Hydrological and environmental assessment of urban growth in a sub-tropical town in India
Himanshu Joshi and Abdul Hameed M. Jawad Al Obaidy

ABSTRACT
Roorkee, a sub-tropical urban town in India, has shown a rapid unplanned growth in the past. This paper presents the findings of a study of characteristics of urban soil, rainwater, and runoff emanating from different sources areas and the stormwater flows in the drains. Urban soil showed significant increase in the concentration of all constituents in comparison to the nearby rural soil. Soil metal pollution index suggested multi-element contamination. The traffic and transportation system emerged as the major source of metals and organics. Concentration of rainwater ions was observed to follow the pattern Ca$^{2+} > $HCO$_3^-$ > Cl$^-$ > NO$_3^-$ > Na$^+$ > Mg$^{2+} > $SO$_4^{2-} > $K$^+$. Runoff results indicated a significant enhancement in the concentration of most measured constituents over their rainfall levels. The values of runoff coefficient varied between 0.05 and 0.58, with the high values displayed by the paved areas. Multiple regression equations were developed relating event mean concentration to various storm characteristics. The total load of all measured constituents was observed to vary considerably among the study sites, the direct runoff loads being much higher than the dry weather loads.

Key words | event mean concentration, rainwater quality, runoff coefficient, soil pollution index, stormwater flows, urban growth

INTRODUCTION
With the progressing urbanization, many types of generated contaminants get accumulated on the soil surface, move down to deeper layers and eventually change physicochemical soil properties directly or indirectly (Kim et al. 2002). Municipal, industrial and transportation sectors are reportedly the major sources of metals and organic pollutants (Banerjee 2005). Rainwater plays an important role in scavenging soluble components from the atmosphere. Runoff is a major carrier of a variety of contaminants accumulated on roads, parking lots, and is roofs and perceived as a major contributor to degradation of many urban streams (Pitt & Bozeman 1982).

Study area
Roorkee (Figure 1) is a medium-sized town located in Haridwar district of Uttarakhand state of India. The town, 274 metres above mean sea level, is situated within 29°51’’ N and 77°63’’ E on the right bank of Solani River, a tributary of the Ganga River. The coldest months are December and January, when the temperature may reach less than 5°C, while the summer season may observe a maximum temperature around 40°C. The monsoon season falls mainly during 15th June to 15th September. The average rainfall is about 1,100 mm. In the past 10 years, the population of Roorkee has grown by about 22% and the built-up area by about 60%, whereas the agriculturally productive land has decreased by about 49%. It may be noted that the industrial area within the municipal limits only houses small units, mainly falling in the electronics sector. A few other small metal-based, equipment manufacturing and fabrication, electroplating, ice production and automotive components units are scattered within the municipal area. Also, the town does not have a sewage treatment plant to date. Liquid and solid waste is collected and taken out of municipal limits for disposal. The growth has mostly been unplanned and haphazard.
METHODS

The study area was divided into three main types of land use, viz. residential, commercial and industrial, and two main source areas within each type of land use, viz. roadside and open areas. National highway, which passes through this area, was considered as an independent land use and source area. From each source area, 15 soil samples were collected from an area of 20 × 20 cm and from a depth ranging up to 15 cm, using a stainless steel spatula and were kept in clean self-sealing plastic bags. They were air-dried in the laboratory, and passed through a 2 mm sieve after they had been disaggregated with a porcelain pestle and mortar. The composite samples were then prepared for each source area of each land use type by mixing an equal weight of each sample of the concerned source area to obtain one sample. These samples were stored in clean self-sealing plastic bags for further analysis.

Rainwater samples were collected in polyethylene bottles through funnels (14.0 cm dia.) which were placed on the roof of the buildings. The collectors were deployed as soon as rain began and retrieved immediately after it stopped. The samples were brought to the laboratory for analysis.

Simple sampling devices were fabricated to contain one polyethylene and one glass bottle (5.0 and 2.5 L respectively). The samplers were installed below the ground at strategic sampling locations so that the runoff would enter the samples bottle by gravity. The bottles were removed immediately after stoppage of runoff. All samples were preserved in the field, whenever needed, and brought to the laboratory for analysis. Internationally accepted practices were followed for soil and water analyses (Jackson 1973; Standard Methods for the Examination of Water and Wastewater 1998).

RESULTS AND DISCUSSION

Urban soil

Table 1 shows neutral to sub-alkaline condition for the urban soil pH, which is in agreement with its calcareous nature (Govinda Rajan & Gopala Rao 1978; Jim 1998). Comparison of source areas indicates that roadside soil displayed higher pH values than open area soil. Also, commercial open area soil displayed higher pH value than residential and industrial open area soils. Higher electrical conductivity (EC) values were observed in the urban area soil in comparison to the nearby rural area soil, which highlights anthropogenic impact clearly.

With exception of industrial roadside soil samples, the concentration of NO3-N and total Kjeldahl nitrogen (TKN) was observed to be higher in open areas than roadsides. Roadside soil exhibited higher values of PO4-P and total phosphorus (TP) (except industrial area) than open area soil. For roadside soil, the commercial area displayed higher values of PO4-P and TP. The source of phosphorus in roadside soil could possibly be the dispersion of additives in motor oil as it has earlier been reported that calcium compounds control solubility of phosphorus in calcareous soil, and organic matter contributes to phosphorus adsorption (Novotny & Chesters 1981).

Soil organic carbon was observed to vary widely among various types of land use. Whereas residential and commercial roadside soil exhibited higher values than open area soil, the pattern was reversed in industrial land use. Total organic carbon (TOC) values around 0.88% have been reported for urbanized locations in Hong Kong by Jim (1998), who has also suggested that TOC below 4% should be rated as low for tropical soil.

With the exception of industrial open area soil, Zn emerged as the dominant metal, while Cd had the lowest concentration in soil in all types of land use. Most of the measured heavy metals displayed higher concentration than in rural (control) soil. Concentrations of Cd, Cu, Ni and Zn were even observed higher than the average mean (calculated for the world scale) reported for unpolluted soils (Kabata-Pendias & Pendias 1992).

Soil pollution index

It is generally agreed that most metal contamination in the surface environment is associated with a cocktail of contaminants rather than one metal. Thus, many workers have used a pollution index of soil to identify multi-element
### Summary of soil-quality data (mean ± SD values)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Residential land use</th>
<th>Commercial land use</th>
<th>Industrial land use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roadside</td>
<td>Open area</td>
<td>Roadside</td>
</tr>
<tr>
<td>pH</td>
<td>7.62 ± 0.16</td>
<td>7.54 ± 0.34</td>
<td>7.75 ± 0.17</td>
</tr>
<tr>
<td>EC (mmhos/cm)</td>
<td>0.65 ± 0.19</td>
<td>0.81 ± 0.55</td>
<td>0.91 ± 0.30</td>
</tr>
<tr>
<td>Ca$^{2+}$ (mg/kg)</td>
<td>211.65 ± 77.18</td>
<td>299.48 ± 201.98</td>
<td>283.09 ± 123.70</td>
</tr>
<tr>
<td>Mg$^{2+}$ (mg/kg)</td>
<td>91.13 ± 23.27</td>
<td>115.96 ± 94.12</td>
<td>127.94 ± 94.49</td>
</tr>
<tr>
<td>K$^+$ (mg/kg)</td>
<td>164.75 ± 88.29</td>
<td>128.38 ± 102.92</td>
<td>290.88 ± 76.58</td>
</tr>
<tr>
<td>Na$^+$ (mg/kg)</td>
<td>225.70 ± 97.15</td>
<td>266.38 ± 179.03</td>
<td>296.75 ± 85.43</td>
</tr>
<tr>
<td>HCO$_3^-$ (mg/kg)</td>
<td>944.64 ± 408.09</td>
<td>1165.34 ± 886.84</td>
<td>1606.50 ± 592.56</td>
</tr>
<tr>
<td>Cl$^-$ (mg/kg)</td>
<td>512.34 ± 235.68</td>
<td>587.28 ± 445.93</td>
<td>556.11 ± 163.70</td>
</tr>
<tr>
<td>NO$_3$-N (mg/kg)</td>
<td>224.80 ± 235.79</td>
<td>305.12 ± 303.67</td>
<td>203.34 ± 165.53</td>
</tr>
<tr>
<td>PO$_4$-P (mg/kg)</td>
<td>4.32 ± 1.53</td>
<td>2.86 ± 1.20</td>
<td>15.31 ± 6.38</td>
</tr>
<tr>
<td>TP (mg/kg)</td>
<td>29.18 ± 13.66</td>
<td>18.62 ± 9.37</td>
<td>61.65 ± 25.46</td>
</tr>
<tr>
<td>TKN (mg/kg)</td>
<td>66.69 ± 30.92</td>
<td>84.19 ± 48.19</td>
<td>117.50 ± 37.29</td>
</tr>
<tr>
<td>TOC (%)</td>
<td>0.97 ± 0.12</td>
<td>0.62 ± 0.29</td>
<td>1.01 ± 0.27</td>
</tr>
<tr>
<td>Cd (mg/kg)</td>
<td>2.25 ± 0.65</td>
<td>1.20 ± 0.52</td>
<td>3.90 ± 1.40</td>
</tr>
<tr>
<td>Cr (mg/kg)</td>
<td>10.50 ± 11.67</td>
<td>6.00 ± 3.59</td>
<td>5.50 ± 4.60</td>
</tr>
<tr>
<td>Cu (mg/kg)</td>
<td>136.25 ± 54.10</td>
<td>68.00 ± 47.42</td>
<td>239.00 ± 27.69</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>259.00 ± 79.76</td>
<td>360.25 ± 51.35</td>
<td>423.75 ± 172.04</td>
</tr>
<tr>
<td>Ni (mg/kg)</td>
<td>27.36 ± 3.23</td>
<td>34.50 ± 11.27</td>
<td>38.61 ± 14.19</td>
</tr>
<tr>
<td>Pb (mg/kg)</td>
<td>24.50 ± 6.86</td>
<td>11.50 ± 6.28</td>
<td>29.93 ± 19.26</td>
</tr>
<tr>
<td>Zn (mg/kg)</td>
<td>395.88 ± 232.13</td>
<td>519.00 ± 494.18</td>
<td>1198.75 ± 414.86</td>
</tr>
</tbody>
</table>
contamination resulting in increased metal toxicity (Chon et al. 1998). Pollution index can be computed as

\[
\text{Pollution index (PI)} = \frac{\sum \text{(metal content in soil/ permissible level of metal)}}{\text{number of metals}}
\]

A value of pollution index more than 1 exhibits a multi-element contaminated soil recommended for treatment, whereas a value less than 1 indicates single metal contamination. The results for roadside soils, open area soils and composite urban soil samples were 1.73, 1.21 and 1.47 respectively, highlighting multi-element contamination.

**Rainwater**

The pH values were higher than 5.6, which is the pH of cloud water at equilibrium with atmospheric CO₂. The rainwater alkalinity is due to the high loading of particulate matter in the atmosphere, a condition which is quite common in India (Khare et al. 2004). The suspended particulate matter that is rich in carbonate and bicarbonate of calcium buffers the acidity of rainwater (Kulshrestha et al. 2003).

In India, pH between 6.0 and 7.5 has been reported in urban areas (Khemani et al. 1989) and 5.22–7.65 in forested area (Rao et al. 1995). Assuming that rainwater acidity originates primarily from sulfuric acid and nitric acid and neutralization by Ca²⁺ and Mg²⁺, the ionic ratio of \((SO_4^{2-} + NO_3^-)/(Ca^{2+} + Mg^{2+})\) can be considered as an indicator for acidity. If this ratio is less than 1, it indicates alkaline nature and, if greater than unity, it indicates the presence of free anions responsible for rainwater acidity. The value for this study was 0.54 against 2.99 for Delhi, where acid rain occurred in 18% of events (Kulshrestha et al. 1995) and 1.06 for Korba (Chandravanshi et al. 1997), where acid rain occurs generally. The average relative magnitude of ionic species (concentration) in rainwater followed the order \(Ca^{2+} > HCO_3^- > Cl^- > NO_3^- > Na^+ > Mg^{2+} > SO_4^{2-} > K^+\). Low Cl⁻ and Na⁺ values were in agreement with the inland site, very much away from the sea. Also, low \(SO_4^{2-}\) concentration highlighted no significant industrial source.

**Source area runoff**

Runoff pH values (Table 2) were within the range of 6.5–8.5. Industrial street runoff reflected largest values of pH, even higher than the highway runoff. The neutral to sub-alkaline pH appears to be derived from the chalk-derived soils and weathering of fresh concrete in the catchment.

The street runoff displayed higher values of total dissolved solids (TDS) than the open area runoff, with commercial street runoff displaying the highest values of TDS. The main sources of total suspended solids (TSS) include wet and dry deposition, pavement wear of road and vehicles, construction operation and erosion of pervious area by wind and water (Ball et al. 1998). Street and highway runoff emerged as the major sources of TSS.

\(Ca^{2+}\) and \(HCO_3^-\) were the dominant ions, possibly due to high content of CaCO₃ in the study area soils and calcite dust deposited on the urban surfaces. Whereas residential and commercial street runoff displayed higher values of all major ions than open area runoff, industrial land use runoff displayed a totally opposite pattern. This could be due to solid waste dumping in the open areas within the industrial estate. Comparison among all source areas indicates that generally all major dissolved ions displayed higher values in the commercial street and open area runoff.

The nitrogen sources in stormwater include fertilizer, animal dropping, combustion of fossil fuels and fallen leaves (Makepeace et al. 1995). For \(NO_3^-\), commercial and industrial open areas displayed higher values than street runoff. The highway runoff exhibited the largest values of \(NO_3^-\). Residential open area runoff was observed to carry more TKN, whereas in commercial and industrial land use, street runoff exhibited more TKN. \(NO_3^-\) and TKN concentrations in the runoff emanating from all source areas were observed to be high enough to allow abundant algal growth in the receiving surface water bodies (Crawford 1985).

Sources of phosphorus generally include atmospheric deposition, domestic and agricultural fertilizers, industrial wastes, detergents and lubricants (Makepeace et al. 1995). Tree leaves also can contribute a large quantity of phosphorus since they are 90–95% organic and contain significant amount of phosphorus (Novotny & Chesters 1981). High values of \(PO_4^-\) were exhibited by the commercial street and open area runoff. Highway runoff exhibited the largest values of \(PO_4^-\) amongst all street runoff samples. The phosphorus concentration observed in the runoff emanating from all source areas would also be sufficient to support a high algal productivity level in the receiving surface water bodies (Crawford 1985).

With the exception of industrial land use, the street runoff displayed higher values of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and TOC than open area runoff. Sources of oil and grease in the study area include food processing and preparation,
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Residential land use</th>
<th>Commercial land use</th>
<th>Industrial land use</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Street</td>
<td>Open area</td>
<td>Street</td>
<td>Open area</td>
</tr>
<tr>
<td>pH</td>
<td>7.44 ± 0.49</td>
<td>7.36 ± 0.51</td>
<td>7.54 ± 0.40</td>
<td>7.50 ± 0.06</td>
</tr>
<tr>
<td>EC (µhos/cm)</td>
<td>220.81 ± 128.59</td>
<td>150.33 ± 113.02</td>
<td>511.14 ± 192.63</td>
<td>525.50 ± 170.85</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>139.19 ± 83.07</td>
<td>95.78 ± 67.65</td>
<td>342.57 ± 140.49</td>
<td>342.50 ± 117.93</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>504.69 ± 512.88</td>
<td>1100.33 ± 1196.01</td>
<td>824.86 ± 441.34</td>
<td>858.00 ± 446.30</td>
</tr>
<tr>
<td>Ca²⁺ (mg/L)</td>
<td>18.50 ± 5.78</td>
<td>16.11 ± 11.73</td>
<td>41.66 ± 18.97</td>
<td>34.89 ± 13.42</td>
</tr>
<tr>
<td>Mg²⁺ (mg/L)</td>
<td>6.98 ± 4.75</td>
<td>3.40 ± 3.21</td>
<td>11.41 ± 4.57</td>
<td>12.60 ± 4.49</td>
</tr>
<tr>
<td>K⁺ (mg/L)</td>
<td>7.47 ± 5.37</td>
<td>6.41 ± 4.71</td>
<td>23.1 ± 18.67</td>
<td>34.20 ± 21.60</td>
</tr>
<tr>
<td>Na⁺ (mg/L)</td>
<td>7.85 ± 7.50</td>
<td>4.63 ± 5.85</td>
<td>35.61 ± 20.80</td>
<td>32.10 ± 10.42</td>
</tr>
<tr>
<td>HCO₃⁻ (mg/L)</td>
<td>95.55 ± 44.51</td>
<td>69.87 ± 54.37</td>
<td>147.25 ± 82.82</td>
<td>264.07 ± 45.05</td>
</tr>
<tr>
<td>Cl⁻ (mg/L)</td>
<td>11.00 ± 7.84</td>
<td>6.78 ± 6.02</td>
<td>54.71 ± 32.05</td>
<td>40.80 ± 5.34</td>
</tr>
<tr>
<td>NO₃-N (mg/L)</td>
<td>3.44 ± 1.22</td>
<td>3.22 ± 1.31</td>
<td>5.75 ± 4.19</td>
<td>5.97 ± 1.55</td>
</tr>
<tr>
<td>PO₄-P (mg/L)</td>
<td>1.23 ± 0.65</td>
<td>1.93 ± 1.54</td>
<td>2.24 ± 1.22</td>
<td>2.53 ± 0.30</td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>2.56 ± 1.54</td>
<td>3.59 ± 1.57</td>
<td>6.96 ± 1.32</td>
<td>4.90 ± 0.59</td>
</tr>
<tr>
<td>TKN (mg/L)</td>
<td>4.32 ± 2.62</td>
<td>3.67 ± 1.78</td>
<td>7.21 ± 3.03</td>
<td>4.22 ± 1.05</td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>64.16 ± 47.61</td>
<td>72.87 ± 61.93</td>
<td>113.76 ± 60.28</td>
<td>83.73 ± 105.10</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>106.77 ± 72.26</td>
<td>129.91 ± 96.74</td>
<td>207.60 ± 102.65</td>
<td>137.10 ± 126.81</td>
</tr>
<tr>
<td>TOC (mg/L)</td>
<td>15.85 ± 13.16</td>
<td>16.65 ± 19.08</td>
<td>38.91 ± 21.26</td>
<td>31.39 ± 20.09</td>
</tr>
<tr>
<td>Oil &amp; grease (mg/L)</td>
<td>2.65 ± 1.58</td>
<td>2.69 ± 4.27</td>
<td>5.37 ± 5.47</td>
<td>1.45 ± 0.52</td>
</tr>
<tr>
<td>Cr (µg/L)</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Cu (µg/L)</td>
<td>76.50 ± 53.35</td>
<td>108.78 ± 42.28</td>
<td>613.00 ± 926.79</td>
<td>366.00 ± 55.91</td>
</tr>
<tr>
<td>Mn (µg/L)</td>
<td>437.00 ± 652.06</td>
<td>475.89 ± 73.14</td>
<td>1464.29 ± 1463.62</td>
<td>619.75 ± 185.64</td>
</tr>
<tr>
<td>Ni (µg/L)</td>
<td>ND</td>
<td>ND</td>
<td>44.71 ± 78.94</td>
<td>42.25 ± 28.56</td>
</tr>
<tr>
<td>Pb (µg/L)</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Zn (µg/L)</td>
<td>161.50 ± 875.65</td>
<td>131.78 ± 55.65</td>
<td>196.00 ± 216.07</td>
<td>261.00 ± 99.02</td>
</tr>
</tbody>
</table>

ND: not detected.
operation and maintenance of vehicles and machinery, and natural compounds leached from vegetative plant litter. The highways contributed much higher value of oil and grease in comparison to streets in general.

Street and open area runoff emanating from the industrial and commercial land use contained significant concentration of Cu, Mn, Ni and Zn, while highway was the main contributor of Cr and Pb. Industrial, commercial and transportation activities in the study area were apparently associated with elevated concentration of the observed heavy metals in runoff.

A significant change in composition of water takes place apparently upon a change in its form from rainwater to runoff water, due to the effect of the accumulated pollutants on the urban surfaces or due to erosion from local soils (Gallo et al. 2013). In order to explain the magnitude of change in quality of water during this transformation, runoff-rainfall water quality ratios were calculated for all constituents considering their median values as

\[
\text{Runoff rainfall water quality ratios} = \frac{\text{Constituent concentration in runoff}}{\text{Constituent concentration in rainfall}}
\]

A closer look at the runoff–rainfall quality ratios indicates that impact on the quality of surface runoff is clearly evident with metals displaying distinctly higher buildup followed by suspended solids, major ions, organics and nutrients respectively. Figure 2 displays the buildup in organic matter.

Stormwater flows in drains

During the monsoon season, 17 events were monitored over a 2-year period. Physicochemical analyses were performed on composite discharge-weighted samples as well as the discrete water samples for monitored events. The dry weather drain flow data monitored during the pre-monsoon period were used to separate the direct (overland) runoff during storm events. The data of direct runoff and the net peak discharge during storm events along with the measured rainfall data were used to estimate rainfall–runoff relationships and the volumetric and peak discharge coefficients.

An accurate estimation of the runoff coefficient is the most important task of the entire calculation, as can be seen when considering the difference in runoff coefficient values among these methods. The values of volumetric runoff coefficient vary between 0.05 and 0.56 with the area weighted mean of 0.22, while the values of site runoff coefficient vary between 0.05 and 0.58 with the area weighted mean of 0.18 (Chow et al. 1988; Bedient & Huber 2002). The highest runoff coefficient was displayed by the catchment that has a high percentage of paved surface. The runoff coefficient at peak discharge, as calculated using rational equation, varied between 0.09 and 0.91 with area weighted mean of 0.34. The highest value was again displayed by the most paved catchment.

Multiple regression equations were developed relating event mean concentration (EMC) values to storm characteristics. The concentration data of flow weighted composite samples were used to calculate the EMC. Table 3 represents the equations resulting from a stepwise regression which ensured that all independent variables were tested (F-test) at a 0.05 level of significance and the insignificant variables were omitted.

Load of constituents for various runoff periods was also calculated (Striegel & Cowan 1987) as below

$$LD = \sum (c_i Q_i \Delta t_i) \times 10^{-3}$$

where LD = load, in kilograms; $c_i$ = concentration of constituent in sample i, in mg/L; $Q_i$ = mean discharge during the time interval representing sample i, in m$^3$/sec; $\Delta t_i$ = time interval that represents sample i, concentration $c_i$, and mean discharge $Q_i$, in second; $10^{-3}$ = coefficient for converting cubic metres to litres and milligrams to kilograms.

The total load of all measured constituents was observed to vary considerably among study sites. Further, at all the study sites, the direct runoff-imparted loads were observed to be much higher than the dry weather loads. Industrial catchment displayed higher load of NO$_3$-N, PO$_4$-P, TP, TKN, BOD, COD and oil and grease, while commercial catchment, with high percentage of paved surfaces, exhibited the largest load of TSS and TOC.

A power relationship between pollutant load and runoff has been most widely adopted for estimation of pollutant export (Chiew & McMahon 1999), as described in the following equation:

$$LD = \alpha V^\beta$$

where $LD$ = pollutant load (kg/ha), $V$ = runoff volume (mm).

The coefficients $\alpha$ and $\beta$ are determined using a log transform and linear regression. Coefficient $\alpha$ indicates the dry weather pollutant load, whereas $\beta$ reflects runoff response to the storm event. The findings suggest that all $\beta$ values (1.34–2.58) are much higher than corresponding $\alpha$ values (0.0005–1.68), indicating a significant influence of storm runoff response in comparison to the dry weather pollutant loads.

**CONCLUSIONS**

The findings have reflected high anthropogenic influence of the urban growth in the Roorkee town on the quality of its soil, surface runoff and stormwater. The system apparently faced an intense pressure along with a steep rise in related domestic, commercial and industrial activities. Better environmental planning and management of resources and
waste products appear to be a crucial need of the hour (Todeschini et al. 2012).

REFERENCES

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