Exploring the National River with land use perspective-A GIS approach

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Abstract

The land along which the river flows has been linked to the river since 1900s by several researchers. Very recently adding to these landscape and riverscape studies is the use of remote sensing and GIS for preparing the land use and land cover (LULC) map of the river basin and subsequently linking it to the water quality of river. After seeing our National River Ganga being untouched exploring such linkages, the present study was designed so as to investigate the effects of land use and land cover on the water quality of the river Ganga. For the purpose of the study the river Ganga stretch of Varanasi region was selected and LULC analysis for buffer radii of 1km along the bank was prepared using Arc GIS 10.2. Further parameters measuring the health of the river were linked to the LULC data obtained. The LULC data revealed that there are two predominant land use type in Varanasi viz. urban and agriculture and there are no forested areas near the river riparian zone. The water quality of the river Ganga near the agricultural land use was comparatively better than the stretches lined with built-up area. The source apportionment analysis conducted via principal component test revealed urban land as principal contributor of metals on the other hand agriculture land contributed organic matter into the river. The present research thus is a first and small initiative to direct the riverine research spatially suggesting its expansion over the entire river stretch so as to come up with different approach to rejuvenate the river Ganga.

Keywords: Arc GIS; agricultural; land use and land cover; principal component analysis urban; water quality

1. Introduction

Land use and humans share a vice-versa relationship. Land use refers to "man's activities on land which are directly related to the land" (Clawson and Stewart, 1965). Land cover on the other hand describes, "the vegetation and artificial contractions covering the land surface" (Burley, 1961). Land cover can be estimated qualitatively as well as quantitatively by remote sensing (Roy and Roy, 2012), on the other hand the land use and its changes requires integration of both natural and social science in order to analyse which human activities are occurring in variable parts of the landscape (Lambin et al., 2001). LULC have been recognized as the core and prime factor catalysing various environmental changes since 1980s (Roy and Roy, 2012) and these changes encompass climate change, biodiversity loss, pollution of air, water and soil (Roy and Roy, 2012).

The rivers have been linked to adjacent land use since 1900s. Integrating river hydrology to land is century older. Since then several limnologists have emphasized the relationship between land and river (Hynes, 1963; Kaushik and Hynes 1971).Understanding the relationship between land use and water quality is important so as to identify the primary threats to water quality, there by targeting critical land use areas and instituting relevant measures to minimize pollutant loadings, thus managing water quality of the region (Abler, et al., 2002).

Several studies points out towards decline in quality of river water as the extent of agricultural land increases within catchments via increasing nonpoint inputs of pollutants (Allan, 2004). The urbanization too have negative impact on water quality as these areas pollute river as a principle point-source thus badly degrading the river water quality (Silva and Willams, 2001; Huang et al. 2013). The relationship between riverine conditions and land use is implicit in tropical areas of developing countries (Ometo, 2000). In Indian context, there are only few studies mainly confined to small basins in South (Chattopadhyay et al. 2005; Raj and Azzez 2010). The river Ganga has yet not been considered sufficiently with this perspective. Beside advancement in remote sensing and geographical information systems has brought a new paradigm to assess water quality in relation to land use (Ierodiaconou et al. 2005; Rothwell et al. 2010). The present study was thus designed so as to investigate the effects of land use and land cover on the water quality of the river Ganga.

2. Material and methods

2.1 Study region

The study was confined to Varanasi district situated on the western bank of the river Ganga. Varanasi lies in lower reach of Ganga catchment in the state of Uttar Pradesh. The total area of the district is 1535 sq. km, supporting population of 3.148 million persons (http://varanasi.nic.in/). The urban agglomeration is stretched between 25°16'06.80''N, 83°01'01.19''E (upstream) to 25°19'40.07''N, 83°02'34.67''E (downstream). This district is densely populated, with 2063 persons per sq. km, as against the state average of 689 persons per sq. km (MCV, 2006). The urbanisation is of concern in Varanasi as it has reached the riverfront of crescent shaped Ganga. The riverfront in Varanasi is lined by beautifully architecture eighty four ghats.

2.2 Study Stretch

The study area covers ~ 20 km of river Ganga stretch extending form 25°12'56.61''N, 83°00'37.98''E (upstream) to 25°20'15.67''N, 83°04'41.32''E (downstream) of Varanasi district.

2.3 Land use and land cover Map of the study region

The land use and land cover (LULC) map for buffer radii of 1km was prepared for study stretch using software Arc GIS 10.2 from high resolution Google earth imagery of the area via. onscreen visual interpretation technique. A total of 23 classes were delineated following the National Resource Census (NRC) of Government of India classification system (NRSA, 2005). The entire river stretch of the study area was divided into 12 zones from upstream to downstream of Varanasi. The area (in hectares) of each land use feature in each zone was calculated via Arc GIS 10.2. Later each land use features were grouped together broadly into agriculture (cropped area, fallow, floriculture, orchards, scrubland) and urban (residential, mixed built-up, recreational, semi-public, public utility, commercial, vegetated area, transportation, open area).

2.4 Collection and analysis of water samples

Water samples were collected using modified Swing sampler at 12 sampling zones in the mid of every month from April 2013 to March 2015 except for the months of August and September in both the year and July in 2013 due to flood (Uttarakhand tragedy). Grab sampling method was applied for collecting the samples. Samples were collected within 5m from river bank at a depth of ~ 0.5m in teflon bottles of 2 L. The samples were transported and stored as per the quality check methods of APHA, 1995. The 17 parameters viz. temperature, turbidity, conductivity, TDS, pH, COD, BOD, DO, hardness, alkalinity, phosphate metals (Cr, Cu, Cd, Pb and Zn) were analysed using standards methods of APHA, 1995. Nitrate was analysed using the method as mentioned in Singh et al. (2012).

2.5 Statistics

Land use wise Principal Component Analysis (PCA) was performed using SPSS 16.

3. Results and Discussion

3.1 Land use land cover analysis

Varanasi city is characterised by the river bank urbanisation since 1822 as evident in the map of old Varanasi city from rivers Assi to Varuna prepared by James Prinsep (http://www.varanasi.org.in/). The eighty four ghats form the unique heritage structure near the river bank resulting in high density of urban built-up areas. Similar characteristics features of high percentage of built up areas near river was evident through the LULC Map of the study stretch (Figure 1). The agricultural areas were confined to zones 1, 2, 3, 4, 11 and 12 (Figure 1 and 2). The maximum percentage of agriculture was observed in zone 12 (92.38%), followed by zone 2 (92.04%), zone 3 (86.65%), zone 11 (75.84%), zone 1 (68.11%) and zone 4 (58.66%) (Figure 2). However urban areas were confined to zones 6, 7, 8 and 9 with variable urban land use classes viz. residential areas, mixed-built up, recreational, public-semipublic, transportation, commercial areas, public utilities and point sources (Figure 1).

The zones 6 and 7 which were characterised with urban land use classes in majority also contained marginal green cover in and around the localities (Figure 1). The varied diversified land use categories were observed in zone 5 and 10 viz. residential, rural, vegetated areas, cropped areas, current fallow, commercial areas, etc. The maximum percentage of urban land use was observed in zone 8 (99.80%) followed by zone 9 (99.47%), zone 7 (99.14%), zone 6 (95.26%), zone 10 (51.26%) and zone 5 (46.29%) (Figure 2). There are no LULC studies performed by other authors for river riparian zone however the LULC analysis for whole city have been made by other authors such as Kumar et al. (2010), Jaiswal and Verma (2013) and Ohri and Poonam

(2012). Jaiswal and Verma (2013) reported 53% rise in built-up area and 5.3% decline in land under agriculture from 2005-06 to 2011-12 in Varanasi district.

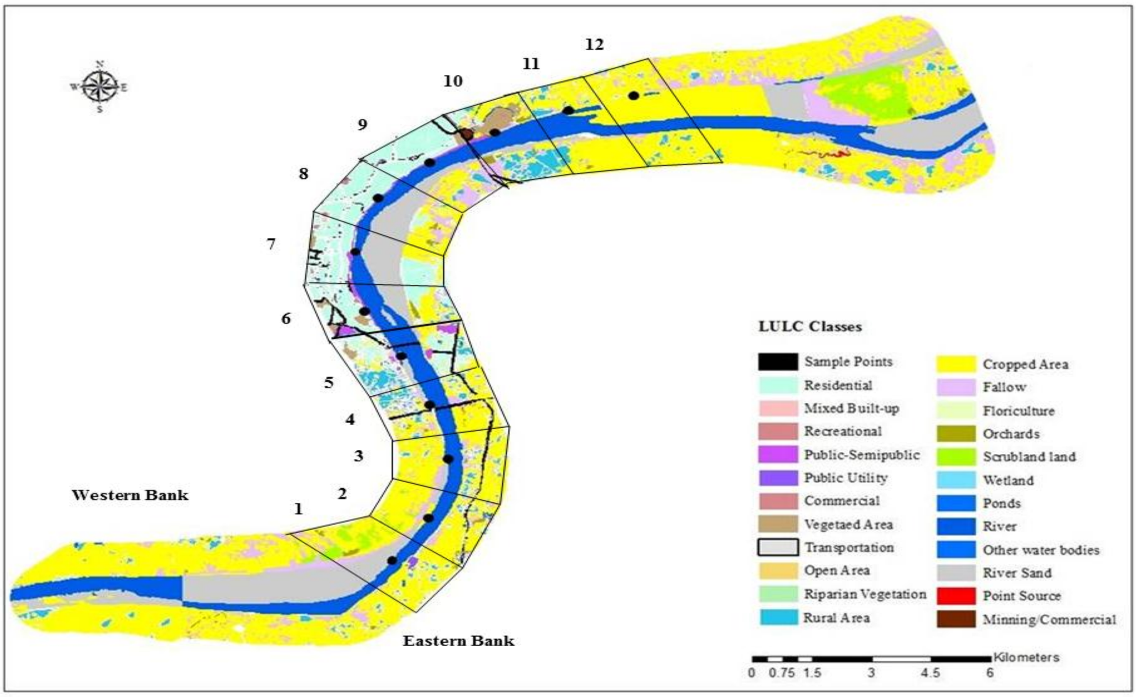


Figure 1 Land use land cover map showing 12 zones of study region (Source: Sharma et al., 2016)

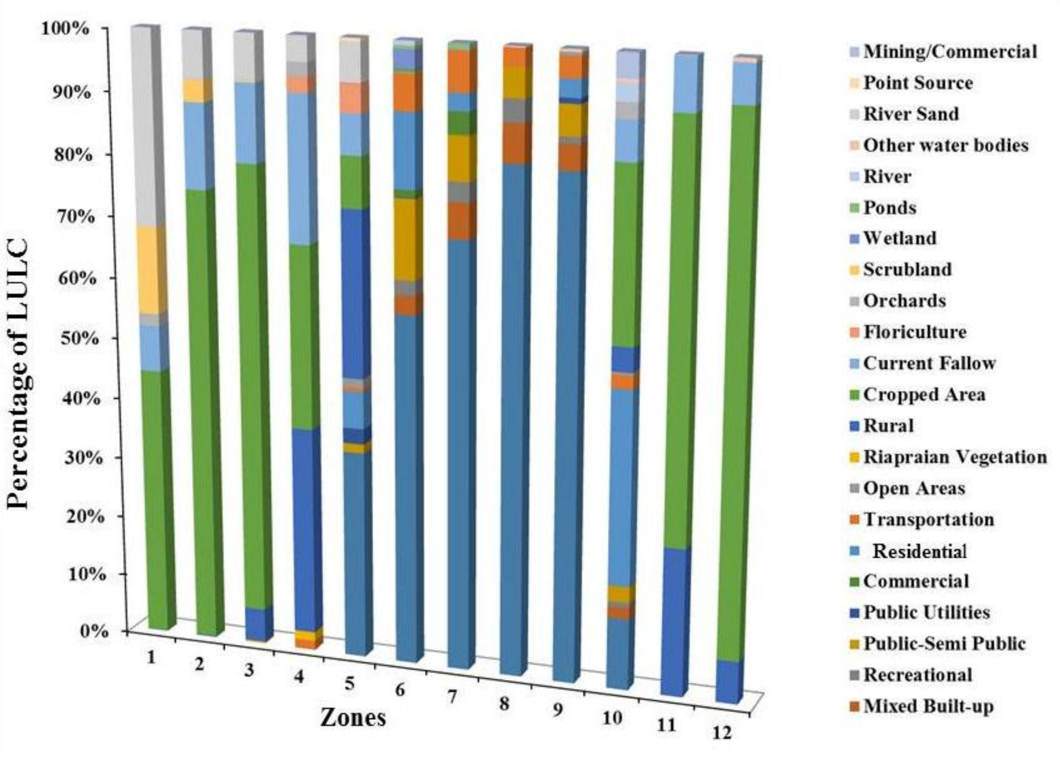


Figure 2 Percentage distributions of the LULC classes in the different zones of the study region

Similar rise in built-up areas have been reported by Ohri and Poonam (2012) as in the year 1976 the agriculture was extensively practised in the Varanasi city and 3860.48 hectares of land was under agriculture, however, in the year 2010 half of the land under agriculture was replaced by built-up areas. A differential study analysing the LULC pattern of planned and unplanned Varanasi reported that core of the city is highly urbanised and some semi-urban area i.e planned areas having considerable amount of tree cover and built-up areas (Kumar et al., 2010).

The most important thing to observe in the LULC analysis was the very minimal percentage of riparian vegetation i.e. 1.76% in 12 sampling zones (Figure 2). Similar observations have been reported by Cooper et al. (2013) in the watersheds of streams and rivers of Mediterranean region where authors observed loss of riparian vegetation due to human encroachments for varied purposes. The forest cover near the river riparian zone was completely absent and there were only two major land use class viz. urban and agriculture. Azyana and Norulaini (2012) also observed similar land use characteristics in Kinta river basin (Malaysia) as authors delineated two dominant land use features i.e. developed land or urban land (which included commercial, residential, industrial and recreational premises) and vegetation (which included vegetable farms, fruit, orchards, rubber and oil palm plantations).

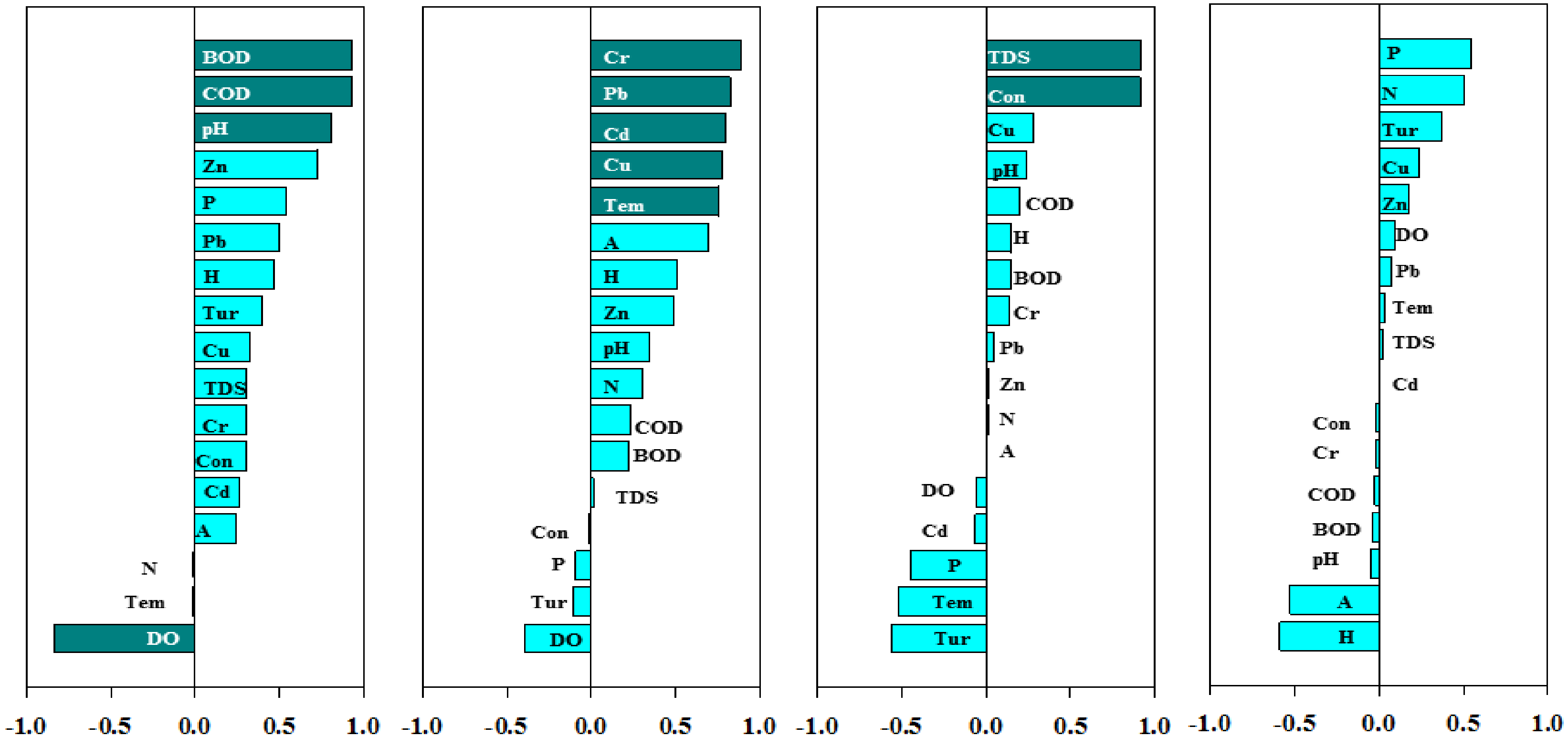
On a contrary there are many studies where in the authors have observed the variable dominant land use classes such as Sliva and Williams (2001) digitised three watersheds of Canada (with variable land use category) viz. most urbanized Highland creek watershed, moderately urbanized Rouge river watershed and least urbanized Duffins creek watershed into four variable categories of land use features viz. field (including pasture lands and golf courses), forested land, agricultural land (including row and non-row crop agriculture) and urbanized land (including industrial and residential areas). Chattopadhyay et al. (2005) in a study confined to Chalakudy river basin (India) studied the LULC of stretch from the Poringalkuttu reservoir to the confluence of the Chalakudy river with the Periyar also reported variability in the land use features.

3.2 Land use wise Principal Component Analysis of water quality parameters

The land use wise PCA analysis of water quality data sets resulted in four principal components (PCs) with eigen value >1 in both land use classes viz. agricultural and urban. The four PCs in agriculture land use explained 81.95% where as in urban land use explained 78.35% of the total variance. In the agriculture land use class, 1st PC represented 29.57%, 2nd PC 28.01%, 3rd PC 15.98%, and 4th PC 8.38% of the total variances. Similarly in the urban land use, 1st PC represented 26%, 2nd PC 24.24%, 3rd PC 16.22% and 4th PC 11.88% of the total variance.

For the agricultural land use class COD, BOD and pH showed strong positive loadings and DO strong negative loading, while Zn and phosphate were with moderate positive loadings in 1st PC, thus explaining for the organic matter and fertilizer sources (Figure 3). The sources of organic matters in agricultural land use can probably from crops grown in the area and use of organic manures. The sources of phosphate and Zn can be through fertilizers as the agricultural soils of Indo-Gangetic plains are deficient in phosphate and Zn (ICAR, 2009; Prasad, 2007), therefore it necessitates providing additional doses of these elements in the form of fertilizers. The maximum variability in urban land use was explained by PC 1 with metals forming the strong loadings suggesting that built-up areas near rivers were sources of metals (Figure 4). The high input of metals from urban areas can be attributed to sewage outfalls in these zones bringing in the waste from small industries and handlooms. Similar strong positive loadings of COD and BOD in PCs were observed in Cauvery River basin (Umamaheswari and Saravanan, 2009) and the river Ganga at Varanasi (Kumari and Tripathi, 2014). On the other hand negative DO and positive BOD loadings in the river Ganga in Varanasi was reported by Mishra (2010).

In agricultural land use PC 2 explained strong positive loadings for temperature, Cr, Cu, Cd and Pb while moderate positive loading for hardness and alkalinity (Figure 3). The heavy loadings of metals suggested that agriculture is also the source of metals. Papafilippaki et al. (2008) also reported significant amounts of metals in the river Keritis of Greece from adjacent agricultural lands. The strong positive loadings of temperature in PC 2 along with metals can be explained by the findings of Iwashita and Shimamura (2003) suggesting that the solubility and release of metals in surface waters are temperature dependent. However in urban land use, PC 2 represented positive strong loading for pH, BOD and COD and moderate loading for Zn (Figure 4) thus representing sources for organic matter. The contribution of organic matter into the river from urban areas can be attributed to wastes from sewage outfalls and floral offerings and dead remains of humans and animals. Thus this PC explains the anthropogenic pollution sources.



Abbreviation used in figures: DO-Dissolved Oxygen, BOD- Biological Oxygen Demand, COD-Chemical Oxygen Demand, Temp-Temperature, Tur-Turbidity, P-Phosphate, N- Nitrate, A- Total Alkalinity, H- Total Hardness, TDS-Total Dissolved Solid, Con-Conductivity, Cu-Copper, Zn-Zinc, Cr-Chromium, Cd-Cadmium, Pb-Lead.

Figure 3 Loadings of water quality parameters on PC 1, PC 2, PC 3 and PC 4 in agriculture land use

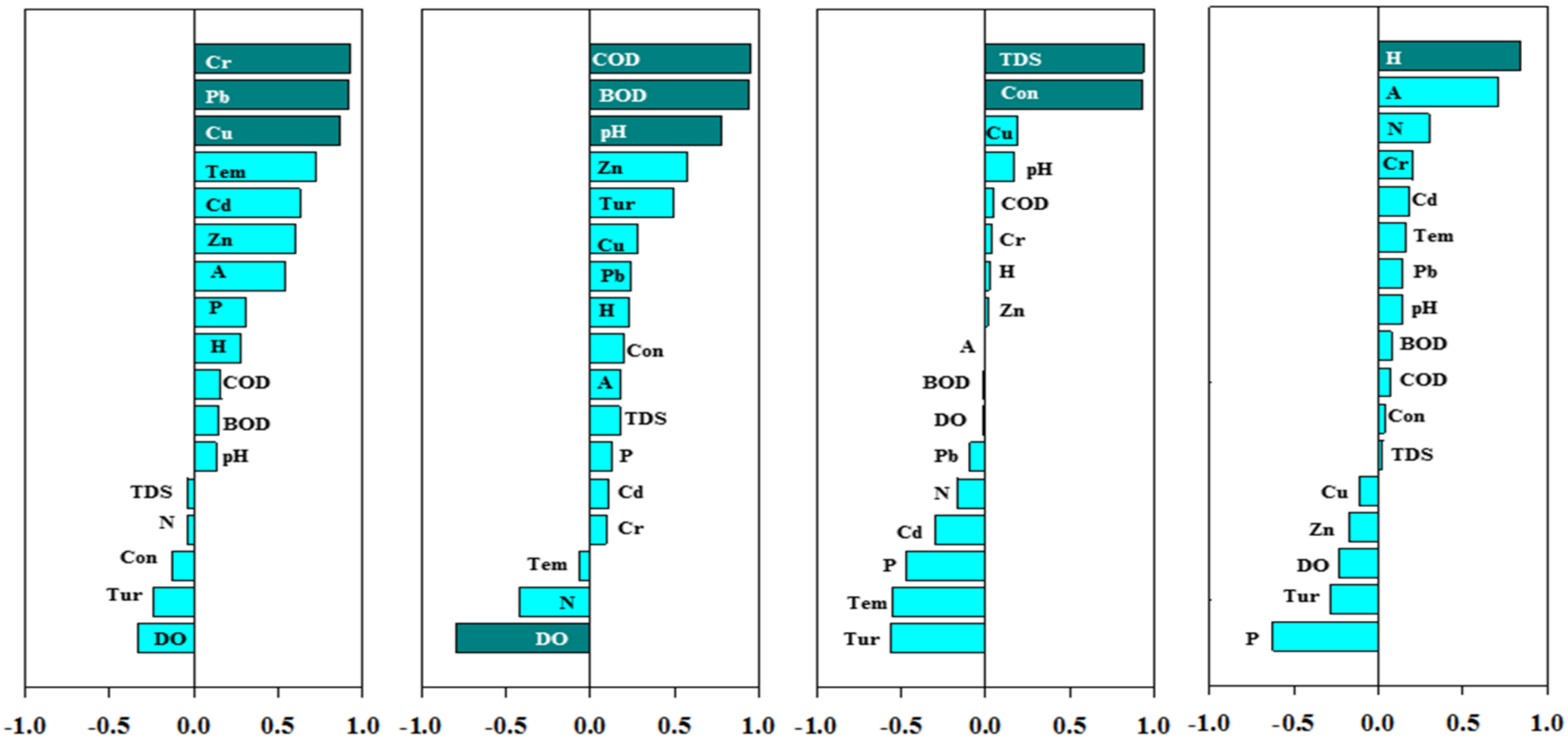


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Figure 4 Loadings of water quality parameters on PC 1, PC 2, PC 3 and PC 4 in urban land use

The 3rd PC in agricultural land use consisted TDS and conductivity with strong positive loading, while in urban land use PC 3 explained strong positive loading for TDS and conductivity and negative moderate loading for turbidity (Figure 3). These PCs in both the land use categories represented the sources of solids indicating towards their origin in run-off from the agricultural fields and waste disposal activities from urban areas. The presence of ions and ionic compounds in water may have led to high loading of these variables. Similar results have been reported by Singh et al. (2004) in Gomti river (India), Mustapha and Abdu (2012) in Jakara river (Nigeria) and Bhardwaj et al. (2010) in Choti Gandhak river (India).

The nitrate and phosphate with moderate positive loading formed 4th PC in agriculture land use whereas temperature and turbidity formed the moderate negative loading (Figure 3). Although 4th PC represented the nutrient group but the loadings score suggests that agricultural land use is not contributing much phosphate and nitrate due to utilisation of these essential nutrients by crops. Similar results have been reported in Tigris river by Varol et al. (2012). However, Mustapha and Abdu (2012) in a study conducted in Jakara Basin observed that nutrient related factors showed minimum variability with strong loadings. The 4th PC in urban land use had hardness with strong positive loading and phosphate and alkalinity with moderate positive loadings (Figure 4) thus representing sources of minerals and ions in water. Similar results were reported by Singh et al. (2004). Urban areas may possibly contribute towards alkalinity as concrete structures add extra weatherable materials (Stets et al., 2014; Barnes and Raymond, 2009).

4. Conclusions

The result of this study revealed that the riparian vegetation is absent near the bank of river Ganga in Varanasi and riparian zone are characterised by the presence of two major land use class viz. agricultural and urban. The land use wise PCA on water quality parameters extracted 11 parameters viz. DO, BOD, COD, pH, temperature, TDS, conductivity and metals (Cr, Cu, Cd, Pb) in agricultural land use as of significance for assessing the water quality of the river Ganga. However in urban land use 10 parameters viz. DO, BOD, COD, pH, TDS, conductivity, hardness and metals (Cr, Cu and Cd) are of prime importance in water monitoring studies in river Ganga of this region. The agricultural land use was source of organic matter and fertilizer mainly and urban land uses that of metals. Thus study suggests implementing plans and policies for curbing rising urbanisation near the river as it will deteriorate the river health.

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