Factors influencing organochlorine pesticides distribution in the Brisbane River Estuarine sediment, Australia

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Graphical abstract

The influence exert by factors affecting OCPs distribution in sediment.

Highlights

- Factors that exert influence on OCP distribution in sediment were ranked.
- OCP inputs in Brisbane River sediment can be considered to be historical.
- There is increase in OCPs concentration after the 2011 and 2013 floods.
- The levels of detected OCPs may cause adverse ecological impacts.

Abstract

Sediment samples collected from Brisbane River were analysed for organochlorine pesticide residues (OCPs). The factors influencing OCPs distribution in the sediment were investigated using multivariate analytical tools. Thirteen OCPs were detected in the sediment with concentrations ranging between below detection to 83.9ng/g, and detection frequency greater than 90%. With the exception of dieldrin, the OCP inputs appear to be historical and may cause adverse ecological impacts. Multi-criteria ranking of the factors influencing the OCPs (except dieldrin) distribution in the sediment revealed that TOC>silt>intensive urban land use>population>seasons. Dieldrin distribution is significantly influenced by season>TOC>silt>intensive urban land use>population. The study helps to prioritise factors required for managing OCPs contamination in sediments and identification of appropriate mitigation measures.

***Keywords*:** Organochlorine pesticides; River sediment; land use; physicochemical parameters; Multi-criteria ranking.

The large scale use of chemicals in agriculture, manufacturing and homes has led to the widespread distribution of contaminants in the environment. These contaminants pose ecological and public health threats because they are toxic to many species, (not just the target species), persistent in the environment and can bioaccumulate or concentrate in species as they move up the food chain (Gilbert, 2012). Typical examples are organochlorine pesticides (OCPs). OCPs are a group of synthetic chlorinated hydrocarbon pesticides, which break down slowly in the environment and usually accumulate in the fatty tissues of animals. They are inherently toxic and often associated with adverse health effects in non-target organisms (US EPA, 2009). Consequently, public awareness of the potential adverse effects of OCPs on ecological and human health has increased. This has led to the ratification of the Stockholm Convention on persistent organic pollutants (POPs) by many countries (UNEP, 2010).

Global production and use of OCPs were extensive between 1940s-1980s for a wide range of applications including agricultural, domestic and public health (Haynes et al., 2000). Most of them were banned about three decades ago. However, their presence and impacts still lingers due to their high photochemical, biological and chemical resistance to degradation in the environment (Duodu et al., 2016a). In Australia, for example, the use of OCPs were banned or restricted from the early 1980s with a complete phase out in October 2010 (Reid et al., 2013). Nevertheless, residues of OCPs are still detectable in the environment (Duodu et al., 2016a; Reid et al., 2013; Elbagir, 2011; Mueller et al., 2011).

In the environment, OCPs tend to accumulate in soils, sediments and biota because of their hydrophobic character and low solubility in water (Duodu et al., 2016a). Sediments provide habitat and nutrients for aquatic flora and fauna and serves as an archive for pollution indexing because of their long residence time (Duodu et al., 2016b; Liu et al., 2017). Therefore, accumulation of OCPs in sediment could undermine water quality and pose adverse impacts on the aquatic ecosystem.

Studies on OCPs in sediments are predominantly centred on analysing their concentrations in order to assess spatial and temporal distribution and ecological and/or human health risk (Hinojosa-Garro et al., 2016; Zhonghua et al., 2016; Alonso-Hernandez et al., 2014; Lebeuf & Nunes, 2005; Barlas, 2002). In terms of OCPs distribution in sediments, factors such as sediment texture, organic carbon, land use and seasonal variation have been found to exert

influence. However, the extent and ranking of these factors in terms of the influence they exert have not been investigated. This has constrained the comprehensive understanding of OCP distribution in sediments and consequently, the effective implementation of sediment pollution mitigation strategies. This paper evaluates the critical factors that affect the distribution of OCPs in sediment in terms of: (a) ranking the influence they exert; (b) the variability in concentrations when sediment pollution is affected by similar land uses; and (c) the distribution characteristics of different OCP species. Such information can provide valuable insight into the characteristics of OCP distribution in sediments and the identification of the critical factors which need to be managed to facilitate sediment pollution mitigation.

The area under study was the Brisbane River estuary, the highly urbanised river system in Southeast Queensland (SEQ) of Australia. It drains a catchment area of 13560 km^2 and supports a population in excess of one million. However, there is no recent comprehensive study on the distribution of OCPs in the sediment of the Brisbane River, especially after the 2011 and 2013 floods. The catchment experiences a sub-tropical climate with distinct wet summer and dry winter seasons (Duodu et al., 2016b). The catchment is categorised by a physio-geographic stratification along a hydrological gradient from lower to upper catchment, varying urbanization and distinct land uses (Tables S1 in Supplementary data). Four primary land use types, namely, natural environment (NA), intensive urban use (IU), agricultural land (AG) and water surfaces (WA) can be identified, with each primary land use consisting of various secondary and tertiary types (Liu et al., 2017). A total of 22 sampling points were selected along a 75 km stretch of the river from the mouth, which can be grouped into four physio-geographical strata, namely, rural (SP1-SP3), residential (SP4-SP12), commercial (SP13-SP18), and industrial (SP19-SP22) sections (Duodu et al., 2017) as shown in Fig. 1 and Table S1 with sampling points coordinates and detailed site description. This enabled the analysis of the spatial distribution of OCPs.

Fig. 1. Location of sampling points (adapted from Google earth).

Land use related parameters associated with each sampling point were determined from the percentages of each primary land use that account for the total stormwater draining the area. Detailed breakdown of the different land use data, including primary, secondary and tertiary levels as well as their area extents and percentages, and resident population (POP) for each sampling point can be found in Liu et al. (2017). Data for total organic carbon (TOC) was obtained from Duodu et al. (2017). Sedimentary features (particle sizes) were obtained from Duodu et al. (2016b). Table 1 gives the summary of land use, population data, percentage of total organic carbon (TOC) and sedimentary features for each sampling point.

Table 1: Land use, population and sedimentary features data for the sampling points

Sampling points	% (NA)[a]	% (IU)[a]	% (AG)[a]	% (WA)[a]	POP (10^3)[a]	% TOC[b]	% Clay[c]	% Silt[c]	% Sand[c]
SP1	24.4	57.8	15.5	2.3	22.2	0.6	34.5	30.3	35.2
SP2	12.1	8.4	78.5	1.1	0.0	1.1	38.4	31.9	29.7
SP3	47.1	26.9	25.0	1.1	25.2	1.1	34.4	32.2	33.4
SP4	43.5	29.5	26.2	0.9	34.2	0.8	38.2	15.3	46.5
SP5	34.3	36.9	28.3	0.6	73.6	0.8	37.2	32.4	30.4
SP6	32.7	46.4	19.8	1.1	73.6	1.0	33.4	16.6	50.0
SP7	36.1	62.3	1.4	0.3	33.1	1.3	36.1	36.1	27.8
SP8	3.0	96.9	0.0	0.2	15.5	1.2	40.2	35.6	24.2
SP9	22.8	74.6	2.4	0.3	5.8	1.3	38.6	34.5	26.9
SP10	4.2	94.3	1.4	0.2	39.5	1.1	33.6	30.1	36.3
SP11	50.7	47.8	0.7	0.9	54.3	1.3	30.5	40.1	29.4
SP12	18.5	76.5	2.7	2.4	144.6	1.1	33.7	42.6	23.7
SP13	40.3	58.3	0.6	0.7	181.0	1.1	38.0	39.2	22.8
SP14	58.8	39.7	0.6	0.9	43.4	1.6	33.3	45.6	21.1
SP15	4.0	95.7	0.3	0.1	52.2	1.3	32.3	45.1	22.6
SP16	5.4	93.8	0.6	0.2	113.3	1.0	30.3	34.6	35.1
SP17	3.1	96.0	0.0	0.9	72.6	1.3	26.9	54.3	18.8
SP18	55.0	43.3	0.3	1.4	92.4	1.3	28.4	56.5	15.1
SP19	12.1	82.4	3.3	2.1	198.5	1.0	31.1	53.5	15.4
SP20	12.8	81.2	3.8	2.2	179.8	2.0	26.4	51.2	22.4
SP21	6.2	62.8	7.0	24.0	14.0	1.0	34.7	33.0	32.3
SP22	21.7	31.1	45.9	1.3	1468.7	0.6	4.3	7.2	88.5

NA-Natural environment, IU-Intensive urban use, AG- Agricultural land and WA-Water surfaces. [a] Liu et al., 2017; [b] Duodu et al., 2017; [c] Duodu et al., 2016b

The sediment samples were collected in the months of June (winter), September (spring), December (summer) 2014, and May (autumn) 2015; thus, spanning both dry and wet seasons. This allowed for the observation of temporal variations in OCP concentrations in sediments. Grab sediment (0-3 cm depth) samples were collected from the 22 sampling locations into pre-cleaned 250mL glass jars, which were initially stored and transported on ice to the laboratory and stored at -20^{O}C until further analysis.

Each sample was tested for 18 OCPs specified in EPA method 8081B, including alpha, beta, gamma and delta benzene hexachlorides (α-BHC, β-BHC, γ-BHC and δ-BHC). The other compounds were heptachlor, aldrin, heptachlor-exo-epoxide, alpha-endosulfan, 1, 1-dichloro-2, 2-bis (p-chlorophenyl) ethylene (p,p'-DDE), dieldrin, endrin, beta-endosulfan, p,p'-

dichlorodiphenyl dichloroethane (p,p'-DDD), p,p'-dichlorodiphenyltrichloroethane (p,p'-DDT), endrin aldehyde, endosulfan sulfate, endrin ketone and methoxychlor. Pentachloronitrobenzene and 2, 4, 5, 6-Tetrachloro-M-Xylene from Supelco Sigma-Aldrich Pty. Ltd (NSW, Australia) were used as internal and surrogate standards, respectively. Dionex accelerated solvent extractor (ASE 300) system (Thermo Fisher Scientific Australia Pty Ltd) was employed for the extraction of the OCPs from the sediment. Detection and quantification of OCPs concentrations in the extracts were performed using a Shimadzu Gas Chromatograph and Mass Spectrometer (GC-MS) TQ8030. For quality control and quality assurance purposes, surrogate and internal standards were used during the extraction and testing while randomly selected duplicate samples, field blanks, method blanks and SRM 1941b were analysed along with the samples. Details of the extraction, clean-up and analysis had been published elsewhere (Duodu et al., 2016a).

OCPs concentrations that were below the detection limit were considered to be half the method detection limit. The average concentration of the detected OCPs were evaluated and compared with similar studies undertaken elsewhere as well as the Australian New Zealand sediment quality guidelines. The spatial and temporal distribution patterns across the various physio-geographic strata were then elucidated. Afterwards, multivariate data analysis techniques such as hierarchical cluster analysis (HCA), Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) and its graphical representation procedure, Geometrical Analysis for Interactive Aid (GAIA), (Duodu et al., 2016b; Mostert et al. 2010; Mostert et al. 2012) were employed to analyze the OCP variability at each sampling location and in each season in order to rank the influential factors. The final step was to investigate the variability of OCPs distribution in sediments with location specific factors (land use, TOC, POP and sediment texture) that have most effect on OCPs distribution in sediments.

Details of the analytical performance of the method can be found in Duodu et al. (2016a). Generally, with the exception of α-BHC and aldrin whose recoveries were low (59.7% and 47.7%, respectively), the remaining pesticides had recoveries > 85% (85.4–117.9%). The method detection limit ranged between 0.06-2.3ng/g with precision (relative standard deviation (RSD)) < 10%. The recovery of OCP content of SRM 1941b ranged between 93.04-105.9% (Duodu et al., 2016a).

Table 2 presents the concentration range and averages of the detected OCPs (γ-BHC, δ-BHC, heptachlor-exo-epoxide, α-endosulfan, p,p'-DDE, dieldrin, endrin, p,p'-DDD, p,p'-DDT, endrin aldehyde, endosulfan sulfate, endrin ketone and methoxychlor) in the Brisbane River estuary sediment. The remaining OCPs were below detection in all samples and were not included in the data analysis. The concentration of the detected OCPs ranged between below detection and 83.9ng/g with detection frequency greater than 90%. With the exception of γ-BHC, δ-BHC heptachlor-exo-epoxide and endosulfan sulfate, the average concentration of the detected OCPs in the current study were significantly higher (ANOVA P = 0.723, 0.633, 0.075, <0.001, <0.001, 0.006, <0.001, 0.045, 0.045, 0.006, <0.001, 0.195, <0.001 and <0.001, respectively) than that of sediments from lakes along the middle-lower reaches of the Yangtze River and the Huaihe River in China (Zhonghua et al., 2016). Conversely, the average concentrations of the detected OCPs were all significantly lower (ANOVA P<0.043 and <0.001 for all OCPs) in the current study than in the sediments in the Ogbese River, Nigeria and Mae Klong River, Thailand, respectively (Ibigbami et al., 2015; Pokethitiyook and Poolpak, 2012). The average concentrations of 0.03µg/g, 0.012µg/g, 1.0µg/g, 0.89µg/g, 2.0µg/g and 3.1µg/g recorded for γ-BHC, heptachlor-exo-epoxide, p,p'-DDE, dieldrin, p,p'-DDD, p,p'-DDT, respectively, in the Brisbane River and Moreton Bay sediments in 1997 (Mueller et al., 2011and references therein) were significantly lower (with the exception of dieldrin) than in

the present study (ANOVA P<0.001, 0.023, <0.001, 0.281, 0.002 and <0.001, respectively). Oetken et al. (2005) reported that flooding could possibly cause a decrease in the contamination level at "hot spots" and slight increase in concentration at previously less contaminated sites. However, there was an increase in the average OCP concentrations after the flood events. A similar trend was observed for PAH concentrations in the sediment (Duodu et al., 2017). This can be attributed to the exposure of previously contaminated buried sediment or pesticides from flooded areas have also been washed into the river after recent flooding events.

The two threshold values in the Australia and New Zealand interim sediment quality guidelines: Low (ISQG-L) and High (ISQG-H) were applied to evaluate the possible ecological risks associated with OCPs in the sediment (Table 2). The ISQG-L represents the chemical concentration below which an adverse effect would rarely occur, while the ISQG-H represents the concentration above which adverse effects are probable. From Table 2, the average concentrations of γ-BHC and dieldrin were equal or greater than the ISQG-H and could cause adverse ecological impacts. On the other hand, p,p'-DDE, endrin, p,p'-DDD and p,p'-DDT have the potential to occasionally cause ecological impacts as their average concentrations were greater than ISQG-L, but below ISQG-H.

Table 2. Concentration (ng/g) of OCP residues in sediments Brisbane River compared with ISQG and some concentrations around the world

OCP	Average	MIN	MAX	Detection frequency (%)	a	b	c	ISQG-L	ISQG-H
γ-BHC	1.0±0.2	<0.25	2.2	98.0	1.1±1.3	31.7±23.8	90	0.3	1.0
δ-BHC	1.6±0.02	<0.26	2.3	92.0	2.8±11.7	45.5±43.8	3100		
Heptachlor-exo-epoxide	4.1±3.3	<0.12	15.1	90.0	6.5±5.5	43.3±31.5	38200		
α-Endosulfan	8.5±3.6	3.9	18.0	100.0	0.2±0.8	102±68.5	90.0		
p,p'-DDE	11.4±5.4	3.7	25.4	100.0	2.3±3.8		140.0	2.2	27.0
Dieldrin	11.0±18	<0.51	83.9	93.0	0.8±6.2	37.9±40		0.0	8.0
Endrin	3±0.9	1.9	5.1	100.0	0.4±0.9	54.5±31.7		0.0	8.0
p,p'-DDD	13.6±6.7	7.7	38.8	100.0	8±11.4	26.5±19.4	210.0	2.0	20.0
Endrin Aldehyde	5.9±10.1	3.5	7.3	100.0	0.5±1.5				
p,p'-DDT	7.1±1.2	<0.15	9.0	99.0	0.3±1.5	12±9.37	690	1.6	46.0
Endosulfan sulfate	8.2±23.8	7.1	9.5	100.0	2.4±4	28.7±23.3	820.0		
Endrin Ketone	4.3±0.4	3.7	5.4	100.0	1.9±2.4				
Methoxychlor	4.3±0.2	4.1	4.8	100.0	2±1.6				

a- Zhonghua et al., 2016; b- Ibigbami et al., 2015; c- Pokethitiyook and Poolpak, 2012

Compositional profile of DDT and its metabolites (DDE and DDD) in the environment could be used to infer different sources of contamination. A ratio of (DDE + DDD)/∑DDT > 0.5 is assumed to be due to long term weathering (Alonso-Hernandez et al., 2014). From Fig. 2, the ratio of the compositional profile of p,p'-DDT and its metabolites (p,p'-DDE + p,p'-DDD)/∑ p,p'-DDT) is > 0.5 at all sites, which indicates that p,p'-DDT input in Brisbane River is historical. Upstream (rural stratum), DDT and other persistent OCPs were used for crop and livestock protection from the 1950s. In the residential, commercial and industrial strata, DDT was applied for mosquito control (Mueller et al., 2011).

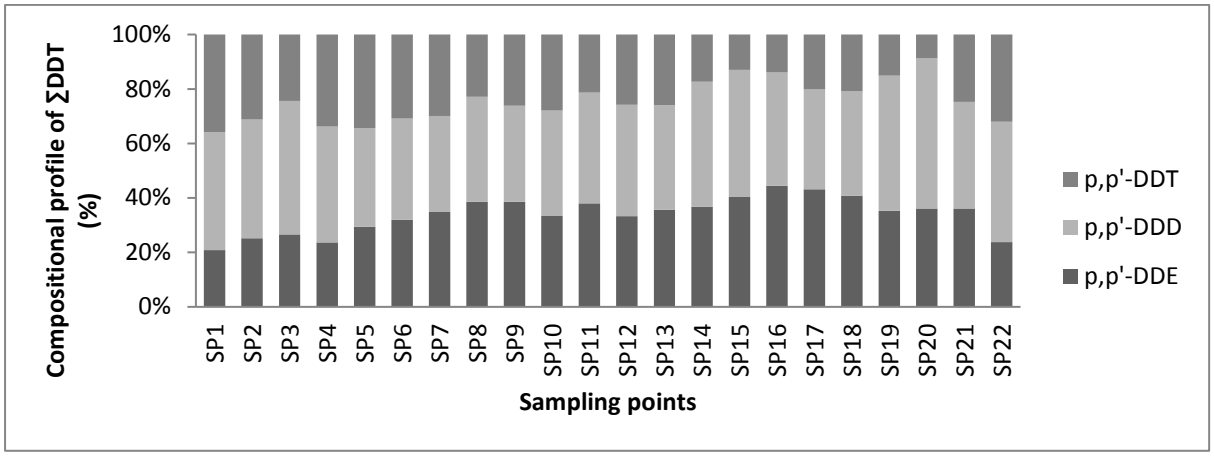

Fig. 2. Percentage of p,p'-DDE, p,p'-DDD and p,p'-DDT in Brisbane River sediment.

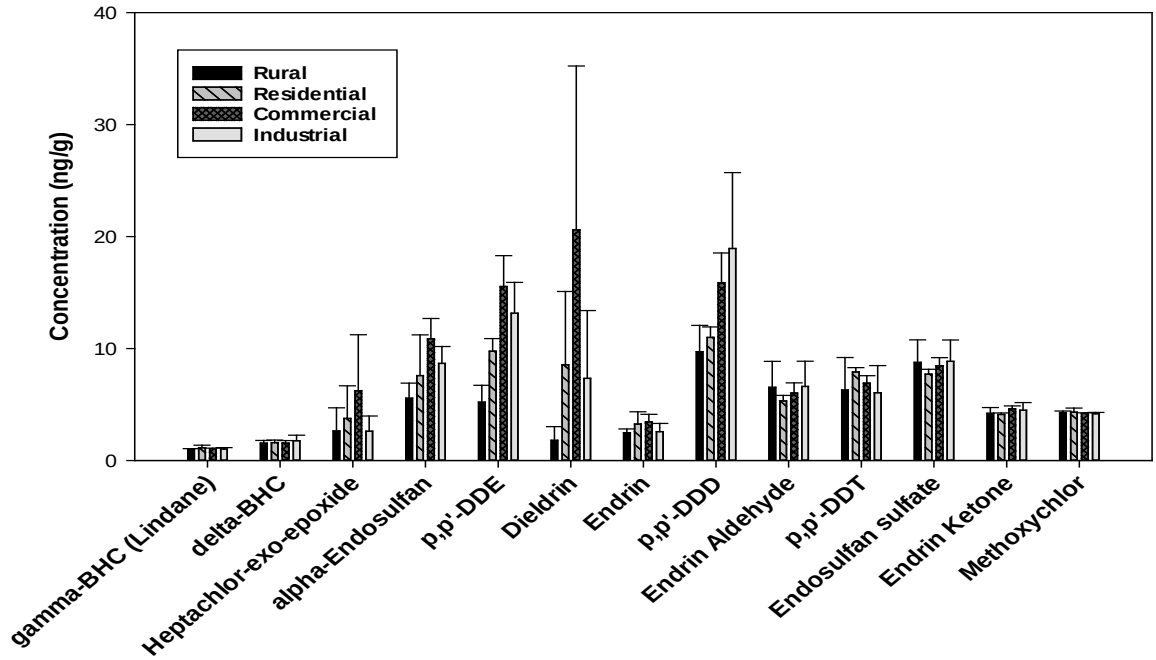

Fig. 3. Spatial distribution of OCPs in Brisbane River sediment.

Fig. 3 shows the spatial distribution of OCPs in Brisbane River estuarine sediment along physio-geographical strata. It can be seen that the average concentrations of γ-BHC, δ-BHC, endrin, p,p'-DDT, endrin aldehyde, endosulfan sulfate, endrin ketone and methoxychlor are fairly stable among the strata. This lends credence to the earlier findings that input of these OCPs is historical in nature. The concentration of heptachlor-exo-epoxide is relatively high in the commercial stratum followed by residential with both rural and industrial strata being equal. Similarly, the concentration of α-endosulfan was high in the commercial stratum, then industrial, followed by residential with the rural stratum being the lowest. However, ANOVA analysis of the mean concentrations of both OCPs among the strata revealed no statistical difference ($P = 0.314$ and 0.056, respectively). Therefore, the variations might not be due to

their sources, but due to other factors. Conversely, there is a statistical difference among the mean concentrations of p,p'-DDE, p,p'-DDD and dieldrin (ANOVA P <0.001. 0.001 and 0.034, respectively) among the strata. The variation of p,p'-DDE and p,p'-DDD follow a similar pattern. They increase from the rural to the residential and peak at the commercial and industrial strata. Though it appears that there are differences between the concentrations of p,p'-DDE and p,p'-DDD in the commercial and industrial strata (Fig. 3), pairwise ANOVA analysis indicates no statistical difference (ANOVA P = 0.086 and 0.300, respectively). Both p,p'-DDE and p,p'-DDD are metabolites of p,p'-DDT, which was extensively used in the past for mosquito control at the commercial and industrial strata (Mueller et al., 2011). The concentration of dieldrin, on the other hand, peaks in the commercial stratum then decreases in the residential and industrial strata (with similar concentration, ANOVA P = 0.829) and further decreases in the rural stratum. Dieldrin was extensively used for termite control in the commercial stratum (Mueller et al., 2011).

Fig. 4 also presents the temporal trends in OCPs distribution in the Brisbane River sediment. In the Rural stratum, the concentrations of most OCPs tend to be relatively stable during the sampling period (June, 2014 – May, 2015). Heptachlor-exo-epoxide, p,p'-DDD and p,p'-DDT show some slight variations. However, ANOVA analysis revealed no statistical difference (AOVA P = 0.236, 0.849 and 0.328, respectively) during the four sampling periods.

Except for dieldrin, the variations in the OCPs concentrations in the residential, commercial and industrial strata were not significant. Dieldrin recorded its highest concentration during the September 2014 sampling (in spring), that is, the beginning of the wet season. It was then followed by the May 2015 sampling, with the December 2014 and June 2014 samplings recording the least concentrations. This observation may be attributed, partly to the introduction of dielrin from urban runoff, and partly to the resuspension of historical dieldrin inputs. Past studies confirm that dieldrin is still entering the Brisbane River through runoff from urban areas where it was widely used until 1995 for termite control (Mueller et al., 2011). Also, the Brisbane River estuary is micro-tidal, with limited inflow of freshwater as a result of various water storages and diversions along the river. Due to the relatively low freshwater inflow, strong tidal mixing acts as a dominant mixing mechanism in the estuary, thereby causing resuspension of fine sediment (Howes et al., 2002).

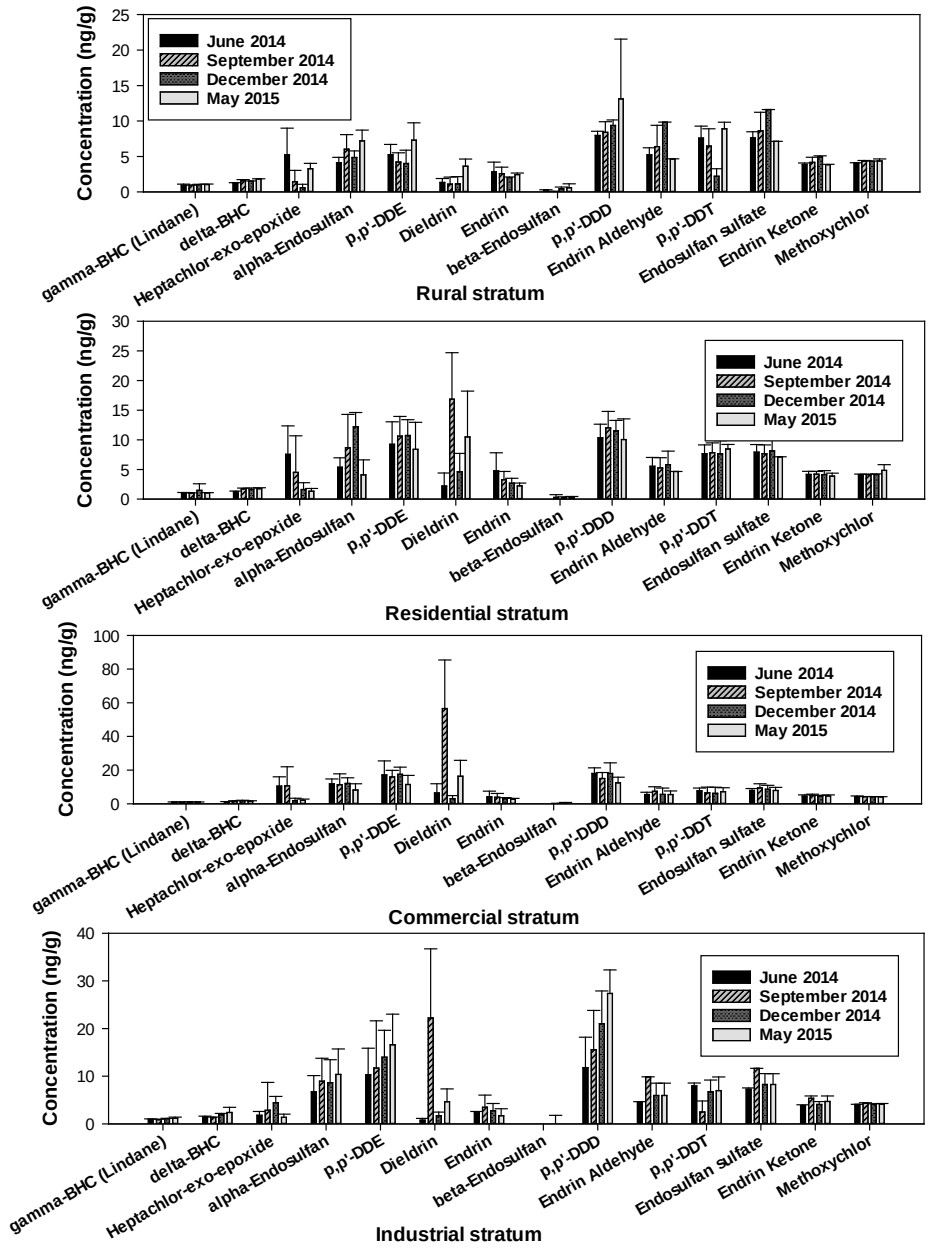

Fig. 4 Temporal trends in OCPs distribution in Brisbane River sediment.

The influence of location (spatial) and seasonal variability were investigated using the coefficients of variation (CV) values of the OCP concentrations calculated in relation to locations and seasons. The location CV values were calculated from the standard deviation (SD) values divided by the average concentrations for each sampling period. On the other hand, CV values for seasons were obtained from SD values divided by the average concentrations at each sampling point. This gave a matrix of 26 objects (consisting of 4 location variability and 22 season variability objects) and 13 variables (OCPs) (Table S2 in Supplementary Data). PROMETHEE was then used to rank the objects based on maximum variability using the V shape preference function, resulting in the GAIA biplot shown in Fig. 5.

The GAIA biplot (Fig. 5) separated the spatial and seasonal variability objects into two groups. The first group (Group “a” in Fig. 5) was made up of all the spatial variability factors (A1-A4) with all OCP vectors except dieldrin projected in the direction of this group. In addition, the decision axis (Pi) point towards these objects, confirming that the location factors exert significant influence on all OCPs except dieldrin distribution in the sediment. Dieldrin distribution is significantly affected by seasonal factors as it is projected towards group b consisting of seasonal variability factors. The results indicate that the spatial distribution of OCPs (except dieldrin) in sediments is more significant than their temporal distribution. Therefore, any pollution mitigation strategy based solely on seasonal factors might be effective for only dieldrin and not for other OCPs.

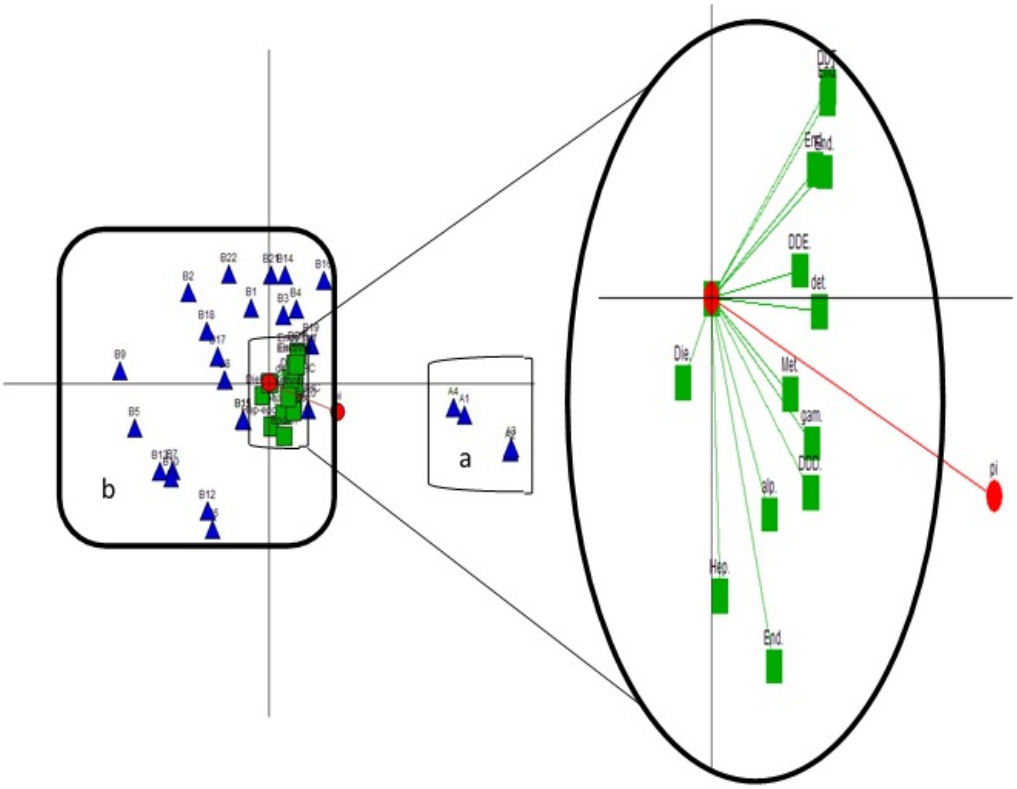

Figure 5. GAIA biplot of the influence of spatial and seasonal variability to OCP distribution in sediment. (*Objects A1-A4 denotes spatial variability while B1-B22 denotes seasonal variability. Variables gam, det, Hep, alp, DDE, Die, End, DDD, DDT, EndA, Endo, EndK and Met represents γ-BHC, δ-BHC, heptachlor-exo-epoxide, α-endosulfan, p,p’-DDE, dieldrin, endrin, p,p’-DDD, p,p'-DDT, endrin aldehyde, endosulfan sulfate, endrin ketone and methoxychlor respectively)*

Since location factors have the most significant influence on all OCPs except dieldrin distribution in the sediment, comparison of the various physicochemical parameters specific to location was undertaken. PROMETHEE and GAIA was used to analyze the influence exerted by primary land use types (IU, AG, WA and NA), POP, TOC, sediment texture (clay silt sand) on total OCP distribution at a sampling point. The results were subsequently validated using HCA (Fig. 6a and 6b).

In Fig. 6a, TOC and silt vectors form the smallest angles with the total OCPs vector while PO and IU also have relatively acute angles with the total OCPs vector. This implies that

the TOC and silt content in sediment have the closest relationship with total OCP concentrations followed by PO and IU. The HCA (Fig. 6b) also clustered silt, TOC and IU together with the remaining factors separately grouped. This indicates that IU, TOC and Silt are the correlated parameters to OCP concentrations in sediments. The other parameters have relatively less influence on OCP distribution in sediment. The most influential factors for all other OCPs except dieldrin distribution follow the order: TOC>silt>intensive urban land use>population>seasons. The distribution order for dieldrin are: season>TOC>silt>intensive urban land use>population.

The results from Fig. 6a and 6b show that although OCPs (except dieldrin) inputs in the sediment might be related to anthropogenic activities including residential, commercial and industrial land use as well as the number of people resident in the drainage area, TOC and silt content of the sediment dictates OCPs distribution. This confirms the earlier observation that OCPs (except dieldrin) inputs is historical (Mueller et al., 2011). Conversely, seasonal input of dieldrin is very important in determining its distribution.

Conclusions

The study confirmed that the concentration of OCPs in Brisbane River sediment increased after the 2011 and 2013 floods. However, with the exception of dieldrin, OCPs input into sediment is historical. Multi-criteria ranking of the factors influencing OCPs (except dieldrin) distribution in the sediment revealed that TOC>silt>intensive urban land use>population>seasons. Dieldrin distribution is affected in the order: season>TOC>silt>intensive urban land use>population. This information will help in the prioritization of factors for managing OCPs contamination and the selection of the appropriate mitigation approaches. The generic outcomes of this study are expected to enhance the management of the pollution risk posed by OCPs in river sediments worldwide.

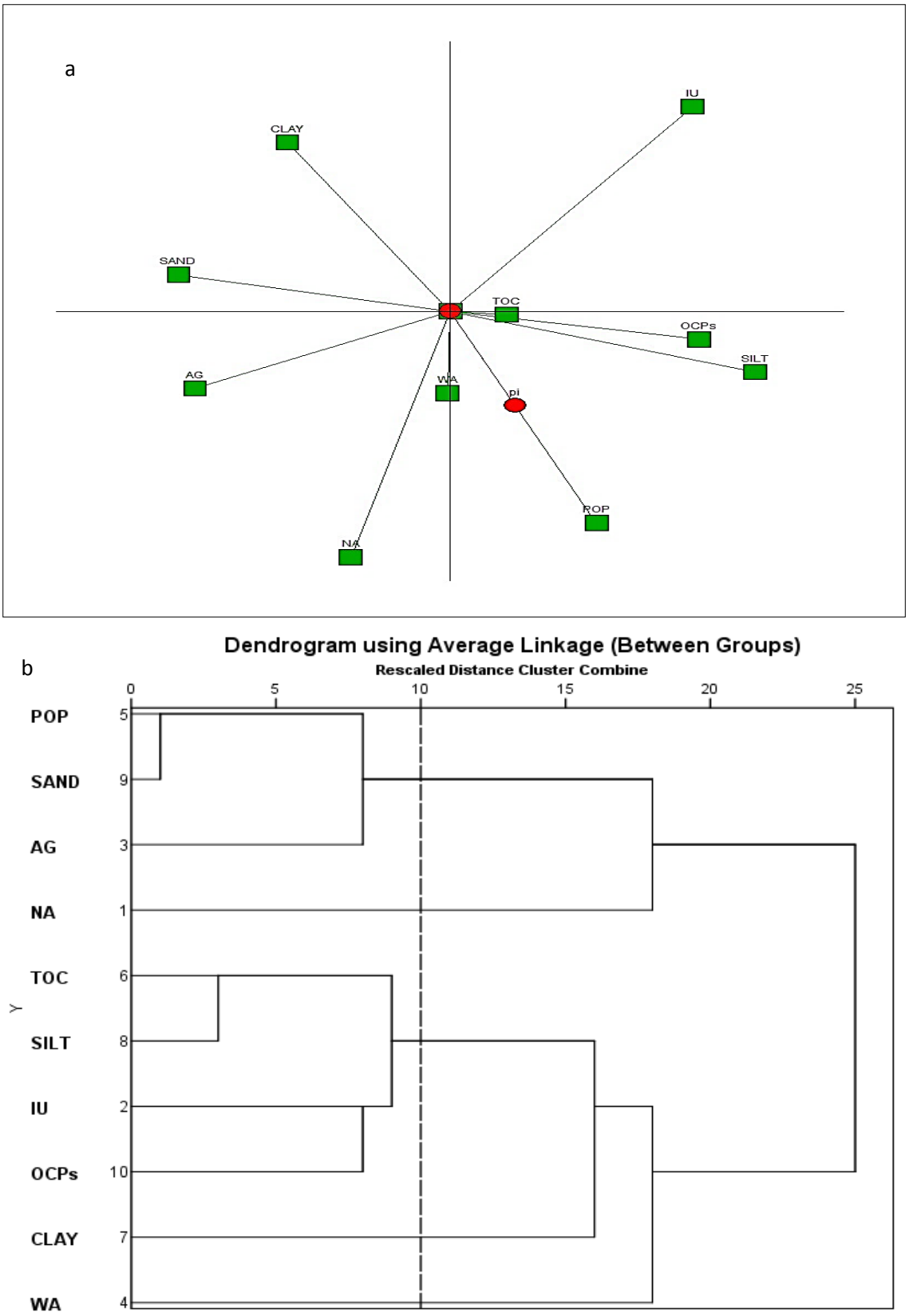

Fig. 6 Comparison of the influence of physicochemical parameters on OCP distribution in sediment (a. GAIA biplot of physicochemical parameters; b. HCA cluster of physicochemical parameters).

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Appendix A. Supplementary data

Supplementary data to this article provides information on sampling location and description as well as OCP concentrations in RDS, CV values matrix relating to locations and seasons

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Appendix A.

Supplementary data for

Factors influencing organochlorine pesticides distribution in the Brisbane River Estuarine sediment, Australia

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This supplementary material contains information on sampling location and OCP concentrations in RDS, CV values matrix relating to locations and seasons.

Table S1: Location and description of sampling sites for 2014-2015 sampling period

Site ID	Latitude	Longitude	Site Description
SP1	27°32'20.81"S	152°51'1.55"E	Forestland
SP2	27°34'49.65"S	152°50'34.36"E	Major confluence (Bremer River) and forestland
SP3	27°35'36.03"S	152°51'22.86"E	Ferry crossway and forestland
SP4	27°35'24.88"S	152°53'16.39"E	Moderately residential, and bushland
SP5	27°36'11.52"S	152°54'3.66"E	Moderately residential, minor confluence (Woogaroo Creek) and bushland
SP6	27°34'7.21"S	152°54'6.80"E	Slightly residential, forestland and minor confluence (Wolston Creek).
SP7	27°33'1.65"S	152°54'11.81"E	Forestland and minor confluence (Pullen Creek).
SP8	27°32'31.73"S	152°55'31.35"E	Slightly residential, forestland and minor confluence (Mt Ommaney Creek).
SP9	27°31'47.16"S	152°55'37.18"E	Boat ramp, moderately residential, forestland and minor confluence (Moggill Creek).
SP10	27°31'41.20"S	152°56'48.21"E	Motor bridge, moderately residential and bushland
SP11	27°31'19.19"S	152°58'8.20"E	Moderately residential and bushland
SP12	27°31'28.09"S	152°59'42.47"E	Highly Residential, parklands, marinas , wastewater treatment and major confluence (Oxley Creek)
SP13	27°29'54.51"S	153° 1'17.51"E	Motor bridge, moderately residential and commercial, parklands, marinas
SP14	27°29'21.12"S	152°59'46.07"E	Busy highway, highly Residential and commercial, parklands and marinas
SP15	27°28'48.33"S	153° 1'46.55"E	Motor bridge and highway, highly commercial and parklands
SP16	27°27'51.92"S	153° 2'6.54"E	Motor bridge, highly residential and commercial, parklands, marinas
SP17	27°28'38.10"S	153° 3'0.10"E	Highly residential and commercial, parklands and confluence of major tributary (Norman Creek)
SP 18	27°26'30.07"S	153° 2'47.44"E	Highly residential and commercial, parklands and confluence of major tributary (Breakfast Creek).

SP19	27°26'45.60"S	153° 6'0.69"E	Motor highway and boat building yards
SP20	27°26'0.40"S	153° 7'45.32"E	Highly industrialised: Boat building and repair yards, marine fuel stations and confluence of major tributary (Bulimba Creek).
SP 21	27°25'19.63"S	153° 8'22.61"E	Highly industrialised, petrochemical industries
SP 22	27°22'39.37"S	153° 9'40.86"E	Mouth of the river. Highly industrialised, port activities and waste water treatment

Table S2. Location and season variability matrix

	gamma-BHC	delta-BHC	Heptachlor-exo-epoxide	alpha-Endosulfan	p,p'-DDE	Dieldrin	Endrin	p,p'-DDD	Endrin Aldehyde	p,p'-DDT	Endosulfan sulfate	Endrin Ketone	Methoxychlor
A1	57.06	64.72	103.44	134.50	270.43	165.17	85.27	111.28	99.26	126.53	100.16	65.29	84.80
A2	1157.03	520.10	136.48	232.32	270.81	84.86	574.56	969.86	258.11	154.99	397.24	497.84	3178.40
A3	2027.66	803.62	131.94	172.72	100.14	51.38	673.80	871.56	260.03	122.49	396.60	762.48	3748.05
A4	175.25	154.51	96.67	74.35	36.98	60.55	117.27	89.86	100.75	79.03	99.84	153.16	117.92
B1	6.72	14.76	122.04	28.11	48.03	80.88	31.81	8.41	45.39	53.94	28.03	13.84	2.85
B2	3.90	16.72	105.53	32.17	15.06	130.84	11.39	8.70	40.38	42.16	25.49	11.54	5.98
B3	15.55	16.58	107.94	33.52	33.79	35.72	11.29	54.23	38.62	59.15	26.34	15.93	3.36
B4	21.10	14.97	62.05	38.38	57.59	133.66	23.34	22.62	45.33	32.40	28.12	19.99	3.60
B5	13.37	13.21	85.99	68.38	37.07	202.59	28.30	10.29	0.36	6.23	1.24	1.08	0.51
B6	103.84	14.06	212.88	103.52	59.23	107.39	32.64	24.39	4.34	9.27	0.56	2.87	2.56
B7	2.05	15.03	174.91	16.75	33.15	113.97	95.51	20.89	0.18	4.64	0.69	16.04	20.34
B8	14.86	21.77	204.55	34.89	7.68	41.08	26.66	8.35	40.53	31.47	25.75	9.49	2.75
B9	5.07	2.72	68.70	65.49	11.00	74.60	14.87	11.25	0.08	4.60	0.12	10.20	22.36
B10	8.87	16.98	78.81	83.48	32.44	106.49	57.18	28.22	0.15	4.64	0.14	7.05	0.65
B11	17.00	19.58	107.12	30.16	19.54	106.41	43.26	15.10	34.05	43.87	22.71	11.95	24.09
B12	5.57	18.74	222.72	106.95	14.59	44.75	31.82	26.18	0.19	6.67	0.16	11.84	8.87
B13	8.11	16.28	170.73	14.48	5.30	221.29	91.24	24.51	62.62	0.76	0.14	7.66	1.17
B14	7.85	21.08	75.78	39.62	36.13	46.79	23.07	18.00	44.34	62.03	29.16	10.25	2.04
B15	5.89	11.62	85.88	56.56	59.85	119.99	54.18	76.03	35.01	53.29	25.28	5.88	8.58
B16	9.18	22.56	59.21	17.34	109.05	29.29	19.26	99.40	38.48	60.09	24.90	18.52	3.81
B17	4.86	19.98	111.19	74.67	7.94	68.64	17.35	13.84	38.61	44.53	25.41	12.20	2.51
B18	4.27	21.39	95.56	41.00	13.03	35.07	15.08	20.53	34.28	13.24	22.88	17.74	3.32
B19	14.69	22.66	194.38	46.69	14.79	50.55	8.63	40.67	38.51	59.05	26.57	22.90	3.78
B20	36.45	57.73	93.95	37.55	34.52	55.39	65.45	52.05	38.57	40.84	24.76	16.88	2.77
B21	8.64	19.23	73.27	43.04	36.93	117.84	17.40	10.31	38.74	64.52	25.17	20.09	3.15
B22	4.93	12.44	75.79	57.90	99.86	194.62	14.84	11.47	38.46	81.64	25.21	13.12	2.67