

# Assessing quality and distribution of surface runoff and soil from a mixed-use catchment, Teluk Intan in Malaysia

Xin Yan Lye<sup>1\*</sup>, and Akihiko Nakayama<sup>1</sup>

<sup>1</sup>Department of Environmental Engineering, Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia.

**Abstract.** Surface water quality of river channels has been well examined over the years, without much focus on one of the potential contributors, that is surface runoff transporting contaminants from surrounding land. By analysing the amount of contaminants present in surface runoff and soil on the ground, the potential extent of contamination can be examined in addition to the influence of different land use. The quality of surface runoff and soil from a mixed-use catchment in Teluk Intan, Malaysia was investigated for one storm event in 2023. A total of 10 points along a main road were sampled for surface runoff and soil, both of which were analysed for Total Kjeldahl Nitrogen (TKN) and lead (Pb). Both parameters concluded a higher concentration in soil compared to runoff, indicating transport across different medias. TKN was measured at a maximum of 0.0911% in runoff and 0.473% in soil. The highest Pb concentrations of 0.423 mg/L for runoff and 66.48 mg/kg for soil were recorded at the points near the Perak River bend, which is in line with Smoothed Particle Hydrodynamics (SPH) simulation results. According to the National Water Quality Standard (NWQS), the Pb concentration in runoff was beyond the Class III limit. Herein, surface runoff exhibits a significant role in contaminant transport along the observed main road and poses a risk of entry into the Perak River. The present analysis may benefit as an estimation or comparison of typical runoff pollutant loading to improve the environmental quality of similarly mixed urban-agricultural catchment in Malaysia.

## 1 Introduction

A complete management of surface water quality is associated with surface runoff, which is widely acknowledged as a major transport route for pollutants. Vehicular transportation, construction works, and agricultural practices are examples of anthropogenic sources which deposit pollutants on the ground, with varying pollutant types according to different land use. These pollutants remain static until the occurrence of rain which washes away sediments and conveys pollutants through surface runoff to adjacent land or water bodies. The migration and accumulation of pollutants is important to understand the spread and magnitude of pollution, which is specific to each type of pollutant.

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\*Corresponding author: [xinyan.28@lutar.my](mailto:xinyan.28@lutar.my)

Lead (Pb) represents one of the heavy metals which is often associated with land pollution. In its natural environment, Pb exist in the Earth's crust with localised speciation depending on soil constituents. Amid the natural composition of Pb in soil, anthropogenic activities can escalate Pb concentration in the soil, air, and water. Sources of Pb range from paint, fuel combustion, vehicle additives, water pipes soldering to mining and coal burning [1]. Moreover, dissolved organic matters released from green areas which possess strong affinities to bind with heavy metal can potentially transport Pb during its migration as well [2]. Transport routes for Pb into the human body include dermal absorption, ingestion, or inhalation, which can potentially disrupt neurological function, reproductive system, gastrointestinal tract, organs, and cellular biological processes [3]. Although intake dosage may be low, Pb poses a chronic health risk due to its potential to accumulate.

Nitrogen is a vital component in the soil which accentuates plant growth. The application of fertiliser fortifies soil nitrogen commonly in the form of ammonium sulphate or urea. However, excess nitrogen can leach from the soil and into surface runoff as nitrate, its water-soluble form. In receiving water bodies, the excess nitrogen may cause microflora blooms leading to eutrophication. If excess nitrogen reaches drinking water sources, the intake of nitrate-contaminated water may lead to methemoglobinemia [4].

Despite the risks posed by these pollutants, there are limited studies which quantify pollutant concentration in surface runoff, let alone, propose stormwater control or management practices. However, monitoring data remains as the crucial pioneer in visualising the extent of pollution and as an input to stormwater models in formulating control strategies. In this study, surface runoff and soil samples from a mixed-use catchment in Teluk Intan, were collected and analysed. The selected pollutants for analysis were Pb and nitrogen in the form of Total Kjeldahl Nitrogen (TKN). The catchment area is located adjacent to Perak River which represents the second longest river in Peninsular Malaysia. With proximity of the river body and agglomerate of residential, industrial, and commercial land use in the catchment area, this study area provides an insight towards the interlink between pollutant distribution as influenced by or influencing different land use. Aside from the distribution, a numerical model, specifically Smoothed Particle Hydrodynamics (SPH) is employed to visualise the pollutant transport of Pb originating from a main road in the selected catchment.

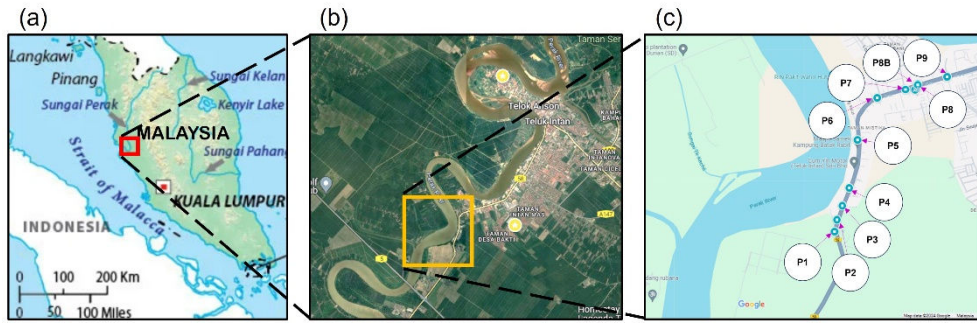
## **2 Materials and methods**

### **2.1 Site description**

The study site is located in Teluk Intan, Perak, Malaysia, bounded by the coordinates of (331,029.3, 439,975.0) m and (333,529.3, 442,475.0) m on geocentric datum GDM2000 for Peninsular Malaysia. A section of Perak River cuts through the centre of the study site and divides a mix of residential, commercial, industrial, and agricultural land uses to the East and agricultural area to the West. The study site as highlighted in a yellow box in Figure 1b.

### **2.2 Sample collection**

During a rainfall event on 29<sup>th</sup> August 2023, soil and surface runoff samples were collected along a main road (Figure 1c), Jalan Maharajalela within mixed land use area on the East side of Perak River. A total of 10 points were sampled for surface runoff. However, there was an absence of soil at one of the points, specifically P8, hence, there were only 9 points for soil samples. The point adjacent to it, P8B was located within a minor road behind the main road, and this soil sample was taken as a representative for this sampling zone.



**Fig. 1.** Location of study site in Teluk Intan, Perak, Malaysia.

Roadside soil samples were collected using a garden trowel and stored into individual zipper bags. Surface runoff samples along the roadside were gathered using plastic scoops and transferred into high density polyethylene (HDPE) sampling bottles. The collected surface runoff samples were then stored in a refrigerator at 4°C.

### 2.3 Sample analysis

Soil samples were subjected to analysis of particle size distribution Both soil and surface runoff samples were analysed for Pb and TKN content.

#### 2.3.1 Physical soil properties

Physical properties of the collected soil samples were determined in terms of particle size distribution and moisture content. Soil samples were air-dried until constant weights were achieved, prior to being sieved using a mechanical sieve shaker. Moisture content of soil samples was determined by drying the soil samples in the oven at 105°C for 24 hours, or longer, until a constant weight was achieved.

#### 2.3.2 Lead

Pb content was analysed using Atomic Absorption Spectrometry (AAS) which requires sample to be in a digested liquid state. Prior to the AAS analysis, microwave digestion was performed on 0.5g of soil samples using a mixture of 9 mL concentrated nitric acid (HNO<sub>3</sub>) and 1 mL concentrated hydrochloric acid (HCl). The microwave digester is set at 175°C for 10 min according to EPA Method 3051A.

Acid digestion was performed on surface runoff samples by heating 100 mL of surface runoff samples with 5 mL concentrated HNO<sub>3</sub> on a stirring hot plate, according to APHA Standard Method 3030 E. This acid digestion step serves to reduce disturbances due to organic matters and prepare the surface runoff samples for AAS analysis. The digested soil and surface runoff samples were analysed for Pb content using Agilent 280FS Series AA.

#### 2.3.3 Total Kjeldahl Nitrogen

TKN analysis was conducted on Buchi K-355, which consisted of a speed digester unit and a distillation unit. Soil and surface runoff samples were first digested with concentrated sulphuric acid and catalysts, potassium sulphate and copper (II) sulphate. This acid digestion was carried out in the speed digester which is connected to a scrubber unit to capture

corrosive fumes emitted during the process. Digested samples were transferred to the distillation unit in which the addition of concentrated sodium hydroxide was performed to release ammonia gas. A receiving vessel with boric acid captures the ammonia gas as ammonium, which is then titrated to determine the TKN content.

### 3 Results

#### 3.1 Sample analysis

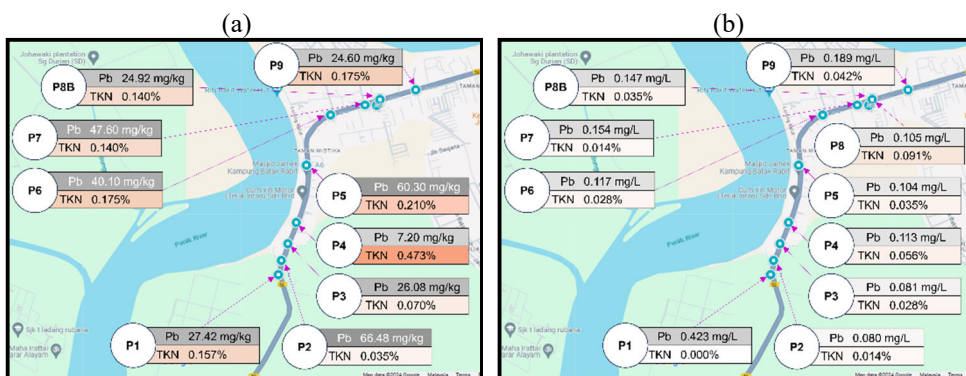
##### 3.1.1 Physical soil properties

Table 1 lists the median sizes ( $D_{50}$ ) of the soil samples at each sampling point. Most of the median sizes were below 1 mm, except for point P3 and P10. All of these median sizes fall within the range of 0.063 mm to 2 mm, which is classified as sand.

Also tabulated in Table 1, the moisture content of each soil sample indicated the amount of water retained by soils during this rainfall event. The moisture content was recorded as 7.51% as the lowest, up to a peak of 22.83%. These two extremes were just located at points next to one another, specifically P7 and P8. The variability of median size and moisture content showed the individuality of each specific sampling point and the difficulty in lumping them into one representative value.

**Table 1.** Physical soil properties (median size ( $D_{50}$ ) and moisture content) of collected soil samples.

| Soil sample | $D_{50}$ (mm) | Moisture content |
|-------------|---------------|------------------|
| P1          | 0.541         | 9.70%            |
| P2          | 0.560         | 16.85%           |
| P3          | 1.543         | 20.61%           |
| P4          | 0.619         | 12.05%           |
| P5          | 0.245         | 15.07%           |
| P6          | 0.659         | 22.18%           |
| P7          | 0.918         | 7.51%            |
| P8          | 0.319         | 22.83%           |
| P9          | 0.182         | 16.93%           |
| P10         | 1.065         | 9.70%            |



**Fig. 2.** Pb and TKN contents in (a) soil and (b) surface runoff samples within the mixed-use catchment in Teluk Intan, Perak.

### 3.1.2 Lead

The points along Jalan Maharajalela were annotated with their measured Pb content for both (a) soil and (b) surface runoff samples in Figure 2. Pb content ranges from 7.20 mg/kg to 66.48 mg/kg for soil samples. The lowest reading was recorded next to a residency. The maximum soil Pb content was located near a machinery factory. All soil Pb concentrations fell below a limit of 300 mg/kg, which represents the maximum allowable concentration of Pb in soil as specified by Chinese Environmental Quality Standard for Soils, grade II (GB15618-1995) [5] and European Union standards [6].

Surface runoff samples were found to contain Pb concentration from 0.080 mg/L to 0.423 mg/L. Runoff Pb was identified as the lowest at the same point where soil Pb content peaked. The highest runoff Pb content was measured near an electrical substation. The range of runoff Pb concentration resembles that of 0.007 mg/L to 0.422 mg/L measured by [7] at a residential catchment. In the subsequent year, [8] recorded similar maximum Pb concentrations of 0.30 mg/L, 0.43 mg/L and 0.46 mg/L in urban runoff at a residential-commercial catchment within their previous study site at Miri, Sarawak. In this study, all runoff Pb content exceeded Class III limit of Pb 0.02 mg/L according to the Department of Environment (DOE) National Water Quality Standard (NWQS) [9]. This indicates a need for extensive treatment if the runoff is routed to water supply bodies.

In their digested state, all sampling points showed a higher Pb content in soil compared to that in surface runoff. It indicates that a transfer of concentration occurred from the soil media to the runoff. Although both sample types did not exhibit similar trend along the sampling points, however, it is evident that surface runoff carried Pb concentration away from their sources. The soil complexity may also contribute to speciation and mobility of Pb, to dissolve into the contacted surface runoff.

### 3.1.3 Total Kjeldahl Nitrogen

Nitrogen exists in surface runoff as a wide range of chemical forms: nitrate, nitrite, ammonium, dissolved organic nitrogen and particulate organic nitrogen. Encompassing total organic nitrogen and ammonium, TKN measurement draws insight on the organic and ammonium content of soil and surface runoff in the study area. TKN content of soil samples ranged from 0.035% to 0.473%, which corresponds to 350 mg/kg to 4727 mg/kg. This range of TKN exceeded the range of 320 to 700 mg/kg recorded by [10] for one agricultural plot with Bermuda grass growing. The point of maximum TKN content coincided with the lowest Pb soil content, which is next to a residency. The least soil TKN was identified as the machinery factory location.

Surface runoff samples contained TKN starting from 0.000% to 0.091%. The highest TKN in runoff samples was identified in front of a bus stop. Similar to the soil findings, the least runoff TKN content was located nearby the electrical substation which recorded the maximum runoff Pb concentration.

Similar to the Pb analysis, TKN measurements were measured higher in soil samples compared to runoff samples. This finding solidifies the occurrence of cross media transfer, whereby nitrogen compounds were transferred across soil to surface runoff.

## 3.2 Simulation outcomes

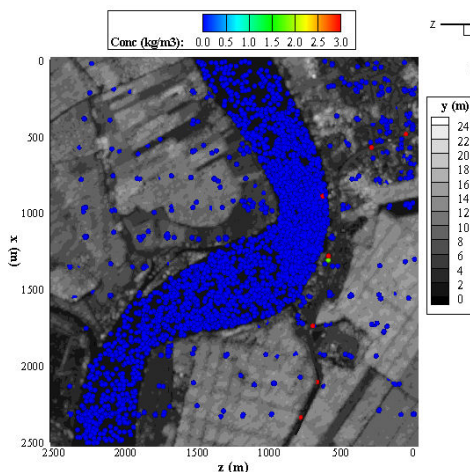
The laboratory analysis depicted discrete concentration at various points along the main road Jalan Maharajalela. A numerical model using SPH was used to simulate one rainfall event at the same catchment area to visualise pollutant transport from the ground source into surface runoff and towards the surrounding area. Pb was selected as the form of pollutant to be

simulated, with the main road acting as the source of Pb. Mean Pb concentration calculated from the analysed soil samples was assigned to the entire stretch of the main road. Despite the vast variability of parameter values shown by the analysis, a lumped or mean value is still adopted for the numerical simulation which serves as a preliminary study for transport pathway. The terrain particles were assigned with different moisture content depending on the land use type. The amount of runoff formed in excess of precipitation is determined by Soil Conservation Service (SCS) Curve Number (CN), which accounts for land use, soil cover and antecedent moisture level. CN values of 65 and 98 were assigned to agricultural land use and mixed urban land use, respectively.

Figure 3 illustrates the distribution of rain, runoff and Pb contaminated particles at a time of  $t=33.75$  min. Rain particles are generated a distance away from the ground and allowed to free fall. Upon reaching the ground, rain particles either infiltrate or move along the terrain, depending on the moisture content of that point. Terrain particles with sufficient rain particles infiltrated shall transform from unsaturated to saturated, which would then encourage runoff particles. Pools of runoff particles can be observed in the upper right zone, which represents mixed urban land use with lower moisture retention potential compared to the surrounding agricultural land.

The distribution of Pb contamination can be observed according to the colour gradient. Non-contaminated fluid particles are coloured in blue. The transition between blue and red indicates the concentration of Pb contamination, with red being the highest. Runoff particles which fell onto the contaminant source – main road, are marked as contaminated, with concentration transferred from terrain particles to the runoff particles.

One of the contaminated particles, coloured in red, can be observed in the river body next to the second highest runoff Pb concentration point P5. This marks one of the possible pollutant pathways, which is from land to water body. The SPH simulation indicated that these points close to the river bend may act as significant entry points of pollutants into the Perak River. From the surface runoff analysis, Pb concentration fell below  $0.423$  mg/ L, which indicated a restricted transfer from soil samples compared to the idealistic diffusion implied in the simulation. Although the simulation indicated an overestimation of the runoff Pb content, it was able to pinpoint affected locations affected by contamination with time.



**Fig. 3.** SPH simulation of Pb concentration distribution along a main road in Teluk Intan, Perak, Malaysia.

## 4 Conclusion

During a rainfall event in August 2023, soil and surface runoff samples were collected at a mixed-use catchment in Teluk Intan. Particle size distribution, moisture content, Pb and TKN analysis were conducted. All soil samples exhibited a median size of 0.063 mm to 2 mm, within the range for sand. Moisture content for soil samples started from 7.51% to a maximum of 22.83%. TKN varied from 0.035% to 0.473% for soil samples and 0.000% to 0.091% for runoff samples. The range of Pb was 7.20 mg/kg to 66.48 mg/kg for soil samples and 0.080 mg/L to 0.423 mg/L for runoff samples. The soil Pb concentration was regarded acceptable and well within the maximum allowable Pb concentration in soil of 300 mg/kg as set by Chinese Environmental Quality Standard for Soils, grade II (GB15618-1995) and European Union standards. With regards to DOE NWQS, runoff Pb content was above the Class III limit of 0.02 mg/L. A numerical simulation using SPH was conducted to illustrate the transport pathway of Pb pollutant within the same study area. Points adjacent to the riverbend are considered possible entry points for pollutants on the ground and into Perak River. Higher priority and caution could be imposed on these riverbend points for effective stormwater management plans, leading to enhanced environmental quality of both stormwater and river.

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