# IMPACT OF SULLAGE AND DIFFUSE POLLUTION LOADING ON THE HEALTH OF RIVER SYSTEM IN MALAYSIA

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## ABSTRACT

Increased urban activities are deteriorating the health of the rivers in Malaysia. Despite controlled measures taken by the government and other relevant authorities, pollution loading from point and diffuse (non-point) sources are affecting the rivers in various ways. The Department of Environment (DOE) Malaysia is doing its level best to control pollution from the industrial areas and wastewater treatment plants. However, there is lack of adequate enforcement in controlling sullage and diffuse pollution from various urban sources. Therefore, this study was conducted on domestic sewage, sullage and diffuse sources of an urban residential area to determine the pollution source that affects the health of the rivers in an urban area. It was calculated that TSS (78.4%), COD (51.8%), Pb (100%), Zn (80%), Cr (100%) and Cu (52.7%) were mostly generated from the diffuse pollution sources. This finding indicated that diffuse sources contributed more annual TSS, COD and heavy metal loads than point sources of the urban residential area. However, amounts of BOD (39.1%) and TDS (20%) loadings were less than those generated from the point sources. First flush phenomenon in the study area was weak and irregular. Capture of first flush only would not be effective for the control of diffuse pollution from the area. The median water quality index (WQI) of sullage during the working, weekend and non-working days were, 30.2, 31.2 and 26.8, respectively; which was equivalent to Class V of Malaysian Standards. The median WQI values of storm runoff during minor, medium and large rain events were 38.3, 44.1 and 39.9, respectively (Class IV); indicating an improvement of overall quality of wastewater discharged form the study area although annual pollution loading was high from the diffuse sources. Annual loading of sullage was, generally, higher than those of sewage. Therefore, pollution from sullage and diffuse sources need to be controlled to maintain good and healthy rivers in the urban areas.

**KEYWORDS:** Diffuse Pollution, Pollution Loading, Residential Area, River Health, Sewage, Sullage, Water Quality Index.

## INTRODUCTION

Rivers are degraded due to addition of pollutants from various types of point and non-point (diffuse) sources in the catchment. Increased urban and urbanising activities are deteriorating the health of the rivers in Malaysia. Despite controlled measures taken by the government and other relevant authorities, pollution loading from point and diffuse sources are affecting the river health in various ways. The Department of Environment (DOE) Malaysia is doing its level best to control pollution from the industrial premises and wastewater treatment plants. However, there is lack of adequate surveillance and enforcement in controlling sullage and diffuse pollution from various urban sources. Out of 120 main rivers monitored in the country, only 44.8% is identified as clean (DOE, 2004a). Domestic sewage treatment plants, industries, commercial areas and urban diffuse sources are the main cause of river pollution in the country (DOE, 2004b; 2003a, 2003b). Very limited information is available on the quality of runoff from agricultural and forested catchments. Sullage (grey-water) from residential and commercial activities is another source of pollution, which bypasses the sewage treatment plants and directly discharged in the river system. The impact of diffuse pollution from the urban and rural sources is realised by the government of Malaysia. As a result, the urban stormwater management manual is endorsed by the cabinet, in June 2000, for implementation in the country. However, the possible cumulative effect of sullage, especially on the urban rivers, is often neglected. Data on runoff quality and sullage form the urban areas in Malaysia, from a systematic and detailed study, is not available. Therefore, it was necessary to study the pollution characteristics from sullage and diffuse sources to evaluate the possible impact on the quality of rivers in the country. Quality water is important for good health. About 98% of the treated water is supplied form the rivers in Malaysia. Therefore, a healthy river is very important for potable and palatable water supply in the country. This study was conducted on domestic sewage, sullage and diffuse sources of an urban residential area to determine the pollution source that affects the health of the rivers in an urban area.

## METHODOLOGY

### The Study Area

The selected study area (6.14 ha) was located at Taman Sri Serdang, which is adjacent to University Putra Malaysia (UPM). It is a typical Malaysian "Taman" (park) type of urban area and consists of 283 units of single-story terrace houses. The housing area was built by the private developer in 1981. Sullage (grey-water) and storm runoff from this area are discharged, through concrete open drainage system, in a tributary of Kuyoh River. The total population in the area was surveyed to be 1415 (230 per ha). The drainage outlet of the study area was selected for sampling of sullage and storm runoff (Figure 1).

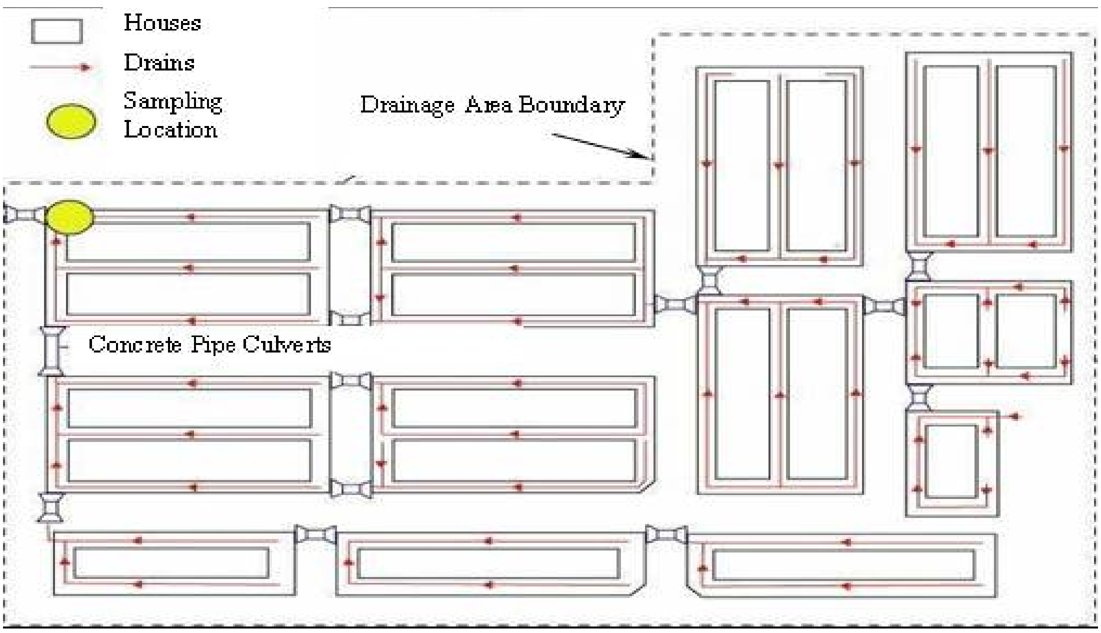



Figure 1. Schematic of the drainage system (not to scale)

## Field Survey

The study area was surveyed to delineate boundary of the catchment. It was verified that the runoff from nearby commercial lots does not enter into the selected drainage area. Slope of the outlet culvert was determined by conducting level survey. The Manning formula was used to calculate discharge rate. The Manning roughness "n" was calibrated by field measurements of discharge and water depth in the 1.23 m diameter outlet culvert. Questionnaires were used to evaluate environmental awareness and housekeeping practices of the residents.

## Sampling and Laboratory Works

Water level data was recorded every minute. Hourly samples were collected to characterise the sullage quantity and quality for one working day, one Saturday and one Sunday. Four aliquots of 250 ml samples were collected at 15-minute interval to prepare an hourly composite sample of sullage. Seventy two (72) samples were collected from the drainage outlet (Figure 1) within three days and sent to the laboratory for analyses of sullage quality. These data was used to determine the quality of runoff by deducting the sullage concentration from the combined quality of wastewater during storm events.

Twenty-four (24) samples were collected from the drainage outlet for each storm event. Non-uniform sampling intervals were chosen to cover the runoff hydrographs and also to suit the requirements of studying the first flush phenomenon. During the rainy days, the first 10 samples were collected at 1-minute interval, the next 9 samples at 3-minute and the rest 5 samples at 5-minute intervals. Flow-weighted samples were prepared for the determination of event mean concentration (EMC) of runoff quality. Ice cubes were placed inside the auto sampler to minimise the degradation of samples. The following parameters were tested using standard methods (APHA, 1998), calibrated sensors and instruments:

1. pH
2. Dissolved Oxygen (DO)
3. Turbidity
4. Total Dissolved Solids (TDS)
5. Biochemical Oxygen Demand (BOD)
6. Chemical Oxygen Demand (COD)
7. Total Suspended Solids (TSS)
8. Ammoniacal Nitrogen (AN)
9. Orthophosphate (OP)
10. Zinc (Zn)
11. Copper (Cu)
12. Total Chromium (Cr)

## Analytical Method

The event mean concentration (EMC) was computed as the total pollutant mass divided by the total runoff volume (Equation 1). As the samples during the rainy day were a mixture of sullage and runoff, EMC was calculated from the following equation:

$$EMC_{stormwater} = \frac{\Sigma Q_{total} C_{total} - \Sigma Q_{ww} C_{ww}}{\Sigma Q_{total} - \Sigma Q_{ww}} \qquad (1)$$

where, the subscripts "*ww*" and "*total*" denote the wastewater and the total (wastewater and stormwater) flows (*Q*) and concentrations (*C*). The sullage flow and concentration were measured during the dry weather whereas the total flow and concentration were measured during the rainy days. First flush was analysed by following the procedure mentioned by Bertrand-Krajewski et al. (1998).

Water quality index (WQI) was calculated using Equations 2 (DOE, 1994). Sub-indices were calculated by the equations proposed by the Department of Environment Malaysia. Six parameters, namely dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, (SS), ammoniacal nitrogen (AN) and pH, were considered for the evaluation of overall status of the river waters.

$$WQI= 0.22SIDO + 0.19SIBOD + 0.16SICOD + 0.15SIAN + 0.16SISS + 0.12SipH \quad (2)$$

Where, WQI is Water quality index; SI indicates sub-index of the six parameters considered in water quality index.

## RESULTS AND DISCUSSION

### Sullage Characteristics

Results of the questionnaire survey revealed that about 91% of the houses discharge sullage from washrooms and/or kitchens directly in the drains, which are mend for the conveyance of storm runoff only. Annual water consumption data collected from the water supply agency (PUAS) indicated that average monthly consumption, in the study area, was about 33 $m^3$/house. This was equivalent to 111,070 $m^3$ per year. From the analysis of mean daily hydrographs (Figure 2) the annual volume of sullage was calculated at 89,967 $m^3$. Therefore, it was found that 81% of the total water consumed was discharged as sullage and remaining 19% water went to the sewage treatment plant. This was an important finding, which indicated that a significant portion of the domestic water is discharged from the old housing areas as untreated sullage. The ratio of sullage to sewage may be different in other urban sub-catchments. However, the areas where all domestic wastewater are not connected to the sewage treatment plants, the proportion between sewage and sullage may be similar to what is found in this study.

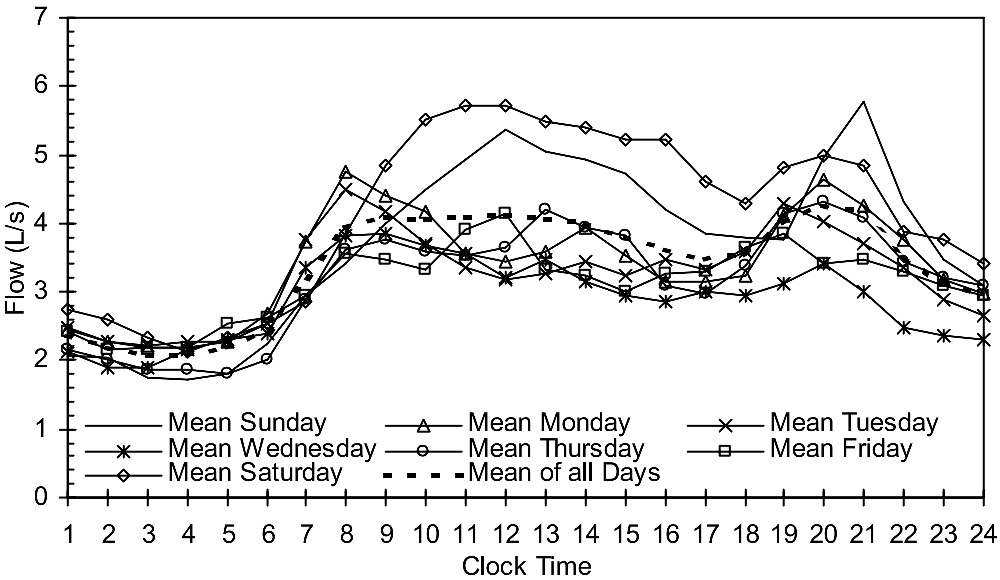
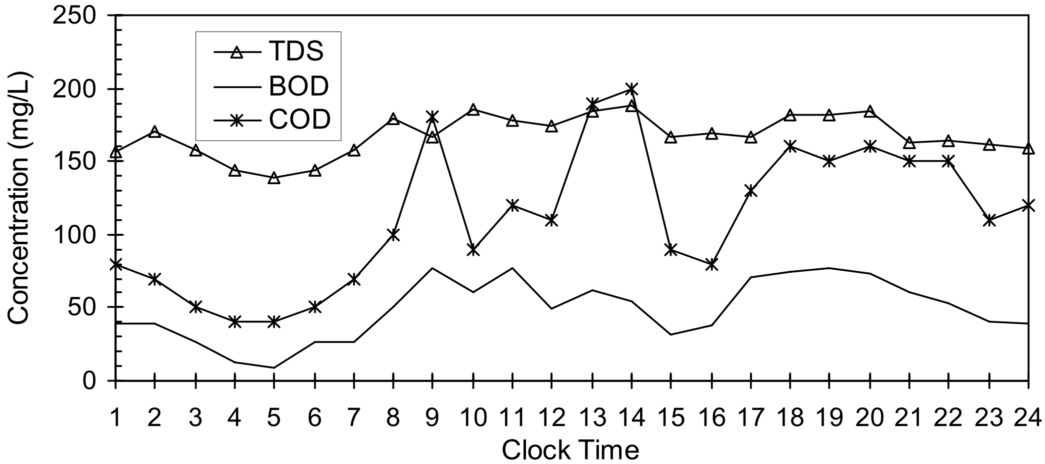


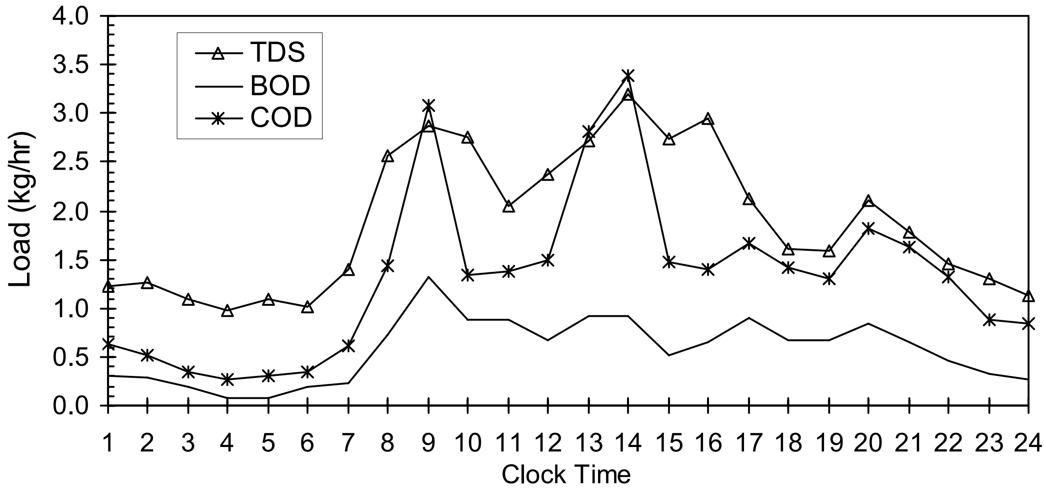

Figure 2: Flow Rate of Sullage from the Study Area.

Discharge of sullage was not constant throughout the day. The average hourly minimum & maximum sullage flow from the study area during working and non-working days were 2.07 & 4.05 L/s and 1.93 & 5.53 L/s, respectively. It was observed that the sullage flow was high in the weekends, which was in accordance with the response obtained from the public survey. Fluctuations were observed in the concentrations of the pollutants in a day. Hourly variation of pollutant concentrations of a few parameters are shown in Figure 3a. Pollutant concentrations were generally high during the high flow periods of each day.

Similar to the pollutographs, loadographs were also plotted for the selected pollutants in sullage (Figure 3b), to study the variation of pollutant loading due to sullage. Hourly pollution loads were calculated by multiplying the hourly concentration with hourly mean flow rate. The loadographs generally followed the pattern of flow hydrographs.




(a) Pollutograph




(b) Loadograph

Figure 3: Variation of TDS, BOD and COD of Sullage in a Working Day.

**Pollution from Sewage Sullage and Diffuse Sources**

Pollutographs and loadographs were constructed to study the runoff quality from the diffuse sources and effluent from the sewage treatment plant of the residential area. However, only grab samples were taken on three different days to study the pollution characteristics and to calculate the pollution loading from the domestic sewage of the study area. The sewage was partially treated by an oxidation pond (without any aerator). Therefore, effluent quality from other sewage treatment plants, which are equipped with aerators and other facilities, would be of better quality. It was calculated that untreated sullage, discharged form the domestic premises, were more polluted than sewage for TSS, BOD and COD (Table 1). Due to high discharge ratio, annual loading rate for the major pollutants were also higher for sullage. On the other hand, diffuse sources contributed more annual TSS, COD and heavy metal loads than point sources of the urban residential area. It was calculated that 78.4% of TSS, 51.8% of COD, 100% of Pb, 80% of Zn, 100 of Cr and 52.7% of Cu were generated from the diffuse pollution sources of the study area. Contribution of annual loading from the sources is shown in Figure 3.

Table 1: Mean Pollutant Concentration and Loading Rate from Sullage, Sewage and Runoff.

| Source | Pollutant Concentration | | | | | |
|---|---|---|---|---|---|---|
| | TSS (mg/L) | TDS (mg/L) | pH (Unit) | DO (mg/L) | BOD (mg/L) | COD (mg/L) |
| Sullage | 41 | 172 | 6.72 | 1.58 | 50 | 116 |
| Sewage | 39 | 295 | 7.23 | 1.10 | 31 | 97 |
| Runoff | 173 | 54 | 6.13 | 3.64 | 38 | 173 |
| Effluent Standard – A | 50 | NA | 6.0 – 9.0 | NA | 20 | 50 |
| Source | AN (mg/L) | Turbidity (NTU) | OP (mg/L) | Zn (mg/L) | Pb (mg/L) | Cu (mg/L) |
| Sullage | 4.90 | 35 | 2.05 | 0.064 | ND | 0.009 |
| Sewage | 18.17 | 50 | 2.39 | 0.190 | ND | 0.018 |
| Runoff | 0.75 | 46 | 0.29 | 0.306 | 0.057 | 0.021 |
| Effluent Standard – A | NA | NA | NA | 1.0 | 0.10 | 0.20 |
| Source | Loading Rate (kg/ha/yr) of Major Pollutants | | | | | |
| | BOD | TSS | COD | AN | OP | Zn |
| Sullage | 731 | 512 | 1733 | 72 | 29.45 | 0.80 |
| Sewage | 99 | 129 | 320 | 59 | 8.14 | 0.60 |
| Runoff | 534 | 2328 | 2208 | 11 | 4.76 | 5.61 |

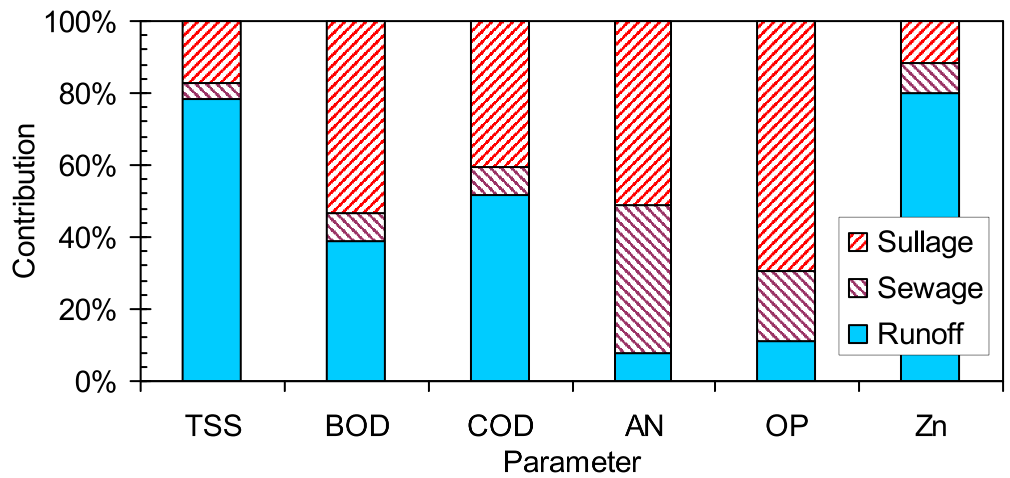



Figure 3: Ratio of Annual Pollution Loading from the Point and Diffuse Sources.

## First Flush and Control of Diffuse Pollution

Due to high annual rainfall, ranging between 1700 mm and 4000 mm (DID, 2000), annual pollution load generated from the urban residential areas of Malaysia is substantial compared to that produced form the point pollution sources (sewage and Sullage). Therefore, it is necessary to control pollution from the nonpoint sources through appropriate methods. Separation of first flush is considered a way to isolate the concentrated portion of runoff to minimise the treatment cost (Bertrand-Krajewski et al., 1998). This method would be effective if a significant amount of pollutant (e.g. 70% – 80%) can be captured by isolating small amount (20% – 30%) of the runoff volume. Due to torrential rainfall, nature of the first flush at the drainage outlet of the study area was weak and irregular (Figure 4). For instance, analysing Figure 4a, one can identify that about 70% of the runoff volume need to be isolated from the study area to capture 80% of the TSS. This is not in accordance with the philosophy of capturing fist flush from the runoff. Therefore, isolation of first flush only (20 – 30% of runoff volume) would not be sufficient to control diffuse pollution from the study area.

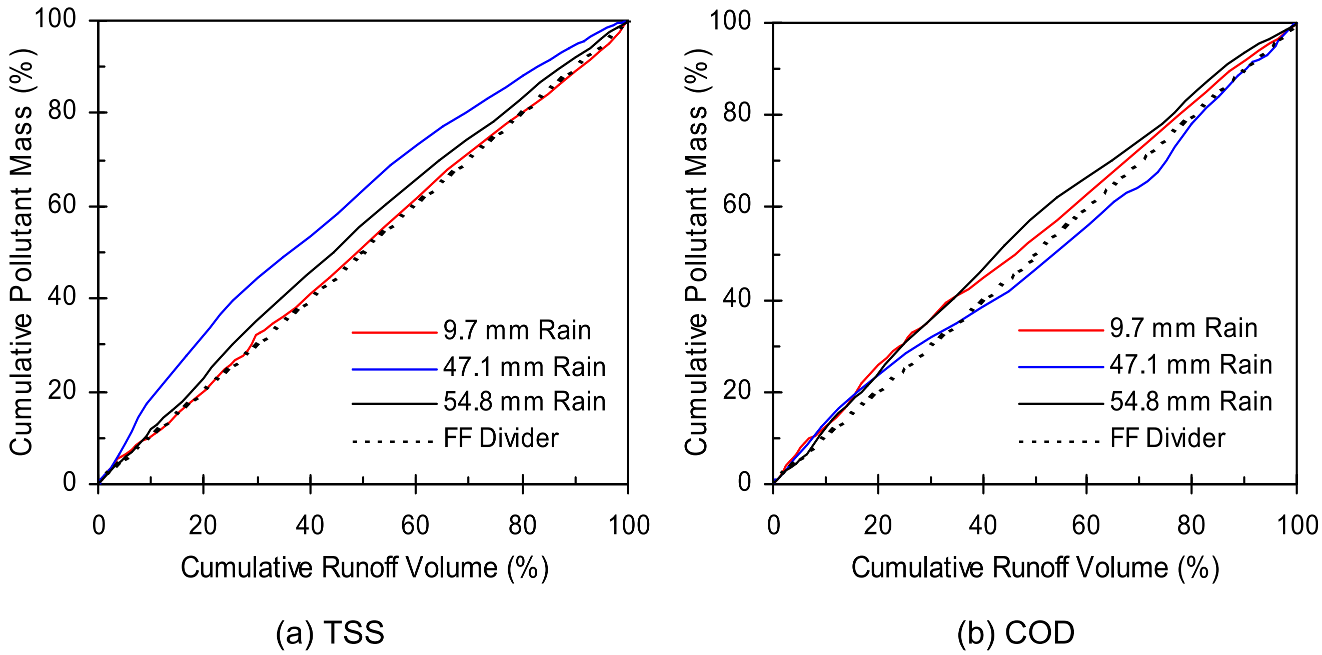



Figure 4: Typical Nature of First Flush in the Study Area.

## Water Quality Index (WQI)

Average quality of the water from sewage, sullage and diffuse sources was assessed based on the water quality index, as given in Equation 2. In terms of WQI values, quality of the waters in different days (working and non-working) was comparable (Table 2). The median water quality index of sullage during the working, weekend and non-working days was 30.2, 31.2 and 26.8, respectively; which was (on average) equivalent to Class V of Malaysian standards. The WQI values of storm runoff during minor, medium and large rain events were 38.3, 44.1 and 39.9, respectively (Class IV); indicating an improvement of overall quality of wastewater discharged from the study area although annual pollution loading was high from the diffuse sources. This improvement was due to the dilution of sullage due to addition of comparatively pure rainwater during the storm events. Quality of sewage from the oxidation pond was slightly better than that of sullage. However, concentrations of the pollutants were higher than the allowable standards (Table 1), indicating that the effluent need to be further treated before discharging in the river systems.

Environmental flow of the Kuyoh River is very low, due to urbanisation. The returned waters from sewage and sullage constitute major portion of the river flow. As such, it is highly important that the returned water is of better quality, to maintain better health of the river. Currently the river is so polluted that only Tilapia and hardy species of fish can be seen in the water. According to the local practice, the minimum WQI value for the suitability of raw water supply with is 51.9 (Class III). If the returned waters are not treated up to the quality of Class III, it may not be possible to maintain a healthy river, which has low environmental flow (baseflow).

Table 2: Water Quality Index (WQI) of Sullage, Sewage and Runoff.

| Sample | DO | BOD | COD | SS | AN | pH | Sub-indices | | | | | | WQI | Water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | Unit | DO | BOD | COD | AN | SS | pH | | Class |
| Sullage (Wednesday) | 1.60 | 50 | 110 | 32 | 4.93 | 6.76 | 11.6 | 8.7 | 17.4 | 0.0 | 80.1 | 98.7 | 30.2 | V |
| Sullage (Saturday) | 1.55 | 50 | 115 | 36 | 3.35 | 6.60 | 10.9 | 2.7 | 12.4 | 7.1 | 78.5 | 97.7 | 31.2 | IV |
| Sullage (Sunday) | 1.60 | 48 | 160 | 48 | 5.15 | 6.79 | 11.6 | 4.6 | 10.9 | 0.0 | 72.9 | 98.9 | 26.8 | V |
| **Sullage (Mean)** | **1.58** | **50** | **128** | **39** | **4.48** | **6.71** | **11.4** | **2.1** | **8.6** | **0.0** | **77.1** | **98.5** | **28.4** | **V** |
| Runoff (Minor Storm) | 2.85 | 33 | 190 | 103 | 0.64 | 6.36 | 32.6 | 17.7 | 5.8 | 58.4 | 56.8 | 95.6 | 38.3 | IV |
| Runoff (Medium Storm) | 3.73 | 38 | 155 | 118 | 0.41 | 6.08 | 50.1 | 10.0 | 8.2 | 66.4 | 56.0 | 92.1 | 44.1 | IV |
| Runoff (Major Storm) | 4.10 | 37 | 160 | 291 | 0.99 | 6.10 | 57.6 | 10.6 | 5.8 | 48.4 | 40.2 | 92.4 | 39.9 | IV |
| **Runoff (Mean)** | **3.56** | **36** | **168** | **170** | **0.68** | **6.18** | **46.7** | **11.5** | **0.6** | **57.1** | **51.5** | **93.5** | **40.6** | **IV** |
| Sewage (Friday) | 0.90 | 33 | 110 | 44 | 13.30 | 7.20 | 3.7 | 14.3 | 13.9 | 0.0 | 74.6 | 98.6 | 29.5 | V |
| Sewage (Saturday) | 1.30 | 32 | 90 | 38 | 18.20 | 7.12 | 7.8 | 15.9 | 21.5 | 0.0 | 77.3 | 99.0 | 32.4 | IV |
| Sewage (Sunday) | 1.10 | 28 | 90 | 36 | 23.00 | 7.36 | 5.6 | 21.0 | 21.5 | 0.0 | 78.2 | 97.7 | 32.9 | IV |
| **Sewage (Mean)** | **1.10** | **31** | **97** | **39** | **18.17** | **7.23** | **5.6** | **16.9** | **18.7** | **0.0** | **76.7** | **98.5** | **31.5** | **IV** |

## Probable Impact of Untreated Sullage and Runoff on River Health

Effluent from the sewage treatment plant at Taman Sri Serdang (the study area) is not properly maintained and it is also overloaded due to rapid growth of residential and commercial activities in the area. Therefore, sewage from the oxidation pond is of inferior quality compared to most of the new sewage treatment plants within the river basin. As such, one of the main concerns of this particular study was to characterise and quantify the pollution loading from the sullage and diffuse sources, and to anticipate the probable impact on the river health. These two sources are silently affecting the river system as waters are being released to the river without any treatment. Although concentrations of a few pollutants in sewage were higher than those of sullage (Table 1), annual pollution loads generated from the untreated sullage were higher than those of sewage. Low dissolved oxygen (DO), high BOD and COD rapidly decrease the oxygen content of the river making it difficult for the fish and other valuable aquatic fauna to survive. Ammonia ($NH_3$) from sullage would make the river water more toxic to the aquatic fauna and at high concentration photosynthesis of the aquatic plants can be inhibited. Orthophosphate would increase the nutrient content in the water and cause severe eutrophication or algal bloom. The main problem associated with the discharge of untreated runoff from the diffuse sources of the study area is the siltation in river bed with metal-laden sediments. Uncontrolled sediment from the urban areas destroys the habitat of the aquatic fauna and alters the morphology of the river systems, which in turn affect overall condition of the river. High turbidity due to direct discharge of runoff from the urban areas may block the fish gills and interrupt their respiration process.

The plausible impacts of discharging untreated sullage and runoff from the study area are inevitable for small urban rivers, where the environmental flow is small. However, monitoring of water quality parameters only may not detect the overall health condition of a river, due to degradations of physical habitat and flow modifications (Judy et al., 1984). Besides WQI, additional methods such as Index of Biological Integrity – IBI (An et al. 2002), Australian River Bioassessment System – AUSRIVAS (Hart, et al., 2001) could be used to evaluate overall condition of a river.

## CONCLUSIONS

Due to lack of public environmental awareness and surveillance activities by the enforcement authorities a significant portion of the waste water from the domestic premises is discharged untreated from the urban areas as grey-water or sullage. The situation is severe in the housing areas built before 1990s. The study conducted in a small urban residential area identified that about 81% of the palatable water is discharged in the Kuyoh River as untreated sullage. Concentration of BOD and COD in sullage was higher than those in the partially treated sewage discharged form the oxidation pond. However, the annual pollution load due to sullage was higher than that of sewage. Polluted storm runoff from the diffuse sources of the study area was another issue which was affecting the river system. Diffuse sources contribute more annual TSS, COD and heavy metal loads than point sources of the urban residential area. The first flush was irregular and weak in the study area and capturing first flush to minimise the effect of diffuse pollution on the river system would not be a viable option. Concentrations of many pollutants in sullage and runoff were unacceptable with respect to the effluent quality standard in Malaysia. Therefore, proper laws and enforcement should be devised to control pollution from sullage and diffuse pollution sources to maintain healthy river systems in the urban areas.

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