Concentrations of mercury and cadmium in small pelagic fish from Lake Victoria, Kenya: The case of dagaa fishery

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Abstract

The toxicity of heavy metals is in part because they bioaccumulate in biological tissues. The objective of this study was to assess the concentrations of lead (Pb) and cadmium (Cd) in dagaa from open and gulf waters and compare the concentrations to their maximum permissible limits under Kenya Bureau of Standards (KEBS), European Commission (EC) and World Health Organization (WHO) regulations. The study was undertaken in December 2020 (dry season) and samples (dry and wet) were collected from six dominant dagaa landing sites along Lake Victoria, Kenya (Marenga, Uhanya, Litare, Sori, Asat and Bao) for heavy metal analyses. The study indicated that *Rastrineobola argentea* from different sources had different concentrations of heavy metals (Table 1). Mercury and cadmium were detected in all dagaa samples analysed; however, their concentrations were within the permissible limits of 0.5ppm as recommended by World Health Organization (WHO, 2010; EC, 2001; SDF&BE, 2018). Cadmium was highest at Sori with an average 0.028ppm and lowest at Asat with an average of 0.008ppm. Mercury was highest at Sori with an average 0.339ppm and lowest at Asat with an average 0.093ppm for both dry and wet samples. We recommend continued surveillance measures necessary in containing industrial and sewerage effluents discharge and agricultural inputs run-off impacts towards heavy metal deposition in the lake and bioaccumulation in fish.

Keywords: Heavy metals; bioaccumulation; toxicity; concentrations.

1. Introduction

The toxicity of heavy metals is in part because they bioaccumulate in biological tissues. The endemic silver cyprinid fish (*Rastrineobola argentea* ~ Pelegrin, 1904), locally known as dagaa or omena, is one of the three main commercial species of Lake Victoria, together with the Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*). Recent lake-wide biomass estimates of dagaa show that the standing stock was 936,247 tons, accounting for 35% of the total fish biomass in the lake, which was 42% higher than the biomass estimated during the 2018 survey (Lake Victoria hydroacoustic report, 2019). Dagaa currently contributes to about 60% of the total catch with more than 60% being utilised for human consumption and the rest being used for stock feed (Odongkara. *et al.,* 2018).

Fresh dagaa is highly perishable and sun drying is the most commonly used method to extend its shelf life. The consumer preference for dried dagaa is not only because of the flavour, but also the reasonable price (Oduor-Odote *et al*., 2010). Dagaa are a short-lived species with a massive regeneration potential and a highly affordable pricing index for low-income earners. The Eastern Africa region is projected to realize increased fish consumption from 4.80 kg in 2013 to 5.49 kg by 2022 (Obiero *et al*., 2019) and dagaa accounts for about 35% of the total fish consumption in Kenya.

During the 1980s, the ecosystem of Lake Victoria underwent major changes in its physical and biological characteristics (Hecky *et al*., 2010). Recently, anthropogenic activities have led to increased levels of pollution of the lake's waters posing serious threats to human life, degradation of aquatic ecosystems and loss of biodiversity. The plummeting catches from wild capture fisheries from the lake has led to introduction of aquaculture cages which have subsequently led to environmental concerns especially due to unutilized fish feeds which end up sedimenting. Anthropogenic activities from the lake's catchment including the effects of farms' run-off, soil erosion and even effluent discharges calls for concerted efforts on regular monitoring of heavy metal deposition in the lake's ecosystem (water and sediments) and bioaccumulation in fish (Obiero *et al*., 2015).

Food contains a wide range of elements such as carbon, sodium, potassium, iron, calcium, boron, magnesium, selenium, copper and zinc. These elements are essential in trace quantities for maintenance of cellular processes. Other elements that have no functional effects in the body can be harmful to health if foodstuffs containing them are consumed regularly in the diet. These elements can be naturally present in food or can enter food systems as a result of human activities such as industrial and agricultural processes. The toxicity of heavy metals is in part due to the fact that they bioaccumulate in biological tissues (Food Safety Authority of Ireland, 2007). The elements of particular concern in relation to harmful effects on human health are mercury, lead, cadmium, tin and arsenic, mercury and lead. The toxicity of these metals has two main aspects: (a) the fact that they have no known metabolic function, but when present in the body they disrupt normal cellular processes, leading to toxicity in a number of organs; (b) the potential, particularly of the so-called heavy metals mercury and lead, to accumulate in biological tissues, a process known as bioaccumulation (European Commision, 2004). The study aimed to assess the heavy metal concentrations of Mercury (Hg) and Cadmium (Cd) in dagaa from Lake Victoria, Kenya, to ascertain if there could be any potential health risks poised to the fish consumers.

2. Methodology

2.1 Study Area

The study was carried out in dominant dagaa landing sites in Lake Victoria (Figure 1.) between 18th – 23rd December, 2020, which represents the dry season. Six landing sites were selected with two beaches (Asat and Bao) from the Winam Gulf and four beaches (Litare, Uhanya, Marenga and Sori) representing the open waters of the lake. The sites were selected according to dagaa catch data statistics from the catch assessment surveys (CAS); accessibility of the beaches; and county representation with a beach from each of the five riparian counties annexing Lake Victoria, Kenya. The following steps were carried out from sample collection to preparation for heavy metals analyses.

2.2. Sample collection and handling

A total of twelve dagaa samples, 100g each, for both dry and wet categories were purposively purchased from the selected landing beaches and placed in labelled zip lock bags. The wet/fresh samples were put in a Coleman’s cooler box with ice for transportation to the laboratory for analysis. Wet dagaa samples were washed with clean water to remove any dirt and particles prior to any subsequent analysis.

2.3 Sample digestion and spectrometric analysis

All reagents used were of analytical grade. Ultrapure water was used for the preparations of reagents. Five grams of dagaa, homogenized using a blender, was placed in a 250ml beaker and 10ml of concentrated Nitric acid (HNO3) added. The mixture was boiled for 45 minutes until the solution became clear (to remove all oxidizable matter). After cooling, 5ml of HClO4 (Perchloric acid) was added and the mixture boiled until white fumes were observed.

20ml of distilled water was added and the mixture boiled for a further 20 minutes to release any gas. Finally, the mixture was filtered through a membrane filter paper (Whatman No. 42) according to AOAC (1990). Deionized distilled water was used as blank for the analysis. The solution was made up to known volume with deionized distilled water. Cadmium was analyzed using an Atomic Absorption Spectrophotometer (AAS Model GPC A932 ver. 1.1) and mercury was analyzed by Inductively Coupled Plasma – Mass Spectrophotometer (7900 ICP-MS; Model No. G8403A from Agilent Technologies) at mass 201 due to its high volatility. The results obtained were expressed in parts per million (ppm) and R 3.6.2 was used for data analysis.

3. Results and Discussion

The concentrations (in ppm) of Cd and Hg from the analyzed dagaa fish samples are presented in Table 1. The concentrations of Cd were highest (0.028) and lowest at (0.002) with a mean of (0.012) where higher concentrations were observed in dry samples as compared to wet samples from all stations. The concentrations of Hg were highest (0.580) and lowest at (0.082) with a mean of (0.243) where higher concentrations were observed in wet samples than in dry samples from all stations. There was no significant difference in Cd concentration between dry and wet dagaa samples with a p-value = 0.286. There was no significant difference in Hg concentration between dry and wet dagaa samples with a p-value = 0.658. Data indicates that the order of concentrations of the heavy metals in the dagaa fish samples were Hg>Cd for both dry and wet dagaa from all stations. Results of the current study indicated no differences in Cd concentrations from gulf and open waters dagaa samples, whereas Hg concentrations were higher in dagaa samples from open waters as compared to those from the gulf waters.

The study indicated that *Rastrineobola argentea* from the different sources had different concentrations of heavy metals (Table 1). Mercury and cadmium were detected in all dagaa samples analyzed, however their concentrations were within the permissible limits of 0.5ppm as recommended by World Health Organization (WHO, 2010; EC, 2001; SDF&BE, 2018; (Table 2). Studies indicate heavy metals (such as Cd and Pb) have high affinity for thiol groups, which turn proteins and peptides prone to structural modification in tissues and skeletal muscle (Cucuk and Engun, 2005). Pratap and Wendelaar Bonga (2007) noted that Cd distorts calcium homeostasis. Cd is a renown environmental pollutant which is exceedingly unsafe and has no biological role (Hallenbeck, 1984; Castano *et al*., 1998; Beauvails *et al*., 2001). Dagaa fish are planktivorous and their habitats are strongly related to the accumulation of different heavy metals. Variations in heavy metals concentrations can also be attributed to physiological conditions, size (body weight and length), age, gender, and growing rates of fish species (Canli and Atli, 2003; Raja *et al*., 2009). Other factors that may affect the concentration of heavy metals in fish include type and level of water pollution, pH value, the form of metals and chemical in water, water transparency, dissolved oxygen and water temperature (Bahnasawy *et al*., 2009). Other studies have documented that catch season and geographical locations could lead to various concentrations of metals in the same species of fish (Dural *et al*., 2007; Bahnasawy *et al*., 2009). According to Oluoch-Otiego *et al*. (2016) high concentration of pollutants in Lake Victoria is attributed to the discharge of polluted water from the rivers which are near the urban centres in the lake. The current study detected considerable levels of metals in dagaa fish. Specifically, Cd was detected with a mean concentration of 0.012 ppm and Hg with a mean concentration of 0.243ppm. The concentrations of these heavy metals were within the permissible limit by World Health Organization (≤0.5 WHO) and national guidelines (≤0.5 SDF&BE) (Table 2). Based on this, fish may take in heavy metals and dissolved elements from their surrounding water and feeds thereby resulting in accumulation to notable levels. This could explain the concentration of the detected proportions reported in dagaa fish.

4. Conclusion and recommendations

From this study we conclude that there was no significant difference between the heavy metal concentrations of dry and wet dagaa samples from gulf and open waters of Lake Victoria. The levels are still within safe human consumption as recommended by WHO. Therefore, close monitoring of heavy metal loads in Lake Victoria is recommended given the potential risk to consumers' health. Heavy metal concentrations in dagaa fish were well below the permissible limits proposed for fish by various standards and guidelines such as WHO (2010); EC (2001), EU (1881), EU (2006), US-FDA (1971) and the State Department of Fisheries and the Blue Economy in Kenya. The study recommends strong management measures are necessary to mitigate both the industrial and agricultural impacts of heavy metal deposition and bioaccumulation in fish and aquatic ecosystems. Future research should focus on assessing heavy metal concentration in fish feeds as dagaa is highly utilized as key protein source in the manufacture of feeds for farmed fish like Nile Tilapia (*Oreochromis niloticus*).

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REFERENCES:

Bahnasawy, M., Khidr, A. A., Dheina, N., 2009. Seasonal variations of heavy metals concentrations in mullet, Mugil cephalus and Liza ramada (Mugilidae) from Lake Manzala, Egypt. J. Appl. Sci. Res. 5(7), 845–852.

Beauvias, S.L.; S.B. Jones; J.T. Parris; S.K. Brewer and E.E. Little, 2001. Cholinergic and behavioural neurotoxicity of Carbayl and cadmium to larval Rainbow Trout (Oncorhynchus mykiss). Ecotoxicol. Environ. Safety, 49, 84–90.

Canli, M., Atli, G., 2003. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. Environ. Pollut. 121(1), 129–136.

Castano, A.; W. Carbonell; G. Carbalo; C. Fernandez; S. Boleas and J.V. Tarazona, 1998. Sublethal effects of repeated intra peritoneal cadmium injections on Rainbow Trout (Oncorhynchus mykiss). Ecotoxicol. Environ. Safety., 41: 29-35.

Cucuk, B., Enugun, K., 2005. The effects of cadmium on levels of glucose in serum and glycogen reserves in the liver and muscle tissues of Cyprinus carpio (L. 1758). Turk. J. Vet. Anim. Sci. 29,113–117.

Dural, M., Göksu, M.Z.L., Özak, A.A., 2007. Investigation of heavy metal levels in economically important fish species captured from the Tuzla lagoon. Food Chem. 102(1), 415–421.

EC, 2001. Commission Regulation (EC) No 466/2001 of 8 March 2001. Official Journal of European Communities 1.77/1

EFSA (2005). Opinion of the Scientific Panel of Contaminants in the food chain related to mercury and methyl mercury in fish.

EC, 2007. European Commission Factsheet on Food Contaminants: Lead, Mercury, Cadmium and arsenic.

Hallenbeck, W.H., 1984. Human health effects of exposure to cadmium. Cell. Mol. Life Sci. 40, 136–142.

Kalay, M., Aly, O., Canil, M., 1999. Heavy metal concentrations in fish tissues from the Northeast Mediterranean Sea. Bull. Environmental Contamination Toxicology. 63, 673–681.

Nyamweya C. S., Natugonza, V., Kashindye, B. Mangeni-Sande, R., Ongore, C., Mlaponi, E., Wabeya, U., Odada, E. Magezi, G. (2018). A technical report on annual fish biomass survey (hydro-acoustic survey) in Lake Victoria. Technical report KMF/RS/2018/C1.7.i). Kenya Marine and Fisheries Research Institute (KMFRI). 48 pp.

AOAC 2015. Standard Method Performance Requirements. Journal of Association of Analytical Chemists International https://doi:10.5740/jaoac.int.2012.007

Obiero K., Meulenbroek P., Drexler S., Dagne A., Akoll P., Odong R., Kaunda-Arara B. and Waidbacher H. (2019). The Contribution of Fish to Food and Nutrition Security in Eastern Africa: Emerging Trends and Future Outlooks. https://doi:10.3390/su11061636

Obiero, K.O.; Abila, R.O.; Njiru, M.J.; Raburu, P.O.; Achieng, A.O.; Kundu, R.; Ogello, E.O.; Munguti, J.M.; Lawrence, T. The challenges of management: Recent experiences in implementing fisheries co-management in Lake Victoria, Kenya. Lakes Reserv. Manag. 2015, 3, 139–154.

Odongkara K., Akumu, J., Mbilingi, B., Namatovu, S., Okwong, C., Naula, E., Olokotum, M. and Nasuuna, A. (2014). Strategies to improve profitability and market access for fisheries enterprises on Lakes Albert, Kyoga and Victoria, Uganda. National Fisheries Resources Research Institute, Jinja, Uganda: 41 pp.

Oduor-Odote, P., Shitanda, D., Obiero, M., Kituu, G., 2010. Drying characteristics and some quality attributes of Rastrineobola argentia (Omena) and Stolephorus delicatulus (Kimarawali). African J. Food, Agriculture Nutrition Development. 10, 2998–3014.

Oluoch-Otiego, J., Oyoo-Okoth, E., Kiptoo, K.K.G., Chemoiwa, E.J., Ngugi, C.C., Simiyu, G., Omutange, E.S., Ngure, V., Opiyo, M.A. (2016). PCBs in fish and their cestode parasites in Lake Victoria. Environmental Monitoring Assessment. 188(8), 483. https://doi.org/10.1007/s10661-016-5483-0

Pratap, H.B., Wendelaar-Bonga, S.E., 2007. Calcium homeostasis in low and high calcium water acclimatized Oreochromis mossambicus exposed to ambient and dietary cadmium. J. Environ. Biol. 28, 385–393.

The Fisheries (Safety of fish, Fishery products and fish feed) Regulations, 2007. Fisheries Department. Nairobi, Kenya

World Health Organization, 2010. Evaluation of Certain Food Additives and Contaminants. seventy-third report of the Joint FAO/WHO Expert Committee on Food Additives. Geneva, Switzerland.

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Table 1. Heavy metal concentrations in dagaa dry and wet samples from various landing sites (D = Dry samples, W = Wet samples).

Station	**Nature**	**Cadmium**	**Mercury**
Sori	D	0.022	0.098
Sori	W	0.022	0.58
Marenga	D	0.015	0.212
Marenga	W	0.002	0.439
Uhanya	D	0.014	0.091
Uhanya	W	0.011	0.395
Litare	D	0.028	0.231
Litare	W	0.002	0.098
Bao	D	0.014	0.258
Bao	W	0.009	0.338
Asat	D	0.012	0.082
Asat	W	0.004	0.104

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Table 2. Mean dry-wet heavy metal concentrations per landing site versus various Maximum Permissible Limits.

Station	**Cadmium (ppm)**	**Mercury (ppm)**
Asat	0.008	0.093
Bao	0.0115	0.298
Litare	0.015	0.1645
Marenga	0.0085	0.3255
Sori	0.022	0.339
Uhanya	0.0125	0.243
[redacted]	[redacted]	[redacted]
MPL for (ppm)	EC (≤ 0.05) SDF&BE (≤0.05) WHO (≤0.05)	EC (≤ 0.4) SDF&BE (≤0.5) WHO (≤0.5)

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Figure 1. Map showing the study area and sampled landing sites around L. Victoria, Kenya.

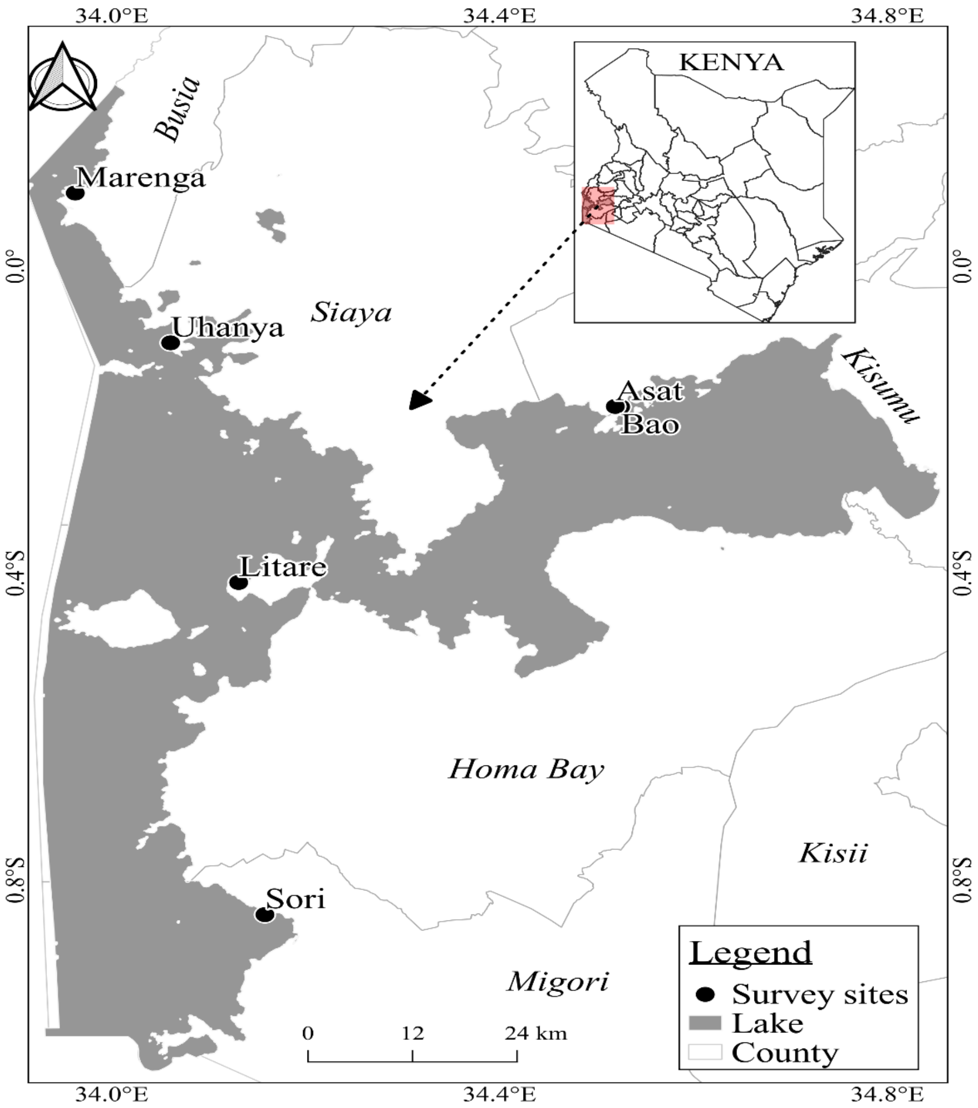

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Figure 2. Mercury concentrations comparisons for dry versus wet samples per landing site (D = Dry, W = Wet).

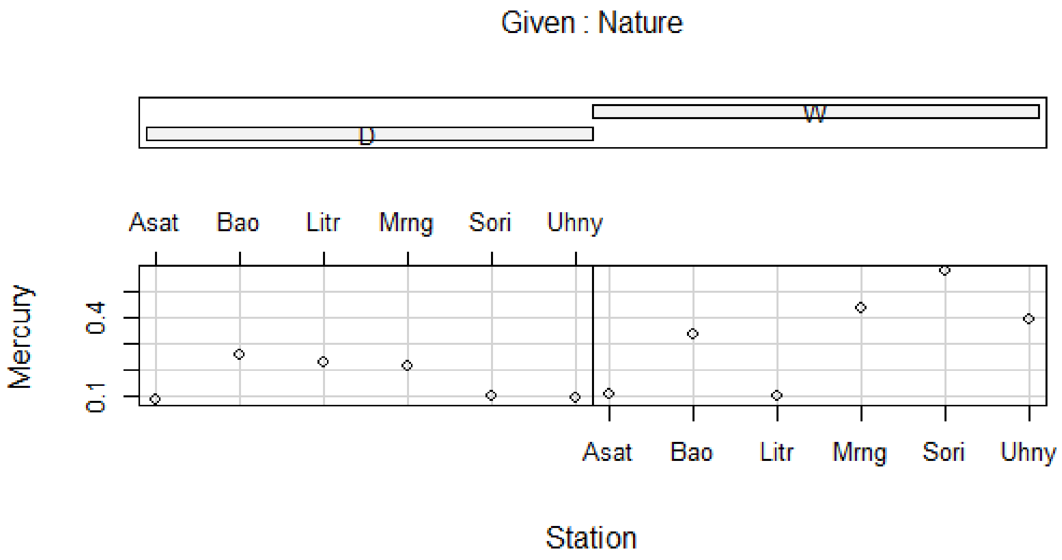

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Figure 3. Cadmium concentrations comparisons for dry versus wet samples per landing site (D = Dry, W = Wet).

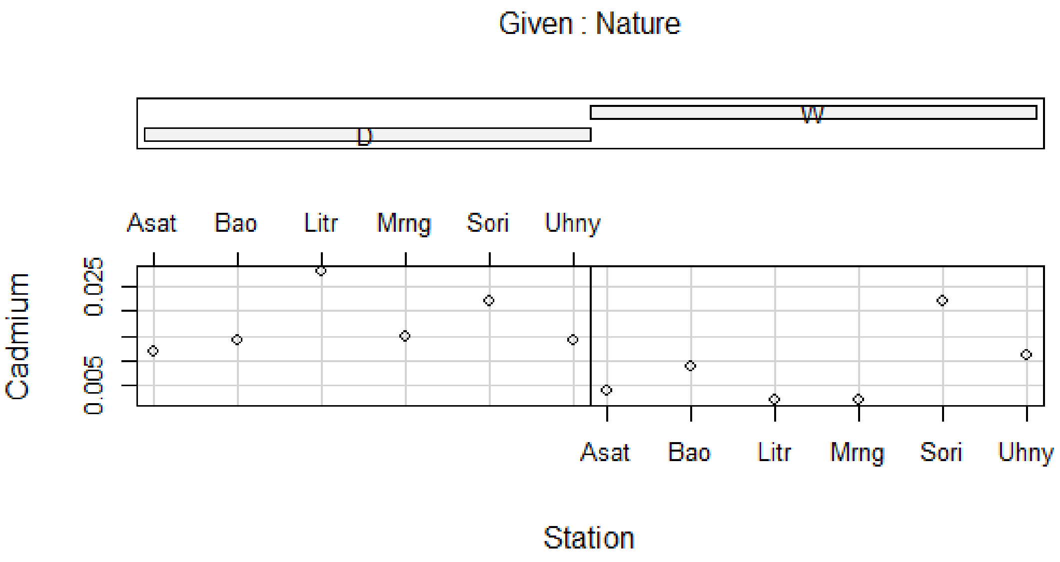

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Figure 4. Grouped boxplots of mean dry-wet concentrations of Cd and Hg per landing site