International Journal of Advanced Multidisciplinary Research (IJAMR)
ISSN: 2393-8870
www.ijarm.com

Research Article

Modeling of water contamination in Peri Urban locations of Tiruchirapalli Region, Tamil Nadu, India

Rajendran Vidyalakshmi[1], Balan Brindha[1], Sundaram Rajakumar[2] and Marimuthu Prashanthi Devi [3*]

[1]Research Scholar, Department of Environmental Management, Bharathidasan University, Tiruchirapalli – 620 024.
[2]Assistant Professor, Department of Marine Biotechnology, Bharathidasan University, Tiruchirappalli – 620 024.
[3]Assistant Professor, Department of Environmental Management, Bharathidasan University, Tiruchirappalli – 620 024.
*Corresponding Author : *prashanthidevi@gmail.com/kodairaj@gmail.com*

Keywords

Safe Drinking Water,
Peri-Urban areas,
GIS, Model Building,
DWQI

Abstract

Peri-Urban areas are the interface between urban and rural areas having their own characteristics and are prone to areal expansion with often neglected urban developmental and conservatory plans. During the course of changing land use pattern during the urban sprawl surface and ground water resources are worst affected. The present study is an approach to assess the increase in urban sprawl in Tiruchirappalli Corporation which is one of the fast growing cities in Tamil Nadu, India over the period of 5 years (2005-06 to 2011-12) and its related impacts on drinking water quality. Water Samples were collected randomly from 22 locations during monsoon season (August to November (2011) in and around Tiruchirappalli Municipal Corporation. The physico-chemical and microbial characteristics were estimated as per the standard analyzing procedures and attributed to the geo-coded sampling locations. GIS models were generated to identify the individual parameters contributing to water quality deterioration and to assess the spatial distribution of the water contamination. Model Builder was used to derive the overall DWQI in GIS environment. The results of the estimated parameters show that EC and Total coliforms exceed the permissible levels in the water samples. It is reported that in terms WQI the parameters such as EC and total coliforms were very poor in almost all the locations and the overall water quality within the corporation ranges poor to very poor and beyond the corporation boundary the water quality ranges from good to very poor. Hence appropriately planned urban expansion and proper maintenance of common water supply and storage facilities and treated water supply are required to mitigate the exposure of drinking water to feacal contamination.

Introduction

Safe drinking water is one of the basic necessities for the sustenance of life, since it is directly associated with the health of the human community. Proper access to adequate amount of drinking water through improved sources, has occupied the top priorities in the development agenda of many developing countries and the countries with transition economies. One such evidence is the target 7c, “to halve the proportion of population without sustainable access to drinking water” set up by the United Nation’s Millennium Development Goals (MDGs) to be achieved by 2015. A joint Monitoring Programme was initiated by WHO/UNICEF to monitor the progress among world nations in improving the drinking water supply and sanitation systems. According to the recent report published by WHO/UNICEF (WHO/UNICEF, 2013) India was on-track towards the achievement of the target; around 33% of India’s population gained improved access to drinking water sources since 1995 with a estimation that 92% of India’s population avail drinking water through improved sources. But the fact was that “improved sources” stated by WHO/UNICEF reports have very limited evidence regarding the quality of water supplied (WHO/UNICEF, 2011).

Despite improved provisions for drinking water, detrimental changes in the environmental conditions could be seen as a result of economic development which is also rapidly increasing in the recent decades. Activities such as rapid industrialization, urbanization, intense agriculture and related activities are the major reasons behind the increasing demand for water that leads to overexploitation of water resources. However this consequently threatens the quantity and deterioration of its quality of existing ground water and surface water resources through the discharges from these anthropogenic activities. It leads to local water scarcity and contamination.

Increasing areal spread of the cities

The contaminants of water are broadly classified into point sources (eg. discharge of untreated effluent from industries) and non-point sources of pollution (eg. Run-off from croplands and urban areas). Several studies revealed that the quality of water is closely connected with the landscape and land use (Tong And Chen, 2002; Scanlon et.al., 2006; Lerner and Harris, 2009; Weatherhead and Howden, 2009). The commonly observed land use pattern in recent decades is the lateral development of the metropolitan cities. During the early part of the 20^{th} century, the growth of Indian cities was largely confined within the municipal boundaries (Brush, 1968). Even in 1970s it was noted that the population growth and migratory population into the cities has been accommodated by crowding more and more population in existing urban areas rather than the expansion of cities into sub-urban and fringe areas. However this pattern of growth and population absorption has significantly changed in the last two to three decades (Brush, 1977), which was evident in the major metropolitan cities of Mumbai, Delhi, Kolkata and Chennai. A sharp increase was observed not only in the population but also the areal spread. The lateral spread of the larger metropolitan cities accounted for about 38,504 sq.km in 1961 to 64,026 sq.km in 1991 (Shaw, 2003). Kundu (2002) stated that the lateral spread of urban areas to accommodate the incremental population during 1991 – 2001 and the successive years has been substantial. Such outward expansion of the metros has complex interactions with the adjoining rural areas and transforms them into “semi-urban” or “peri-urban” areas (Shaw, 2005)

Environmental Vulnerability of the Peri -Urban Areas

Douglas (2006) stated that peri-urban areas were the transition or interaction zones, where the urban and rural environments were juxtaposed and the landscape features are subjected to rapid modification induced by human activities. These areas are environmentally unstable than the core-urban and rural areas (McGranahan, Satterthwaite and Tacoli (2004). Such areas are particularly vulnerable to environmental damages because of their proximity to city which could degrade the water and land resources. For instance, improper dumping of solid waste in the shallow water body, discharge of effluent/sewage in the adjacent seasonal water body or land surface and overcrowding of population has strained the carrying capacity of the surrounding areas. These outlying areas are away from the city and have unsatisfactory levels of environmental infrastructural services such as water supply sanitation, drainage facilities, and disposal sites for solid wastes which are worse than the core urban areas. Thus the peri-urban regions are not facilitated with basic services which in the core-urban area are taken for granted resulting in local inequalities. Hence, suitable monitoring programmes were required in these areas to assure the sustainable development.

The Tiruchirappalli Corporation covers an area of 167.23 sq.km [16]. Densely-populated industrial and residential areas have recently been built in the northern part of the city, and the southern edge also has residential areas. The older part of Tiruchirappalli, situated within the Rockfort, is unplanned and congested while the adjoining newer sections are better executed [17].Water supply is provided by the Tiruchirappalli Municipal Corporation through public distribution system such as pipelines or tanker Lorries. About 400 tonnes of solid waste are released from the city every year. The principal garbage dumping ground is at Ariyamangalam. Recently, the Tiruchirappalli city corporation has gone in for scientific closure of the garbage dump and its replacement with a sewage treatment plant. Waste water management in the Trichy-Srirangam underground drainage (UGD) areas are handled by the Tamil Nadu Water Supply and Drainage Board (TWAD) and in other areas by the Tiruchirappalli Municipal Corporation. The common sewage treatment plant is located in Panchapur. The high toxicity of the waste water released by the Trichy Distilleries and Chemicals Limited (TDCL) is also a major cause of concern for the corporation.

Data used and Methodology

Attribute database

Water Samples were collected randomly from 22 locations during monsoon season (August to November (2011) in and around Tiruchirappalli Municipal Corporation (8 locations from existing urban areas (2005-2006) and 14 locations from newly formed urban areas (2011-2012)). A ‘Micro flex’ DGPS was used to obtain the geo-coordinates of each sampling location. The physicochemical characteristics such as pH, EC, TDS were analyzed using Deep Vision Deluxe Soil and Water Analyzer Kit; Chloride, Total Hardness, Total Alkalinity, DO, BOD, are analyzed through standard titration methods in the laboratory; Sulphate, Nitrate have been analyzed spectro-photometrically as per the standard analyzing procedures of American Public Health Association APHA (1989). The microbial parameters such as Total Coliforms have been analyzed by MPN (Most Probable Number) index. The multi-criterion water quality parameters can be represented in an easily understandable manner to the non-technicians and decision makers through the Drinking Water Quality Index

(DWQI). The DWQI is a single number that expresses water quality by aggregating the measurements of water quality parameters such as physiochemical and biological (Pradhan, Patnaik and Rout, 2001; Adak, Purohit and Datta, 2001; Bhargava, 1983a; Bhargava 1983b). To determine the suitability of water for drinking purposes a Drinking Water Quality Index (DWQI) was formulated by Tiwari and Misra, 1985 which was widely used in India for the studies regarding the surface water (Kumar and Dua 2009) as well as ground water for drinking purposes (Asadi, Vuppala and Reddy, 2007; Singh et.al, 2011 ; Gibrilla et.al, 2011; Vidyalakshmi et.al, 2013)

.

The water quality index mainly involves four steps: Calculation of Unit Weight (*Wi*) for the selected parameters, Rating of parameters with respect to its concentration (Vr), Calculation of Sub-indices for each parameter and Derivation of Overall Water Quality Index. The initial step i.e deriving a unit index for the estimated parameters was done through equations (1) and (2).

$$W_i \propto \frac{1}{V_i} \; (or) \; W_i = \frac{k}{V_i} \quad \text{.............................. (1)}$$

Where k = constant of proportionality, W_i= unit weight of the *i*th parameter, V_i = recommended permissible limit of the *i*th parameter. The value of k can be calculated by the following equation

$$k = \frac{1}{\sum_{i=0}^{n} 1/V_i} \quad \text{.. (2)}$$

The second step involves rating of each parameter (V_r) with a scale of 0 -100 based on the estimated concentration of the parameter with respect to recommended standard permissible limits. Each parameter will be given a score, the higher score (Vr = 100 and Vr = 80) alludes to better water quality (Very Good, Good) i.e the concentration of the estimated parameter was within the recommended desirable limit for drinking purpose or slightly exceeding the permissible limit and lower (Vr=40 and Vr = 0) score to degraded water quality, i.e, the concentration of the parameters were close to the recommended maximum permissible limit or beyond the maximum permissible (Bad, Very Poor) and the average score to moderate water quality i.e, the concentration ranges between the desirable limit and maximum permissible limit (Table 1).

Table 1. Derivation of unit index (Wi) and rating (Vr) of each parameter.

Parameters	Desirable limits Recommended by BIS (1992),2012/ ICMR (1975)	Assigning Unit weight (*Wi*)	Rating (Vr)				
			100	80	60	40	0
pH	6.5-8.5	0.075	7.0 - 7.4	7.5 – 7.8	7.9 - 8.2	8.3 - 8.5	>8.5
EC µS	250	0.002	<75	75.1-150	150.1-225	225.1-300	>300
TDS ppm	500-2000	0.001	<500	501-1000	1001-1500	1501-2000	>2000
Cl mg/l	250 - 1000	0.003	<250	251-500	501-750	751-1000	>1000
TH mg/l	300- 600	0.003	<300	301-400	401 - 500	501-600	>600
TA mg/l	200-400	0.003	<200	201-300	301-400	401-600	>600
DO mg/l	>5.00	0.128	>7.0	5.1-7.0	4.1-5.0	3.1 -4.0	<3
BOD mg/l	>5.00	0.128	<3	3.1-4.0	4.1-5.0	5.1 -7.0	>7
SO4 mg/l	200 - 400	0.003	0-200	201-250	251-300	301-400	>400
NO3 mg/l	45 - 100	0.014	0-10	10.1-20	21.1-30	31.1-45	>45.1
T.C CFU/100ml	1-10	0.639	<1	2-4	5-7	8-10	>10

Spatial Database

The Survey of India toposheet 58J/1 to 58 J/16 was geo-registered and projected using Universal Transverse Mercator (UTM) Projection (Zone 44N) using Arc GIS 10.0. The Administrative boundary of Tiruchirappalli District and Tiruchirappalli Municipal Corporation was digitized. The sampling locations were geo-coded with the co-ordinates obtained using DGPS.

Data processing

The estimated water quality parameters, along with the unit index and ranking were attributed to each location. Based on the concentration of the water quality parameters with respect to the recommended permissible limits (Vr) thematic maps have been generated for each parameter to identify the influence of individual parameters on water quality.

Using model building tools a model has been generated (Figure 1) to extract the locations showing different levels of water quality (Vr = 0, Vr = 40, Vr = 60, Vr = 80, Vr = 100) for each of the estimated parameters.

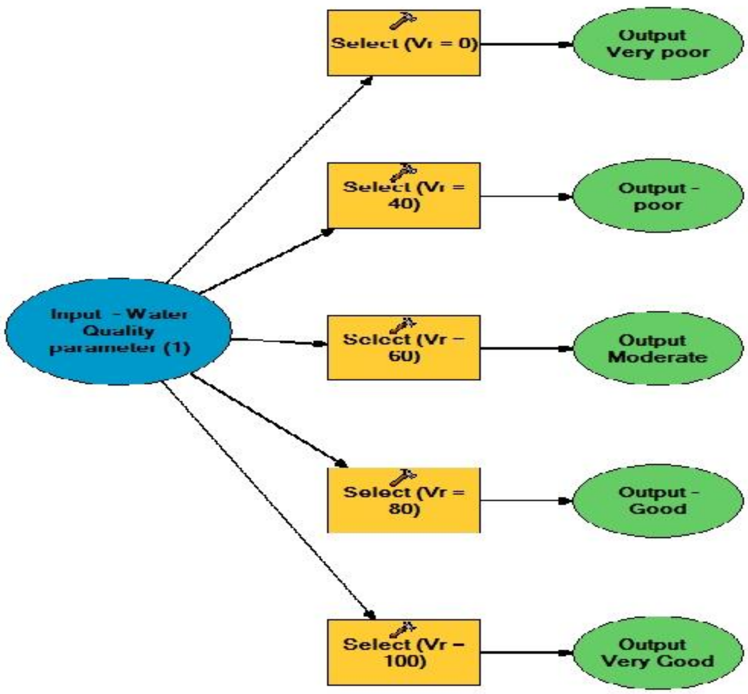


Figure 1: Model to extract the parameters with different levels of water quality

The model was run to all the estimated parameters and the extracted layers at each level. The extracted layers were merged together (Figure 2) to generate a composite map for each water quality range. Similarly a composite map was prepared for each range of water quality.

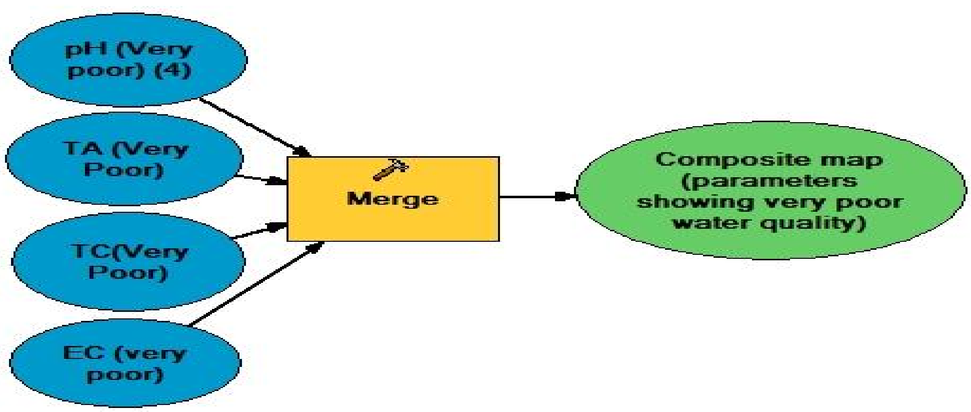


Figure 2: Model to merge the parameters showing very poor range of water quality

Another model was generated to calculate the sub-index for each parameter which constitutes the product of the assigned unit index *(W_i)* and the rating *(V_r)* (equation 4) and the cumulative sum of all the sub-indices gives the overall DWQI (equation 5) of the particular location.

Figure 3: Model to extract the parameters with different levels of water quality

$$Sub\ Index\ of\ the\ ith\ parameter = W_i \times V_r \quad \text{..............} \quad (3)$$

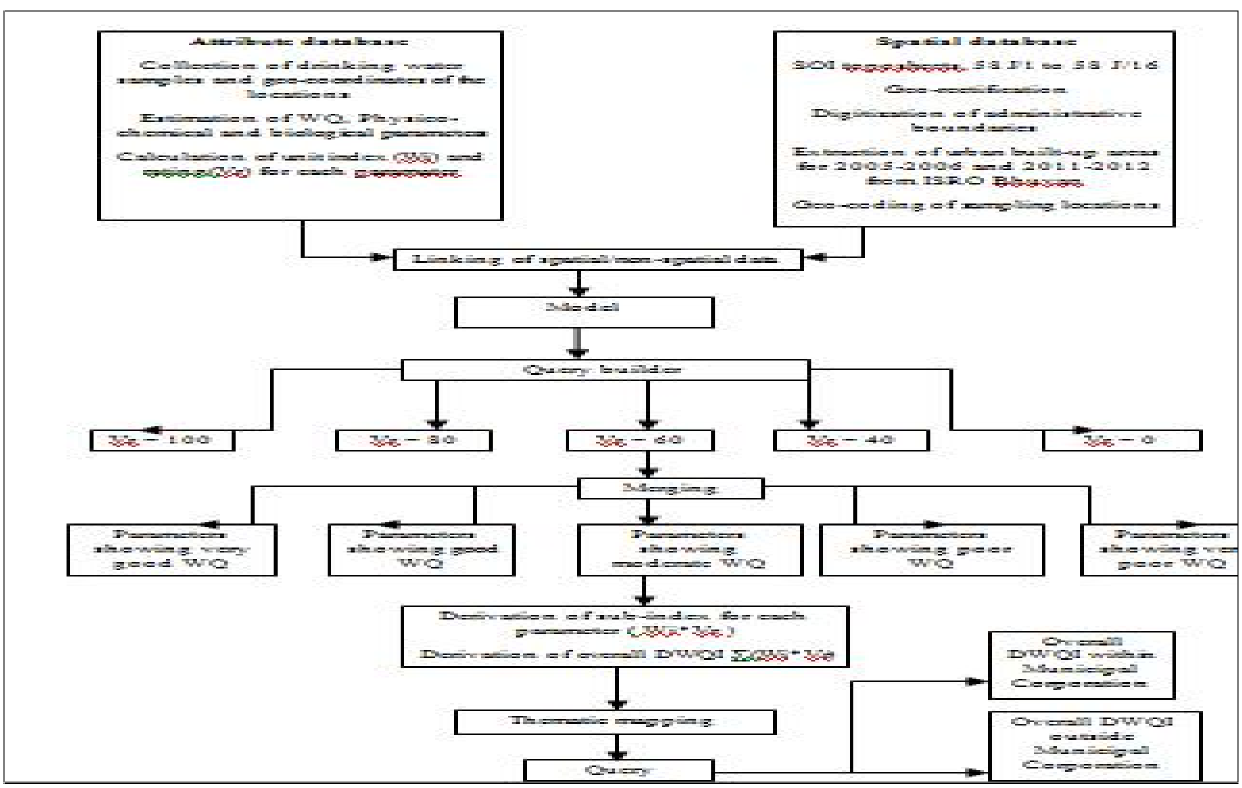
$$Overall\ DWQI = \sum W_i \times V_r \quad \text{...................................} \quad (4)$$

The overall DWQI is a number ranging 0-100 will be given a ranking based on the index chart (Table 2) .The water quality of the locations within and beyond the corporation boundary was extracted and thematic map was prepared based on the overall DWQI to understand the difference in the water quality. The flowchart of the overall methodology is shown in (Figure 4).

Table 2: DWQI Ranking Index

DWQI Range	Overall Water Quality
0 - 30	Very Poor
30 - 50	Poor
51 - 70	Medium
71 - 90	Good
91 - 100	Excellent

Figure 4. Flowchart of the overall methodology



Results and Discussion

Determination of Water Quality

As mentioned in methodology, physico-chemical parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chloride (Cl), Total Hardness (TH), Total Alkalinity, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Sulphate (SO_4), Nitrate (NO_3) and Biological parameter (Total Coliforms) has been estimated and its descriptive statistics were presented in Table 1.From the results (Table 1), the pH of the water samples ranges from 7.5 to 8.6 in the existing urban areas and in the newly formed urban areas respectively. 1 sample from the existing urban areas and 4 samples from the new urban area exceeded the recommended standard permissible limit by WHO (1993) and BIS (1992). The Electrical Conductivity of the existing urban areas ranges from 400 to 660 µS in the existing urban areas and 540 to 980 µS in the newly formed urban areas, whereas all the samples in both the regions were beyond the maximum permissible limits. The Total Dissolved Solids ranges from 280 to 520 ppm in the existing urban areas and 380 to 690 in the new urban areas. With respect to the recommended permissible limits 1 sample from the existing urban areas and 8 samples from the new urban areas were observed to be above the desirable limit (500 ppm) but the TDS of all the samples were within the maximum permissible limit. Chloride of the water samples ranges from 60 to 223 mg/l and from 74 to 238 mg/l in the existing and newly formed urban areas respectively while all the samples were within the recommended permissible limits. The Total Hardness (TH) ranges from 50 to 140mg/l in the existing urban regions and 60 to 160 in the newly formed urban regions whereas all the samples in both the regions were within the recommended limits. The Total Alkalinity (TA) ranges from 50 to 225 in the existing urban regions and 50 to 275 in the new urban areas. Around 2 samples from the existing urban regions and 4 samples from the new urban regions exceeded the recommended desirable limits of BIS (200mg/l) whereas 1 sample from existing urban areas and 2 samples from new urban areas were above the desirable limits recommended by WHO (120 mg/l). The Dissolved oxygen ranges from 4.736 to 6.315 mg/l in the existing urban areas and 3.55 to 7.10 mg/l in the new urban areas whereas 3 samples were found to be beyond the recommended permissible limit. The Biological Oxygen Demand (BOD) of the water samples ranges from 0.394 to 3.157 (mg/l) in the existing urban regions and 0.39 to 4.34 (mg/l) in the new urban areas. All the samples were within the recommended permissible limits. Sulphate (SO_4) ranges from 16.95 to 23.07 (mg/l) in the existing urban areas and 14.7 to 24.67 (mg/l) in the new urban areas. The nitrate ranges between 9.42 and 12.64 (mg/l) in the existing urban areas whereas in the new urban areas the range of nitrate is between 7.5 and 13.5 (mg/l). The Total Coliforms (TC) ranges from 7 to 540 (CFU/100ml) in the existing urban areas and 2 to 910 (CFU/100ml) in the new urban areas. With respect to the recommended standard almost all the samples exceeded the desirable limit.

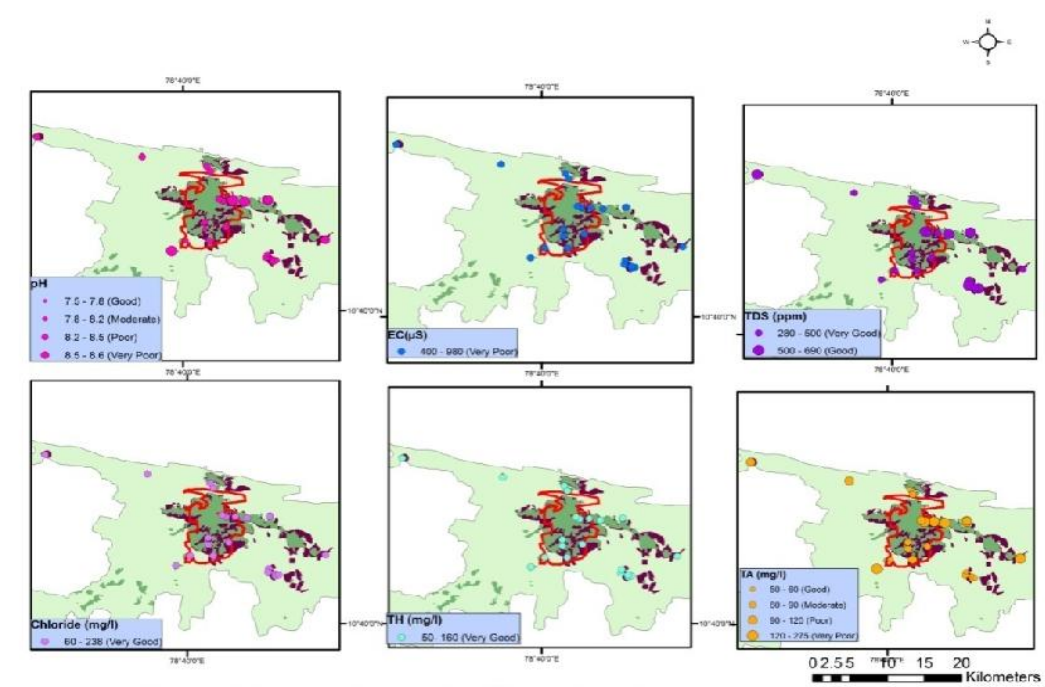
Table 3. Descriptive Statistics of Water Quality Parameters

Parameters	Recommended Standards		Existing Urban (N=8) (2005-06)					Newly formed Urban (N=14) (2011-12)				
	BIS/ICMR	WHO	Min	Max	Mean	S.D	N*	Min	Max	Mean	S.D	N*
pH	6.5-8.5	7.0 – 8.5	7.5	8.6	803	0.30	1	7.5	8.6	8.13	114.2	4
EC (µS)	<300	250	400	660	581.25	82.22	8	540	980	793.57	168.76	15
TDS(ppm)	500-2000	1500	280	520	421.25	69.72	1	380	690	502.14	116.93	8
Cl(mg/l)	250-1000	250	60	223	106.37	50.02	0	74	238	130	45.14	0
TH(mg/l)	300-600	200	50	140	103.75	38.38	0	50	160	92.5	28.83	0
TA(mg/l)	200-600	120	50	225	109.37	55.89	2	50	275	116.07	72.95	4
DO(mg/l)	> 5	ND	4.736	6.315	5.67	0.51	0	3.55	7.10	5.80	1.05	1
BOD(mg/l)	< 5	ND	0.394	3.157	1.38	0.81	0	0.39	4.34	1.60	1.07	0
SO_4(mg/l)	200-400	250-500	16.95	23.07	19.84	2.59	0	14.7	24.675	20.905	2.67	0
NO_3(mg/l)	45-100	50	9.42	12.64	10.45	1.09	0	7.5	13.5	10.26	1.72	0
TC(CFU/100ml)	1-10	0	7	540	115.25	175.71	8	2	910	78.07	230.88	14

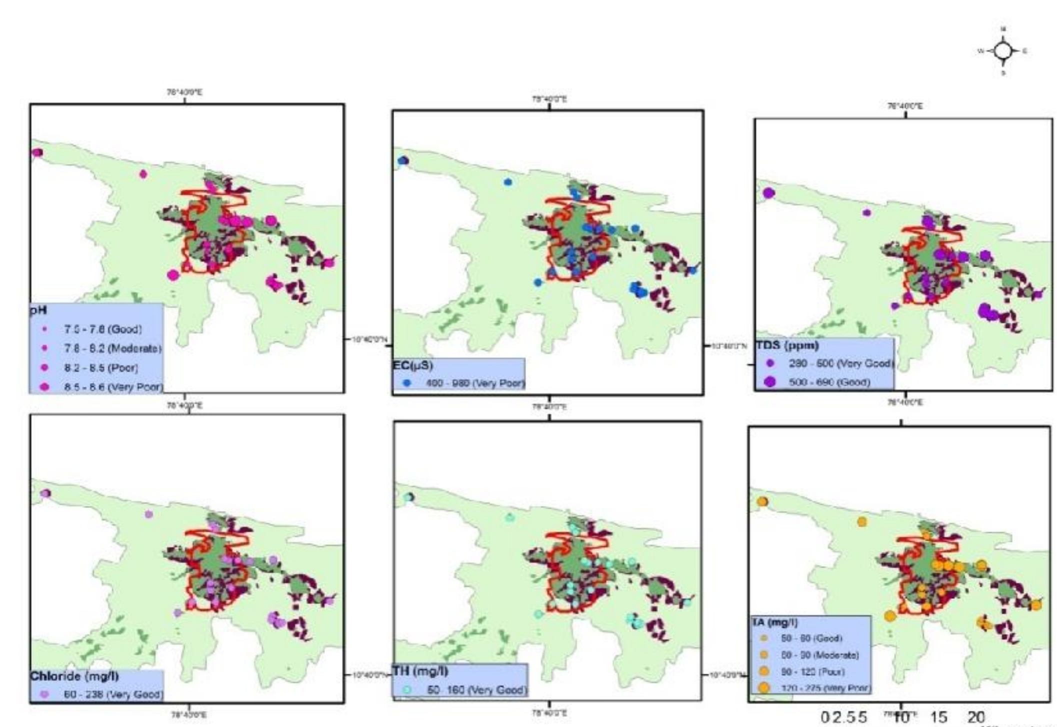
Mapping of Water Quality parameters and Identification of Risk Zones

The newly formed urban areas were estimated using area calculation tools in Arc GIS (10.2). The urban areas of Tiruchirappalli were observed to be 76.483 sq.km in 2005 – 2006 and have been expanded up to 129.43 sq.km in 2011-2012 inside and beyond the Tiruchirappalli Corporation. The urbanization can be observed in the periphery of the existing urban areas (2005-2006) viz along the Tiruchirappalli-Karur Highways in Andhanallur region and

Tiruchirappalli-Thanjavur highways in Thiruverumbur region. Thematic maps have been generated based on the estimated concentration of each water quality parameter corresponding to the standard permissible limits (Map 1a and 1b).

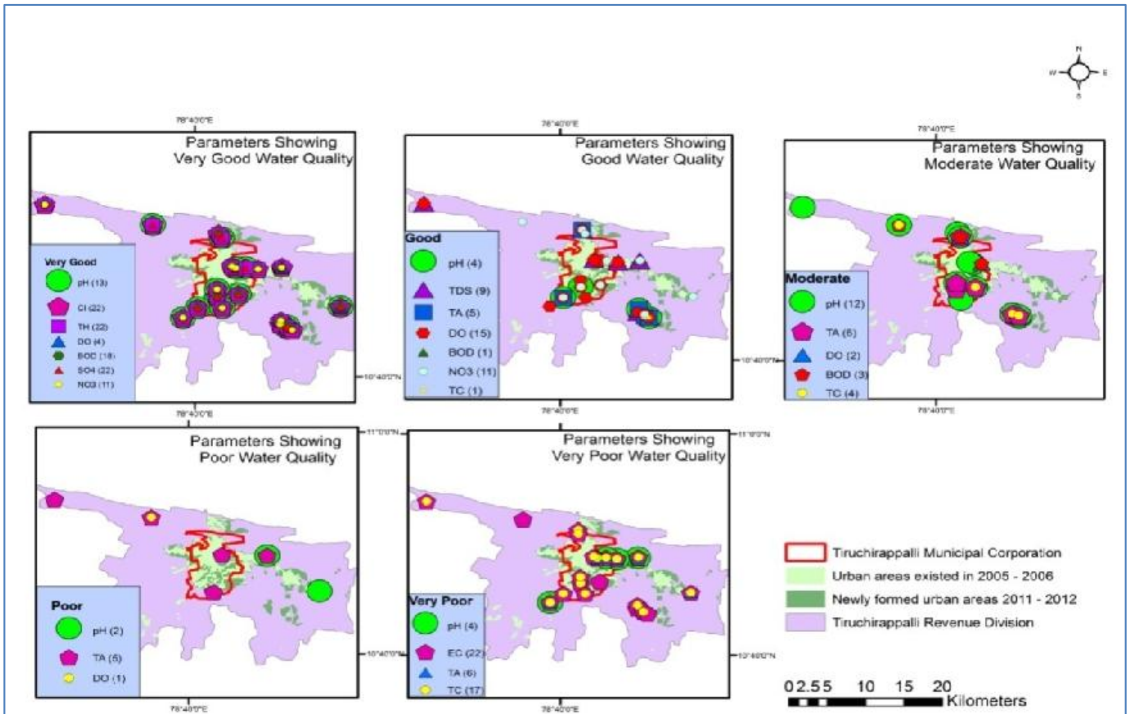


Map 1a: Water Quality Mappping in existing and newly formed urban areas of Tiruchirappalli.

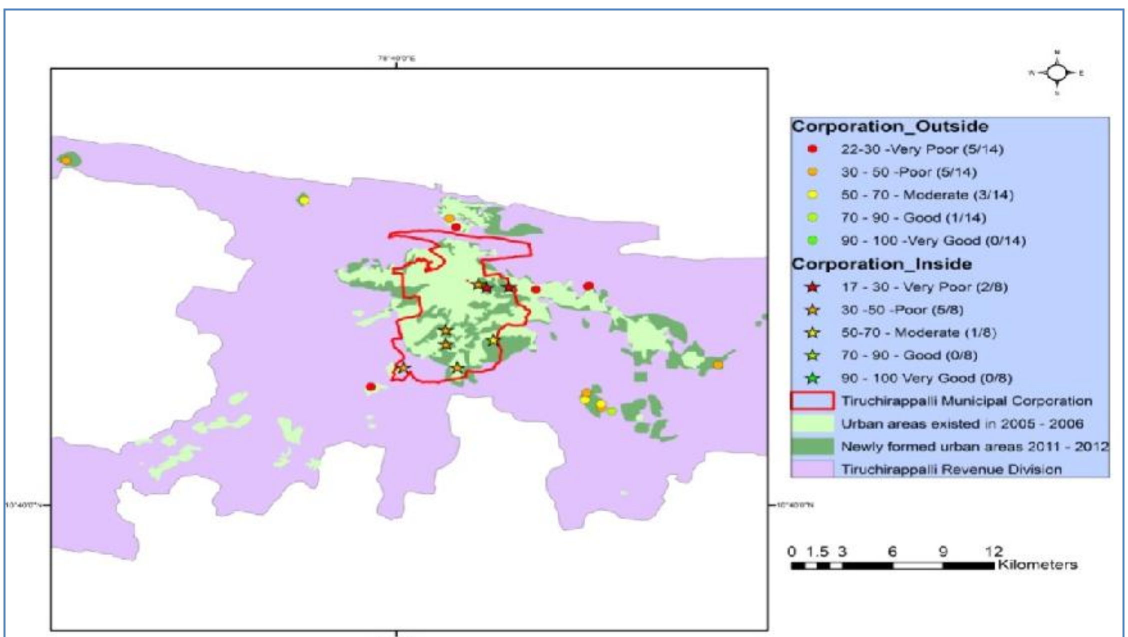


Map 1a: Water Quality Mappping in existing and newly formed urban areas of Tiruchirappalli.

To understand the influence of each individual parameter on the overall water quality, the parameters showing different levels of water quality were grouped together (Map 2).



Map 2. Water Quality Mapping



Map 3. Map of Overall Drinking Water Quality: within and outside Corporation

A sub-index is calculated using field calculation technique for each parameter by the product of Unit Weight (Wi) and Rating Vr (Equation 3). The summation of sub-indices of all the parameters in a location using equation (Equation 4) gives the overall Drinking Water Quality Index. The overall water quality index within and outside corporation boundary was mapped (Map 4).From the results (Table 4) it was observed that, the water quality within the corporation ranges poor to very poor which makes all the locations under risk and beyond the corporation boundary the water quality ranges from good to very poor (Figure 5). High risk is observed in 10 locations, moderate risk is observed in 3 locations and low risk is observed in one location (Figure 6).

Table 4. Overall Water Quality

DWQI Range	Overall Water Quality	Existing Urban Areas (8)	Newly formed Urban Areas (14)
0 - 30	Very Poor	2 (25%)	5 (36%)
30 - 50	Poor	5 (63%)	5 (36%)
51 - 70	Medium	1(12%)	3 (21%)
71 - 90	Good	0	1 (7 %)
91 - 100	Excellent	0	0

Figure 5. Overall DWQI in existing urban regions

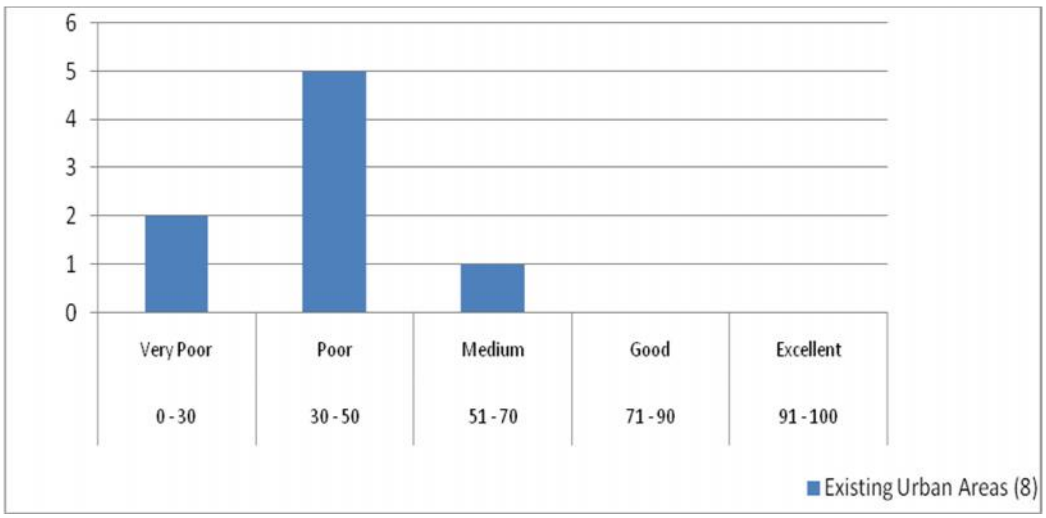
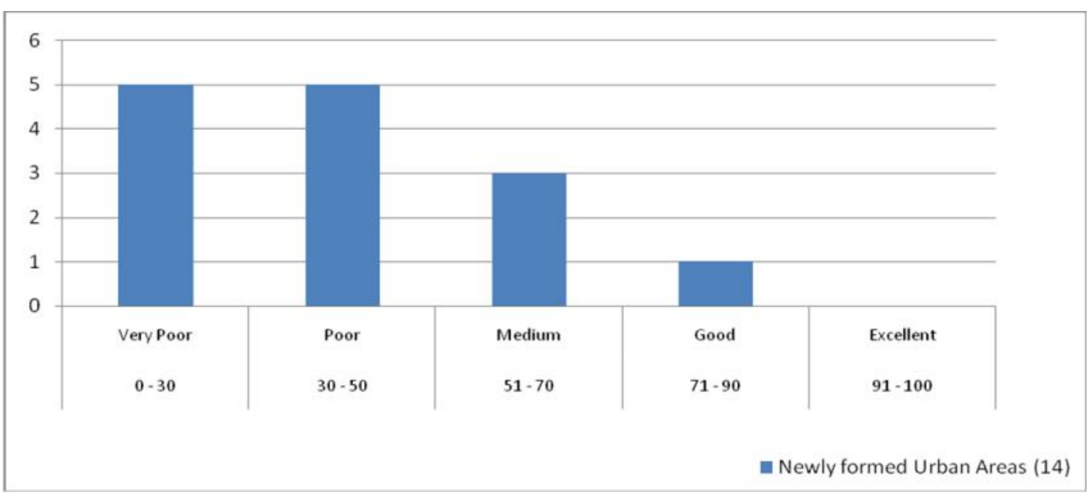


Figure 6. Overall DWQI in existing newly formed urban areas



From the observed urbanization pattern, it is evident that, Thiruverumbur region (the major industrial hub of the city) encounters the sprawl at higher rate. It houses major industries like BHEL, Kothari sugar industries, Trichy distilleries, mushrooming industries and the major solid waste dumping yard as well (Ariyamangalam). The emissions, discharges and leakages from the aforesaid firms are an already existing threat to the water quality of the region and the government imparts pressure on the industries to minimize their pollutants through stringent regulations. Moreover the run-off from the urban areas, as well as rural areas ends up in the lateral areas of the city. Despite of the existing stress, the cheap land rates and easy access to the urban facilities leads to ever increasing inhabitation in the periphery of the city. Such sprawl leads to over-exploitation of water resources ultimately, the quantity and quality of the water quality in the new areas is highly affected.

From the results of water quality determination, it is evident that pH, TA, DO and BOD were the parameters that exceeds the recommended desirable limits desirable limits in some locations. The EC exceeds the permissible limits in all locations and the total coliforms exceed the recommended limits in 21 locations except 1 location. An alkaline trend is observed in the pH of the water samples. Since most of the human body consists of 50-60% of water the pH levels of the drinking water has profound influence on the health, body chemistry and diseases. pH greater than 8.5 causes changes in the taste of the water. The TDS and EC do have any direct influence on health, but it indicates the presence of excess dissolved ions in the water. Though the Chloride and Total Hardness of the water was observed within the permissible limits, it has an influence on the taste of the water. If Total Hardness is beyond the permissible limits it leads to cardiac disorders. Total Alkalinity is influenced by the pH of the water samples. The Dissolved oxygen and Biological Oxygen Demand do not have any direct health impacts. The sulphate and nitrate was found within the permissible limits and if observed excess, it leads to gastro-intestinal disorders and blue-baby syndrome respectively.

Conclusion

Spatial modeling is a customized application which creates a sequential flow for integrating and processing the spatial data. In the present study, an attempt was made to generate interactive models using spatial model building tools for more precise visualization of the high risk regions of water contamination at Tiruchirappalli peri-urban areas. From the resultant maps the spatial variation of the water quality parameters in urban and peri-urban regions of Tiruchirappalli region is clearly understood as well as the individual parameters influencing the overall poor water quality is identified. GIS based models helps to integrate the cause and effect spatial relationships of water quality with the other factors such as water treatment before supply, direct discharge of sewage from households, open drainage systems, unplanned tap locations (adjacent to open drainages), common street water taps (sharing systems), water supply through lorries and improper maintenance of the storage facilities in the peri-urban regions. Such modeling of water quality is applicable even at the local and regional levels and serves for the appropriate planning to mitigate and control the water contamination and efficient decision making purposes in a holistic way.

Acknowledgments

The authors express our sincere gratitude to University Grants Commission for the funds provided to carry out this project.

References

Adak, M.A.G., Purohit, K.M., Datta, J. (2001) Assessment of drinking water quality of river Brahmani. *Indian Journal of Environmental Protection* 2001, 8(3), 285–291

APHA (1989)., *Standards methods for the examination of water and wastewater* 17th edition, Washington, DC, APHA, AWWA,WPFC.

Asadi, S.S., Vuppala, P., Reddy, A.M., Remote sensing and GIS techniques for evaluation of ground water quality in municipal corporation of Hyderabad (zone-V), India. *International Journal of Environmental Research and Public Health*, 2007, 4(1), 45–52.

Bhargava D.S., Most rapid BOD assimilation in Ganga and Yamuna rivers. *Journal of Environmental Engineering, American Soceity of Civil Engineers*,1983b, 109(1), 174–188.

Bhargava, D.S., A light-penetration model for the rivers Ganga and Yamuna. *International Journal of Development Technology (England)*,1983a,1(3), 199–205

BIS (Bureau of Indian Standards)., 10500 *Indian standards drinking water specification*, (1992) 1st rev, pp 1–8

BIS (Bureau of Indian Standards)., 10500 *Indian standards drinking water specification*, (2012) 1st rev, pp 1–8

Brush John E., Growth and Spatial Structure of Indian cities In *Indian Urbanization and Planning: Vehicles of Modernization, Allen* G Noble and Ashok K Dutt, Eds., Tata McGraw-Hill: New Delhi, India,1977, pp.64-92.

Brush John E., Spatial population in Indian Cities. *Geographical Review* 1968, 58, 362 – 391.

Douglas, I., Peri -urban ecosystems and societies transitional zones and contrasting values. In *Peri -Urban Interface: Approaches to Sustainable Natural and Human Resource Use*, D. McGregor, D. Simon, and D.

Thomps Eds, Earths can Publications Ltd: London, UK, 2006, pp. 18-29.

Gibrilla, A., Bam, E.K.P., Adomako, D., Ganyaglo, S., Osae, S., Akiti, T.T., Kebede, S., Achorido, E., Ahialey, E., Ayanu, G., Agyeman, E.K., Application of water quality index (WQI) and multivariate analysis for ground water quality assessment of the Birimian and Cape Coast granitoid complex: Densu River Basin of Ghana. Water Quality Exposure and Health 2011, 3, 63–78.

Indian Council of Medical Research (ICMR)., *Manual of standards of quality for drinking water supplies*. Indian council of medical research, 1975, Spe ref no 44:27.

Kumar, A., Dua, A., Water quality index for assessment of water quality of river Ravi at Madhopur (India). *Global Journal of Environmental Sciences*, 2009, 8, 49–57.

Kundu., Amitabh, Basanta K Pradhan and Subramanian A. Dichotomy or Continuum: Analysis of Impact of Urban centres on their Periphery. *Economic and Political Weekly December 14,2002*, pp 5039 -5046

Lerner, David N., Bob Harris. The relationship between land use and ground water resources and quality. *Landuse Policy* 2009, 26S, S265 – S273.

McGranahan G., Satterthwaite, D and Tacoli, C. Rural-urban change, boundary problems and environmental burdens. *Human Settlements Working Paper Series Rural-Urban Interactions and Livelihood Strategies* 2004, No. 10. IIED, London.

Pradhan S.K., Patnaik, D., Rout S.P. Water quality index for the quality of ground water in and around a phosphatic fertilizer plant. *Indian Journal of Environmental Protection*, 2001, 21,355–358

Rajendran, S., Arumugam, M.; Chandrasekaran,V.A. Potential Use of High Resolution IRS 1-C Satellite Data and Deletion of Urban Growth in and around Tiruchirappalli city, *Federation International Congress*, 2002,Washington, DC, USA

Scanlon Bridget R., Ian Jolly., Marios Saphocleous., Lu Zhang. Global impacts of conversions from natural to Agricultural ecosystem on Water Resources: Quantity versus Quality. *Water Resources Research* 2007, 43, (1-18) doi: 10.1029/2006WR005486 Available online: http://onlinelibrary.wiley.com/doi/10.1029/2006WR005486/abstract (accessed on 12.12.2013)

Selvan., Dennis. Trichy stakeholders brainstorm on development plans. *The Times of India*. Retrieved 7 September 2013

Shaw Annapurna. Peri Urban Interface of Indian cities: Growth, Governance and Local Initiatives. *Economic and Political Weekly*, 2005, 40 (2) pp 129 -136.

Shaw Annapurna. Urban Growth Basic Amenities and Waste Management in India. In *Challenges of Sustainable Development: The Indian Dynamics,* Ramprasad Sengupta and Anup K Sinha, Eds., Manok Publications, New Delhi, India, 2003, pp 298 -338.

Singh C.K., Shashtiri, S., Mukherjee S., Rina Kumari, Avatar R., Singh A., Singh R.P. Application of GWQI to assess the effect of Landuse Change on Groundwater Quality in Lower Shiwaliks of Punjab: Remote Sensing and GIS based Approach. *Water Resources Management*, 2011, 25, 1881 -1898.

Tiwari, T., Mishra, M., A preliminary assignment of water quality index of major Indian rivers. *Indian Journal of Environmental Protection*, 1985, 5(4), 276–279

Tong Susanna T.Y., Chen Wenli. Modeling the relationship between land use and surface water Quality. *Journal of Environmental Management* 2002, 66, (377-393) doi:10.1006/jema.2002.0593. Available online: http://www.idealibrary.com (accessed on 12.12.2013)

Vidyalakshmi, R., Brindha, B., Benedict Roosvelt, P., Rajakumar, S., Prashanthi Devi, M., Determination of Land Use Stress on Drinking Water Quality in Tiruchirappalli, India Using Derived Indices. *Water Quality Exposure and Health*, 2013, 5 (1), 11 - 29.

Weatherhead, E.K., Howden, N.J.K. The relationship between landuse and surface water resources in the UK. *Landuse Policy* 2009, 26S, S243 – S250.

World Health Organization, WHO, UNICEF (2011)., Drinking water, Equity, safety and Sustainability (http://www.wssinfo.org/fileadmin/user_upload/resources/report_wash_low. pdf accessed on 12.12.2013)

World Health Organization, WHO, UNICEF (2013)., Progress on Drinking Water and Sanitation. (www.who.int/iris/bitstream/10665/81245/**1**/9789241505390_eng.pdf accessed on 12.12.2013)