptotic length (71.98 cm) observed indicate a population that may be under stress from fishing pressures, as indicated by the M/K ratio (2.35) being within the normal range. However, the Z/K ratio being higher than 4 suggests that the fishery is highly mortality-dominated [22].

Table 6 Accumulation of heavy metals (µg/g) in muscle of *Scomberomorus guttatus* fish in station 2 during study period of June 2022 - July 2023 (Mean ±S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	3.25	2.4	0.3	1.42	0.27	4	3
	Std. Er	0.01	0.02	0.01	0.11	0.2	0.27	0.11
	Range	0.36	0.2	0.04	0.04	0.02	0.6	0.2
	Min	3.1	2.3	0.28	1.40	0.26	3.8	2.9
	Max	3.4	2.5	0.32	1.44	0.28	4.2	3.1
Monsoon	Mean	4.2	3.45	0.59	2.19	0.41	6.05	5.6
	Std. Er	0.02	0.02	0.02	0.10	0.2	0.27	0.19
	Range	0.2	0.4	0.05	0.13	0.04	0.7	0.4

	Min	4.1	3.3	0.57	2.13	0.38	5.7	5.4
	Max	4.3	3.6	0.62	2.25	0.44	6.4	5.8
Post monsoon	Mean	3.65	2.5	0.46	1.75	0.32	5.1	4.3
	Std. Er	0.01	0.01	0.02	0.11	0.11	0.11	0.10
	Range	0.3	0.22	0.04	0.07	0.04	0.4	0.5
	Min	3.5	2.4	0.44	1.72	0.30	4.8	4.1
	Max	3.8	2.62	0.48	1.79	0.34	5.2	4.6
One-way	F-value	1.37	1.14	1.06	0.46	0.25	0.11	0.1
ANOVA	*p-value*	0.00*	0.00*	0.32	0.66	0.86	0.94	0.80

These heavy metals in the muscle of *Scomberomorus guttatus* fish were collected from Station 2, from June 2022 to July 2023. In the pre-monsoon season, heavy metal concentrations were as follows: Zn (0.3 µg/g), Cd (0.27 µg/g), Ni (1.42 µg/g), Mn (2.4 µg/g), Pb (3.25 µg/g), Cu (3.0 µg/g), and Cr (4.0 µg/g).

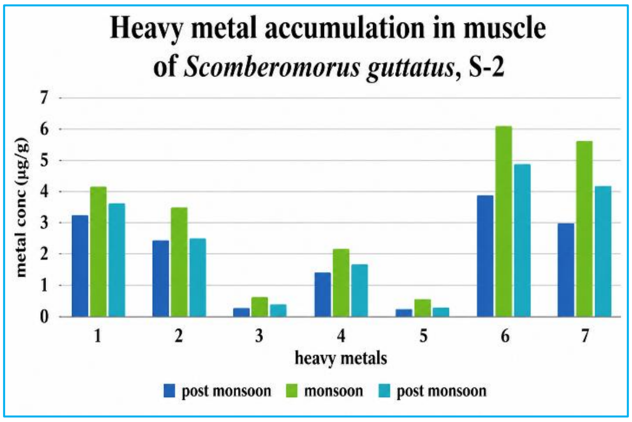

Fig 10 Heavy metal analysis in muscle of *Scomberomorus guttatus* Station-2 (Kothapalem Beach)

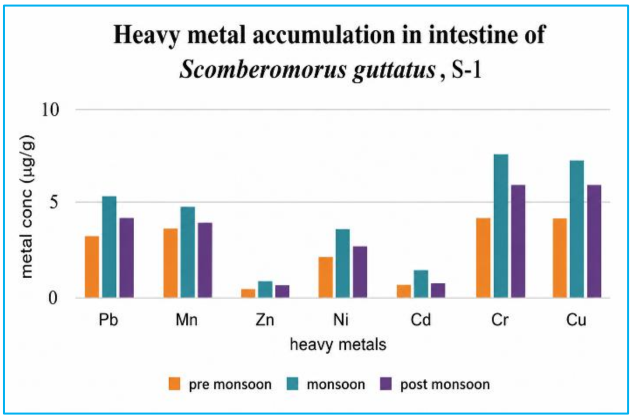

Fig 11 Heavy metal analysis in intestine of Scomberomorus guttatus Station-1 (Nizampatnum Harbour)

Here, zinc and cadmium were the lowest concentrated, while chromium and copper exhibited significant levels. These concentrations may reflect localized pollution sources, such as agricultural runoff or urban discharges that could influence metal accumulation in fish. During the monsoon, heavy metal concentrations were observed: Zn (0.59 µg/g), Cd (0.41 µg/g), Ni (2.19 µg/g), Mn (3.45 µg/g), Pb (4.2 µg/g), Cu (5.6 µg/g), and Cr (6.05 µg/g). The most notable increases were in lead and chromium, suggesting a strong correlation with increased rainfall and runoff [23]. In the post-monsoon period, concentrations were recorded: Zn (0.46 µg/g), Cd (0.32 µg/g), Ni (1.75 µg/g), Mn (2.5 µg/g), Pb (3.65 µg/g), Cu (4.3 µg/g), and Cr (5.1 µg/g). Although zinc and cadmium levels decreased, lead and chromium remained elevated, indicating prolonged exposure and potential contamination from residual runoff or sediment resuspension.

Table 7 Accumulation of heavy metals (µg/g) in intestine of *Scomberomorus guttatus* fish in station 1 during study period of June 2022 - July 2023 (Mean ±S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	4.4	4.6	0.53	1.83	0.73	5.9	5.6
	Std. Er	0.01	0.02	0.01	0.10	0.02	0.07	0.11
	Range	0.6	0.4	0.04	0.07	0.04	0.6	0.6
	Min	4.1	4.4	0.51	1.80	0.71	5.6	5.3
	Max	4.7	4.8	0.55	1.87	0.75	6.2	5.9
Monsoon	Mean	6	5.5	0.97	3.7	2.1	8.55	8
	Std. Er	0.02	0.02	0.02	0.11	0.02	0.02	0.1
	Range	0.4	0.6	0.06	0.6	0.2	0.7	0.2
	Min	5.8	5.2	0.94	3.6	1.9	8.2	7.9
	Max	6.2	5.8	1.0	3.8	2.3	8.9	8.1
Post monsoon	Mean	4.6	4.65	0.79	2.9	1.2	7.1	6.5
	Std. Er	0.03	0.02	0.02	0.01	0.03	0.1	0.10
	Range	0.4	0.3	0.07	0.2	0.18	0.7	0.2
	Min	4.4	4.5	0.75	2.8	1.1	6.8	6.4
	Max	4.8	4.8	0.83	3.0	1.3	7.5	6.6
One-way	F-value	1.47	1.15	1.0	0.45	0.15	0.10	0.11
ANOVA	*p-value*	0.00*	0.00*	0.32	0.66	0.86	0.94	0.80

In the pre-monsoon season, the concentrations of heavy metals were: Zn (0.53 µg/g), Cd (0.73 µg/g), Ni (1.83 µg/g), Mn (4.6 µg/g), Pb (4.4 µg/g), Cu (5.6 µg/g), and Cr (5.9 µg/g). Here, zinc and cadmium levels were relatively low, while lead, manganese, copper, and chromium were more concentrated.

The monsoon season marked a significant increase in heavy metal concentrations: Zn (0.97 µg/g), Cd (2.1 µg/g), Ni (3.7 µg/g), Mn (5.5 µg/g), Pb (6.0 µg/g), Cu (8.0 µg/g), and Cr (8.55 µg/g). Lead and chromium levels were particularly high, suggesting a strong link to increased rainfall and surface runoff that can transport contaminants into aquatic habitats. In the post-monsoon period, metal concentrations were as follows: Zn (0.79 µg/g), Cd (1.2 µg/g), Ni (2.9 µg/g), Mn (4.65 µg/g), Pb (4.6 µg/g), Cu (6.5 µg/g), and Cr (7.1 µg/g); While zinc and cadmium levels decreased compared to the monsoon, lead and chromium concentrations remained high, indicating persistent contamination (Table 9-10, Fig 10-12). This suggests that despite reduced runoff post-monsoon, residual metals may continue to affect aquatic organisms. The findings from this study align with those from Priyadharshini *et al*. [24].

Table 8 Accumulation of heavy metals (µg/g) in intestine of *Scomberomorus guttatus* fish in station 2 during study period of June 2022 - July 2023 (Mean ±S.E.)

Seasons	Heavy metal (µg/g)	Pb	Mn	Zn	Ni	Cd	Cr	Cu
Pre monsoon	Mean	5.3	5.5	0.58	1.96	0.85	6.9	6.2
	Std. Er	0.01	0.02	0.01	0.10	0.02	0.07	0.11
	Range	0.4	0.6	0.05	0.06	0.09	0.6	0.6
	Min	5.1	5.2	0.56	1.93	0.81	6.6	5.9
	Max	5.5	5.9	0.61	1.99	0.89	7.2	6.5
Monsoon	Mean	6.8	6.3	1.2	4.1	2.65	9.55	8.4
	Std. Er	0.02	0.02	0.02	0.11	0.02	0.02	0.1
	Range	0.4	0.6	0.08	0.6	0.3	0.7	0.2
	Min	6.6	6.0	1.1	3.8	2.5	9.2	8.3
	Max	7.0	6.6	1.3	4.4	2.8	9.9	8.5
Post monsoon	Mean	5.1	5.15	0.88	3.5	2.25	8.15	7.7
	Std. Er	0.03	0.02	0.02	0.01	0.03	0.1	0.10
	Range	0.4	0.5	0.07	0.2	0.3	0.7	0.2
	Min	4.9	4.9	0.84	3.4	2.1	7.8	7.6
	Max	5.3	5.4	0.92	3.6	2.4	8.5	7.8
One-way	F-value	1.57	1.20	1.1	0.48	0.17	0.11	0.12
ANOVA	*p-value*	0.00*	0.00*	0.32	0.66	0.86	0.94	0.80

Investigation on heavy metals in the intestine of *Scomberomorus guttatus* fish at Station 2 from June 2022 to July 2023. The results highlight significant variations in heavy metal concentrations across different seasons, which can impact both ecological health and human consumption. During the pre-monsoon season, heavy metal concentrations were as follows: Zn (0.58 µg/g), Cd (0.85 µg/g), Ni (1.96 µg/g), Mn (5.5 µg/g), Pb (5.3 µg/g), Cu (6.2 µg/g), and Cr (6.9 µg/g). Zinc and cadmium levels were relatively low, while lead, manganese, copper, and chromium were significantly higher. This distribution may reflect the influence of local pollution sources and the sedimentation of metals in aquatic environments. The monsoon season Zn (1.2 µg/g), Cd (2.65 µg/g), Ni (4.1 µg/g), Mn (6.3 µg/g), Pb (6.8 µg/g), Cu (8.4 µg/g), and Cr (9.55 µg/g). The notable increases in lead and chromium concentrations during this season are indicative of enhanced bio availability due to increased rainfall and runoff, which can transport contaminants into the aquatic ecosystem. In the post-monsoon period, Zn (0.88 µg/g), Cd (2.25 µg/g), Ni (3.5 µg/g), Mn (5.15 µg/g), Pb (5.1 µg/g), Cu (7.7 µg/g), and Cr (8.15 µg/g).

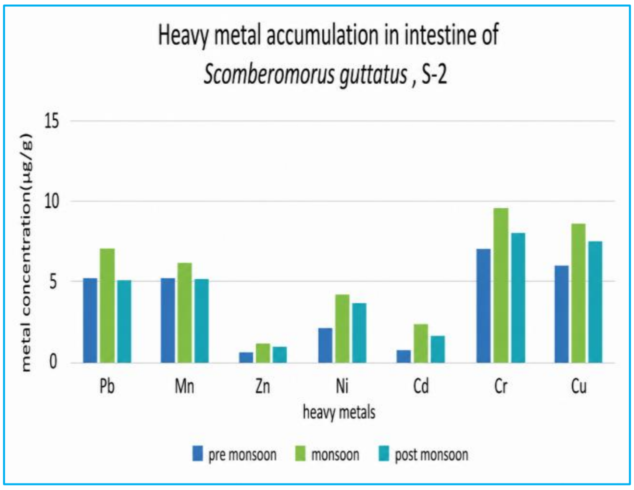

Fig 12 Heavy metal analysis in intestine of *Scomberomorus guttatus* Station-2 (Kothapalem Beach)

CONCLUSION

In the present study, the concentrations of heavy metals observed during the monsoon season indicated a potential exceedance of permissible limits, thereby posing possible health risks to human consumers who depend on these fish as a dietary source. Seasonal increases in metal concentrations may be associated with enhanced surface runoff, industrial discharge, and agricultural inputs entering the aquatic ecosystem during the monsoon period. Considering the significant variability in heavy metal accumulation and its potential impacts on both human health and ecosystem stability, continuous monitoring of heavy metal levels in aquatic environments is essential for effective environmental management and pollution control. The work helps in assessing the impact of industrial discharge, agricultural runoff, and anthropogenic activities on coastal water quality and marine organisms. Since heavy metals such as lead (Pb), chromium (Cr), cadmium (Cd), copper (Cu), manganese (Mn), zinc (Zn), and nickel (Ni) are toxic even at low concentrations; their accumulation in fish tissues may pose serious ecological and human health risks through the food chain. The findings revealed that chromium (Cr) showed the highest concentration in sediments, indicating possible contamination from nearby industrial activities. The research also highlights tissue-specific accumulation patterns of heavy metals. The intestine exhibited the highest accumulation compared to gills, skin, and muscle, suggesting its important role in metal absorption and metabolism. This information is useful in identifying suitable bio-indicator organs for pollution assessment studies.

Author contribution

The practical design and manuscript preparation were carried out under the guidance of our research supervisor, Prof. Sumanth Kumar Kunda, Department of Zoology and Aquaculture, Acharya Nagarjuna University. The first author, Nagaseshulu K., conducted the fieldwork, performed the laboratory experiments, and assisted the research supervisor throughout the study.

Conflict of interest statement: *The authors declared that they have no interest of conflicts*.

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