6

Land use and urban stormwater quality

6.1 Background

In Chapter-5, the role of rainfall characteristics on urban stormwater quality has been discussed. Many researchers have pointed out that land use plays an important role in determining stormwater quality [6, 68, 204]. Concentrations of pollutants in stormwater runoff have a close relationship with the types of land use because the nature of human/ anthropogenic activities is different according to land use [6]. Thus, the land use practices in a catchment significantly influence the generation and accumulation of pollutants on the catchment surface and eventually, the wash-off [204]. It is important to further investigate the role of land use on stormwater quality to understand the stormwater treatment and management processes.

According to literature, stormwater quality is multifaceted and therefore, a limited number of factors may not be adequate to explain the complexity of stormwater quality [205]. Liu and his co-authors confirmed that land use and impervious fraction alone are inadequate to provide detailed understanding about the characteristics of stormwater quality [153]. Site specific factors also plays significant role in characterizing stormwater quality. Stormwater quality can vary within a particular land use with a range of site specific factors such as urban form and pervious area location [11]. Therefore, investigating the variability of stormwater pollutants within the same land use is also an important necessity to know the influence of other site specific factors on stormwater quality. Thus, this chapter mainly focuses on the investigation of the variability of pollutants with different land use and within the same land use practices.

6.2 Selection of stormwater pollutants

In urban areas, deterioration of stormwater results from the introduction of pollutants. A variety of pollutants accumulate on urban impervious surfaces during the dry days due to both natural and anthropogenic activities which are common in the urban areas. These pollutants are washed into water bodies during storm events and degrade the quality of receiving water [6]. The degree of degradation depends on the nature of the pollutants in the wash-off and the pollutant loads. The important pollutants in stormwater responsible for the degradation of receiving water quality are solids, nutrients and organic matter [11]. Suspended solids play a significant role in stormwater pollution as other pollutants such as heavy metals and nutrients can attach to solid particles [106, 107]. Reports suggested that the primary pollutants in urban stormwater are suspended solids, organic carbon, hydrocarbons, nutrients and heavy metals [35, 99].

Keeping the above facts in mind, the stormwater quality parameters selected for monitoring in this work were-

(i) Nitrate (NO_3^-),

(ii) Phosphate (PO_4^{3-}),

(iii) Oil and grease (OG),

(iv) Total suspended solids (TSS) and

(v) Heavy metals viz. cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb) and zinc (Zn).

Detailed procedures for the analysis of these pollutants are discussed in Chapter-4.

6.3 Analysis of stormwater quality

The stormwater quality data set is analysed to understand the influence of land use on stormwater quality. The original dataset is given in Appendix B. The results obtained for the different parameters and their variation with different land uses are discussed in this chapter.

6.3.1 Nutrients (PO_4^{3-} and NO_3^-)

Nutrients that play a vital role in the degradation of receiving water quality are nitrogen and phosphorous [126]. In stormwater runoff, nitrogen and phosphorous can be available in both organic and inorganic forms [1]. The most important forms of nitrogen in terms of water quality impact are ammonium and NO_3^- [129] and the most dominant forms of phosphorous in water is PO_4^{3-} [130]. Therefore, in the present study, the nutrients selected for the analysis are NO_3^- and PO_4^{3-}. Concentrations of PO_4^{3-} and NO_3^- from different land use types are presented in Table 6.1 and Table 6.2 respectively.

The sources of nutrients in urban stormwater are fertilizer applications, plant matter, vehicular activities and atmospheric deposition [129]. Goonetilleke and Thomas have also shown that the primary sources of nutrients in urban stormwater runoff could be lawn fertilizer, animal waste, vegetation debris, vehicle exhausts, sewer overflows, power generation, industrial activities and atmospheric dry and wet deposition [22]. Dry and wet precipitation, lawns and other soils within the catchment, fertilizers, leaf litter, organic decomposition processes, pets, and wildlife may release nitrogen and phosphorus to the urban environment [130]. In a residential area, lawns could contribute to more than 50% of annual total phosphorous (TP) loads [135].

Atmospheric deposition is also an important source of nutrients in stormwater as it inputs both nitrogen and phosphorous to urban stormwater runoff. Atmospheric deposition supplies a larger proportion of nitrogen in urban runoff in comparison to phosphorous [136]. Wet atmospheric deposition alone is attributed to 28% of nitrogen loading in stormwater [206]. The species of nitrogen found mainly in atmospheric deposition are NO_3^- and ammonia. In comparison to ammonia, NO_3^- have high atmospheric lifetime [94] which means that NO_3^- is the dominant form of nitrogen present in atmospheric deposition. Nitrogen can exist in both dissolved and particulate phases in surface runoff [126] and the most important form of nitrogen in water is NO_3^-.

Table 6.1 Concentration of PO_4^{3-} in stormwater

Land use	PO_4^{3-} (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.32	1.05	0.67	0.26
Commercial land use	0.18	0.86	0.61	0.20
Industrial land use	0.22	1.45	0.84	0.36
Heavy traffic Zone	0.25	0.84	0.55	0.19

Table 6.2 Concentration of NO_3^- in stormwater

Land use	NO_3^- (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	4.21	17.21	10.29	3.87
Commercial land use	5.47	22.02	12.27	5.17
Industrial land use	4.87	24.65	14.05	5.48
Heavy traffic Zone	3.49	11.98	5.98	2.86

Phosphorus in aquatic systems is present almost exclusively as PO_4^{3-} and occurs in water in both particulate (>0.45 μm) and dissolved forms [130]. Particulate phosphorous has a tendency to adsorb onto soil particles and therefore it is transported to surface water via soil erosion. Thus, the sediments play an important role in the delivery of particulate phosphorous to the receiving waters [68]. Phosphorous loads would be high in the areas with high sediment loads.

From Table 6.1 and Table 6.2, it is observed that the concentration of PO_4^{3-} and NO_3^- varies considerably in the stormwater with different land use practices. This is shown in Fig. 6.1 and Fig. 6.2 respectively. The figures reveal that the industrial area has the highest concentration for both PO_4^{3-} and NO_3^- in comparison to the other three land use types. The sources of PO_4^{3-} and NO_3^- in the industrial land use area under the present study (Noonmati) can be leaf litter, industrial waste water, industrial emissions and atmospheric deposition.

Due to the presence of intensive tree canopy in the surrounding areas of the industrial land use area, it can be postulated that the primary source of PO_4^{3-} and NO_3^- in this area is plant materials such as leaf litters and other similar organic materials. Various reports have also identified grass clippings and leaves as a significant source of nutrient to stormwater [100, 207]. The main sources of nutrients in other land uses can be residential sewage, human excreta due to the failing of septic tank, soap and detergents, pet wastes and fertilizers in the residential land use, vegetables and fruits residue in the commercial land use and vehicular emissions and detergents released from vehicle washing in the heavy traffic area.

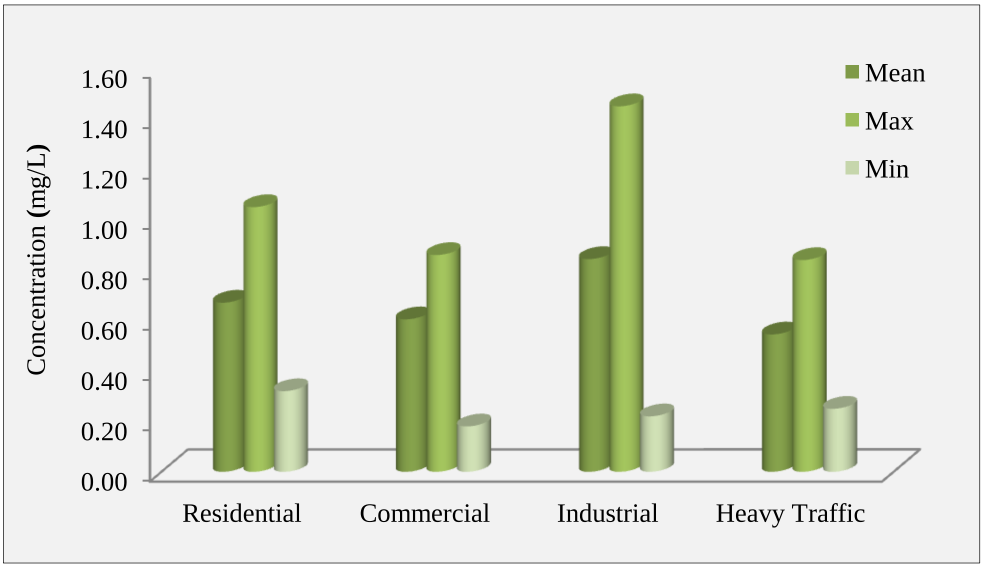


Fig. 6.1 Mean, maximum and minimum PO_4^{3-} contents of stormwater

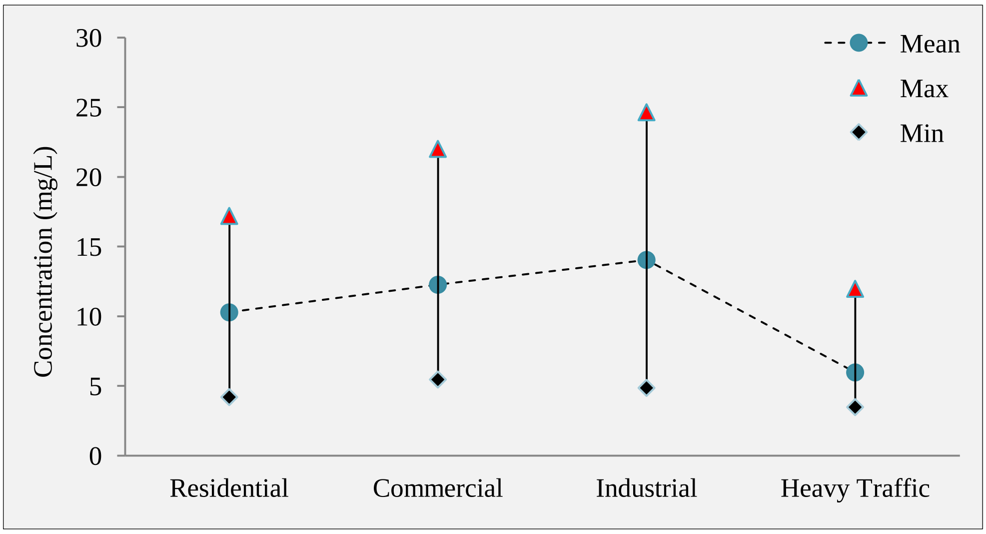


Fig. 6.2 Mean, maximum and minimum NO_3^- contents of stormwater

The problem of nitrogen and phosphorous pollution is very challenging because their deleterious effects often occur hundreds or thousands of miles from the point of origin [127]. Nutrient pollution affects the ecosystem of receiving water body in various ways. The presence of nutrient-enriched sediment in receiving water decreases the light available for the submerged aquatic vegetation, and the shading leads to their death. After death, their decomposition processes consume oxygen from the water too [208]. Excessive levels of nutrients in receiving water body cause faster growth of algae. Large algal blooms can entirely eliminate the dissolved oxygen of the water body that virtually kills all the aquatic organisms unable to escape these so-called dead zones [127].

Toxins produced by harmful algal blooms can also have adverse impact on human health. If these toxins have ingested or contacted, they can cause skin irritation, stomach cramps, vomiting, nausea, diarrhoea, fever, headache, muscle and joint pain, blisters of the mouth, and liver damage [209].

On an average, about 50% of phosphorous and a greater proportion of nitrogen in receiving water are originating due to uncontrolled urban runoff [210]. Nutrient export rates vary considerably with urban catchment. It is difficult to determine the nutrient export rates for any given catchment, because the nutrient build-up and wash-off process in urban catchment is influenced by a large number of factors such as soil type, rainfall and runoff characteristics, land use, climatic conditions during the preceding dry period and anthropogenic activities in the catchment [22].

According to Miguntanna, the finer fraction of solids is the most important for nutrient build-up and particulate nutrient wash-off process because the nutrients are mostly associated with finer particles (size range below 150 µm) in both build-up and wash-off samples irrespective of land use types [94]. Therefore, to reduce the particulate nutrient loads effectively, the stormwater treatment design should target to reduce the particles of size range below 150 µm irrespective of land use types.

Various best management practices (BMPs) can be employed to reduce nutrient pollution from urban sources. Detention basins, constructed wetlands, vegetative swales, and bio-retention systems can all be used to capture stormwater and biologically degrade the nutrients before they reach waterways. Moreover, practices like leaf collection in the fall, bagging of dog waste, and prohibitions on phosphorus in lawn fertilizers can also reduce the nutrient load in runoff from developed areas [211].

6.3.2 Oil and grease

Hydrocarbon compounds in stormwater are typically measured as OG which can include animal fats, vegetable oils, soaps, and other biological oils, in addition to petroleum constituents [212]. The presence of OG in water is of great concern because, oil and by-products of oil contain harmful constituents such as metals and PAHs. However, it is difficult to establish the ecological and human health impact of OG at the typical concentrations found in stormwater because, a large number of factors such as the presence of other chemicals in oil, the type and size of the receiving water body, the frequency and duration of the stormwater discharge, the potential for dispersion, and the biological diversity of the receiving water ecosystem etc. influence the ecological effect of used oil. Human health impact may occur due to the ingestion of oil contaminated water or via food chain. Used oil contains small amounts of Cd, Cr, Pb and Ni, which can cause acute and chronic toxicity in aquatic organisms even at an extremely low level [213] and a wide range of toxic effects in human beings including cancer, and skin irritation and even death if large dose is injected.

Table 6.3 depicts the concentrations of OG in the stormwater collected from different land use sites in the present study. A large number of factors such as precipitation, land use, physical characteristics of the watershed, pollutant sources and release mechanisms, and the physical and chemical characteristics of the pollutant, etc., affect the contamination level of OG in stormwater. It is also evident that OG concentrations in highway runoff are higher in the areas with higher traffic volumes [212]. It is observed from Table 6.3 that OG contents vary in the stormwater of the different land use practices. This is shown in Fig. 6.3.

Fig. 6.3 revealed that the industrial land use has the highest maximum value of OG in the stormwater but the heavy traffic areas have the highest mean value. According to OEHHA (2006), areas that experience a high volume of vehicular traffic, such as highways, parking lots and gasoline stations are commonly considered as discrete sources of OG in runoff, as are certain industrial facilities with operations that involve petroleum products. However, stormwater runoff from these industries occasionally show higher level of OG than from highways and parking lots, the probable reason of which may be due to the ineffectiveness of engineering controls or BMPs [212].

Table 6.3 Concentration of OG in stormwater

Land use	OG (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.80	10.40	6.88	2.89
Commercial land use	3.20	14.80	10.48	4.09
Industrial land use	4.80	19.60	11.24	5.04
Heavy Traffic zone	5.20	17.60	12.44	4.08

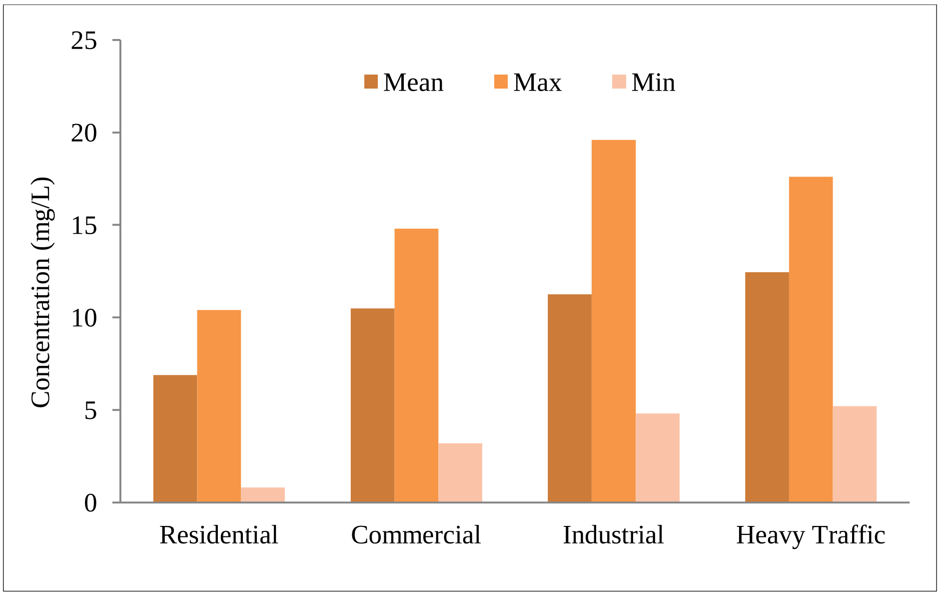


Fig. 6.3 Mean, maximum and minimum OG in stormwater

In the present study also, it is observed that the stormwater runoff from the industrial areas have occasionally higher concentration of OG than runoff from heavy traffic areas, which implies the ineffective use or lack of BMPs. Hence, the discharge of OG in stormwater runoff from industrial facilities could be greatly reduced by implementing effective BMPs.

According to literature, OG in urban runoff may originate from a myriad of small, non-point sources such as vehicle exhaust, crankcase oils, fuel oils, gas stations, fried chicken stands but the most predominant source will be used automotive crankcase oil [214]. Motor vehicles are the important sources of OG in the environment and hence in stormwater. Hence, areas where a large number of vehicles are regularly present, particularly for over extended periods of time such as parking lots and highways are the major contributors of OG pollution in stormwater runoff. Therefore, these areas are considered as continuous sources of OG in stormwater runoff. In the present study, highest mean concentration of OG was observed in stormwater runoff from heavy traffic area, where a large number of vehicles run and gathered regularly for a considerable periods of time. Therefore, it can be postulated that highest mean concentration of OG in the heavy traffic area is due to the regular presence of large number of vehicles for a long time and hence used automotive crankcase oil will be the major contributor/source of OG in the area.

The OG pollution in urban stormwater runoff may be controlled by controlling the source or by undertaking appropriate treatment for the removal of OG from stormwater runoff.

‘Source control’ is an important approach for controlling OG pollution in stormwater. In stormwater runoff, OG comes from a variety of sources. Therefore, it would be difficult to carry out source control approach to control OG pollution. However, the major source of OG to urban stormwater runoff is used up automotive oil. Hence, an effective source control approach would be the proper car maintenance and disposal of waste oil [214]. Concentration of OG in stormwater runoff could be greatly reduced by carrying this source control approach.

Another source control approach would be the development of land uses by increasing areas for cultivation and impervious surfaces. This approach would be helpful for the optimization of natural biological degradation process of OG and hence important for the reduction OG in stormwater runoff.

There are a variety of treatment techniques which may be undertaken for the removal of OG from stormwater runoff prior to disposal. However, the most commonly used methods for treatment of urban runoff are gravity differential systems and filtration systems using granular materials [214].

The average concentration of OG is strongly correlated to annual average daily traffic [215]. Boyer and Laitinen have identified the automobile exhaust particulates as one of the potential sources of petroleum hydrocarbon in stormwater [216]. Stenstorm and his co-authors have also reported that the important sources of OG in runoff are automobile crankcase oil and automobile exhaust particulates [214]. It was found that, 81-96% of the hydrocarbon load in stormwater runoff is attached to particulates, indicating that adsorption to particles is the primary transportation method of this pollutant [149]. Hence, the reduction of OG from stormwater runoff could be best accomplished by reducing the particulates.

6.3.3 Total suspended solids

Presence of suspended solids in receiving water is harmful for aquatic species of the water body because it increases turbidity of water, reduces light penetration rate, and inhibits photosynthesis leading to decrease in food supply to the aquatic organisms. Besides these, suspended solids exert significant influence in determining stormwater quality as a range of other pollutants like heavy metals, nutrients and hydrocarbon can attach themselves with the solid particles [79, 106, 108]. The transportation of various other pollutants can increase with the increasing sediment loads [110-112]. Concentrations of TSS in different land use types are presented in Table 6.4.

Suspended solid is one of the primary pollutants and basic indicators of urban stormwater pollution. In stormwater runoff, suspended solids may originate from different sources such as erosion of landscaped areas, flood water, construction and demolition activities, open areas that drain to the site, road surface erosion, irrigation activities, vehicles and maintenance activities [7]. According to literature, suspended solid concentrations in stormwater runoff vary in a great deal between different catchments depending upon the potential carrying capacity of the drainage system and the availability of transportable materials [217].

From the Table 6.4, it is clear that concentrations of TSS vary significantly with different land uses. The variation is presented in graphical form in Fig. 6.4.

Table 6.4 Concentration of TSS in the stormwater

Land use	TSS (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	159	3735	1595	986.12
Commercial land use	565	6933	4546.80	1678.73
Industrial land use	3509	8040	6913.30	1285.12
Heavy Traffic zone	3173	6306	4819.30	958.51

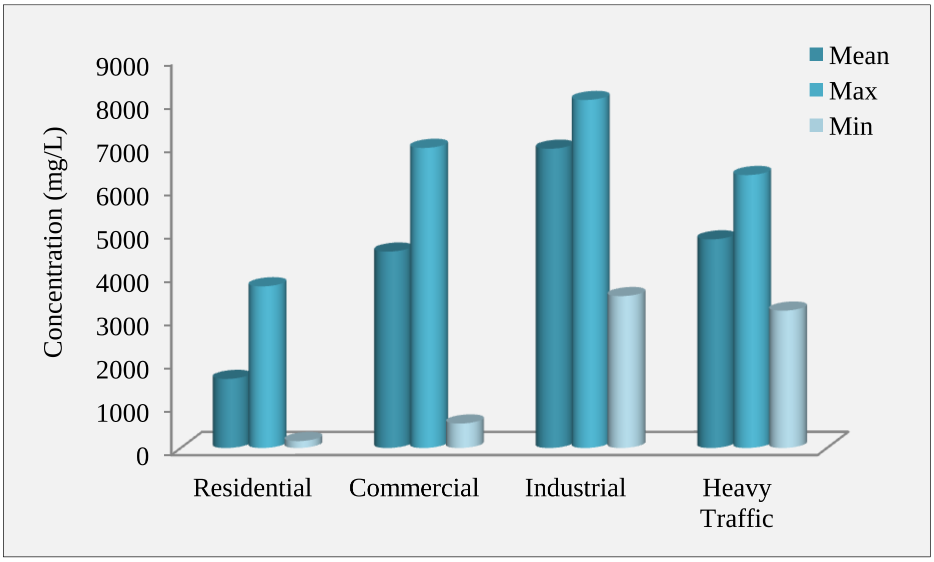


Fig. 6.4 Mean, maximum and minimum TSS content of stormwater

It is evident from Fig. 6.4 that the industrial land uses have the highest mean and maximum value for TSS concentration. In the present study, the higher contents of TSS may be due to vehicles and maintenance activities, erosion of landscaped area and road surface erosion. As the surroundings of the selected industrial site consist of a hilly terrain, the roads are sloping in nature and the stormwater runoff from the road surface flows with speed to the receiving water bodies. This can lead to higher rate of road surface erosion and hence contribute to higher concentration of TSS. Another reason of higher concentration of TSS may be due to the presence of the decomposition product of plant materials because large number of tree canopy is available in the surroundings of the selected industrial area.

Most of the conventional stormwater pollutants originate from automobile use and maintenance activities which are strongly associated with the particulates suspended in the stormwater and hence the effectiveness of most stormwater control practices is dependent on their ability in reducing these particulates from the water, or from intermediate accumulating locations such as streets or other surfaces [218].

Sizes of solid particles have significant influence on pollutant transportation process. The finer particles, which are generally known as suspended solids, can be easily transported by stormwater runoff, take the longest time to settle and are more easily re-suspended due to any turbulence [219]. With the increasing suspension time of particles, the degree of adsorption and desorption also increases and hence the transformation of degradable compounds will be more extensive [115]. Moreover, pollutants such as heavy metals and hydrocarbons are more heavily adsorbed by fine particulates than by coarse particulates [79, 110], because the fine particulates have relatively higher surface area to volume ratio and the electrostatic charge on the particle surface [22]. Herngren and his co-authors suggested that the majority of pollutants are associated with fine particulates [220]. Therefore, to effectively minimize the associated pollutant loads, the stormwater treatment facilities should target for reducing the fine particulates.

6.3.4 Heavy metals

Heavy metals are naturally present in all ecosystems at varying concentrations. They are also released to environment due to various anthropogenic activities. Within a limit, certain heavy metals are essential for aquatic organisms, plant growth and for human survival but almost all of them are toxic at higher concentrations and some are lethal even at very low concentrations. When heavy metals are ingested, they combine with the body's biomolecules, like proteins and enzymes to form stable biotoxic compounds, thereby mutilating their structures and hindering them from the bioreactions of their functions [137].

As per various reports, urban stormwater runoff contains a significant amount of heavy metals [80, 138,146]. In urban stormwater runoff, metals can exist in both solid and liquid phases. As compared to solid phase, releasing of liquid phase metals in receiving water is of great concern because of their enhanced bioavailability, potential toxicity and non-degradable nature. A significant amount of heavy metals in stormwater runoff is found to be transported in the solute phase which may be in inorganic or organic form [77]. The primary anthropogenic sources of heavy metals in urban stormwater runoff may be vehicular traffic, combustion of fossil fuels and industrial processes. Other potential sources of heavy metals in urban area include corrosion of buildings and their fittings, atmospheric deposition, transport and various industrial activities and intentional and accidental spills [138]. Corrosion of roofing materials can also release heavy metals [71]. As acids can dissolve metals, acidic rainfall would increase the leaching of metals from components of building and other metallic components. The lowering of the pH level of rainwater can enhance the corrosion process of metals and hence can lead to an increase in the amount of heavy metals dissolved in stormwater runoff. Thus, acid rainfall can contribute to metallic pollution in stormwater runoff.

Some of the most commonly found heavy metals in stormwater runoff are Cd, Cr, Cu, Fe, Pb, Ni, and Zn and these are derived from the tyre and other vehicular parts, road surface break up, oil and fuel drips and corrosion products [90-92]. Tyre wear on the roads is a source of Zn and Cd, brake wear generates Cr, Cu, Ni and Pb, engine wear and fluid leakages are the sources of Cr, Cu and Ni, vehicular component wear and detachment release Cr, Fe and Zn [93].

In the present study, stormwater from different land uses was analysed for eight commonly occurring heavy metals viz. Cd, Co, Cr, Cu, Fe, Pb, Ni, and Zn. The concentrations of these metals in stormwater collected from different land use types and the probable sources as well as the toxic effects of these metals in stormwater are discussed below.

(i) Cadmium

Cd is highly toxic to both humans and animals even at extremely low concentration. In humans, long term exposure to Cd results in renal dysfunction and high exposure can lead to obstructive lung disease [137]. Symptoms of severe exposure to Cd include vomiting, diarrhoea, abdominal pains, nausea and muscular weakness. Cd toxicity can cause bone deformation, impaired kidney and reproductive function, growth retardation, hypertension, tumour formation and teratogenic effects [221]. Cd can replace Zn in enzymes and destroy their catalytic activity. It can also replace calcium (Ca^{++}) in bones and thus can cause a bone disease, termed as “itai itai”.

In the present work, Cd concentrations in the stormwater (Table 6.5) are observed to vary with different land use practices. These variations are shown in Fig. 6.5, which shows that heavy traffic areas had the highest mean concentration of Cd and the industrial areas had the highest maximum concentration of Cd. The common traffic related sources which can generate heavy metals are tyre wear, brake wear and fuel leakage [222]. According to Charlesworth and his co-author, the sources of Cd in urban environment are batteries, plastics, pigments and paints, printing and graphics, corrosion of metals, wear of car tyres, metallurgical industries [223].

The higher mean concentration of Cd in the stormwater of the heavy traffic area is due to the presence of a large number of vehicles all the time in the area and the emissions and the wear and tear from them. As per available literature, consumption of tyre and use of brake shoes release Cd to the environment [224]. Therefore, it can be postulated that Cd in the present study may be generated from vehicular activities.

Table 6.5 Concentration of Cd in the stormwater

Land use	Cd (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.00	0.71	0.23	0.21
Commercial land use	0.00	0.66	0.19	0.21
Industrial land use	0.00	2.29	0.41	0.75
Heavy Traffic zone	0.00	2.11	0.44	0.76

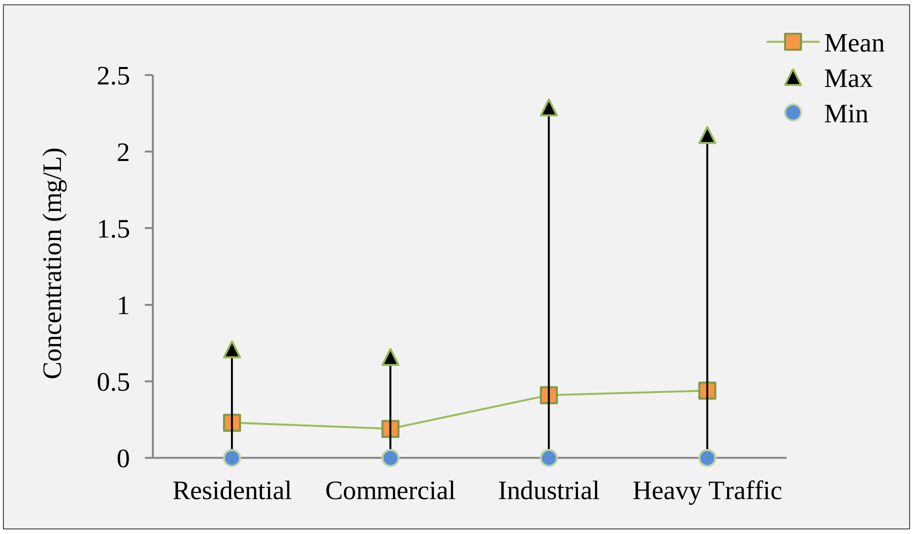


Fig. 6.5 Mean, maximum and minimum Cd in stormwater

However, the maximum Cd concentration is observed in the industrial land use site which may be due to the presence of site specific sources like corrosion of metals, batteries, vehicular activities at that specific site, plastics and medical use (because the Indian Oil Corporation, Noonmati refinery hospital is situated near the specific sampling site).

Concentration Cd can be effectively removed from stormwater runoff by using bio-retention technology. However, the removal efficiency depends upon the bio-retention media used. It was found that, the Cd removal efficiencies of the four bio-retention media viz. fine sand, zeolite, sand and quartz sand were different, but all of their efficiencies were greater than 90% [225].

(ii) Cobalt

Co is a naturally occurring element which is present in small amount in earth's crust, sea water, plants, animals and human body. It occurs in earth's crust at a concentration of approximately 25 μg/g [226]. It is often associated with Ni, Pb, Cu and Fe ores. Co is primarily used in the production of some steel, various alloys, and magnet. It is also used as catalyst in the petroleum industry, in batteries, as an ingredient of coloured pigment in glass, ceramics, and paints.

Co is an integral component of vitamin B_{12} and hence it is essential in small amounts for maintaining human health. It is also used in the treatment of anaemia because it increases red blood cell production. It is also a micronutrient essential for some blue-green algae [227]. However, at higher concentrations, Co is toxic to human beings, aquatic animals and plants. Human health effects due to high dose of Co include diarrhoea, lung irritation, bone defects and paralysis.

In the present work, concentrations of Co at the different land use sites are given in Table 6.6 with their basic statistics.

Primary sources of Co in urban stormwater runoff are burning of coal and oil, metallurgical industries and vehicular exhaust. The results of the study revealed that, the heavy traffic areas have the highest Co concentration compared to other land uses. This may be due to the vehicular activities present in the heavy traffic area. According to literature, engines and oil leaks release Co to the stormwater runoff [224].

Table 6.6 Concentration of Co in the stormwater

Land use	Co (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.00	0.47	0.16	0.15
Commercial land use	0.00	0.76	0.18	0.23
Industrial land use	0.00	0.63	0.23	0.20
Heavy Traffic zone	0.04	1.84	0.55	0.63

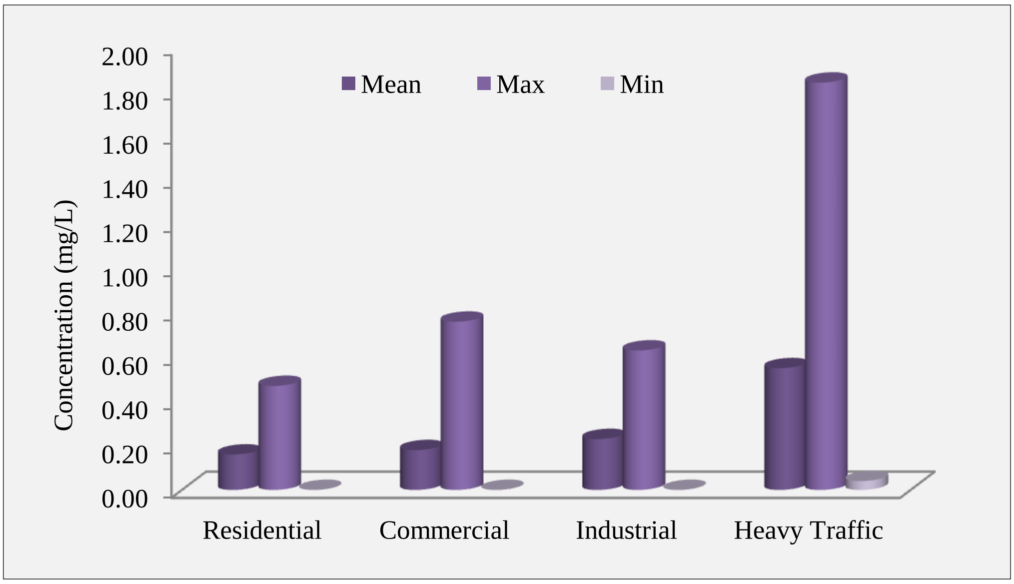


Fig. 6.6 Mean, maximum and minimum concentration of Co in stormwater

(iii) Chromium

It occurs naturally as chrome iron ore ($FeO.Cr_2O_3$). Cr is present in earth's crust, sea water, soil, plants and in human body. It is used in the manufacturing of steels, jet engines, toots, paints, photography, electric cells, rubber goods and matches [221].

Concentrations of Cr in the stormwater collected from different land use sites in the present study are given in Table 6.7. At higher concentration, chromium is toxic to human beings and other animals. In human, it can cause cancer, gastrointestinal ulcer and can also affect central nervous system. In stormwater runoff, Cr may be derived from industrial processes, vehicular activities and corrosion products [228]. Fig. 6.7 shows variation of Cr with different land use practices.

In the present study, highest mean concentration of Cr is observed in the industrial land use area and the maximum Cr concentration in the heavy traffic area. The higher mean concentration of Cr in the industrial land use area may be originated from the corrosion of the building materials, paints and also from the heavy vehicular traffic of the road of industrial areas.

Table 6.7 Concentration of Cr in stormwater

Land use	Cr (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.00	0.56	0.12	0.17
Commercial land use	0.00	0.61	0.18	0.18
Industrial land use	0.01	1.33	0.40	0.41
Heavy Traffic zone	0.00	1.36	0.36	0.49

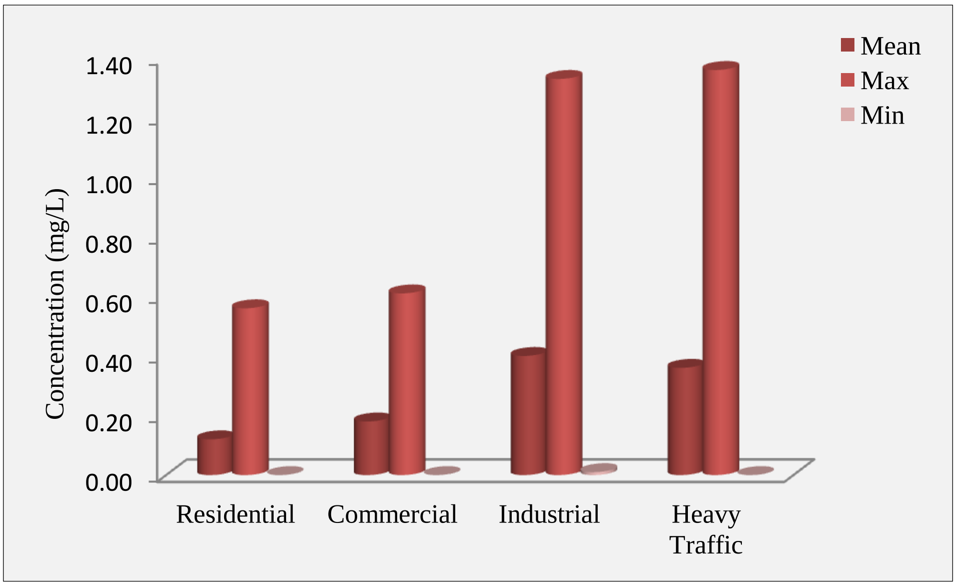


Fig. 6.7 Mean, maximum and minimum Cr contents of stormwater

The maximum Cr concentration in heavy traffic area can be due to the presence of vehicular sources such as brake ware, engines and oil leakage and parts of vehicle at that specific site.

(iv) Copper

Cu occurs in nature as a native metal in the form of sulphide ores. It is a micronutrient. It is present in rich amount in human brain and liver and also present in plants. Cu is used to manufacture various products such as plumbing pipe, radiators, industrial catalysts, jewellery and other decorations, utensils, coins, firework ingredient, coating in cathode ray tubes, animal feed additive, dietary supplement, roofs, gutters, and other architectural elements, components motor vehicles like bearings, bushings, gears, and wiring, present in pesticides (algaecide, fungicide, wood preservative, bactericide), batteries (as an electrolyte or contaminant; an ingredient in alkaline batteries), blue colouring for consumer products and semiconductor [229]. However, excess concentration of Cu in human body is toxic and can cause hypertension, sporadic fever, and pathological changes in brain tissue, coma and even death [221].

In the present work, concentrations of Cu in stormwater collected from different land use sites are depicted in Table 6.8. Sources of Cu in urban runoff include vehicle brake pads, copper pesticides such as wood preservatives, pool, spa, and fountain algaecides, diesel and gasoline fuel combustion, industrial facilities, residential wood burning, forest fires, construction activities, hydro modification and domestic water discharged to storm drains etc. According to USEPA, Cu in road runoff originates from metal plating, bearing and brushing wear, moving engine parts, brake lining wear, fungicides and insecticides [228]. Electronic waste and metallurgical industries also release Cu to urban stormwater runoff [223].

The variation of Cu in the stormwater of different land use sites is presented in Fig. 6.8. The figure shows that the stormwater from industrial land use has relatively higher mean and maximum value of Cu compared to the other three land use types.

Table 6.8 Concentration of Cu in stormwater

Land use	Cu (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.00	0.42	0.19	0.14
Commercial land use	0.01	0.29	0.14	0.10
Industrial land use	0.04	2.15	0.54	0.64
Heavy Traffic zone	0.02	1.62	0.46	0.53

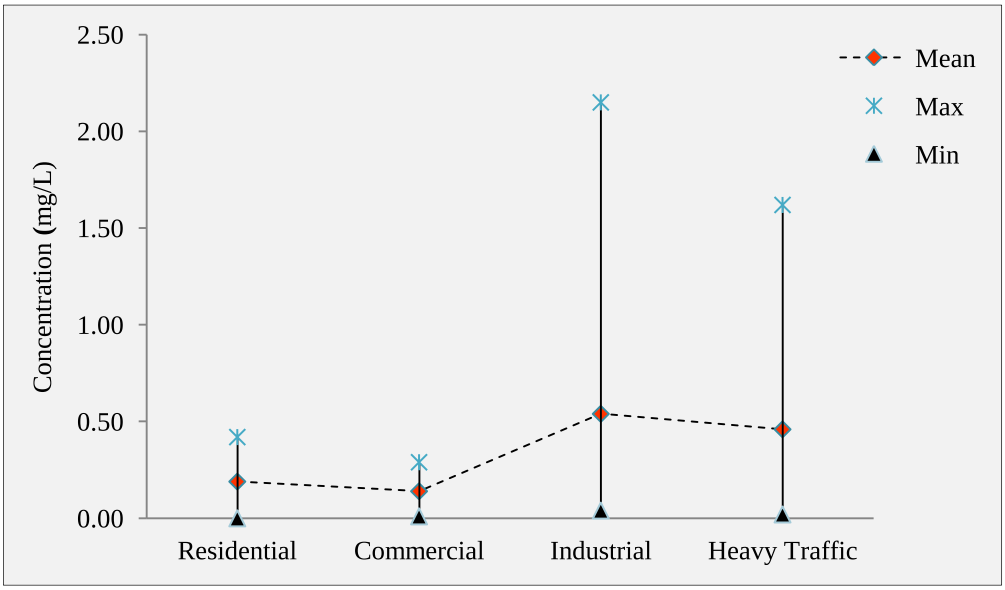


Fig. 6.8 Mean, maximum and minimum Cu contents of the stormwater

(v) Iron

Fe is the most abundant element in the earth's crust. It is an essential micronutrient. Human body contains about 4.5 g of Fe, about 70% of which is present in haemoglobin. However, excess level of Fe in human body (more than 10 mg/kg) causes rapid increase in respiration and pulse rate, congestion of blood vessels, hypotension and drowsiness [221].

Variation of Fe concentration in stormwater samples collected from different land use sites is presented in Fig. 6.9.

Table 6.9 Concentration of Fe in the stormwater

Land use	Fe (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.29	22.05	3.52	6.57
Commercial land use	1.53	14.91	6.61	4.54
Industrial land use	5.01	18.00	12.26	5.74
Heavy Traffic zone	0.21	21.41	11.02	8.96

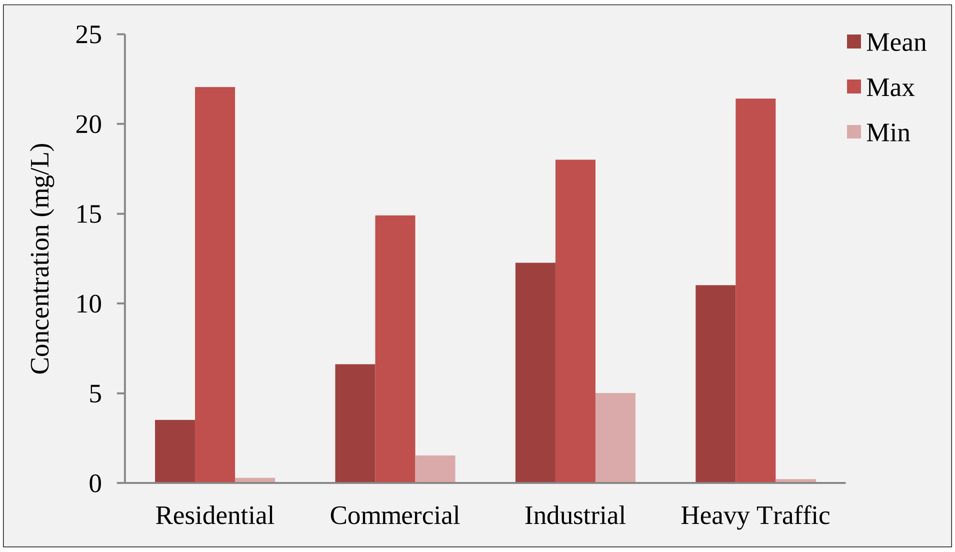


Fig. 6.9 Mean, maximum and minimum Fe contents of stormwater

The environmental mobility and bioavailability of metals depend upon their aqueous concentration and therefore, the fractionation of the metals into particulate and dissolved phases exert significant influence on the runoff quality [230]. The presence of iron oxides influences the fractioning of heavy metals into dissolved and particulate phases [231, 232]. Fe is known to attach mostly to sediment particles and iron oxides may exist as surface coatings on particles.

Sources of Fe in stormwater runoff are automobile body rust, steel, highway structures such as bridges and guardrails and moving engine parts [228]. Fe in stormwater can also originate from the equipment and vehicle brakes, disposal of paint, tires, or materials which are made of Fe etc. In the present study, industrial area shows a relatively higher mean concentration of Fe in comparison to the other three land use sites.

(vi) Nickel

Ni is an essential trace metal for several animals, micro-organisms and plants. It is a naturally occurring element and is the 24th most abundant element on earth. Earth's crust contains 80 mg/kg of Ni. Throughout the world, it is found in metal ore deposits. There are about 100 minerals of Ni which have many industrial and commercial uses [233]. Ni containing materials play an important role in our everyday life. It is used in producing many things from coins to knives, weapons and so on. Ni-containing materials are used in food preparation equipments, mobile phones, computers, cars, aircraft, medical equipment, transport, building, power generation and many more. It is a key part of several rechargeable batteries. However, presence of higher amount of Ni in human body may cause changes in muscle, brain, lung, liver and kidney. It can also result in cancer, tremor, paralysis and even death [221].

Natural sources of Ni include weathering of rocks and soils, volcanic emissions, forest fires and vegetation. Anthropogenic sources include combustion of coal, diesel oil and fuel oil, incineration of waste and sewage, and other miscellaneous sources [234, 235]. Batteries and metallurgical industries also generate Ni to the urban environment [223]. USEPA reported that the common sources Ni in road runoff are diesel fuel and gasoline, lubricating oil, metal plating, bushing wears, brake lining wear and asphalt paving [228]. It can also be originated from brake wear, engine wear and fluid leakage [93].

In the present study, concentrations of Ni in the stormwater collected from the different land use sites show variations from one type of land use to another. The Table 6.10 shows the differences in Ni contents for the different land use types.

Table 6.10 Ni in stormwater of different land use sites

Land use	Ni (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.00	0.84	0.50	0.31
Commercial land use	0.00	0.63	0.12	0.22
Industrial land use	0.00	3.70	0.67	1.21
Heavy Traffic zone	0.00	3.25	0.69	1.34

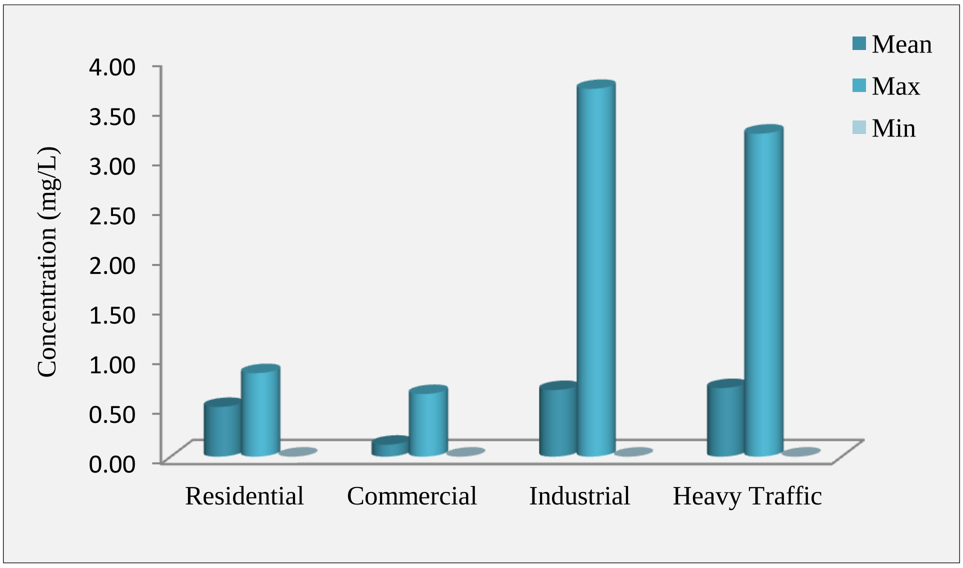


Fig. 6.10 Mean, maximum and minimum Ni contents of stormwater

Results shows relatively higher mean concentration of Ni in the stormwater of heavy traffic areas which may have originated from combustion of diesel oil and fuel oil, brake wear, engine wear and fluid leakages. However, the maximum concentration of Ni is observed in industrial areas, which may be due to the site specific sources such as metal plating, asphalt paving, combustion of fuels in industries and vehicular sources present at that specific site.

(vii) Lead

A low level of Pb is found in earth’s crust, mainly as lead sulphide (galena). However, the anthropogenic sources of the metal include mining, smelting, refining and recycling processes, use of leaded petrol, production of lead-acid batteries and paints, jewellery making, soldering, ceramics and leaded glass manufacture industries, electronic wastes, etc. These have led to widespread occurrence of Pb in the environment [236]. Pb is a very toxic pollutant. It affects multiple body systems, including the neurological, haematological, gastrointestinal, cardiovascular and renal systems. Particularly children are vulnerable to the neurotoxic effects of Pb. In some cases it can cause irreversible neurological damage [237]. Acute exposures to Pb may cause gastrointestinal disturbances, hepatic and renal damage, hypertension and neurological effects that may lead to convulsions and death [236].

Concentrations of Pb in the stormwater collected from the different land use sites are given in Table 6.11 and Fig. 6.11. In the present work, the higher concentration of Pb is found in the heavy traffic area which may be originated from corrosion of bearing wear, tyre wear, and leakage of lubricating oils, grease, paints, plumbing work, soldering, etc.

The sources that generate Pb in an urban environment are combustion of fossil fuel, batteries, pigments and paints, printing, graphics, medical uses and metallurgical industries [223]. USEPA have reported that the sources of Pb in road runoff included leaded gasoline from auto exhaust, tire wear, lubricating oil and grease, bearing wear and atmospheric fallout [228].

Table 6.11 Concentration of Pb in stormwater

Land use	Pb (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.22	1.86	1.14	0.51
Commercial land use	0.00	1.35	0.53	0.43
Industrial land use	0.33	3.17	1.20	0.87
Heavy Traffic zone	0.49	3.73	1.68	1.09

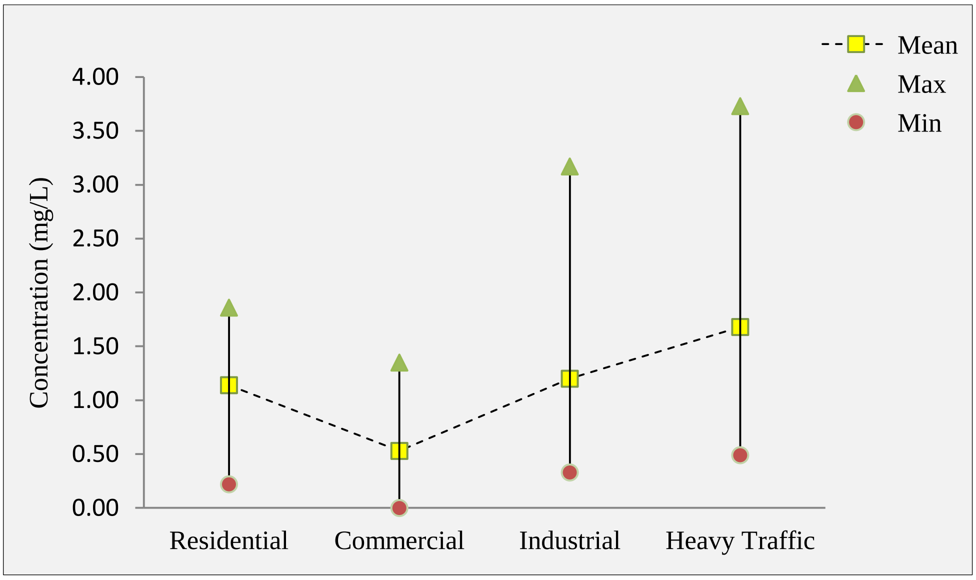


Fig. 6.11 Mean, maximum and minimum Pb contents of stormwater

As the exposure to Pb is rising [238], which is a severe health issue, therefore, it is one of the significant concerns for everyone. It can have irreversible effects on both children as well as adults. Pb is particularly dangerous to children because their growing bodies absorb more Pb than adults do and their brains and nervous systems are more sensitive to the damaging effects of Pb [239].

In US, an estimated 5,35,000 children of age between 1 to 5 years have blood Pb levels of ≥5 µg/dL, which is the threshold for adverse health effects of Pb exposure in young children [240]. Even at low levels of Pb in the blood of children can leads to behavioural and learning problems, lower IQ and hyperactivity, slowed growth rate, hearing problems and anaemia. In case of pregnant women, exposure to Pb can cause serious effects including reduced growth of the foetus and premature birth. Health impacts of Pb in other adults include cardiovascular effects, increased blood pressure and hypertension, decreased kidney function and reproductive problems in both men and women [241].

The most important step for reducing these adverse health impacts is to prevent Pb exposure before it occurs. Therefore, every effort should be made to protect the children as well as the adults from all potential sources of exposure to Pb. From stormwater runoff, Pb can be effectively removed by implementing bio-retention system. Bio-retention systems can remove 95.4-99.9% of Pb content from stormwater runoff [242].

(viii) Zinc

Zn is one of the most commonly occurring elements in the earth's crust. It is an essential trace element for human body. Therefore, too little Zn in the diet can lead to poor health, reproductive problems, and lowered ability to resist disease. However, too much Zn can also be harmful to human health [243]. Heavy doses of Zn can cause vomiting, renal damage and cramps [221]. Zn and its compounds are used in the manufacturing of various products such as white paints, ceramics, rubber, dyeing fabrics, tires, dry cell batteries, deodorants, acne and poison ivy preparations, and antidandruff shampoos [243].

The major sources of Zn in stormwater runoff are galvanized metals, motor oils or hydraulic fluids exposed on the ground, or absorbed by solid particles such as dust and dirt, tire dust from forklifts, trucks, and other vehicles [243]. According to Charlesworth and Lees, the sources that generate Zn in an urban environment are wear of car tyres, corrosion of metals, fossil fuel combustion, electronics, batteries, pigments and paints, plastics, printing graphics, medical uses and metallurgical industries [223]. In the present work, Zn contents of the stormwater from different land uses vary as shown in Table 6.12 and Fig. 6.12.

Table 6.12 Concentration of Zn in stormwater

Land use	Zn (mg/L)			SD
	Min.	Max.	Mean	
Residential land use	0.00	2.56	1.05	0.76
Commercial land use	0.46	3.48	1.60	0.94
Industrial land use	0.62	3.99	1.89	1.15
Heavy Traffic zone	0.38	7.46	2.38	2.47

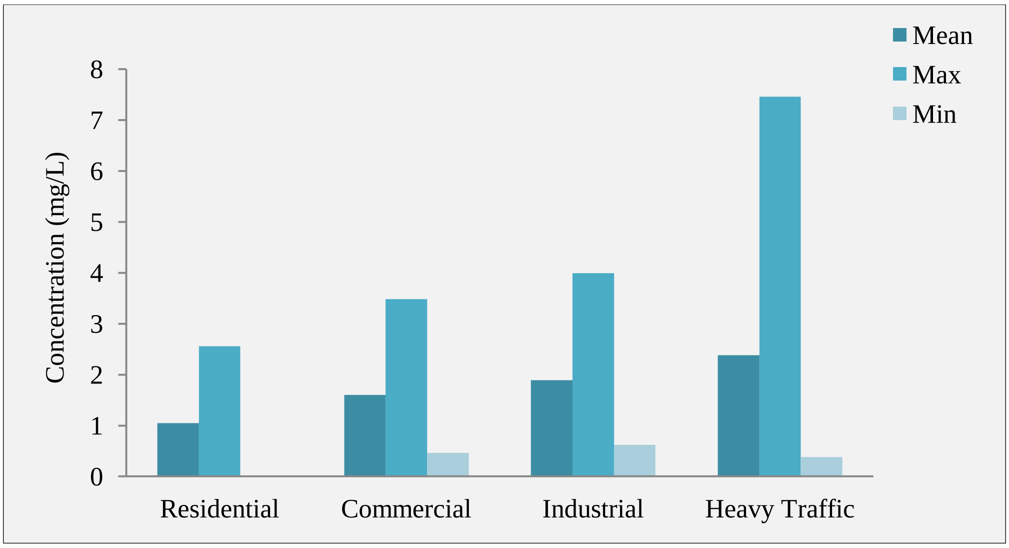


Fig. 6.12 Mean, maximum and minimum concentration of Zn in stormwater

The results of the experiments show a sort of higher mean and maximum concentration of Zn in the heavy traffic areas. This may be due to the presence of vehicle related sources such as fossil fuel combustion, tyre wear, leakage of motor oil, grease, etc.

The concentration of Zn in stormwater runoff can be reduced by preventing the leakage of motor oils from vehicles and by sweeping of the paved areas. The solid particles such as dust and dirt can absorb motor oil and hydraulic fluid. Tyre dust is also a major source of Zn. Therefore, sweeping of particulates from paved areas can remove Zn with them. Zn can also be removed from stormwater by implementing appropriate BMPs like bio-retention systems. In an investigation, Rycewicz-Borecki and his associates found that bio-retention systems can remove 91.7-97.6% of Zn from stormwater [242].

6.3.5 Land use and stormwater quality

The primary aim of this chapter was to understand the influence of land use on stormwater quality. For this purpose, the mean values of the investigated stormwater pollutants were compared with different land uses as shown in Fig. 6.13.

The results show that the stormwater of industrial land use area have higher concentration of PO_4^{3-}, NO_3^-, TSS, Cr, Cu and Fe in comparison to other land uses. A similar study conducted by Sood and his associates in Chandigarh, India also found higher concentration of these pollutants (*i.e.*, PO_4^{3-}, NO_3^-, TSS, Cr, Cu and Fe) in stormwater of industrial land use area [244].

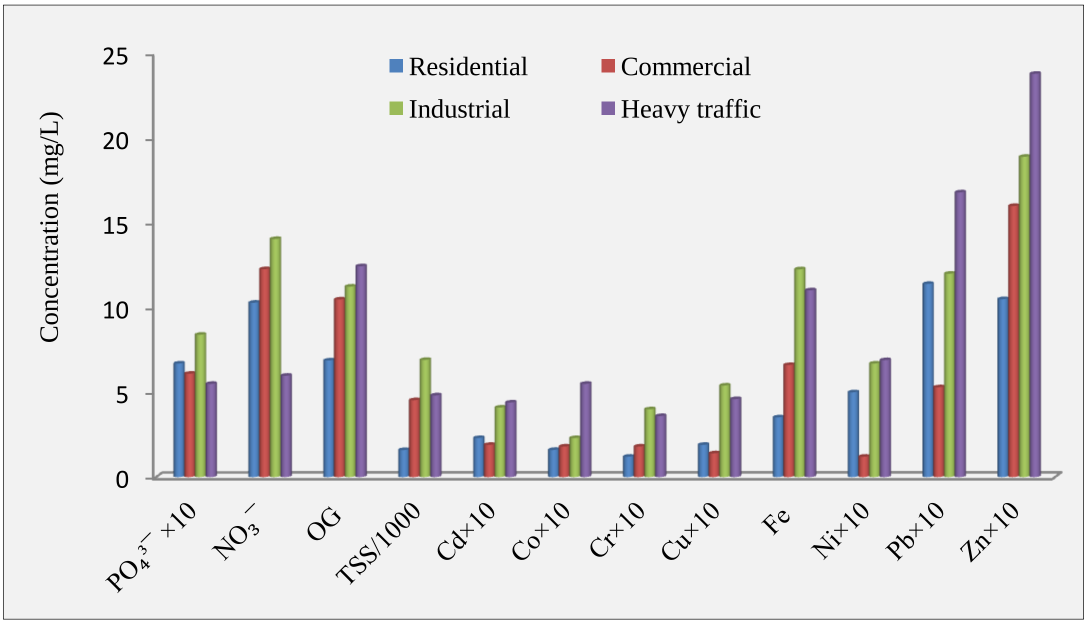


Fig. 6.13 Mean concentration of stormwater pollutants in different land uses

The industrial area under the present study is located nearby a hilly area. The roads of this area have greater slope, having large number of tree canopy. Therefore, it can be surmised that, besides industrial waste water and emissions, stormwater of the area is also polluted from plant related nutrient materials. This can be the main reason of higher nutrient (PO_4^{3-} and NO_3^-) contents in the area. Moreover, higher concentration of TSS in the present industrial area may be due to the greater slope of the road surfaces. On highly sloped surfaces, water flows with high velocity leading to a higher rate of surface erosion. This in turn contributes to higher solid load in the water. Higher concentrations of Cr, Cu and Fe in the area may be originated from the corrosion of building materials, brake ware of equipments and other activities practiced in the area.

In the heavy traffic area, concentrations of OG, Cd, Co, Ni, Pb and Zn were found higher in comparison to other three land uses. The heavy traffic area under the present study is Inter State Bus Terminal. A large number of vehicles regularly gathered here for long period of time. Therefore, higher concentration of OG, Cd, Co, Ni, Pb and Zn in this area may be originated from vehicular sources like used crankcase oil. However, the residential and commercial land use area showed relatively lower concentration value for all of the stormwater pollutants. Thus, the result indicated that the pattern of land use have a significant influence on stormwater pollution.

From the above discussion, it can be concluded that the introduction of pollutants in stormwater of an area is primarily dependent upon the anthropogenic activities present in the area. As the anthropogenic activities vary with the land use pattern of an area, therefore, the loads and species of pollutants in stormwater also vary accordingly. Hence, the land use pattern of an area plays a significant role in determining stormwater quality. Industrial and heavy traffic areas have more significant influence on stormwater pollution as they produce higher pollutant loads in comparison to residential and commercial areas. Therefore, special consideration should be taken for the management of stormwater of these areas.

6.3.6 Comparison of pollutants concentration with previous study

The mean concentration of the selected stormwater pollutants for each of the specified land use were compared with a study conducted by Sood and his associates in Chandigarh (India) which has similarity with the present study on the basis of climate, average annual rainfall and the area covered. The comparison of the results is presented in Table 6.13.

Table 6.13 Comparison of pollutant concentration with previous study

Pollutants	Residential land use		Commercial land use		Industrial land use		Heavy traffic zone	
	Present study	Sood *et al.* 2012 [244]	Present study	Sood *et al.* 2012 [244]	Present study	Sood *et al.* 2012 [244]	Present study	Sood *et al.* 2012[244]
NO_3^- (mg/L)	10.29	50.8	12.27	355.6	14.05	365	5.98	190
PO_4^{3-} (mg/L)	0.67	10.1	0.61	9.1	0.84	8.7	0.55	7.6
OG (mg/L)	6.88	960	10.48	2000	11.24	2950	12.44	2310
TSS (mg/L)	1595	614	4536.80	8180	6913.30	10136	4819.30	6250
Cd (mg/L)	0.23	-	0.19	-	0.41	-	0.44	-
Co (mg/L)	0.16	-	0.18	-	0.23	-	0.55	-
Cr (mg/L)	0.12	0.15	0.18	1.02	0.40	1.69	0.36	0.45
Cu (mg/L)	0.19	0.18	0.14	5.6	0.54	6.7	0.46	1.7
Fe (mg/L)	3.52	5.615	6.61	15.3	12.26	46.65	11.02	22.55
Ni (mg/L)	0.50	0.34	0.12	6.35	0.67	8.7	0.69	3.4
Pb (mg/L)	1.14	0.018	0.53	0.165	1.20	0.145	1.68	0.038
Zn (mg/L)	1.05	0.26	1.60	3.7	1.89	5.6	2.38	3.1

It is observed that the mean concentration of Cr and Cu found in the residential land use area of the present study are 0.12 mg/l and 0.19 mg/l respectively which are very similar to the 0.15 mg/l and 0.18 mg/l as reported by Sood et al., 2012 [244]. As shown in Table 6.13, the concentration of Ni and Zn is little higher, Fe is little lower and the concentration of other pollutants (*i.e.*, NO_3^-, PO_4^{3-}, OG and TSS) are significantly lower than the concentration values found in the study conducted by Sood et al., 2012 [244].

For commercial land use area, concentration values of all the pollutants found in the present study are significantly lower than the values reported by Sood et al., 2012 [244]. For industrial and heavy traffic zone, the concentration of Pb is higher in the present study and the concentrations of all the other pollutants are significantly lower than the result found by Sood and his co-investigators [244].

Although both of the study is conducted within the same country (India), still there are significant variations between the location of the study sites, climate and other factors that have significant influence on stormwater pollution. Therefore, the differences between the concentrations of pollutants in the stormwater of the two studies are not surprising.

6.3.7 Comparison of pollutants concentration with standard value

To know the pollution level of stormwater runoff from the different land use of the present study, the concentrations of stormwater pollutants were compared with the general standard value for discharge of environmental pollutants prescribed by EPA [245]. The comparison is presented in Table 6.14 and in Fig. 6.14.

Table 6.14 Comparison of stormwater pollutants concentration with standard value

	PO_4^{3-}	NO_3^-	OG	TSS	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
	mg/L											
Residential land use	0.67	10.29	6.88	1595	0.23	0.16	0.12	0.19	3.52	0.50	1.14	1.05
Commercial land use	0.61	12.27	10.48	4536.80	0.19	0.18	0.18	0.14	6.61	0.12	0.53	1.60
Industrial land use	0.84	14.05	11.24	6913.30	0.41	0.23	0.40	0.54	12.26	0.67	1.20	1.89
Heavy traffic zone	0.55	5.98	12.44	4819.30	0.44	0.55	0.36	0.46	11.02	0.69	1.68	2.38
Standard value (EPA, 1986)	5	10	10	100	2	-	2	3	3	3	0.1	5

EPA (1986). General Standards for discharge of Environmental Pollutants, Environmental Protection Act, Schedule VI, Ministry of Environment and Forest, Govt. of India, New Delhi

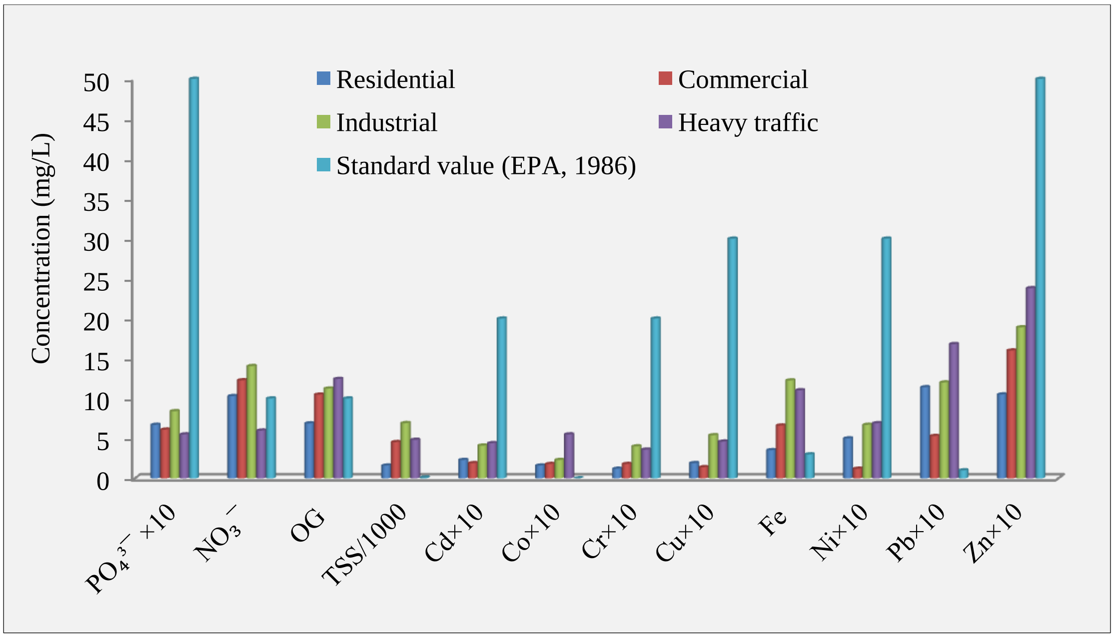


Fig. 6. 14 Comparison of stormwater pollutants with standard value

The Table 6.14 revealed that in residential area, concentration of NO_3^-, TSS, Fe and Pb exceeded the standard value and the concentrations of all the other pollutants are below the standard level. Except for NO_3^-, OG, TSS, Fe and Pb, concentration of all the other pollutants found in the commercial and industrial areas are lower than the prescribed standard values. In comparison to the prescribed standard value, stormwater of heavy traffic area have the higher concentration of OG, TSS, Fe and Pb and lower concentration of other pollutants.

6.3.8 Correlation analyses

Correlation matrix

To know the relationships between the pollutants in the stormwater of different land uses, a correlation analysis was carried out using SPSS 13.0 software and the correlation matrix was developed for each land use area as given in Tables 6.15, 6.16, 6.17 and 6.18. The correlation between the stormwater pollutants was investigated by applying a linear correlation (Pearson's correlation). The linear correlation coefficient measures the strength and the direction of a linear relationship between two variables [78]. Generally, correlations of greater than 0.7 are considered as strong, whereas correlations of less than 0.5 are considered as weak [246].

Table 6.15 Correlation matrix for residential area

	PO_4^{3-}	NO_3^-	OG	TSS	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
PO_4^{3-}	1.00											
NO_3^-	0.60	1.00										
OG	0.47	0.57	1.00									
TSS	**0.73**	0.62	**0.73**	1.00								
Cd	0.60	0.48	**0.79**	**0.89**	1.00							
Co	0.57	0.63	0.67	**0.86**	**0.86**	1.00						
Cr	0.54	0.60	0.55	**0.74**	**0.78**	**0.72**	1.00					
Cu	0.34	0.46	0.19	0.61	0.57	**0.83**	0.52	1.00				
Fe	0.50	0.25	0.34	**0.72**	**0.78**	**0.71**	**0.86**	0.61	1.00			
Ni	0.59	0.53	0.64	0.70	0.49	0.56	0.42	0.36	0.24	1.00		
Pb	0.49	0.38	**0.74**	**0.79**	**0.76**	0.67	0.45	0.42	0.46	0.67	1.00	
Zn	0.22	0.63	0.39	0.66	0.62	0.69	0.83	0.69	0.69	0.32	0.33	1.00

Statistically significant correlations are bolded here.

Table 6.16 Correlation matrix for commercial area

	PO_4^{3-}	NO_3^-	OG	TSS	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
PO_4^{3-}	1.00											
NO_3^-	0.24	1.00										
OG	0.17	0.37	1.00									
TSS	0.63	0.60	**0.71**	1.00								
Cd	0.57	0.63	0.65	**0.74**	1.00							
Co	0.61	0.58	0.51	0.64	**0.88**	1.00						
Cr	0.59	0.52	0.63	**0.72**	**0.89**	**0.97**	1.00					
Cu	0.32	0.12	**0.72**	0.55	0.69	0.65	0.67	1.00				
Fe	0.62	0.62	0.65	**0.80**	**0.90**	**0.89**	**0.92**	0.64	1.00			
Ni	0.57	0.45	0.57	0.66	**0.90**	**0.96**	**0.96**	**0.78**	**0.91**	1.00		
Pb	0.46	0.51	0.54	0.70	0.69	0.60	0.65	0.30	0.61	0.54	1.00	
Zn	0.36	0.32	0.42	0.59	0.53	0.64	0.59	0.68	0.56	0.66	0.57	1.00

Statistically significant correlations are bolded here.

Table 6.15 shows the correlations among the different stormwater pollutant parameters in the residential land use area. In the residential land use area, TSS is significantly correlated ($r > 0.70$) with PO_4^{3-}, OG, Cd, Co, Cr, Fe and Pb. Hence, by reducing TSS from the stormwater of residential area, these pollutants can also be reduced to some extent. OG is significantly correlated with Cd and Pb, and therefore Cd and Pb along with OG can be minimized effectively from the stormwater of this land use area. Cd is significantly correlated with Co, Cr, Fe and Pb; Co is significantly correlated with Cr, Cu and Fe; and Cr is significantly correlated with Fe and Zn.

Table 6.16 shows the correlations within the different stormwater pollutant parameters in the commercial land use area. Here, TSS is closely correlated with OG, Cd, Cr, and Fe. This indicates that if TSS is reduced from the stormwater of commercial area, OG, Cd, Cr, and Fe will also be simultaneously reduced.

Significant positive correlation is also observed between OG and Cu ($r=0.72$), Cd and Co ($r=0.88$), Cd and Cr ($r=0.89$), Cd and Fe ($r=0.90$), Cd and Ni ($r=0.90$), Co and

Cr (r=0.97), Co and Fe (r=0.89), Co and Ni (r=0.96), Cr and Fe (r=0.92), Cr and Ni (r=0.96), Cu and Ni (r=0.78), Fe and Ni (r=0.91).

Correlations within the different stormwater pollutant parameters in the industrial land use area are presented in Table 6.17. In industrial area, TSS showed significant positive correlation with PO_4^{3-} (r=0.70). Hence, the common structural stormwater improvement measures such as sediment trap and wetland will effectively minimize TSS and PO_4^{3-} together but not the other pollutants such as OG and heavy metals. However, it is observed that OG is significantly correlated with almost all of the heavy metals except Zn. Therefore, these metals will be effectively reduced if any suitable measure is taken to reduce OG. The most commonly used treatment techniques such as gravity differential systems and filtration systems using granular materials can effectively reduce OG from stormwater runoff and hence, in the same process, the heavy metals present in the stormwater coming from industrial land use area will be simultaneously reduced.

Table 6.17 Correlation matrix for industrial area

	PO_4^{3-}	NO_3^-	OG	TSS	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
PO_4^{3-}	1.00											
NO_3^-	0.48	1.00										
OG	0.43	0.37	1.00									
TSS	**0.70**	0.65	0.63	1.00								
Cd	0.44	0.15	**0.77**	0.47	1.00							
Co	0.50	0.39	**0.90**	0.70	**0.91**	1.00						
Cr	0.44	0.32	**0.88**	0.59	**0.94**	**0.96**	1.00					
Cu	0.32	0.29	**0.84**	0.54	**0.89**	**0.88**	**0.95**	1.00				
Fe	0.36	0.45	**0.70**	0.64	0.58	**0.82**	**0.76**	0.64	1.00			
Ni	0.27	0.35	**0.79**	0.46	**0.85**	**0.83**	**0.90**	**0.98**	0.56	1.00		
Pb	0.54	0.23	**0.86**	0.63	**0.95**	**0.96**	**0.96**	**0.89**	**0.72**	**0.82**	1.00	
Zn	0.49	0.26	0.63	0.59	**0.78**	**0.82**	**0.86**	**0.78**	**0.84**	0.68	**0.86**	1.00

Statistically significant correlations are bolded here.

Significant positive correlations are also observed between Cd and Co, Cd and Cr, Cd and Cu, Cd and Ni, Cd and Pb, Cd and Zn, Co and Cr, Co and Cu, Co and Fe, Co and Ni, Co and Pb, Co and Zn, Cr and Cu, Cr and Fe, Cr and Ni, Cr and Pb, Cr and Zn, Cu and Ni, Cu and Pb, Cu and Ni, Fe and Pb, Fe and Zn, Ni and Pb, Pb and Zn.

Correlations between the parameters in the heavy traffic area are presented in the Table 6.18. In the heavy traffic area, TSS is significantly correlated with OG and almost all the metals except Ni. Hence, in the heavy traffic area, if any structural stormwater management measures such as sediment traps and wetlands are taken, they will be effective in reducing OG, and the heavy metals, Cd, Co, Cr, Cu, Fe, Pb and Zn together. However, the other pollutants such as NO_3^-, PO_4^{3-} and Ni are not likely to be affected.

Table 6.18 Correlation matrix for heavy traffic area

	PO_4^{3-}	NO_3^-	OG	TSS	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
PO_4^{3-}	1.00											
NO_3^-	0.52	1.00										
OG	0.39	0.15	1.00									
TSS	0.51	0.53	**0.74**	1.00								
Cd	0.33	0.42	0.49	**0.73**	1.00							
Co	0.24	0.25	0.63	**0.77**	**0.93**	1.00						
Cr	0.13	0.08	0.64	**0.76**	0.51	**0.72**	1.00					
Cu	0.38	0.37	0.57	**0.73**	**0.97**	**0.96**	0.58	1.00				
Fe	0.18	0.49	0.56	**0.87**	0.59	0.63	0.63	0.52	1.00			
Ni	0.25	0.41	0.42	0.67	**0.97**	**0.91**	0.45	**0.93**	0.60	1.00		
Pb	0.36	0.49	0.49	**0.73**	0.43	0.56	**0.81**	0.51	0.57	0.32	1.00	
Zn	0.14	0.38	0.56	**0.77**	**0.92**	**0.90**	0.53	**0.87**	**0.76**	**0.90**	0.43	1.00

Statistically significant correlations are bolded here.

Significant positive correlations are also observed between Cd and Co (r=0.93), Cd and Cu (r=0.97), Cd and Ni (r=0.97), Cd and Zn (r=0.92), Co and Cr (r=0.72), Co and Cu (r=0.96), Co and Ni (r=0.91), Co and Zn (r=0.90), Cr and Pb (r=0.81), Cu and Ni (r=0.93), Cu and Zn (r=0.87), Fe and Zn (r=0.76) and between Ni and Zn (r=0.90).

Bio-retention systems are very suitable structural measures in removing heavy metals from stormwater. It is well documented that, the metal removal efficiency of bio-retention systems are very high [242, 247, 248]. They can remove up to 96.5-98.6% of Cu, 95.4-99.9% of Pb and 91.7-97.6% of Zn from stormwater [242]. Therefore, bio-retention system should be implemented at all of the land uses to reduce heavy metal pollution.

Correlation of TSS with other parameters

The increasing sediment loads may increase the transportation of various pollutants by acting as a mobile substrate on which pollutants can absorb, adsorb or adhere [111, 112]. TSS is one of the basic indicators of urban stormwater pollution. Therefore, to know the contribution of TSS in stormwater pollution, it is essential to explore the relationship between TSS and other stormwater pollutants. For this purpose, a linear correlation between TSS and other pollutants for each land use area was explored as given in Figs. 6.15, 6.16, 6.17 and 6.23.

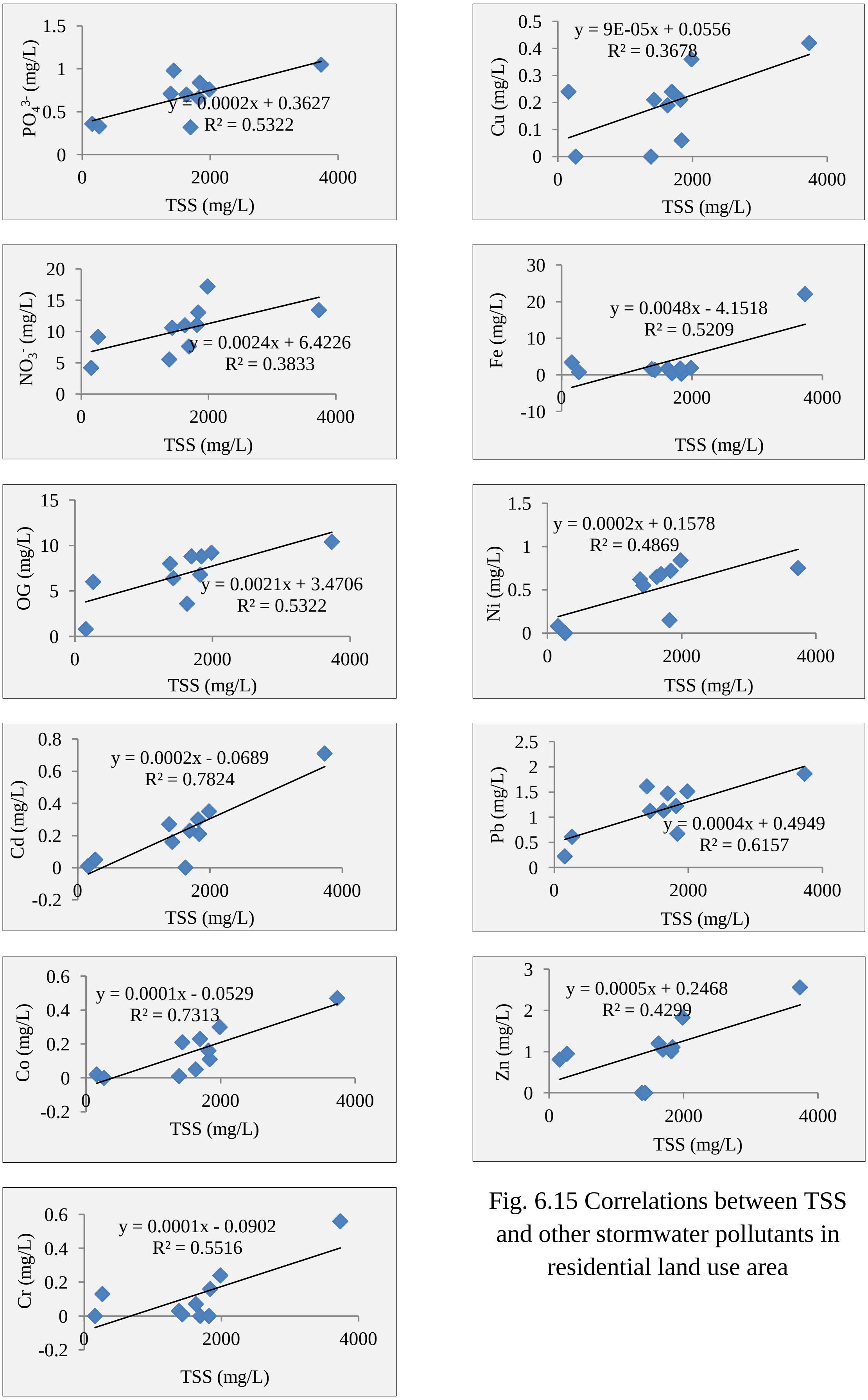
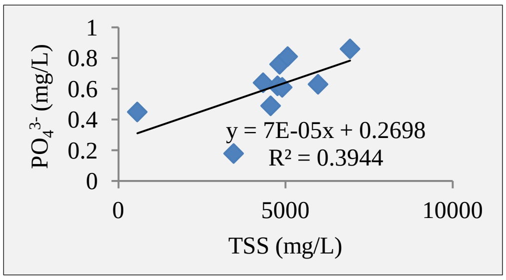
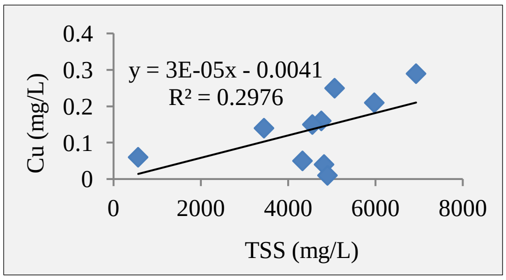
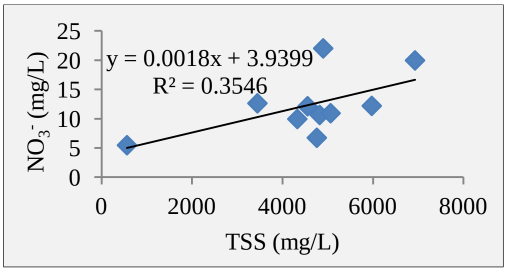
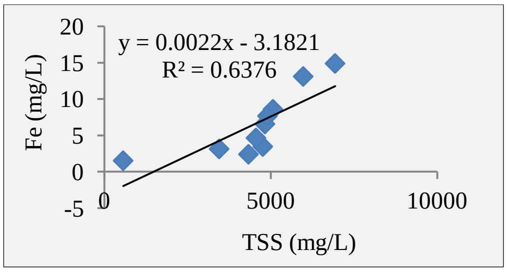


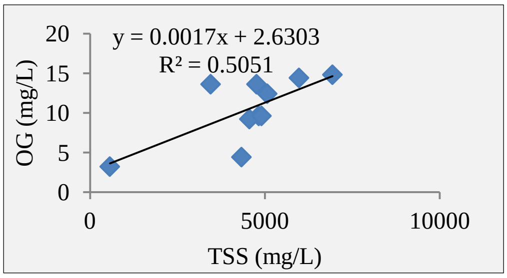
Fig. 6.15 Correlations between TSS and other stormwater pollutants in residential land use area

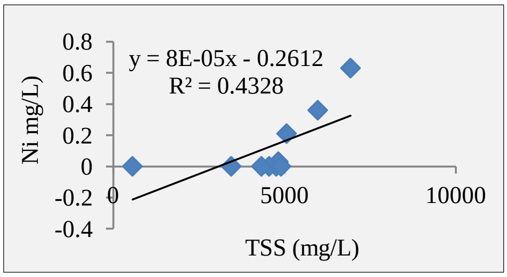


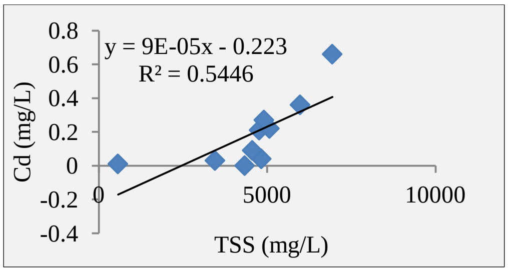


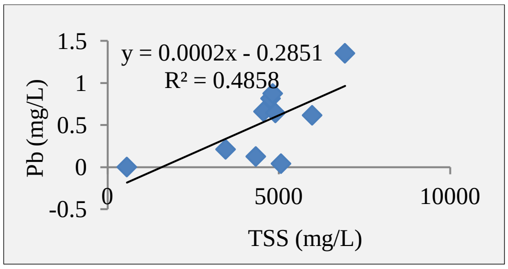


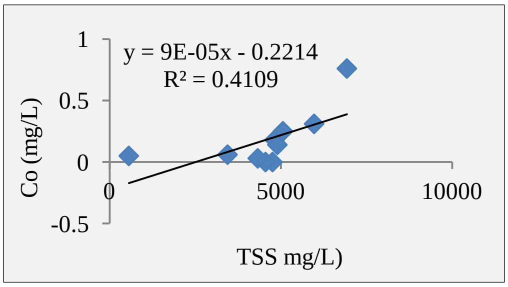


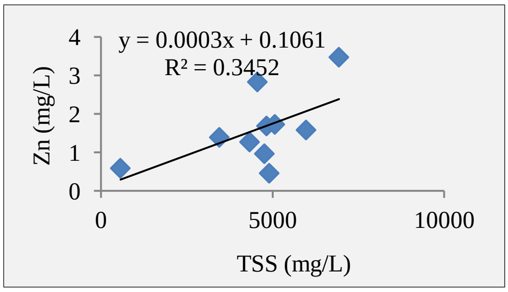












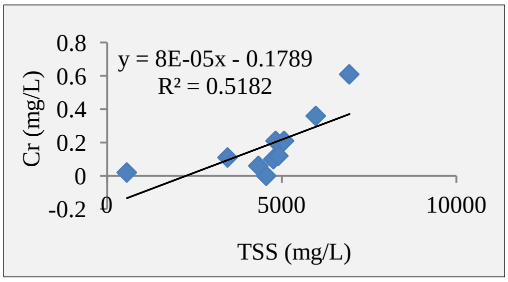


Fig. 6.16 Correlations between TSS and other stormwater pollutants in commercial land use area

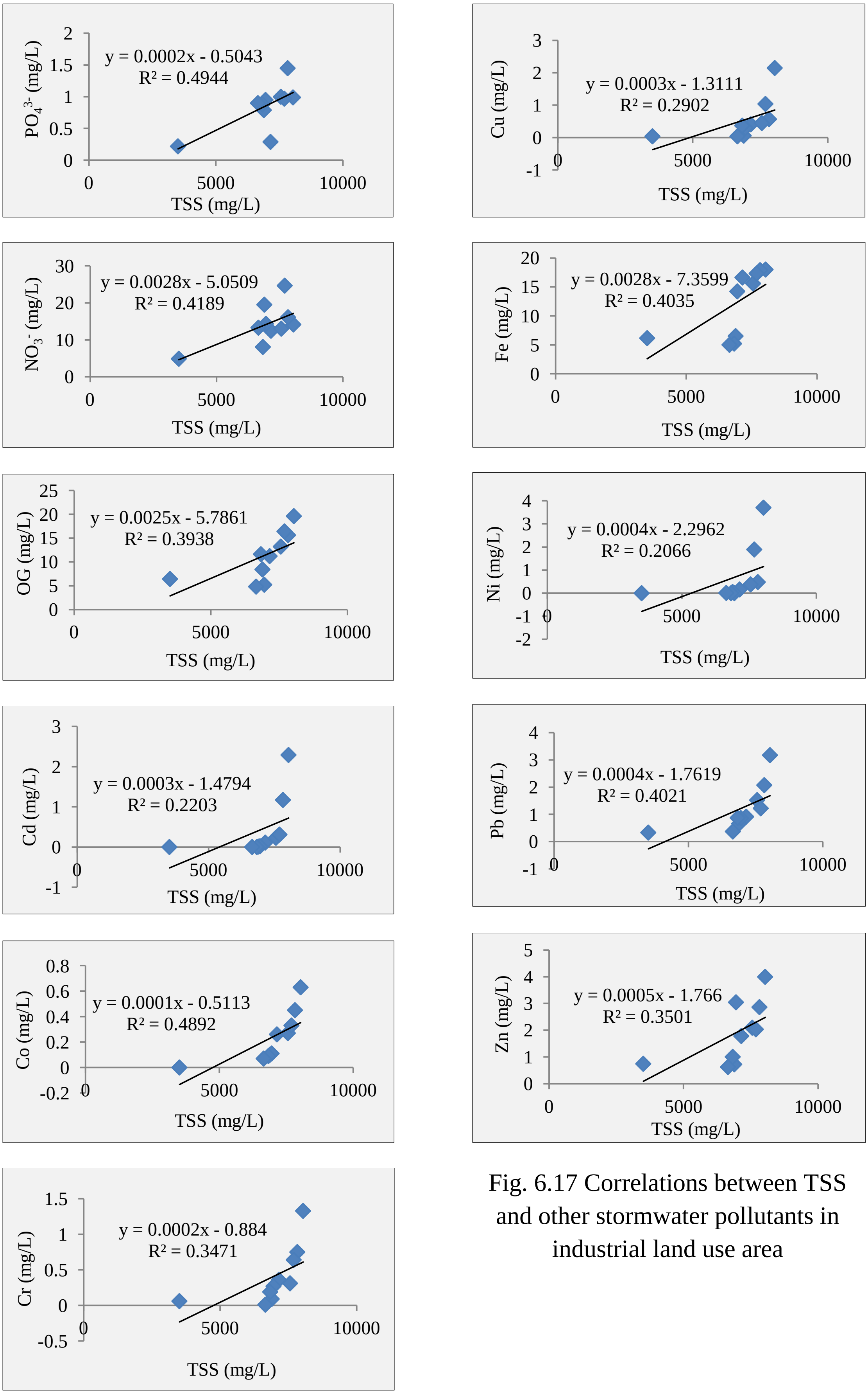
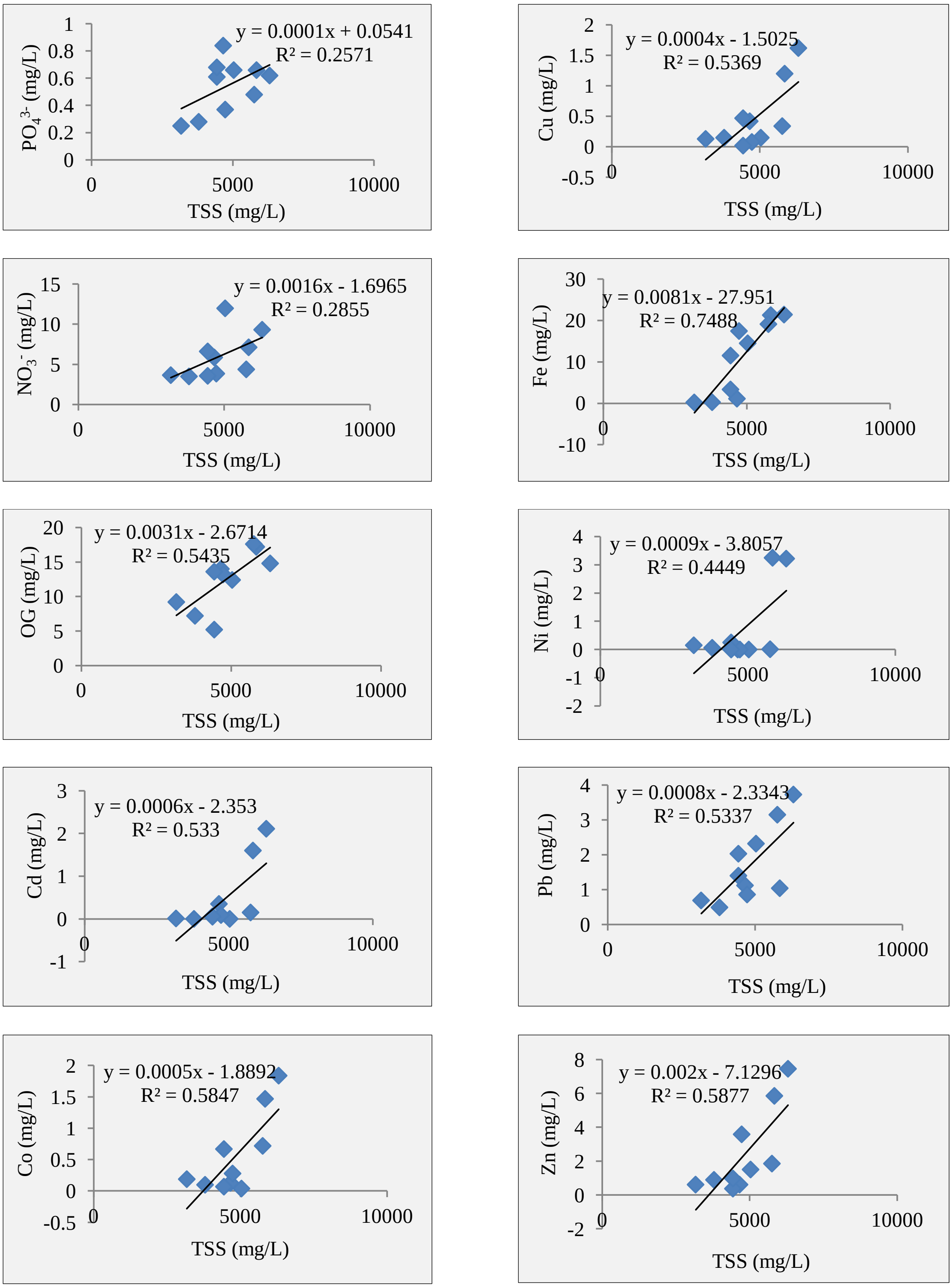


Fig. 6.17 Correlations between TSS and other stormwater pollutants in industrial land use area



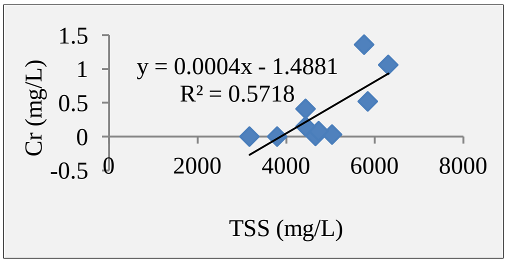


Fig. 6.18 Correlations between TSS and other stormwater pollutants in heavy traffic land use area

It is evident from the figures that the correlation coefficient ranged from 0.21 to 0.78, indicating a weak to moderately strong correlation between TSS and other parameters chosen (*i.e.*, nutrients, OG and heavy metals). The nutrients (*i.e.*, PO_4^{3-} and NO_3^-) showed weak to moderately strong (R^2=0.26 to 0.53) relationship with TSS. The relationship is relatively stronger in residential and industrial land use areas. Therefore, it can be surmised that most of the nutrients in these two land uses are particulates. Except for the industrial land use area, OG showed strong correlation (R^2>0.50) with TSS at all other land uses.

The correlation coefficient between heavy metals and TSS ranged from 0.21 to 0.78, which suggests a weak to moderately strong correlation between them. Han and his co-researchers found a weak to moderate relationship between concentrations of metals and TSS in their study conducted in USA [48]. However, various researchers reported a very strong relationship (R^2>0.90) between heavy metals and TSS [117, 249, 250]. Djukic and his co-authors also found a strong correlation between the total content of heavy metals and TSS [78]. The differences in the strength of correlation of these studies with the present study may be due to various factors such as the differences in catchment characteristics and analytical methods applied.

In the present study, the strength of correlation between metals and TSS has a slight difference among the different land uses. In residential land use area, Cd, Co, Cr, Fe and Pb showed moderately strong (R^2=0.52 to 0.78) positive relationship with TSS. However, Cu, Ni and Zn showed weak relationship (R^2=0.37 to 0.49) with TSS. In commercial land use area, Cd, Cr and Fe showed moderately strong relationship (R^2=0.51 to 0.64) and the other metals showed weak relationship (R^2=0.35 to 0.49) with TSS. In industrial land use area, all the heavy metals showed weak correlation

(R^2 = 0.22 to 0.49) with TSS. In heavy traffic area, all heavy metals except Ni showed moderately strong relationship (R^2=0.53 to 0.75) with TSS.

From the above observations, it can be assumed that the heavy metal load in stormwater of residential and heavy traffic areas can be effectively minimized by minimizing the TSS content of stormwater. However, in all land use areas, TSS showed positive relationship with all other parameters chosen (*i.e.*, nutrients, OG and heavy metals). Therefore, TSS can be regarded as a primary stormwater pollutant and hence by reducing TSS from stormwater, the concentration of the other pollutants in stormwater can also be reduced to some extent.

6.4 Variability of the stormwater pollutants

The variability of the selected stormwater pollutants were analysed by using coefficient of variation (CV). In the present study, CV of the chosen stormwater quality parameters was derived for each of the four land uses. The comparison of CV values derived for the twelve different parameters for the four different land uses are shown in the Fig. 6.18.

From the figure, it is observed that all other parameters show relatively higher CV values (more than 30%) except for TSS in industrial and heavy traffic area. The CV value of more than 10% is considered as having a high variation [193]. Thus, the present study further confirms the high variations of the pollutant parameters even within the same land use. This implies the highly variable nature of the parameters not only with the different land uses but also with the site specific characteristics.

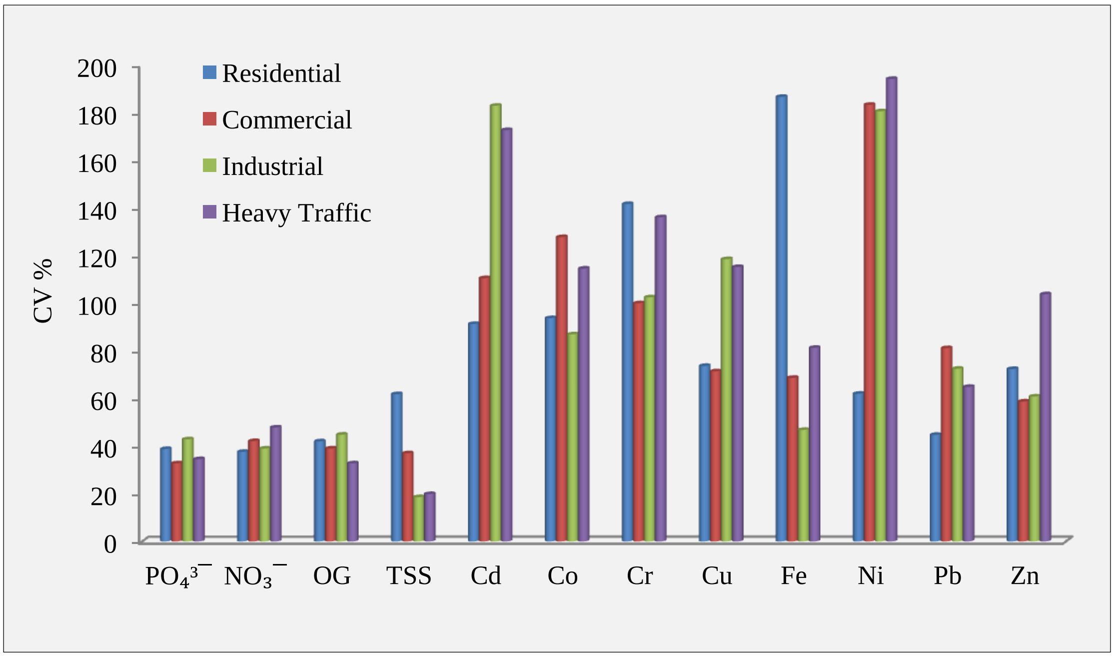


Fig. 6.19 CV of different pollutant parameters

In the residential land use area, Fe shows the highest CV value (more than 100%) in the residential land use while Ni shows high CV values (more than 100%) for the commercial, industrial and heavy traffic areas. Therefore, the variability of these two pollutants within the same land use is relatively higher than that of other pollutant parameters and thus mostly influenced by the existing site specific characteristics.

6.5 Conclusion

This chapter has analysed and discussed the outcomes of the investigation carried out on some selected stormwater quality parameters in the different land uses. The analysis is conducted by using the results of the laboratory analysis for various stormwater quality parameters in the different land uses. To know the influence of land uses on stormwater quality, analysis was conducted by using both univariate and multivariate techniques of data analysis. From the analysis, the following conclusions can be derived-

(i) The industrial area has the highest mean and maximum value for both PO_4^{3-} and NO_3^- in comparison to the three other land uses. The sources of PO_4^{3-} and NO_3^- in the industrial land use (Noonmati) can be leaf litter, industrial waste water, industrial emissions and atmospheric deposition. As, an intense tree canopy is prevalent in the surrounding areas of the industrial land use area, therefore the primary source of PO_4^{3-} and NO_3^- in this area is plant materials such as leaf litter.

(ii) The highest mean concentration of OG was observed in the heavy traffic area which is Inter State Bus Terminal. A large number of vehicles are gather round regularly for a considerable periods of time. This may be reason of highest mean concentration of OG in this area. Therefore, used automotive crankcase oil will be the major source of OG in the area. However, the maximum concentration of OG was observed in the industrial land use area. This occasional high concentration of OG in the industrial land use areas may be due to the ineffective use of engineering controls or BMPs.

(iii) The industrial land uses have the highest mean and maximum value for TSS concentration. In the present study, the higher concentrations of TSS may be due to vehicles and maintenance activities, erosion of landscaped area and road surface erosion. As the surroundings of the selected industrial site is hilly area, the roads have greater slope. Therefore, stormwater runoff from these road surface would flow with great force which can lead to higher rate of road surface erosion and hence contribute to higher concentration of TSS. Another reason of higher concentration of TSS may be due to the presence of the decomposition product of plant materials.

(iv) Heavy traffic areas have the highest mean concentration of Cd and Co which may be due to the presence of a large number of vehicles in the area. In the present study, Cd may be generated from vehicular activities like consumption of tire and use of brake shoes. Co in the heavy traffic areas may be generated from engines and oil leaks because a large number of vehicles are always present there for a long period of time. However, the maximum Cd concentration is observed in an industrial land use site which may be due to the presence of site specific sources like corrosion of metals, batteries, vehicular activities at that specific site, plastics and medical use.

(v) In the present study, highest mean concentration of Cr is observed in industrial land use area. The higher amount of Cr in the industrial land use area may originate from the corrosion of the building materials, paints and also from the vehicular traffic present at the road of industrial areas. However, the maximum Cr concentration is observed in heavy traffic area which can be released from the vehicular sources such as brake ware, engines and oil leakage and parts of vehicle present at that specific site.

(vi) The industrial land use showed relatively higher mean and maximum value of Cu concentration compared to other three land uses. Sources of Cu in the industrial area may be combustion of fuel, corrosion of roof, gutter and vehicular traffic related activities are performed at regular manner around the industrial area.

(vii) In comparison to other three land uses, the industrial land use area shows the relatively higher mean concentration of Fe. In the industrial area of the present study iron may originate from paint, tires and materials which are made from iron, surface erosion, brake ware of equipments and vehicles and other vehicular sources available in the industrial area.

(viii) Relatively higher mean concentration of Ni is observed in heavy traffic areas which may have originated from combustion of diesel oil and fuel oil, brake wares engine wares and fluid leakages. However, maximum concentration of Ni is observed in industrial areas which may be due to the site specific sources such as metal plating, asphalt paving, combustion of fuels in industries and vehicular sources available at that specific site.

(ix) Higher concentration of Pb is found in heavy traffic area which may be originated from combustion of fossil fuel, corrosion of bearing wares, tyre wares, and leakage of lubricating oils, grease and leaded petrol. Environmental and occupational exposures to Pb can be reduced to some extent by reducing the use of lead in petrol, paint, plumbing and solder.

(x) Higher concentration of Zn is observed in the heavy traffic areas which may be due to the presence of vehicular related sources such as fossil fuel combustion, tyre wear, leakage of motor oil, grease present in the area. The concentrations of Zn in stormwater runoff can be reduced by preventing the leakage of motor oils from vehicles and by sweeping of paved areas. As the solid particles such as dust and dirt can absorb motor oil and hydraulic fluid and tyre dust is also a major source of Zn. Therefore, sweeping of particulates from paved areas can remove Zn with them.

(xi) Stormwater of industrial and heavy traffic areas have relatively higher pollutant loads in comparison residential and commercial areas. Therefore, it is important to take special consideration for the management of the stormwater of these areas.

(xii) From the correlation study, it is observed that the nutrients (PO_4^{3-} and NO_3^-) have weak to moderately strong (R^2= 0.26 to 0.53) relationship with TSS. The relationship is relatively stronger in residential and industrial land use areas. Therefore, most of the nutrients in these two land uses are likely to be present mainly in particulate form.

(xiii) Except in the industrial land uses, OG showed strong correlation (R^2>0.50) with TSS at all other land uses.

(xiv) The correlation coefficient between heavy metals and TSS ranged from 0.21 to 0.78, which suggests a weak to moderately strong correlation between them. The heavy metals in the residential and the heavy traffic areas have relatively strong relationship with TSS. Hence, this can be interpreted as effective reduction of TSS also reducing the heavy metal load in stormwater from residential and heavy traffic areas. However, in all land use areas, TSS showed positive relationship with all other parameter chosen. Therefore, TSS can be regarded as a primary stormwater pollutant and hence by reducing TSS from stormwater, the other pollutants in stormwater can also be reduced.

(xv) To evaluate the variability of the parameters within the same land use, CV of the chosen stormwater quality parameters were derived for each of the four land uses. It is observed that all other parameters show relatively higher CV values (> 30%) except for TSS in industrial and heavy traffic area. Thus, the present study confirms a higher trend of variations in the pollutant parameters even within the same land use. This implies the highly variable nature of the parameters not only with the different land uses but also with the site specific characteristics.

(xvi) In the residential land use area, Fe and Ni show the highest CV values (>100%) for residential areas and for commercial, industrial and heavy traffic areas. Therefore, the variability of these two pollutants within the same land use is relatively higher than that of other pollutant parameters and thus mostly influenced by the existing site specific characteristics.