Major Flows for Lead (Pb) Within an Academic Campus

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Abstract This study attempts to understand the major mass flows of lead and processes associated with it in an academic campus. The campus of MNIT Jaipur has been analysed using a combination of data obtained from field sampling and literature review. The main processes under consideration are private household (PHH), wastewater treatment plant (WWTP), planetary boundary layer and different types of soil cover. The major flows for lead identified within the campus are inputs to the PHHs, municipal solid waste from households being transferred to outside of the system and the sewage sludge from WWTP to forest and other soil.

Keywords Material flow analysis · Heavy metals · Lead · Urban contamination · Academic campus

1 Introduction

Mass flows associated with a system can be investigated with material flow analysis. Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system. The system is defined in space and time [2]. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks and outputs of a process. MFA as a method is very useful for resource management, waste management and environmental management. A freeware, STAN, has been developed by Technical University of Vienna for modelling material flow analysis. It includes a graphic user interface and Sankey diagrams [5].

Lead is a heavy metal and has been found to be carcinogenic in humans. Exposure to high levels of lead can cause anaemia, weakness, kidney and brain damage [4]. Exposure to infants at concentrations considered low has been found to affect behaviour and intelligence. The effects include reduced attention span, increased antisocial behaviour and reduced educational attainment [10]. One route for lead

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R. Al Khaddar et al. (eds.), *Advances in Energy and Environment*, Lecture Notes in Civil Engineering 142, https://doi.org/10.1007/978-981-33-6695-4_19

to enter drinking water is through plumbing material that contain lead [9]. Lead has been used industrially in the production of gasoline, ceramic products, paints, metal alloys, batteries and solder. The use of tetra ethyl lead as an anti-knocking agent in gasoline led to automobiles being major contributors of lead emissions to the atmosphere [4]. After leaded motor vehicle fuels were phased out in 1995, the contribution of air emissions of lead from the transportation sector, and particularly the automotive sector, greatly declined.

2 Methodology

In this study, the lead flow within the MNIT campus area is based on the flows and stocks similar to the analysis performed for Bunz Valley [2]. The MNIT has a campus of 317 acres which is covered with buildings, roads, sports ground, parks, etc. Total population of the campus has been taken as 7710. As per the estimations made using Google Earth, the area covered by buildings and roads constitutes approximately 27.4 percent and is considered as urban area. The area covered in MNIT by residential areas is about 87 acres, landscaping soil is about 202 acres, and forest soil is about 28 acres, respectively. The main processes that have been considered are PHH, WWTP, planetary boundary layer, sewer system and different types of soil cover.

In the process PHH, import goods that are relevant include petrol and diesel and consumer goods such stabilizers, electronics, kitchen utensils and toys. Input flows for lead are considered from consumer goods only. The emissions from this system include those from the vehicular emissions, sewage and MSW.

In the process WWTP, while input is wastewater, the outputs are treated wastewater, sewage sludge and some gaseous emissions. Hence, all the lead is assumed to leave the WWTP in sewage sludge and treated wastewater. The quantities of treated wastewater and sludge are calculated based on the information provided by the plant operator regarding the input flows and concentrations and the technology employed. The concentration of lead in influent and effluent wastewater and sludge are determined by taking samples from the treatment plant and testing them in the laboratory at MNIT.

The exchange of lead between anthropogenic activities and the atmosphere is represented by the process of planetary boundary layer. The lowest layer of the atmosphere is represented by the planetary boundary layer. The height of PBL has been considered as 500 m for the analysis. For this study, it has been assumed that all the lead emitted from the campus falls back in this area only, and there is no exchange of lead with the atmosphere from the adjoining regions. For the amount deposited on different kinds of soils, fixed ratios have been assumed from the literature [2].

The sewer system in MNIT receives water from PHHs and the sewage from the various departments and laboratories. The lead concentration in the influent to WWTP was determined by field sampling. Afterwards, performing a mass balance on the sewer system, it was possible to estimate the approximate loading of lead from various laboratories in the campus.

For MNIT, since all the effluent from WWTP is used for irrigation purpose, it was assumed that all wastewater goes to the landscaping soil. The sludge from the treatment plant is discarded in open areas within the campus referred to as forest soils in the study. A separate drain is provided in MNIT for total run-off. The run-off factors adopted in case of urban, landscaping and forests are 0.6, 0.2 and 0.1, respectively.

Finally, an attempt is made to balance the flows around various processes considered in the study. The STAN software developed by Vienna University of technology was used to balance the flows of lead through various processes [6]. The system boundary was chosen based on the physical boundaries of the sites. A period of one year was selected as analysis period and calculations were performed according to the deposition and flows within one year.

3 Result and Discussion

The lead concentrations in the different processes including PHHs, WWTP, PBL, landscaping, forest soil and total run-off were reported. The calculations for PHH are shown in Table 1. The total lead flow in exhaust gas, sewage and MSW is 0.454 kg/year, 9.17 kg/year and 24.59 kg/year, respectively.

Table 1 Material flow for PHH

Description	Units	MNIT	Remarks
Household sewage			
No. of inhabitants	Capita	7710	
Lead emission per person	gm Pb/capita/year	1.19	[3]
Total lead flow	Kg Pb/year	9.1749	
Municipal solid waste (MSW)			
Rate of municipal waste generation	Kg/capita/year	146	[1]
Lead concentration in MSW	gPb/kg MSW	0.0218425	[8]
Total lead flow	kgPb/year	24.58722855	
Exhaust gas			
No. of cars	Number	250	
Mileage	Km/car/year	8030	Taking average mileage as 22kmpl and 1 L consumption per day (informal survey)
Gasoline consumption	l/km	0.045	
Lead content in gasoline	mg Pb/l	5	[7]
Total lead flow	Kg Pb/year	0.45168	

The calculations for WWTP are shown in Table 2. The total lead flow to the WWTP is estimated to be 28.6 kg/year. The total lead flow from the WWTP through effluent and sludge is 4.0 kg/year and 24.6 kg/year, respectively.

The calculations for planetary boundary layer are shown in Table 3. The deposition in forest and other soil is 0.13 kg/year. The deposition in landscaping soil is 0.05 kg/year, and deposition in urban soil is 0.27 kg/year.

The calculations for total run-off are shown in Table 4. The mass flows for lead through run-off from urban areas, landscaping and forest soils are 0.16 kg/year, 0.81 kg/year and 2.47 kg/year, respectively.

For various processes, mass balance was performed using STAN software. For PHHs, major emissions of lead are through municipal solid waste, which directly flows out of the system (Fig. 1). Using mass balance, total input of lead to the households can be estimated as 34.2 kg/year. As all the measurements have some

Table 2 Material flow in WWTP

Description	Units	MNIT	Remarks
WWTP input			
Wastewater flow	L/Year	4.09E + 08	Assuming 80% is converted to sewage
Lead concentration	μg/L	70	Data from MNIT WWTP
Total lead concentration	Kg Pb/Year	28.616	
WWTP output			
Purified water flow	L/Year	4.09E + 08	
Lead concentration	Mg/L	9.8	Data from MNIT WWTP
Total lead flow	Kg Pb/Year	4.008	
Sewage sludge			
Sludge Flow	Kg dry/Year	26,858.16	Calculations done By formulae
Lead concentration	Mg pb/Kgdry	916.22	Data from MNIT WWTP
Total lead flow	Kg Pb/Year	24.608	

Table 3 Material flow from planetary boundary layer

Description	Units	MNIT 0.4518			Remarks
Total lead flow (through emission to the atmosphere)	Kg Pb/Year	Landscaping	Forest Soil	Urban	
Deposition ratio		3	1	5	
Deposition values		0.294	0.098	0.49	
Surface	Ha	11.28	81.83	35.143	
Deposition	Kg Pb/Year	3.31	8.019	17.2207	
		0.0524	0.126879	0.272	Adjusted As Per Area

Table 4 Material flow in total run-off

Description	Units	MNIT			Remarks
		Forest	Landscaping	Urban	
Deposition from PBL	Kg Pb/year	0.126879	0.0524	0.272	
Deposition from WWTP	Kg Pb/year	24.61	4.01	–	
Run-off factor		0.1	0.2	0.6	Sandy soil assumed
Run-off	Kg Pb/year	2.47368	0.81248	0.1634	
Change in stock	Kg Pb/year	22.26312	3.248	0.1088	

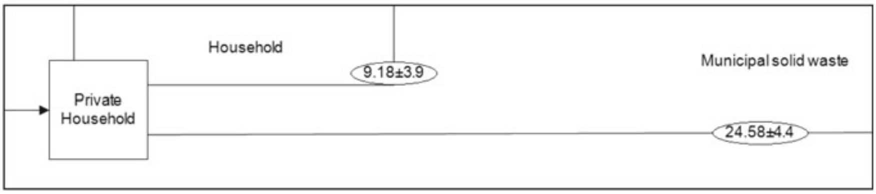

Fig. 1 Flow balance for the process of PHH

uncertainty associated with them, the uncertainties were provided to all the calculated flows while providing input to STAN software. As a result, uncertainty can be observed for all the values in STAN.

Mass balances for sewer system and WWTP are shown in Fig. 2. Total flow to the WWTP is about 28.6 kg/year which is much more than the total lead flow from households. It is suspected that remaining lead flows may be coming from laboratories in the campus. For the WWTP, major emissions of lead occur through

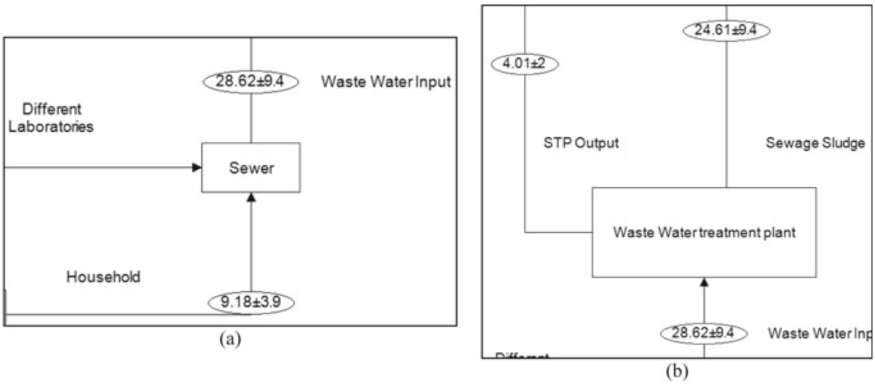

Fig. 2 Mass balance for sewer system and WWTP

sewage sludge. For other process, e.g. planetary boundary layer, soils and storm water, the flows are not significant. It is also important to note here that the estimations made in the study are approximate and have uncertainty associated with them. When these numbers were provided into STAN for modelling, the uncertainty was considered based on the procedure adopted to estimate a value.

4 Conclusions

The study attempts to quantify lead flows in the campus of MNIT Jaipur and identify major flows associated with the system. The major flows identified are input flow to PHH, lead flow through municipal solid waste from PHH to outside the system, flow by wastewater input to WWTP and flow by sewage sludge from WWTP to forest soil. These flows are 34.2, 24.6, 28.6 and 24.6 kg/year. Another major finding of the study is the loading of lead from institute laboratories to the treatment plant. There is major difference between the quantities of total lead flow exiting from PHH through sewer system and that estimated for input to WWTP. Consequently, it can be deduced that there is another substantial flow of lead to WWTP from other sources. Another significant flow of lead is by sewage sludge from WWTP to forest soil. As the sludge is continuously being deposited onto the soil, it may lead to increase in stock of lead already existing in the soil. This, in turn, may lead to increased concentration of lead in the soil and increased risk to human health.

Acknowledgements The authors are thankful to TEQIP-III office at MNIT Jaipur for providing funds for this study. Thanks are also due to Material Research Centre at MNIT Jaipur for providing services regarding analysis of heavy metals.

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