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Original Article

IMPACT OF HIGHWAY RUN OFF ON THE SURFACE AND GROUND WATER QUALITY IN THIRUCHIRAPALLI REGION, TAMIL NADU, INDIA

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Abstract

The runoff due to the pollutants caused by the road traffic significantly affects the receiving water bodies with high loads of particulate matter such as worn and torn out materials of automobiles, toxic substance like heavy metals, PCBs, salts such as chlorides and sulphates, and pathogenic bacteria. Our study assesses the impacts of highway/road run-off on the quality of adjacent drinking water sources. Water samples have been collected from 60 locations along the National Highways and other selected Metal Roads. The physico-chemical and biological parameters such as pH, Electrical Conductivity (EC), Chloride (Cl), Total Hardness (TH), Total Alkalinity (TA), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Phosphate (PO_4), Sulphate (SO_4) and Nitrate (NO_3), Total coliforms were assessed. The heavy metals such as Chromium (Cr), Copper (Cu), Zinc (Zn), Lead (Pb) and Arsenic (Ar) have been assessed randomly for 14 samples along the roads. The results show that pH , EC, TA , Nitrate and Total Coliforms are the major factors affecting the water quality. Cr levels exceed the permissible limits compared to the other metals. Our study shows that highway run-off may also be a potential source of ground water contamination along the urban periphery.

Key words:- Highway Runoff, Water Quality, GIS.

1.0 Highway Runoff – A Significant Source of Water Pollution

Normally, storm water runoff is a composite of runoff from various land-use areas (residential, commercial, and industrial), in addition to road surfaces. Runoff from road surfaces is thought to be a significant source of nonpoint pollution to surface and ground waters (Gupta et.al, 1981). Highway runoff generally has been included as part of storm water studies, but in the 70s and 80s the Highway runoff was recognized as the potential source of pollution by numerous investigators (Sartor and Boyd, (1972); Shaheen, (1975); Novotny and Chesters, (1980); Gupta et.al, (1981) and isolated as a separate area of investigation. The authors noted that data available on storm water at that time were not directly relatable to the materials contributed by street-surface contaminants, and that there was a need to identify the relation between street-surface contaminants, their characteristics, and manner of transport. The study by Sartor and Boyd (1972) resulted in many significant findings, perhaps the most important of which was the association of street-surface contaminants and particle size. The greatest pollution potential is associated with fine-grained particles, 43 µm (micrometers) or smaller in diameter. Some of the most pertinent reports include the results of a study of urban roadways in the Washington, D.C., area by Shaheen (1975); a study of street dust from eight cities in the United States by Pitt and Amy (1973); an extensive six volume report sponsored by the Federal Highway Administration titled "Constituents of highway runoff," by Gupta et.al, (1981); and a study of urban runoff in Bellevue, Wash. Galvin and Moore, (1982), which identified street runoff as a major contributor to storm water constituent loads. The Florida Department of Transportation (FDOT) is the primary agent responsible for the quality of runoff from highways within the State of Florida, and has recognized the need for further study and development of a scientific data base on which to base decisions about highway runoff management (FDOT, 1982). The FDOT has initiated many investigations cooperatively with State universities and Federal agencies, including the U.S. Geological Survey.

1.1 Pollution caused by traffic on Roads/Highways

Traffic pollutes the roads and its periphery and the surface is charged with filth, that later is partly removed through rain wind and agitation/turbulence caused by the vehicles. The list of traffic related pollution sources are (Fritzer H., 1992)

- **The abrasion of road surfaces** in the form of mineral dust resulting from concrete or bitumen. Bitumen abrasion can lead to the liberation of poly aromatic hydrocarbons. Abrasion also liberates a higher quantity of 3.4- Benzpyren than the entirety of abrasion from tyres, loss of oil, and soot.
- **The abrasion of tires** Ninety percent of the abraded material is not readily bio-degradable; this includes rubber and soot as well as sulfur and heavy metal oxides (Pb, Cr, Cu, Ni and Zn). The abrasion material contains a high fraction of carcinogenic substances.
- **Drip loss** originated from fuel, motor or gear oil, lubricating grease, brake fluid and antifreeze. It contains a high level of BOD and COD as well as heavy metals.
- **Combustion emissions** that consist of aerosol gases or soot particles and content hydrocarbons, nitrogen oxides, unburned fuel, soot and tar.
- **The abrasion of brake pads and clutch plates** contains a high level of heavy metals, especially copper, nickel, chrome and lead. On the slippery/congested roads, due to the sudden application of clutching and braking, the abrasion of tyres takes place and leads to the emission of fine particulate matter.

1.2 Chemical Constituents of the Highway Runoff

The typical pollutants that may be found in the Highway run-off is shown in Table 1 (Adapted from Federal Highway Administration (FHWA), Washington, 1984 and United States Environmental Protection Agency (USEPA), 1997).

Table 1. Typical Pollutants Found in Runoff from Roads and Highways

POLLUTANT	SOURCE
Particulates	Pavement wear, vehicles, the atmosphere and maintenance activities, snow/ice abrasiveness and sediment disturbance
Rubber	Tyre wear
Asbestos	Clutch and brake lining wear (No mineral asbestos has been identified in runoff, however, some break-down products of asbestos have been measured
Nitrogen and Phosphorus	Atmosphere, roadside fertilizer application and sediments
Lead	Leaded gasoline from auto exhaust, tyre wear, lubricating oil and grease, bearing wear and atmospheric fallout
Zinc	Tyre wear, motor oil and grease
Iron	Auto body rust, steel highway structures such as bridges and guardrails and moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tyre wear and insecticide application
Chromium	Metal plating, moving engine parts and brake lining wear
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, bushing wear, brake lining wear and asphalt paving
Manganese	Moving engine parts
Sodium and Calcium	Deicing salts and grease
Chloride	Deicing salts
Sulphates	Roadway beds, fuel and deicing salts
Bromide	Exhaust
Petroleum	Spills, leaks, antifreeze and hydraulic fluids, asphalt surface leach ate and blow-by motor lubricants
PCBs	Spraying of highway right-of-ways, atmospheric deposition and PCB catalyst in synthetic tyres
Pathogenic Bacteria	Soil litter, bird droppings and trucks hauling livestock/stockyard waste

Source: Federal Highway Administration, 1984 and USEPA, 1997.

1.3 Attenuation mechanism of the run-off constituent in the subsurface environment

The runoff transports the constituent pollutants such as soluble and particulate forms to ground water, by infiltrating into the soil and percolating through the unsaturated zone to the saturated zone. Constituent loads may be attenuated in the unsaturated zone before reaching the saturated zone through several processes such as filtering, sorption (adsorption and absorption), precipitation and ion exchange. Organic constituents may be decomposed through bacterial activity and some inorganic constituents may be utilized by plants. Clays and organic material have high affinities for adsorbing various constituents, particularly heavy metals. Jenne (1976) indicated that material with large surface areas may serve as mechanical substrates without any chemical interaction between the material and the constituent. Organic matter, hydrous iron, and manganese oxides can deposit on a surface and function as metal collectors. Heterogeneity of the subsurface materials like variation in grain size and permeability variation caused by stratification that occurred in a particular depositional environment is also an important factor that controls the movement of constituents in water in the subsurface environment. In general, constituents moving through the unsaturated zone to the saturated zone are in the dissolved form. Some processes that occur in the saturated zones are similar to those of the unsaturated zones (sorption, ion exchange, and precipitation). However, some water infiltrating through the soil surface may move rapidly through the unsaturated zone along preferred paths (pores, cracks, and other interconnected openings that are wide enough not to exert capillary forces on the moving water), making gravity the primary acting force. This may allow the particulate fraction of some constituents to reach the saturated zone.

1.4. Scope of the present study

The escalating urbanization to cater the housing needs of the growing population was observed in most of the regions in developing countries like India. Simultaneously road network is also developing tremendously in the form of elevated highways, overhead-bridges, outer ring-roads for fast transportation between various regions and to improve the access towards public utilities within and outside the cities. The utility of vehicles/automobiles has also increased dramatically in the recent years. The present study aims at identifying the probable impacts caused by the run-off from the National Highways and other metal roads on nearest drinking water resources (groundwater and surface water) using GIS and Spatial approaches.

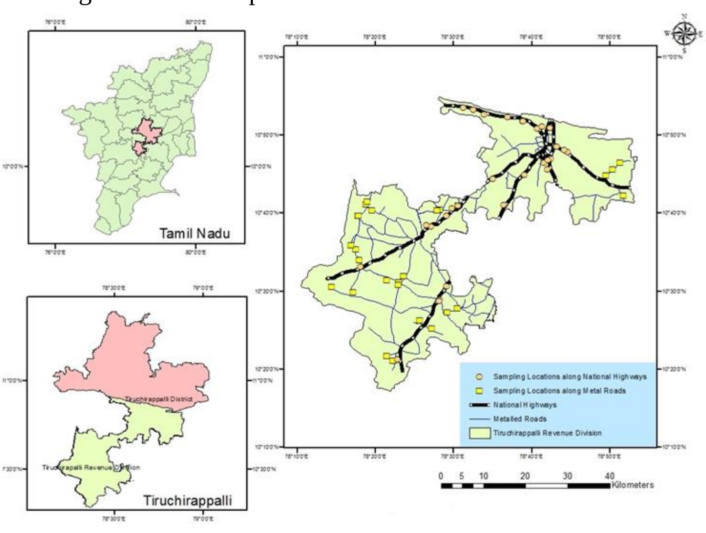
2.0 Geographic Location and Demography of the Study Area

Tiruchirappalli District is located in the central part of Tamil Nadu. It covers a total area of 4511 sq km, situated within the geographical co-ordinates 77°45 –79° E and 10°–11°30N, which is administratively divided into three revenue divisions: Tiruchirappalli, Lalgudi, and Musiri; it has a total population of 2,713,858. Tiruchirappalli (Trichy) City Corporation, Thuvakudy Town and Manapparai Town are the major urban centres located within the Tiruchirappalli Revenue Division

Road Network in Tiruchirappalli

Tiruchirappalli has a well-developed transport infrastructure, as it is located at the geographic centre of the state of Tamil Nadu. This region is well connected by Road to all the cities through the national highways NH 45, NH 45B, NH 67, NH 210 and NH 227.

- NH-45: **Tiruchirappalli** - Viralimalai - Thuvarankurichi - Melur - Madurai - Kariapatti - Aruppukottai - Pandalkudi - Kottur - Ettaiyapuram - Eppodumvenran - Kurukluchalai - Tuticorin.
- NH-45B: Chennai - Tambaram - Tindivanam - Villupuram - **Tiruchirappalli** - Manapparai - Dindigul-Periyakulam - Theni.
- NH-67: Nagapattinam - Tiruvarur - Thanjavur - **Tiruchirappalli** - Karur - Coimbatore - Ooty - Gundalpet (Intersection of NH-212 in Karnataka).
- NH-210: **Tiruchirappalli** - Keeranur - Pudukottai - Thirumayam - Kanadukathan - Karaikkudi - Devakottai - Tiruvadanai - R.S.Mangalam - Devipattinam (Intersection of East Coast Road (ECR)).
- NH-227: **Tiruchirappalli** - Lalgudi - Pullambadi - Paluvur - Udayarpalayam - Jayankondam-Jayamkodacholapuram - Chidambaram.



Map.1 study Area: Tiruchirappalli Revenue Division with selected Road Network

3.0 Data Used and Methodology

3.1 Water Sampling and Analysis

For the present study around 30 sampling locations along National Highways NH45, NH-45B, NH-67 and NH-267 and around 30 more sampling locations along the other metalled roads has been chosen (Map. 1) to identify the probable impacts of Highway run-off on the nearest available drinking water sources (Surface, Sub-surface or Ground Water) during Pre-monsoon season (March – April, 2014). The Specific Conductance, Dissolved Oxygen (DO), pH, and Temperature are water-quality measures that may function as indicators of overall quality, and of the speciation of dissolved species possible in the environment (Schiffer, 1989). The aforesaid parameters, along with other physico-chemical parameters such as chloride, Total Hardness, Total Alkalinity, Biological Oxygen Demand, Chemical Oxygen Demand, nutrients such as phosphates, sulphates and nitrates and metals such as Chromium, Zinc, Copper, Lead, Arsenic were estimated for the collected drinking water samples during the study. The standard procedures for water analysis (APHA, 1989, 2005) were adopted for estimation.

3.2 Derivation of Quality Indices

Water Quality Index is a single number that expresses the overall water quality by aggregating the multi-criterion water quality parameter into a single number (Horton 1965). The Drinking Water Quality Index was derived by adopting the following equation given by Tiwari and Mishra (1985).

$$Wi \propto \frac{1}{V_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$DWQI = \sum_{i=0}^{n} W_i \times V_r \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where, V_i = standard of the $_i$th parameter

W_i = Relative Weight for the $_i$th parameter

V_r = the rating given to each parameter based on its concentration

(Kennel et.al, 2007; Kumar and Dua, 2009) and a ranking is given to the Indices based on the Table 2 (Kumar and Dua, 2009).

Table 2: Ranking Index

DWQI	Rank	Inference
0-30	Very poor	Unfit for Drinking Purpose
31-50	Poor	
51-70	Medium	Can be used for drinking in the absence of alternate source
71-90	Good	Desirable for Drinking Purpose

3.3 Spatial Analysis

The National Highways and other major metalled roads of Tiruchirappalli region was extracted from ISRO Bhuvan website (NRSC, 2014) and the respective administrative maps were prepared from SOI toposheets. The samples were geo coded using Novatech DGPS derived co-ordinates and integrated into the GIS environment. Thematic maps were prepared for all the water quality parameters and DWQI based on the rating factors estimated for the derivation of DWQI using ArcGIS 10.3

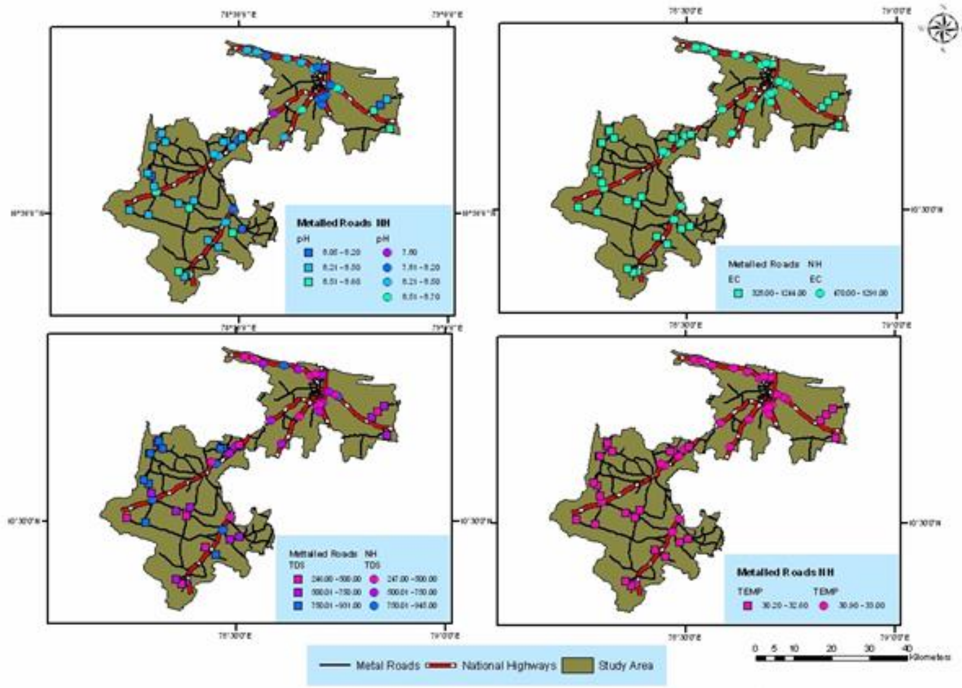
4.0. Results and Discussion

4.1 Determination of Water Quality

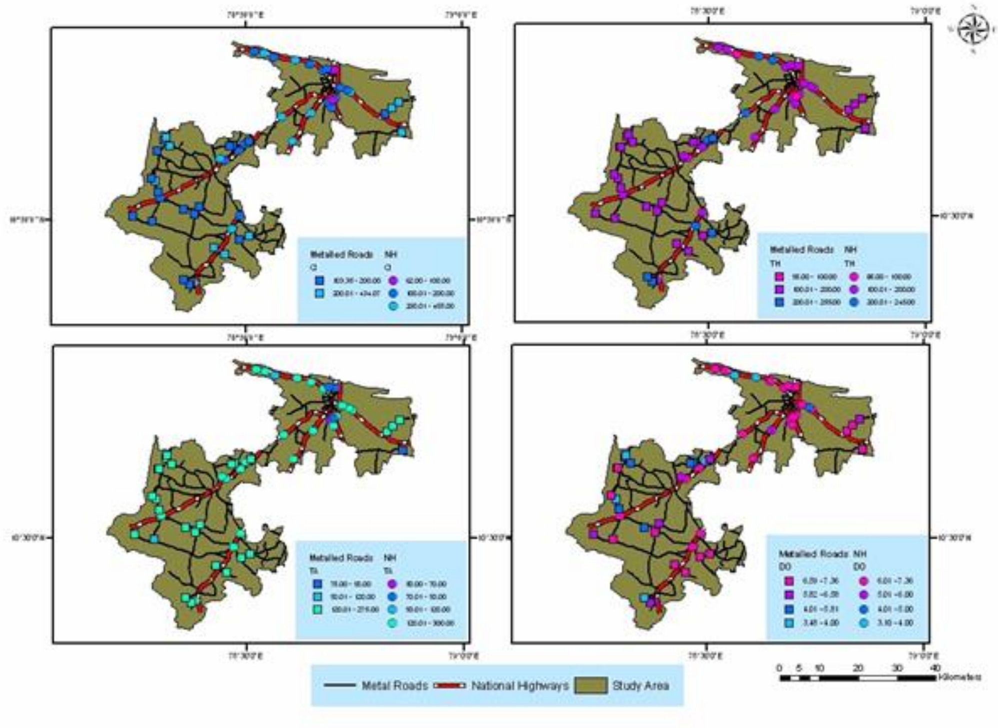
The minimum and maximum observed values for each water quality parameter, the descriptive statistics of the estimated parameters of the water samples and the number of samples exceeding the recommended permissible limits along the National Highways and the metalled roads were presented in Table 3 and 4, respectively.

4.1 Thematic representation of Water Quality Parameters

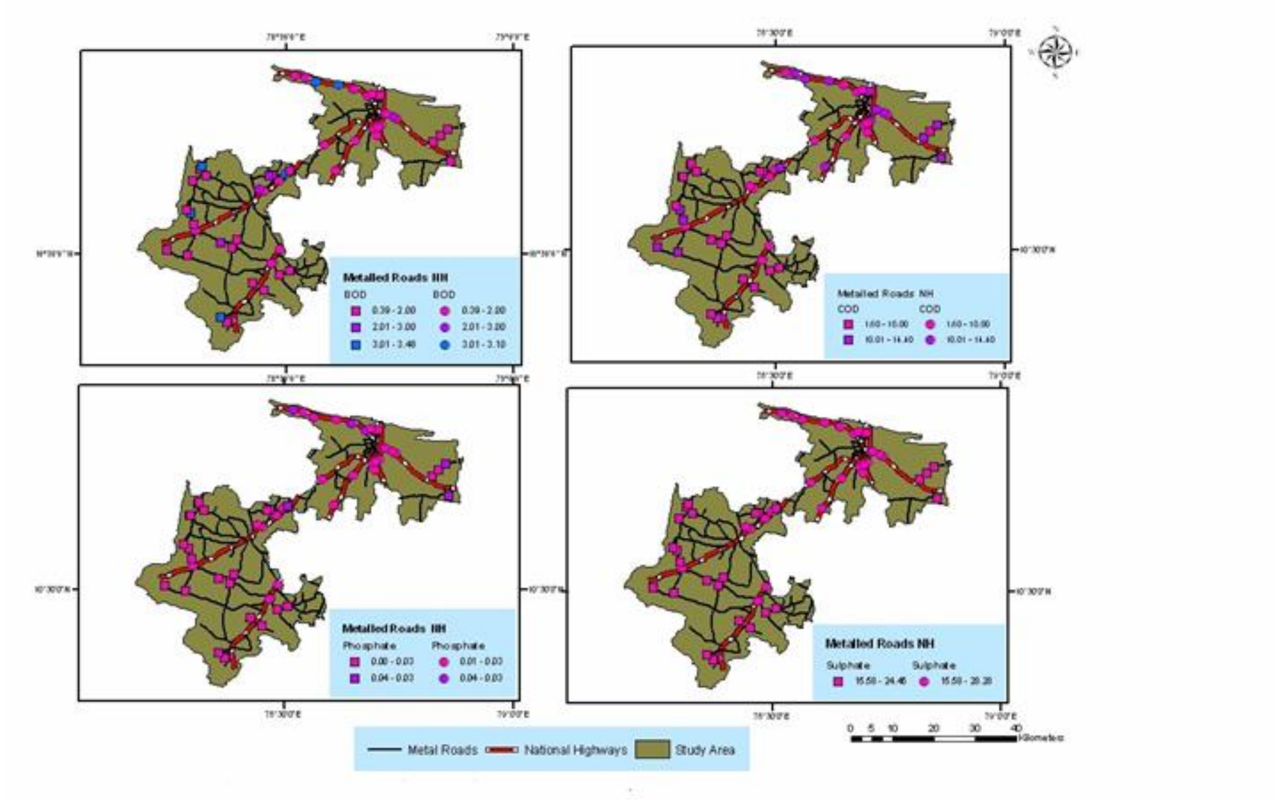
The estimated water quality parameters have been attributed to the geo-coded locations and thematic maps were generated based on the water quality (Map 2 to 6). For the present study the classification was done based on water quality standards and applied to the water quality parameters based on the rating indices used for the derivation of DWQI given by Kennel, et.al, (2007) and Kumar and Dua, (2009). The overall summary of the quality of parameters and the range is as follows in Table. 5.



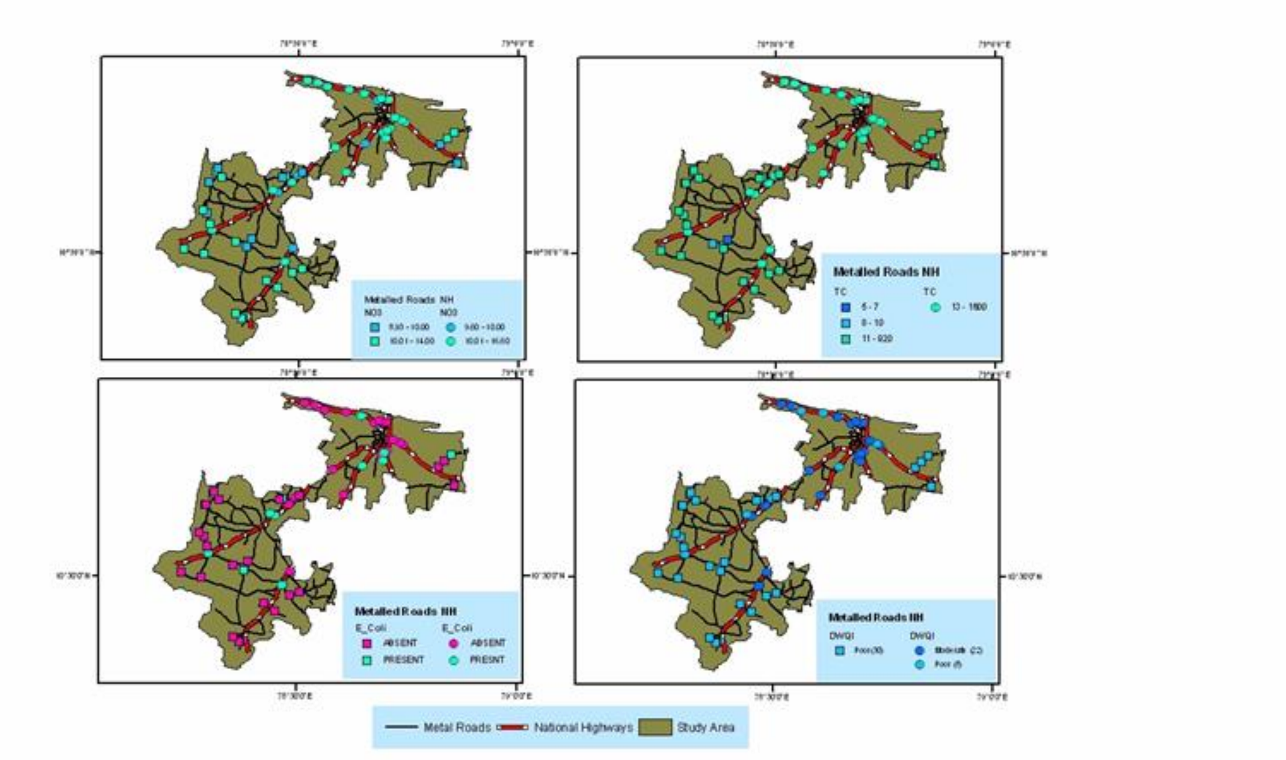
Map 2. Spatial Variations of pH, EC, TDS and Temperature along the selected NH and Metalled Roads



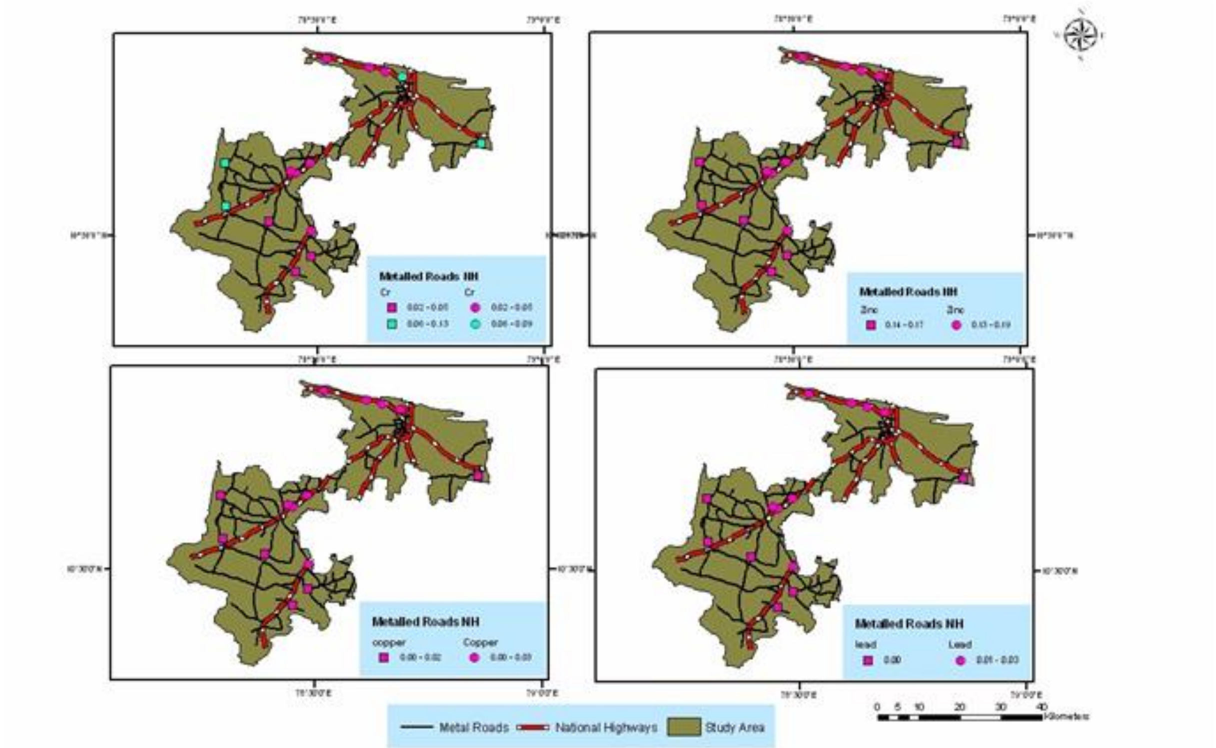
Map 3. Spatial Variations of Cl, TH, TA and DO along the selected NH and Metalled Roads



Map 4. Spatial Variations of BOD, COD, PO_4 and SO_4 along the selected NH and Metalled Roads



Map 5. Spatial Variations of NO_3, TC, E-Coli and DWQI along the selected NH and Metalled Roads



Map 6. Spatial Variations of Cr, Zn, Cu and Lead along the selected NH and Metalled Roads

5.0 Discussion

From the results (Table 5) it is obvious that the parameters such as Electrical Conductivity Total Coliforms, Total Alkalinity and Nitrate contribute very much to the poor and very poor quality rather than other parameters along both Highways and selected metalled roads. From the results of Descriptive statistics (Table 3 and 4) the TDS levels are also observed higher both in

Table 3. Descriptive statistics of the water quality parameters along the National Highways of Tiruchirappalli

Parameter	Unit	Indian Standards	International Standards	Min	Max	Mean	Median	SD	Number of Samples taken for Analysis	Number of samples exceeding the permissible limits
		BIS, ICMR, CPCB, Standards	WHO EU USEPA Standards							
pH	No Unit	6.5 – 8.5	6.5 – 8.5	7.8	8.7	8.28	8.3	0.233	30	4
EC	µS	300	250	470	1291	788.3	731.5	202.1	30	30
TDS	ppm	500-2000	500	247	945	575.6	563	185.2	30	22
Temp.	˚C	ND	ND	30.9	33	32.22	32.45	0.537	30	0
Cl	mg/l	250-1000	200	62.01	454.7	198.4	179.1	92.69	30	13
TH	mg/l	300-600	300	85	245	163.5	160	42.1	30	0
TA	mg/l	200-600	120	50	300	164.2	162.5	61.48	30	6 (20)*
DO	mg/l	>6	ND	3.098	7.357	6.208	6.582	1.205	30	7
BOD	mg/l	< 3	ND	0.387	3.098	1.252	0.774	0.824	30	5
COD	mg/l	10	ND	1.6	14.4	9.013	8.8	3.321	30	11
PO_4	mg/l	ND	0.1	0.006	0.032	0.018	0.018	0.007	30	0
SO_4	mg/l	200-400	500	15.58	28.28	21.47	21.47	2.956	30	0
NO_3	mg/l	45-100	10	9.643	16.64	11.75	11.75	1.825	30	0 (24)#
TC	CFU/100ml	110	0	13	1600	197.6	49	358	30	30
E-coli	CFU/100ml	0	0	ND	ND	-	-	-	30	9
Cr	mg/l	0.05	0.05	0.02	0.09	0.0425	0.035	0.219	8	1
Zn	mg/l	5	5	0.13	0.19	0.157	0.15	0.019	8	0
Cu	mg/l	0.05	0.05	0	0.03	0.013	0.015	0.013	8	0
Pb	mg/l	0.1	0.1	0.01	0.03	0.018	0.02	0.008	8	0
Ar	mg/l	0.05	0.05	0	0	0	0	0	8	0

* Greater than WHO limit in 120mg/l
\# Greater than USEPA standards 10 mg/l

National Highways and metalled roads but lies with the maximum permissible limits. The pollution level of Nitrate and Total Coliforms is higher in National Highways rather than metalled roads. Chromium is the only metal which was observed to exceed the permissible limit and the other metals like zinc, copper, lead, arsenic are found to be within the limits. Overall, it could be inferred that the run-off from the highways may also be a potential source of pollution of ground water along its peripheral region which impacts the water quality. The source of excessive presence of Chromium is due to the wear of brake-linings and moving engine parts. The pathogenic bacteria in water are also higher which may be due to the mixing of sewage with the run-off. The increased level of total alkalinity may be due to the pH change.

According to Tamil Nadu Govt. statistics (2013), around 66,238 vehicular accidents have taken place leading to more vehicle damage and the debris left on the roads can also contribute much amount of heavy metal contaminants to the highly run-off. The seasonal factors such as rainfall, humidity, wind velocity, direction of wind also decides the movement of atmosphere pollutants from the atmosphere and their ultimate settlement in the run-off. The presence of natural barriers such as mountains, buildings along the highways could also contribute to the accumulation pollution in the highways where dispersion is restricted. The present-day roads are 4 lanes separated by the medians in the middle of the road and an embankment on the periphery of the road. It is designed to collect the run-off through a percolated ditch on the sides of the road and drained off in the nearest water bodies. In such case the pollutants from the runoff will be accumulated in the receiving water bodies which eventually end up in ground water contamination.

Table 4. Descriptive statistics of the water quality parameters along the other major metalled roads of Tiruchirappalli

Parameter	Unit	Indian Standards	International Standards	Min	Max	Mean	Median	SD	Number of Samples taken for Analysis	Number of samples exceeding the permissible limits
		BIS, ICMR, CPCB, Standards	WHO EU USEPA Standards							
pH	No Unit	6.5 – 8.5	6.5 – 8.5	8.05	8.6	8.37	8.31	0.15	30	6
EC	µS	300	250	328	1244	880.40	918.00	203.53	30	30
TDS	ppm	500-2000	500	246	931	654.53	689.50	183.72	30	23
Temp.	˚C	ND	ND	30.2	32.6	31.89	32.10	0.69	30	0
Cl	mg/l	250-1000	200	103.35	434.07	207.39	189.48	78.88	30	6
TH	mg/l	300-600	300	95	255	150.83	135.00	40.66	30	0
TA	mg/l	200-600	120	75	275	189.17	175.00	52.39	30	12(29)*
DO	mg/l	>6	ND	3.48	7.36	6.27	6.58	1.13	30	9
BOD	mg/l	< 3	ND	0.39	3.48	1.41	1.16	0.90	30	6
COD	mg/l	10	ND	1.6	14.4	9.12	9.60	2.98	30	8
PO_4	mg/l	ND	0.1	0.00	0.03	0.02	0.02	0.01	30	0
SO_4	mg/l	200-400	500	15.58	24.45	21.16	21.40	2.55	30	0
NO_3	mg/l	45-100	10	8.93	14.00	10.76	10.75	1.14	30	0 (19) #
TC	CFU/100ml	1-10	0	5	920.00	153.77	39.00	247.92	30	30
E-coli	CFU/100ml	0	0	ND	ND				30	4
Cr	mg/l	0.05	0.05	0.02	0.13	0.07	0.07	0.04	8	3
Zn	mg/l	5	5	0.14	0.17	0.16	0.15	0.01	8	0
Cu	mg/l	0.05	0.05	0	0.02	0.01	0	0.01	8	0
Pb	mg/l	0.1	0.1	0.02	0.04	0.03	0.03	0.01	8	0
Ar	mg/l	0.05	0.05	0	0	0	0	0	8	0

* Greater than WHO limit in 120mg/l

Greater than USEPA standards 10mg/l

Table 5. Number of Samples in each category of Water Quality

S.No	Parameters	No. of samples in each category of water quality (along National Highways) Total. No. Samples =30					No. of samples in each category of water quality (Metalled Roads) Total. No. Samples =30				
		Very Good	Good	Moderate	Poor	Very Poor	Very Good	Good	Moderate	Poor	Very Poor
1	pH	0	1	11	14	4	0	0	10	14	6
2	EC	0	0	0	0	30	0	0	0	0	30
3	TDS	12	13	5	0	0	7	13	10	0	0
4	Temp	30	0	0	0	0	30	0	0	0	0
5	Cl	0	2	18	10	0	0	0	21	9	0
6	TH	2	21	7	0	0	1	25	4	0	0
7	TA	1	0	3	1	25	0	0	1	1	28
8	DO	23	3	1	3	0	21	4	2	3	0
9	BOD	25	2	3	0	0	24	3	3	0	0
10	COD	19	11	0	0	0	22	8	0	0	0
11	PO_4	26	4	0	0	0	28	2	0	0	0
12	SO_4	30	0	0	0	0	30	0	0	0	0
13	NO_3	0	0	0	28	2	0	0	0	15	15
14	TC	0	0	0	0	30	0	0	1	1	28
15	E_Coli	20	0	0	0	10	26	0	0	0	4

6.0 Conclusion

The present study shows that the highway run-off from roads is a potential source of non-point source of water pollution. Creation of suitable strips/belts of vegetation, construction of detention ponds/ infiltration facility along the roads, interrupts the flow of run-off and filter the dust, suspended particles and its adsorbs the pollutants like oil and grease and other matter like road, so that clean water percolate into the soil. Proper planning of transportation and land use; highway design; and operation and maintenance of a highway after thorough inspection of the geography of the area can be suggested. General roadway maintenance activities can help to prevent and control highway runoff pollution. Our observation highlights the highway run-off as a potential non-point source of water pollution. The general increase of traffic and the annual renovation and construction of new roadways/highways will be ever increasing in the subsequent years in a developing country like India. Hence proper statutory provisions especially for regulating the highway run-off and to minimize the contaminant could be evolved for the sustainable management of water resources.

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