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RESEARCH ARTICLE

GIS-BASED ANALYSIS OF IMPACT OF LAND-USE ON NITRATE AND TDS IN DRINKING WATER IN KARACHI

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ABSTRACT

The present study aims to evaluate a relationship between land-use and two water quality parameters i.e., nitrate and total dissolved solids (TDS) for selected areas within Karachi city of Pakistan during the year 2014. The water pollution data was combined with satellite land-use coverage in a Geographical Information System (GIS)-interface using Arc view 3.2 followed by Pearson's correlation (statistical) analysis. The study remained highly successful in predicting drinking water pollution source. The nutrient loading in drinking water was positively correlated with vegetation land-use and negatively correlated with undeveloped land.

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INTRODUCTION

One of the major causes of water pollution is land-use. Land-use change has been a critical issue for planning and management of resources and for modernization agenda in most developing countries (Yong and Chen, 2002). Significant measure has been implemented to identify the feasible land-use activities that could lead to disaster to human and issues to the development of infrastructure. Disposal of waste water generated from municipal and industrial sources with little to no treatment prior to discharge is common practice in many developing countries. As a result of rapid urbanization (population growth and increasing industrialization), serious problem of the water quality are commonplace (Zainal *et al.,* 2003, Simeonov *et al.,* 2003). Geographic Information Systems (GIS) are increasingly being used to store information and forecast effects related to the spatial and time variability of the data (Leipnik *et al.,* 1993). Due to its data handling capabilities, GIS is an effective tool in water resources management (Tsihrintzis *et al.*, 1996). Study of non-point source pollution impacts requires the integration and display of different spatial information, a task for which GIS is a suitable choice (Ventura and Kim, 1993).

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GIS allow the user to overlay coverages, analyze and determine pollutant loadings, and prioritize and identify critical areas in a very efficient and economical manner (DeBarry, 1991; Robinson and Ragan, 1993). In Pakistan the problem of water pollution is growing at an alarming rate. The phenomena1 increase in country's population has brought unprecedented pressure on safe drinking water. Water born diseases account for 20 to 30% of all hospital cases and 60% infant deaths (Pakistan Economic Survey, 1999-2000). A substantial amount of work is being done to assess drinking water quality and relevant health concerns since last few decades in various urban (Haydar *et al.,* 2009; Akhtar *et al.,* 2005; Nadeem-ul-Haq *et al.,* 2009) and rural (Ahmed *et al.,* 2012; Malik *et al.,* 2010) areas of Pakistan. Some data regarding the impact of land-use on the quality of surface/source waters is also available (IWASRI, 1997; Sanaullah and Malik, 2014); however, there is a great scarcity of literature regarding the evaluation of GIS-based direct impact of nearby land-use practices on drinking (tap) water for Pakistan and particularly for Karachi, a metropolitan city. Any possible relationship between tap water pollutants and surrounding land-use may be useful in identification of pollution cause after storage from source water into the pipelines (consumer end). Considering this in view, the present study was aimed to seek the impact of land-use on TDS and nitrate loading in drinking water of Karachi City. The Land sat Thematic Mapper (LTM) image was quantitatively categorized to get land-use structure using

GIS-analysis on Arc view 3.2. In addition, Pearson's correlation statistical analysis was employed to evaluate a possible relationship between land-use practices (water, vegetation, built-up land, and vacant land) and pollutants (nitrate and TDS) in tap water samples of the city.

Study area

Drinking water samples were collected from five different regions of Karachi city: commercial (Sadder), residential (Gulistan-e-Juahar), areal (Air port), industrial (SITE) and coastal (Ibrahim Hydri) regions (Table 1, Fig. 1). Karachi is one of the world's fastest growing cities since the creation of Pakistan in 1947. Demographic projections suggest that the population of Karachi by the year 2025 could be 30.91 million. Rapid industrialization and urbanization are the most common sources of water pollution due to poor demographic/municipal management. At present the overloaded sewerage system is subjected to leakages, often overflowing and chocking. At some places water lines are only a few centimeter below the sewerage lines. Pressure gradient develops from sewerage lines towards water lines. In some part of the city water lines are virtually submerged in ground saturated with a mixture of water and sewerage fluids. Due to limited hours of domestic water supply, the consumer use vacuum pump to extract the needed water from the main supply pipes, which is also a source of contamination from domestic and industrial sewage water under suction pressure.

MATERIALS AND METHODS

Chemical Analysis

The chemical constituents (TDS and nitrate) in drinking water samples were analyzed according to ASTM STANDARDS (Water and environmental techniques), section 11, volume 11.02, 2000. Sampling was carried out in cleaned bottles of 0.5 liter capacity. Boric acid was used as preservative in sampling bottles for nitrates (Kahlown *et al.,* 2006).

GIS (Image and Spatial) Analysis

A rectified land-use map from Land Sat Thematic Mapper satellite imagery (2000) was added to Arc view 3.2. A subset image showing only the concerned area from the image was drawn and added to the view (Fig. 1). After activating image analysis extension, the imagery was classified into five land-use classes (Fig. 2): cemetery (very slightly developed land), built-up land, vegetation, vacant land and water. The categorized image was converted into shape file and added to the view (Fig. 3). The sampling point feature data (Table 1, Fig. 1) was layered on the top of the categorized image after adding a new point theme feature to the view. A polygon feature data was also layered in order to create a buffer zone of 232 ft around each sampling point (Fig. 1). After activating geo-processing extension, clipping was performed using categorized image as input layer and polygon / buffer zone as clip feature (Fig. 4). Using tabulate area function of Spatial Analyst extension, the absolute land-use area within each buffer zone was calculated (Table 2). The raw data file was then exported and saved as a text file that was opened in Excel sheet to calculate the percent of each land-use type within each analysis zone (Table 2). The Inverse distance weighted (IDW) interpolated surfaces for TDS and nitrate were also generated through spatial analysis extension (Fig. 5 and 7), which assumes that each measured point has a local influence that diminishes with distance.

Statistical Analysis

Pearson's correlation statistical analysis was performed using Microsoft Excel, and correlation coefficients (R^2) between each water quality parameter (TDS and nitrate) and land-use type were calculated (Fig. 6 and 8).

RESULTS AND DISCUSSION

Nitrate

Nitrate concentrations in the drinking water samples studied were ranged from 19 to 87 ppm (Table 1). Out of 5 samples, 3 samples (SITE, Ibrahim Hydri & Gulistan-e-Jauhar) were found to contain nitrate levels according to WHO standards (≤ 50 ppm). The excessive nitrate levels in drinking water may result in methaemoglobinaemia, particularly in infants (Malik *et al.,* 2010). The highest nutrient loading was found in commercial area, Sadder, probably due to poor water quality pipeline systems allowing penetration of municipal waste water and decaying plant debris indicating potential health hazards and thus requiring immediate attention. It has been widely documented that nutrient loading can be correlated with agricultural land-uses such as pasture and row cropping (Ferguson, 2003; Scott *et al.,* 1998; Smith and Perdek, 2004; Tilman *et al.,* 2001). The present study finds that the percent of vegetation/agricultural land-use is quite a significant (R^2 = 0.86) predictor of nitrate (nutrient) loading in tap waters (Fig. 6a). Hence, it can be deduced that, like surface waters, the nitrate levels in tap waters can also be correlated with agricultural land-uses. Nitrate also depicted a significant negative correlation (R^2 = 0.8) with vacant land (Fig. 6b and 6c). However nitrate did not show any significant correlation with built-up land (Fig. 6d) and water land-use (Fig. 6e).

TDS

TDS comprise inorganic salts and some organic matter dissolved in water. TDS concentrations were ranged from 33 to 1314 ppm in samples studied. Only two sampling sites (Ibrahim Hydri and Gulistan-e-Jauhar) were found to meet WHO standard for TDS (≤500ppm). Reliable data on possible health effects associated with the ingestion of TDS in drinking water are not available, and no health-based guideline value is proposed. However, the presence of high levels of TDS (greater than 1200 mg/litre) in drinking water may be objectionable to consumers (WHO, 2008). The highest TDS level was found in industrial zone, SITE (Fig. 7), indicating poor aesthetic water quality (salty or bitter taste) and high risk of scaling in water pipes, heating boilers and house hold appliances (Malik *et al.,* 2010; Tihansky, 1974). Such scaling can shorten the service life of these appliances (McQuillan and Spenst, 1976).

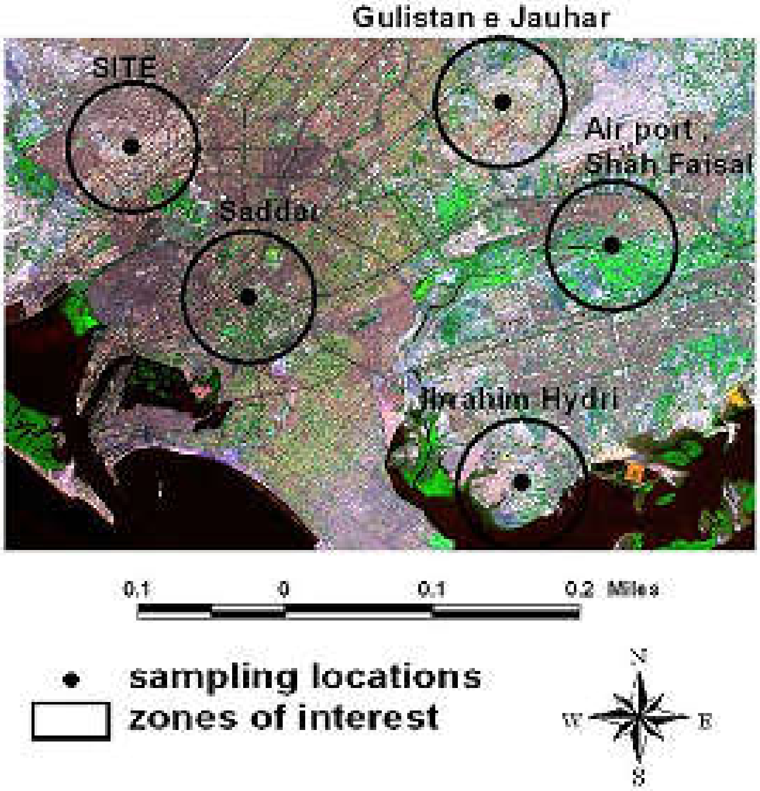

Fig. 1. Subset of rectified land-use image of Karachi layered with selected sampling points and surrounded buffer zones

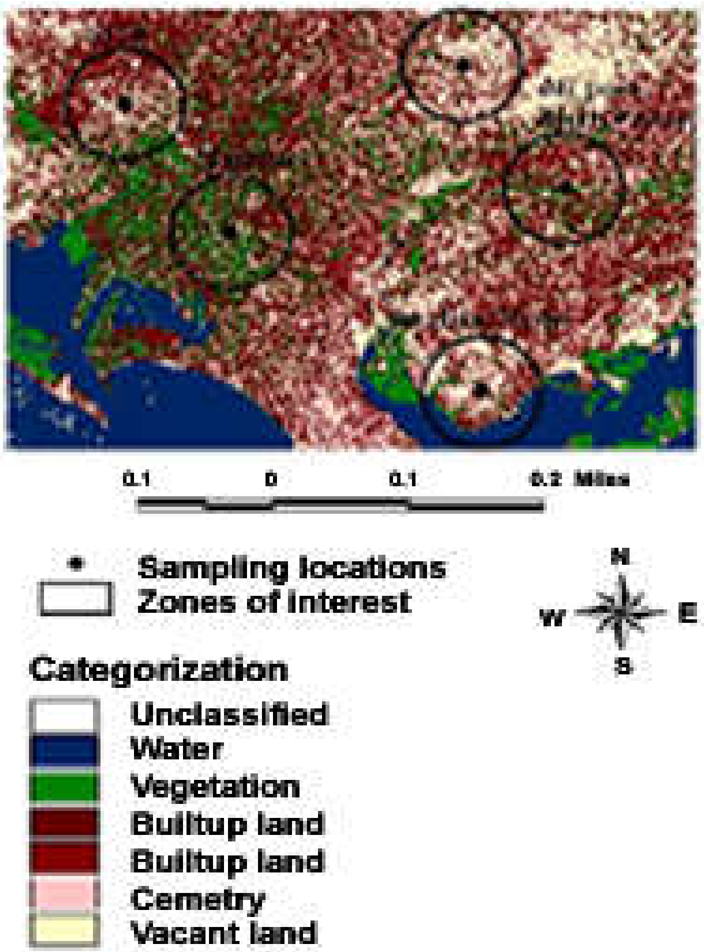

Fig. 2. Categorization of image of Karachi into five different land-uses

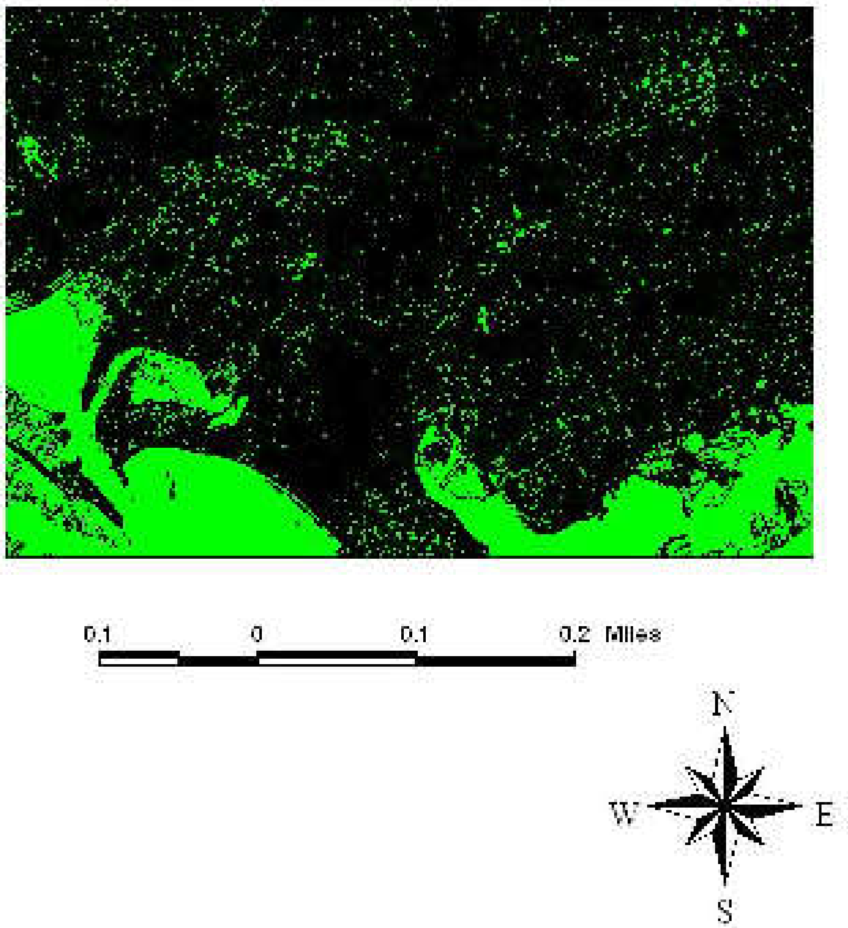

Fig. 3. Image of Shape file

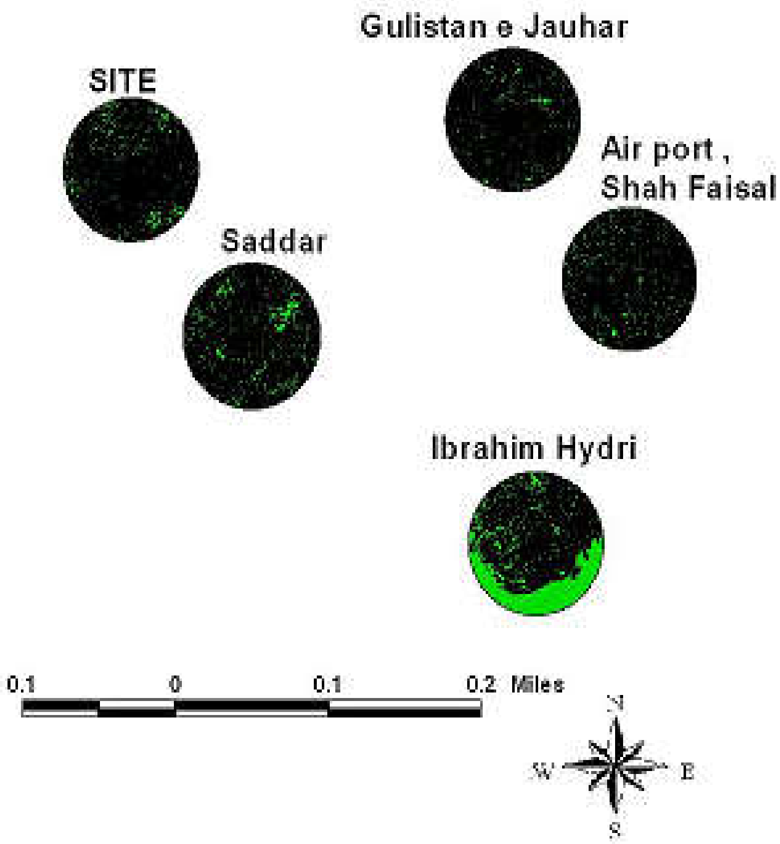

Fig. 4. Clipped image of selected buffer zones and land-uses

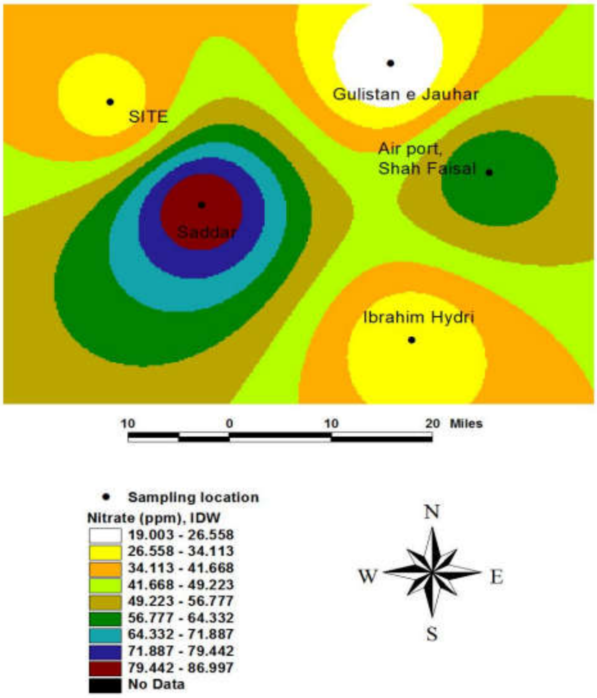

Fig. 5. IDW interpolated surface for nitrate

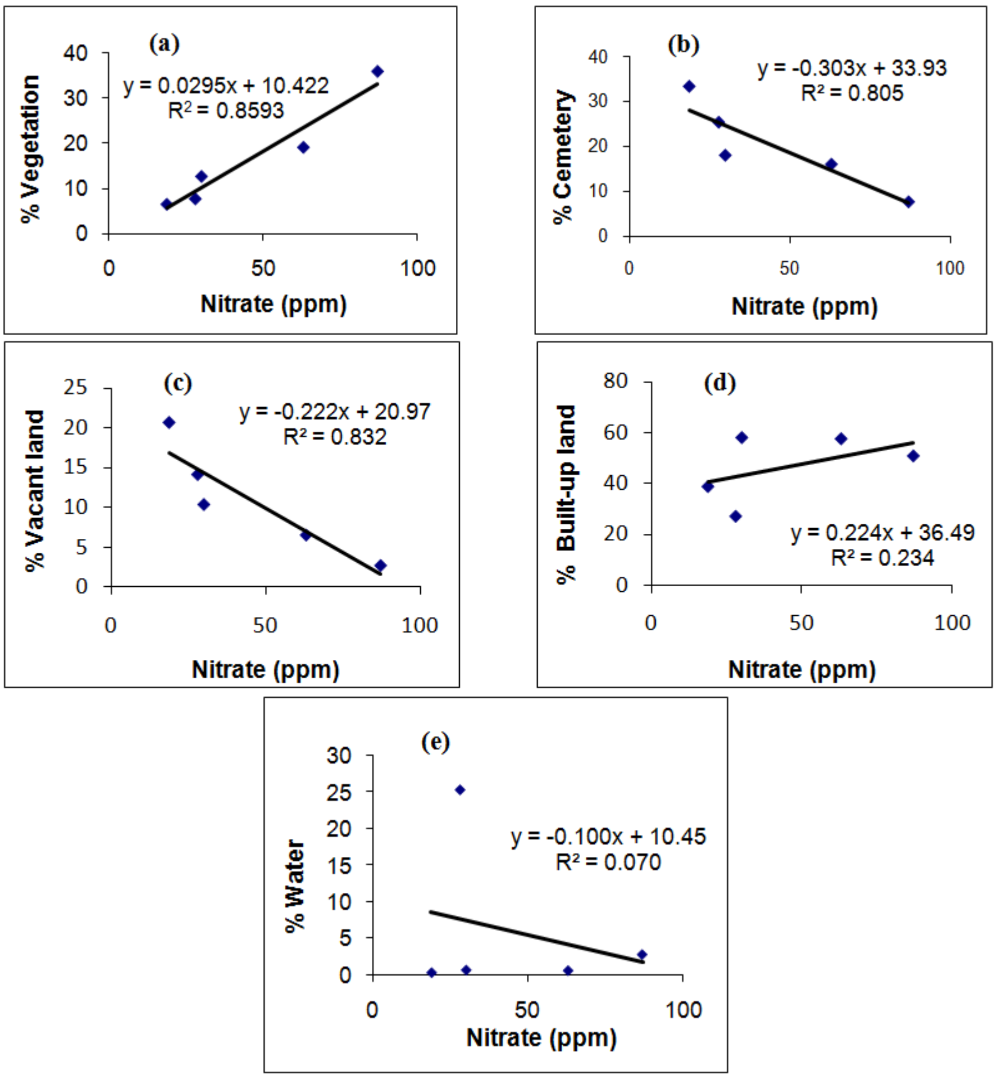

Fig. 6. Correlation between nitrate and different land-uses: vegetation (a), cemetery (b), vacant land (c), built-up land (d) and water (e)

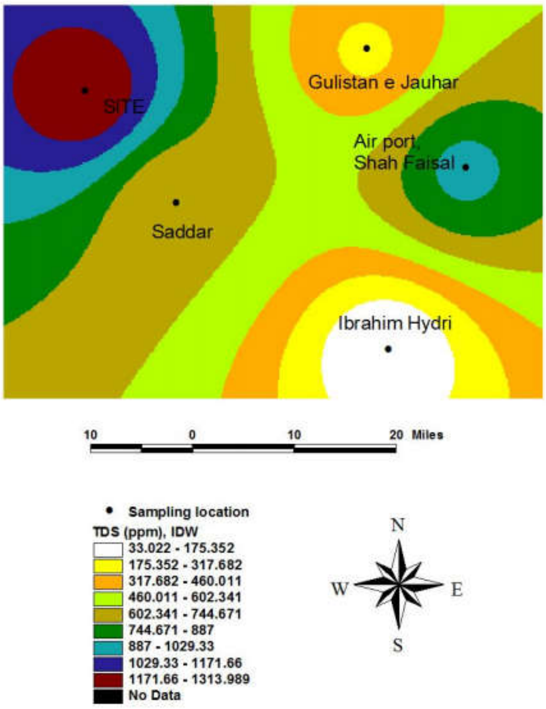

Fig. 7. IDW interpolated surface for TDS

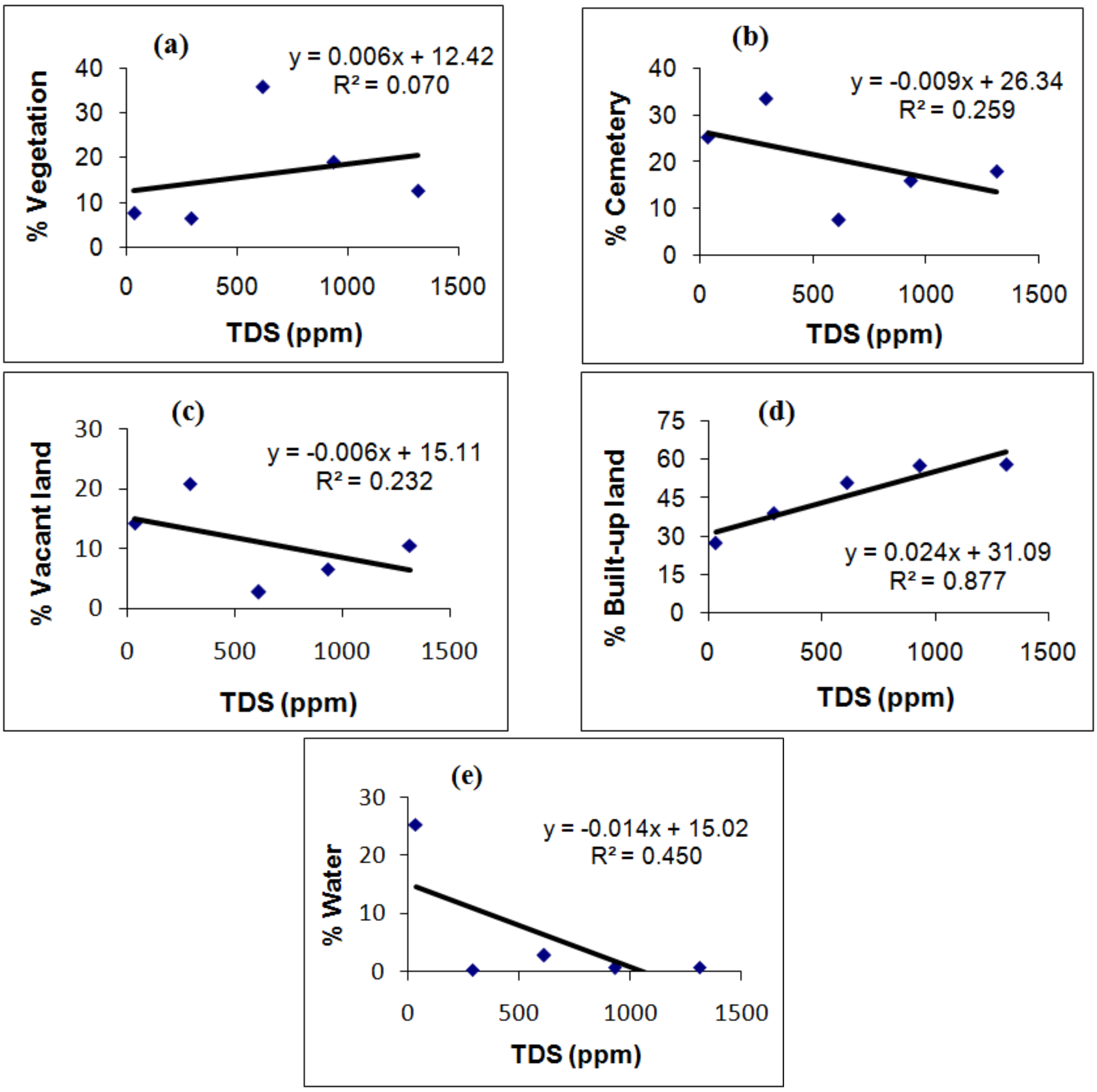

Fig. 8. Correlation between TDS and different land-uses: vegetation (a), cemetery (b), vacant land (c), built-up land (d) and water (e)

Table 1. Sampling points with water quality data

ID	Location	X	Y	Category	TDS (ppm)	Nitrate (ppm)
1	Air port /Shah faisal	67.16	24.99	Aerial	932 ± 5	63 ± 1
2	Gulistan-e-Jauhar	67.02	25.16	Residential	290 ± 7	19 ± 1
3	Ibrahim Hydri	67.05	24.73	Coastal	33 ± 2	28 ± 2
4	Saddar	66.75	24.94	Commercial	612 ± 6	87 ± 10
5	SITE	66.62	25.10	Industrial	1314 ± 2	30 ± 2

X and Y are *x* and *y* coordinates, respectively, obtained from Global positioning System (GPS)
TDS = Total dissolved solids

Table 2. Land-use areas and their percent within buffer zones around five sampling sites

Sample ID	Parameter	Vegetation	Cemetery	Vacant Land	Built-up Land	Water
1	Area	32045.024	27029.848	10942.203	96916.659	911.850
	% Land-use	19.091967	16.103997	6.5192081	57.741560	0.5432671
2	Area	11072.468	56274.189	34975.972	65783.485	455.925
	% Land-use	6.5687791	33.384853	20.749613	39.026275	0.2704790
3	Area	13156.697	42987.228	23968.636	46308.968	42726.699
	% Land-use	7.7782056	25.413939	14.170196	27.377743	25.259915
4	Area	62787.405	13612.622	4689.516	89491.592	4819.780
	% Land-use	35.796509	7.7608614	2.6735983	51.021166	2.7478647
5	Area	21428.482	30546.985	17520.552	98154.170	1042.115
	% Land-use	12.702702	18.108108	10.386100	58.185327	0.6177608

The reason of highest TDS may be the use of poor plumbing systems, use of chemicals for water treatment or poor water quality pipelines contaminated with sewage, industrial waste or agricultural runoff. TDS was not found to have any relationship with vegetation (Fig. 8a) and vacant land (Fig. 8b and 8c). However, TDS revealed a strong positive (R^2 = 0.88) relationship with built-up land (Fig. 8d) and significant negative correlation (R^2 = 0.5) with water land-use (Fig. 8e).

Conclusion

This study was intended to show possible relationship between land-use practices and water pollution parameters for tap waters using remotely sensed data in a GIS environment. It has cleared from the present study that land-use especially vegetation and built-up land are significant predictor of water pollution. Nitrate and TDS have positive relationship with vegetation and built-up land-use, respectively. TDS and nitrate are negatively correlated with water and vacant land-use, respectively.

Recommendation

The current analysis may be improved by methods that look more carefully at the regional composition of land-use types in Karachi and attempts to discretely identify the critical factors. Multiple numbers of samples should be analyzed in order to increase the precision of analysis. Other water quality parameters such as hardness, heavy metals, organic pollutants, microbes etc. must also be studied to more effectively evaluate the effect of land-use in predicting sources of water pollution. Study of temporal changes in the land-use and water quality would also be effective in evaluation of significant correlation between pollutant input and land-use.

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