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Nitrogen Loading from Septic Tanks in the Coastal Plains

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Abstract: The major non-agricultural source of nitrate in groundwater is septic-soak pit systems and unsewered conditions in the east coastal plains of India. This paper deals with the assessment of nitrogen loading from septic tanks in the Kakinada urban east coastal plains of Andhra Pradesh State, India. The proposed assessment methodology makes use of available databases of population, number of houses, sanitary information, soil types etc., in each village or sub-basins which are generally available in India or elsewhere. Two-dimensional Fuzzy c-Means clustering Technique (2 D FCM) was used to classify nitrogen load over the Kakinada urban coastal plain into low, medium and high zones. Further, these zones were validated with the respective average groundwater quality. The average groundwater nitrate and electrical conductivity values are following the patterns of nitrogen loading zones. Therefore, groundwater nitrate contamination is mainly due to the unsewered conditions and high density of septic systems in the study area. The methodology adopted in the present paper is useful for the assessment of nitrogen load from leaky septic systems in the coastal plains and also for prioritizing the villages or sub-basins for better management of non-agricultural sources of nitrate in coastal plains.

Key words: Coastal plains, septic tanks, groundwater pollution, nitrogen, nitrate, fuzzy sets.

Introduction

With the increase in population, groundwater is getting contaminated rapidly and the elevated nitrate concentrations in shallow groundwater are one of the major groundwater contaminants in the coastal plains of India. The sewerage system is nearly negligible in most rural areas and is meagre (less than 50%) in most medium and small towns in India. According to Ministry of Water Resources (MoWR, 2000), Government of India, the rate of waste water generation in the country during the year 1981 was estimated to be 74,529 million L/day (about 27 km^3 annually), which increased to 110,000 million L/day (40 km^3 annually) in the year 2001 due to large increase in population. As a result, the contamination of groundwater by unsewered areas is one of the most important environmental problems in the developing countries. The impact of this polluting source (Septic-soak pit system and unsewered conditions) is more pronounced in coastal plains where the groundwater table is very shallow. The elevated nitrate concentrations (more than 45 mg/L) in shallow groundwater were observed in many urbanized coastal areas (Robertson, 1979; Stuart et al., 1995; Trauth and Xanthopoulos, 1997; Tandia et al., 1999; Voudouris et al., 2004). Many researchers reviewed the sources of groundwater nitrate due to non-agricultural activities (Flipse et al., 1984; Spalding and Exner, 1993; Wakida and Lerner, 2005) and found that nitrate ion is considered as anthropogenic source indicator of the extent of pollution of urban groundwater from domestic wastes and leaky septic tanks (Swamy and Rao, 1989; Reay, 2004; Navarro and Carbonell, 2007).

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High nitrates in groundwater affects the human health (especially infants), animals and marine living features (Zadoo, 1982; Knobeloch et al., 1993; Ward et al., 1996; Majumdar and Gupta, 2000). The epidemiological study carried out by Gupta et al. (1999) on nitrate in drinking water for the Jaipur region, India revealed that there is a significant interdependence among drinking water nitrate concentrations, cytochrome b_5 reductase activity and recurrent stomatitis. The water and excreta-related communicable diseases were reviewed by Mara and Feachem (1999) and found that the percentage of all the deaths and loss of disability-adjusted life years due to communicable diseases occurred in developing countries are 99.9 and 99.85%, respectively. The potential use of Geographical Information System (GIS) in the assessment of non-point source pollution is given by Tsihrintzis et al. (1996) and the GIS was successfully used to assess the extent of non-point source pollution over large regional areas (Ventura and Kim, 1993; Lake et al., 2003). Nizeyimana et al. (1996) developed GIS based methodology to map nitrogen loading from the septic systems for the Pennsylvania watershed, using various hydrologic, soil and census databases. Further, sub-watersheds were given low, medium and high rankings of nitrogen loading by statistical analysis but these rankings were not validated with groundwater quality in their study. In the present paper, the proposed methodology uses 2D FCM clustering technique to classify nitrogen loading into high, medium and low zones and these zones are validated with average groundwater quality.

Study Area

The study area, Kakinada coastal aquifer, is a part of the river Godavari eastern delta system in the East Godavari district of Andhra Pradesh, India (Figure 1). It is one of the highest population density areas along the east coastal Andhra Pradesh. The study area lies between 82° 05′ 00″ to 82° 22′ 41″ E longitude and 16° 55′ to 17° 13″ N latitude. It is bounded by two ephemeral streams namely Eleru and Goree khandi and third side is the Bay of Bengal. The study area is about 415 km^2 and comprises 83 polygons (villages and towns). Each polygon was assigned index numbers from 1 to 83 (Figure 1). The geographical area of the polygons varies between 1 to 21 km^2. The highest elevation of the study area is about +28.5 m at polygon index 64 and +0.5 m along the Bay of Bengal. The largest area (21 km^2) is of the polygon of Kakinada Municipal Corporation (KMC: index 12). The main soil types in the study area are sandy loam, sandy clay loam, sandy clay and clay. The study area is under tropical climate. It is warm during April to June with a maximum temperature of 40° C and the winter months are December and January having minimum temperature of 18° C. The major contribution of rainfall comes from the southwest monsoon during June to October. The annual normal rainfall is 1095 mm and the average evaporation rate varies from 2.5 to 9 mm/day.

The main geology of the area is coastal alluvium underlain by sandstone. The shallow aquifer is under water table conditions and this aquifer is one of the main drinking water sources in the study area. The groundwater table varies between +0.5 to 4 m below ground level from pre-monsoon to post-monsoon periods in the study area. The groundwater table contours and flow direction in the study area during the month of November 2005 is shown in Figure 2. The major direction of groundwater flow is towards the Bay of Bengal and also follows the topographical gradient of the study area. At present no sewerage lines are available for septic effluents disposals in the study area and therefore people are using septic tank-soak pit systems in each house. The detailed groundwater hydrochemistry of the present study area has been studied by Rao et al. (2010) and found that salinity and nutrients are major contaminant types in the shallow groundwater of study area. The spatial correlation of salinity is observed up to 10 km and no spatial correlation observed for nutrients. Among the nutrients, high nitrate concentrations were observed in the shallow groundwater.

Input Data

The census data for the years 1991 and 2001 (which include number of houses) was collected from National Informatics Centre (NIC), Kakinada and Chief Planning Office (CPO), Kakinada, Andhra Pradesh State Government (APSG). The soil types of each village were obtained from agricultural department of APSG. The village map was taken from the East Godavari District Atlas and topographical features were extracted from Survey of India (SOI) Topographical maps on 1:50,000 scale. The field survey was carried out in each polygon (village and towns) during the months of July 2004, December 2004, February 2005 and May 2005 and collected representative groundwater samples (Figure 1), and all these samples (332 nos.) were analyzed for water quality parameters mainly electrical conductivity (EC) and nitrate concentrations.

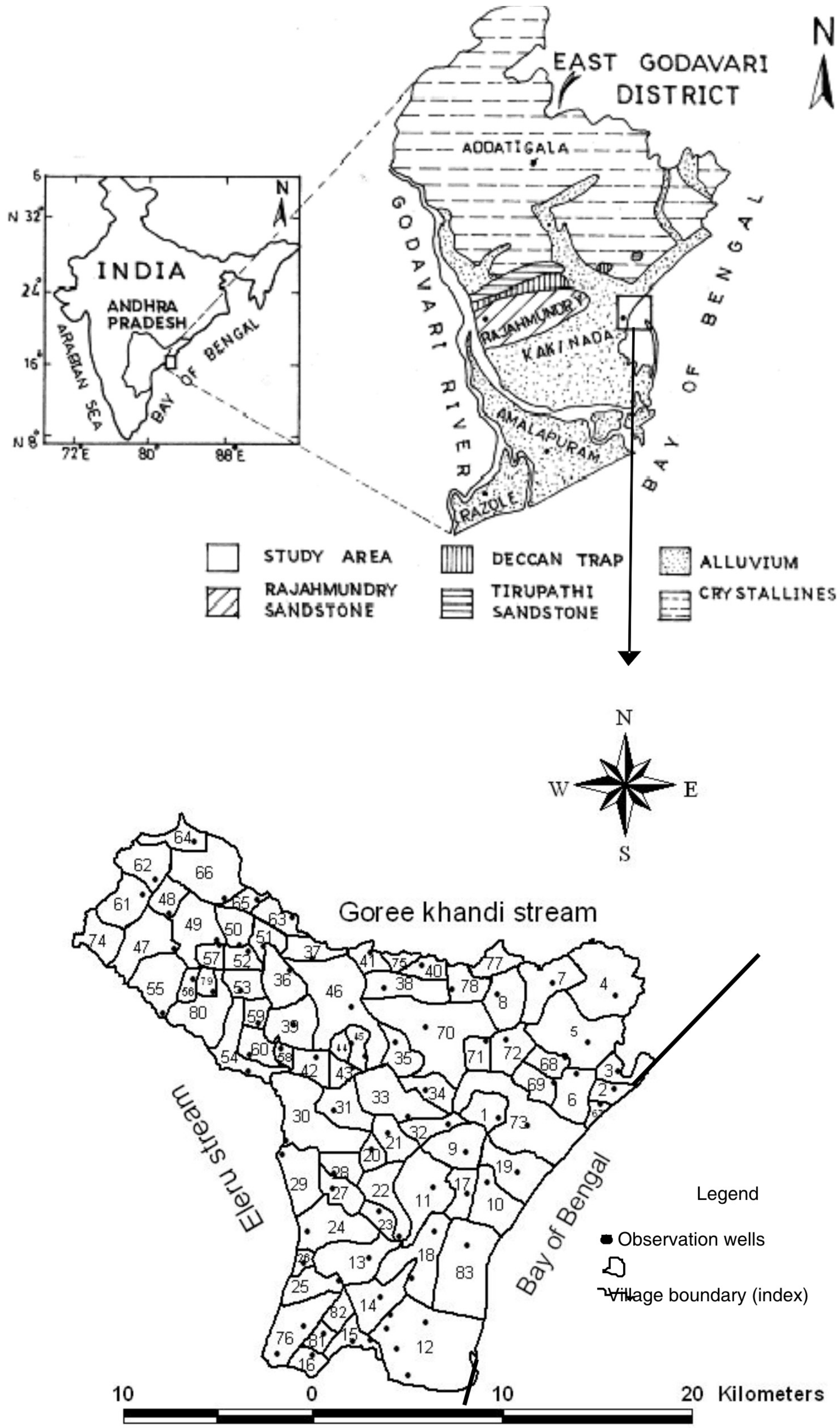

Figure 1: Location of the study area.

The representative groundwater samples were collected from open wells, which are used for domestic and drinking water purposes.

Methodology

Assessment methodology of nitrogen load from septic systems is similar to Nizeyimana et al. (1996). However, it is assumed that each house has septic system in the study area and also due to variant condition, a correction factor has been applied to the number of persons using septic systems because in rural areas some people are using other methods like outhouses. The village map was digitized from atlas of the East Godavari district and topographical features have been digitized from Survey of India (SOI) topographical maps. The attribute data of population, soil type, number of houses, % of malfunctioning of septic system in each soil type were attached to each polygon in the study area. The average number of persons per housing unit was calculated by dividing the number of persons in each polygon (village/town) by the total number of housing units.

It is assumed that the wastewater generated in septic systems by each person per day in India is around 100 L (Bhargava, 1984) and the average nitrogen concentration in septic effluent is around 95 mg/L (Rajashekar et al., 1994) in the study area. Therefore, the total nitrogen (N) produced by each person calculated as 95×10^{-6} N $L^{-1} \times 100$ L $d^{-1} \times 365$ d yr^{-1} = 3.5 kg $person^{-1}$ yr^{-1}. Many authors (Alhajjar et al., 1989; Naranjo and Larsen, 1998; Schouw et al., 2002) reported similar values for other countries irrespective of age and sex. The amount of nitrogen (kg yr^{-1}) produced by each polygon (village/town) is estimated by multiplying 3.5 kg $person^{-1}$ yr^{1} by the total number of people using septic systems by considering the % of malfunction of septic system in each soil type given by Matelski (1975) and Hoover et al. (1981). It is assumed that all nitrogen released as a result of septic system failure reach groundwater without loss due to various biogeochemical processes. Hantzsche and Finnemore (1992) and Costas-Carlos and Gomez-Gomez (1998) also advocated this assumption. The Indian guidelines for proper septic tank construction BIS (1986) also recognize the fact that the septic tank treatment is not efficient in coastal regions where groundwater table is very shallow.

2-D Fuzzy c-Means Clustering (2D FCM)

Fuzzy clustering of numerical data forms the basis of many classification and system modelling algorithms. It can be used as a tool to obtain a partitioning of data where the transitions between the subsets are gradual rather than abrupt. Clustering techniques are among the unsupervised (learning) methods, since they do not use prior class identifiers. The purpose of clustering is to identify natural groupings of data from a large data set to produce a concise representation of a system's behaviour. If the data sets for two different periods were available, the two-dimensional Fuzzy c-Means clustering technique (2-D FCM) would be applied on this data set. The 2-D FCM is a data clustering technique wherein each data point belongs to a cluster to some degree that is specified by a membership grade. This technique was originally introduced by Bezdek (1981), an improvement on earlier clustering methods.

A large family of fuzzy clustering algorithms is based on minimization of the fuzzy c means functional formulated as (Bezdek, 1981):

$$J(Z;\, U,\, V) = \sum_{i=1}^{c}\sum_{k=1}^{N}(U_{ik})^m \left\|zk - v_i\right\|^2 A \tag{1}$$

where Z is the given data set, and objective of clustering is to partition the data set into c clusters and

$$U = [U_{ik}] \in M_{fc} \tag{2}$$

is a fuzzy partition matrix of Z, and contains values of the i^{th} membership function (M_{fc}) of fuzzy subset A_i of Z.

$$V = [v_1,\, v_2,\, \ldots\ldots,\, v_c],\ v_i \in R^n \tag{3}$$

is a vector of cluster prototypes (centres), which have to be determined,

$$D_{ikA}^2 \ = \ \left\|z_k - v_i\right\|^2 A = (z_k - v_i)^T \ A(z_k - v_i) \tag{4}$$

is a squared inner product distance norm, and

$$m \in [1, \infty] \tag{5}$$

is a weighting exponent, which determines the fuzziness of the resulting clusters. The measure of dissimilarity in Equation (1) is the squared distance between each data points z_k and the cluster prototype (means) v_i. This distance is weighted by the power of the membership degree of that point $(U_{ik})^m$. The minimization of the c-means functional (Equation 1) represents a nonlinear optimization problem that can be solved by simple Picard iteration through the first-order conditions for stationary points of Equation (1), known as the fuzzy c-means (FCM) algorithm, which is given below.

Given the data set Z, the number of clusters, $1 < c < N$, the weighting exponent $m > 1$, the termination tolerance $\varepsilon > 0$ and the norm inducing matrix A are chosen. The partition matrix is initialized randomly, such that $U^{(0)} \in M_{fc}$. It is repeated for l = 1, 2, …

Step 1: Compute the cluster prototypes (means):

$$v_i^{(l)} = \sum_{k=1}^{n} \left(U_k^{(l-1)}\right)^m z_k / \sum_{k=1}^{n} \left(U_{ik}^{(l-1)}\right)^m \quad 1 \le i \le c. \tag{6}$$

Step 2: Compute the distances:

$$D_{ikA}^2 = (z_k - v_i^{(v)})^T A(z_k - v_i^{(l)}), \quad 1 \le i \le c, \quad 1 \le k \le N. \tag{7}$$

Step 3: Update the partition matrix:

if $D_{ikA} > 0$ for $1 \le i \le c$, $1 \le k \le N$,

$$U_{ik}^{(l)} = 1/\sum_{j=1}^{c} (D_{ikA}/D_{jkA})^{2/(m-1)} \tag{8}$$

Otherwise

$$U_{ik}^{(l)} = 0 \text{ if } D_{ikA} > 0, \text{ and } U_{ik}^{(l)} \in [0, 1] \text{ with } \sum_{i=1}^{c} U_{ik}^{(l)} = 1 \tag{9}$$

Until $$\left\| U^{(l)} - U^{(l-1)} \right\| < \varepsilon. \tag{10}$$

Matlab (2000) software with fuzzy logic toolbox (Ver., 2.0) was used to perform 2D-FCM algorithm on nitrogen loads computed for each polygon in the study area for the years 1991 and 2004.

Groundwater Quality and Soil Fertility Index

Representative groundwater samples were collected from each polygon (village/towns) and analyzed for nitrate using UV spectrophotometer and electrical conductivity (EC) with electrodes in the water quality laboratory of Deltaic Regional Centre, National Institute of Hydrology, Kakinada as per the procedures of APHA (1971). The depth of the groundwater samples collected from open wells in the study area ranges between 0.5 to 4 m below ground level. A total of 332 samples were analyzed for nitrate and EC during the months of July 2004, December 2004, February 2005 and May 2005. Due to low phosphate values in the study area, these samples were not analyzed for phosphate concentrations (Rao et al., 1997). More groundwater samples have been collected in the larger geographical area of the polygon (12) and the average groundwater quality represents the polygon. The chemical analysis data of all the 83 polygons were grouped as per 2D-FCM clustering of nitrogen loads (low, medium and high zones) and the average groundwater quality in each zone during different sampling surveys are obtained. Further, the percentage of agricultural area in each polygon is collected and the total percentage of agricultural area in each nitrogen zone (low, medium and high) is computed.

The soil fertility index (low, medium and high) in terms of nitrogen (N), phosphorous (P) and potassium (K) for each polygon in the study area is collected from Agricultural Department of Andhra Pradesh, India. The classification of soil nitrogen index as low, medium and high are arrived based on the percentage of organic carbon (OC) present in the soil sample. If OC is less than 0.5%: nitrogen index is low; the OC is between 0.5% and 0.75%, the nitrogen index is medium; and the OC is more than 0.75 %, nitrogen index is high. The classification of phosphorous index as low, medium and high is based on the P_2O_5 concentration in soil solution. If P_2O_5 is less than 20 kg/ha, phosphorous index is low; the P_2O_5 is between 20 and 50 kg/Ha, phosphorous index is medium; and the P_2O_5 is more than 50 kg/Ha, phosphorous index is high. The classification of potassium index as low, medium and high is based on the K_2O concentration in soil solution. If K_2O is less than 150 kg/ha, the potassium index is low; the K_2O is between 150 and 300 kg/ha, potassium index is medium; the K_2O is more than 300 kg/ha: potassium index is high. The details of the soil fertility index of the study area as N, P and K are given in the reports of NBSS & LUP (2005).

Results and Discussions

The nitrogen loading from septic systems for the years 1991 and 2004 was computed for each polygon (village/town) of the study area by performing map calculation in GIS environment as explained in the methodology. The class of soil limitation and percentage of malfunctioning of septic systems for various soil types for the computation of nitrogen load due to septic systems are given in Table 1. The groundwater flow direction and a conceptual field condition of typical septic tank-soak pit system in the study area are shown in Figures 2 and 3 respectively. The field condition indicates that the assumption of nitrogen released from septic systems reaches to groundwater holds good in

Table 1: Soil limitation class and malfunctioning of septic systems

Soil type	*Soil limitation class*	*% Malfunctions of septic systems*
Sandy loam	Severe	65
Sandy clay loam	Moderate	40
Sandy clay and clay	Slight	10

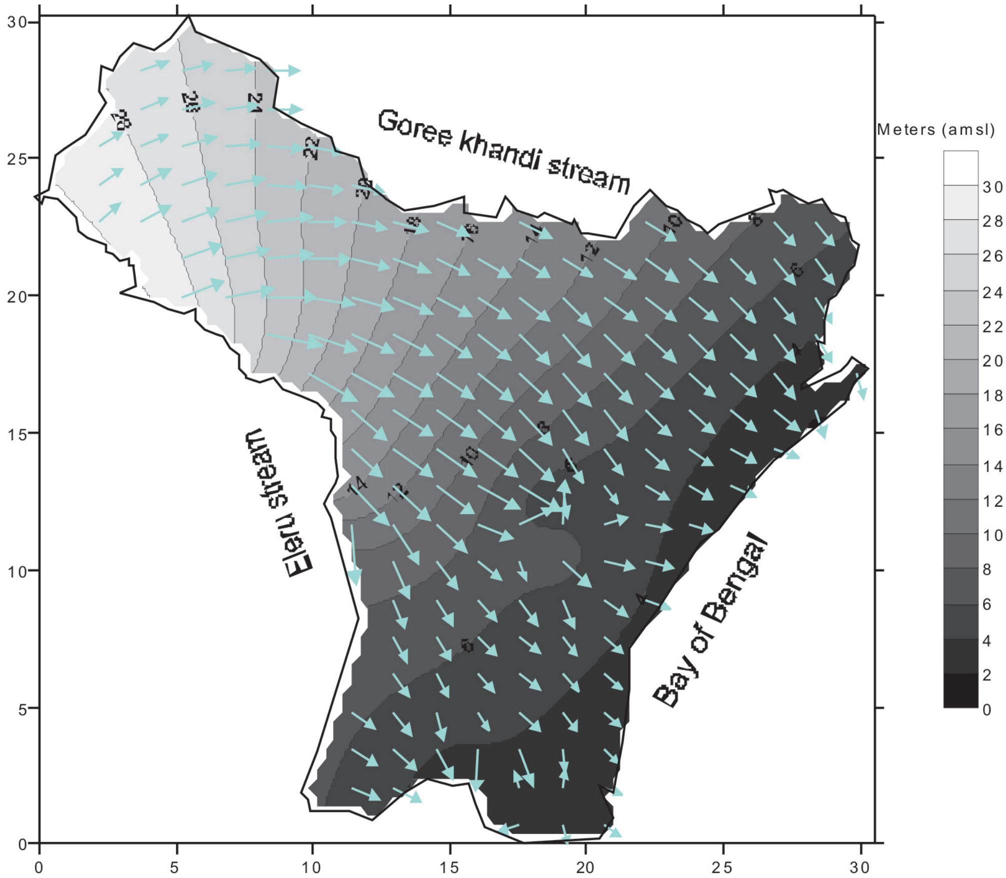

Figure 2: Groundwater table contours and flow direction during the month of November 2005.

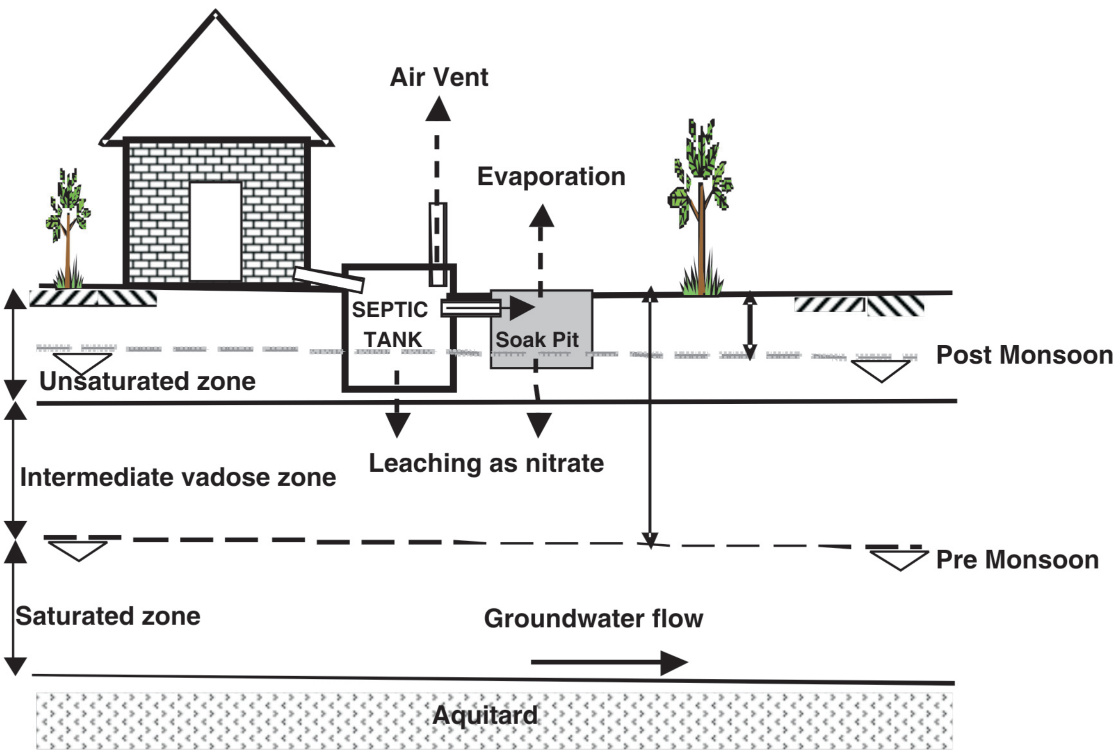

Figure 3: Conceptual field condition of septic-soak pit systems in the study area.

the present coastal plains due to shallow water table conditions. The number of septic tanks per km^2 in each polygon is shown in Figure 4. The nitrogen loading of each polygon from septic systems for the years 1991 and 2004 (updated from 2011 census data) were used to classify the study area into low, medium and high zones using 2D FCM clustering technique. The 2D FCM clustering groups and the corresponding classification of the study area into low, medium and high zones are shown in Figures 5(a) and 5(b) respectively. The range of nitrogen loading (kg/year) in low, medium and high zones classified by 2D FCM technique is 1 to 3255.0, 3434.0 to 10,883.0 and 13,357.0 to 239,313.2 respectively.

It may be noted from Figure 5(a) that the high nitrogen load of KMC (index 12) is not considered in cluster analysis for better clustering groups, therefore only five points are marked (high zone) in the graph. It appears from Figure 5(b) that the spatial distribution of nitrogen loads is mainly a reflection of number of septic tanks and to some extent on soil types. The highest computed nitrogen load in KMC polygon (in index 12), which is not considered in the 2D FCM, is also given in Figure 6 (High zone). To validate high, medium and low nitrogen zones obtained by 2D FCM classification are compared with average groundwater nitrate and EC. Four field surveys data on NO_3 and EC values in each polygon are shown in Figures 7 and 8, respectively. The analysis of samples collected during four surveys revealed that 28% of the villages exceeded the maximum allowable drinking water limits of nitrate (100 mg/L) and 47% of villages exceeded the allowable limit (45 mg/L) of drinking water standards (BIS, 1991). This indicates significant shallow groundwater nitrate contamination in the study area.

Table 2 shows the comparison between average nitrogen loading zones (low, medium and high), number of polygons (villages and towns) in each zone, total geographical area of each zone, and average nitrate concentrations in each zone in the study area. Similarly, the nitrogen loading zones, percentage of agricultural area in each zone and average EC values in each zone are shown in Table 3. It may be noted that instead of comparing nitrogen load in each village and its corresponding groundwater quality, the average nitrogen load in each zone and its corresponding average

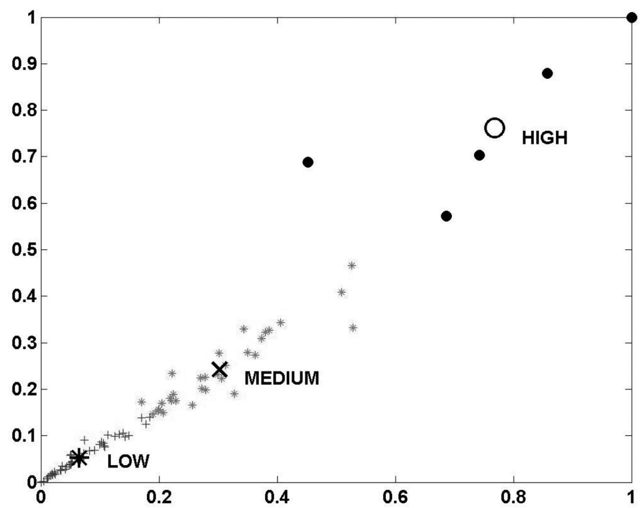

Figure 5(a): 2-D FCM clustering groups.

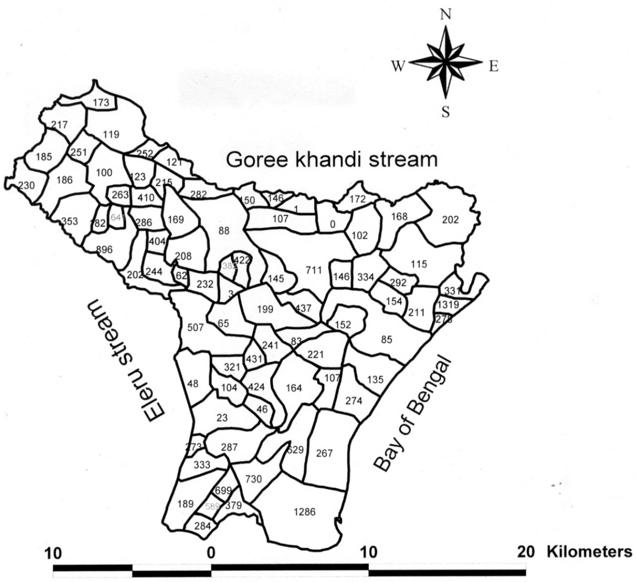

Figure 4: The number of septic tanks per sq. km in each polygon.

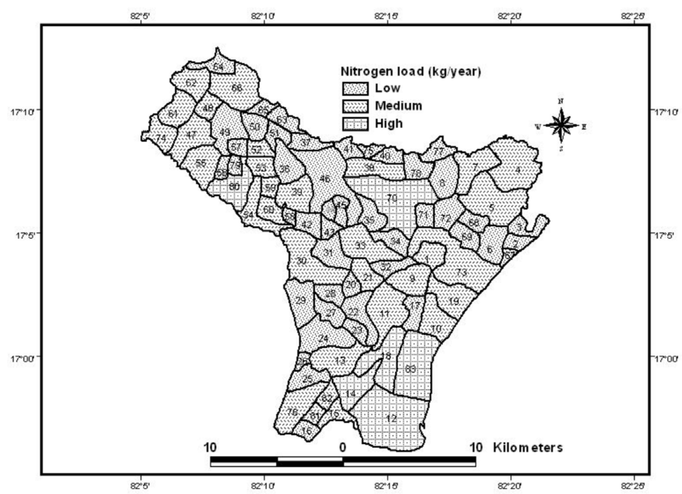

Figure 5(b): Classification of study area into low, medium and high nitrogen zones.

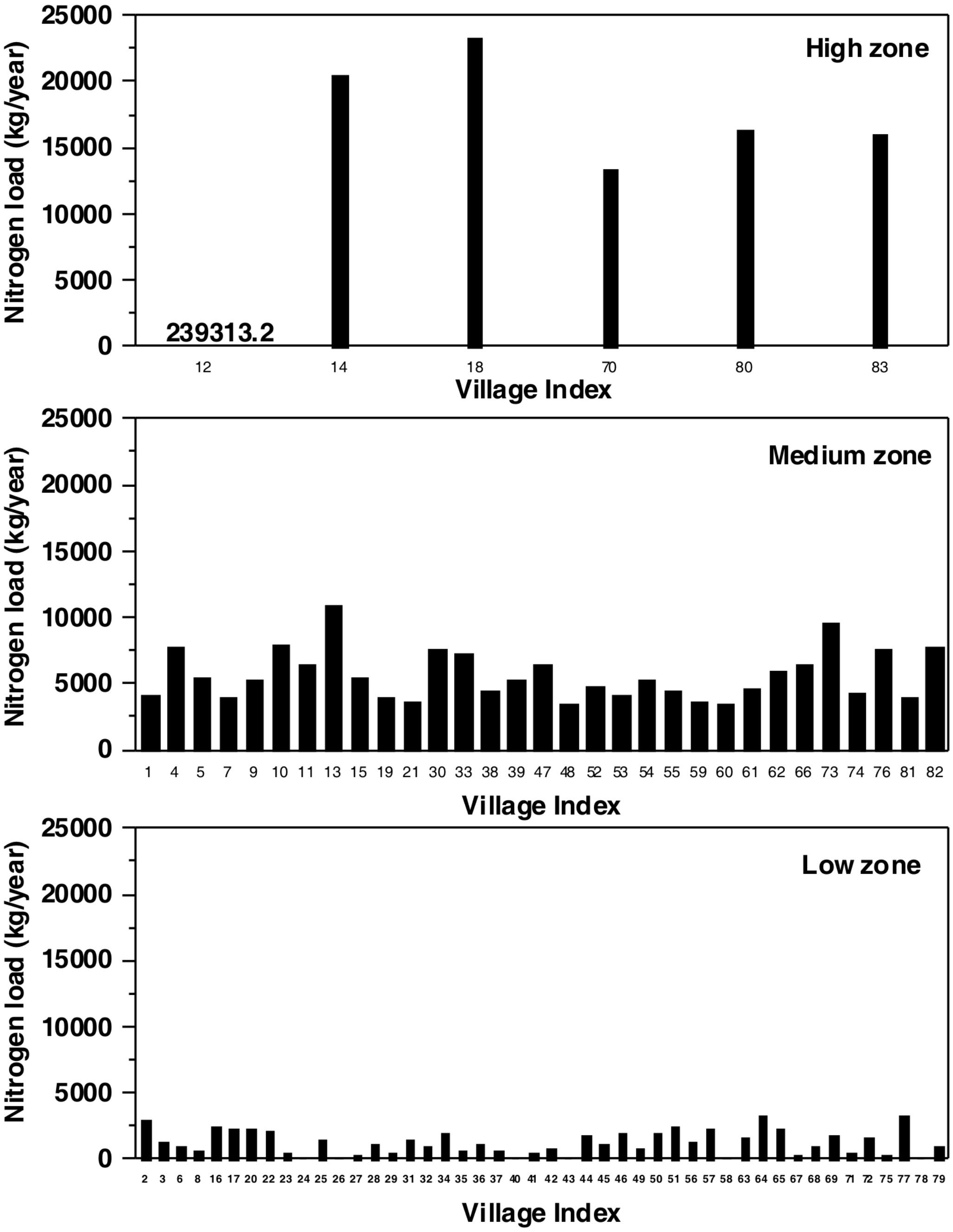

Figure 6: Nitrogen load variations under high, medium and low zones in the study area.

groundwater quality is compared. This is mainly due to the dominant groundwater flow direction as indicated in Figure 2. Similar comparison was also made by Oyarzun et al. (2007) in their study to validate RISK-N model nitrate leaching results with average groundwater nitrate concentrations instead of individual well in the agricultural areas. The average NO_3 and EC values are following mostly the pattern of nitrogen loading zones. This indicates the impact of septic systems more in groundwater NO_3 and EC and also validating methodology adopted to map the nitrogen load from septic systems. Even the percentage of agriculture area is more in medium and low nitrogen zones (from septic system alone), the corresponding groundwater nitrate concentrations are less because of puddling practices in paddy fields and more losses of nitrogen in the form of denitrification.

Further, soil fertility indexes of NPK in each polygon in the study area was analyzed and found that the percentage of low, medium and high nitrogen fertility

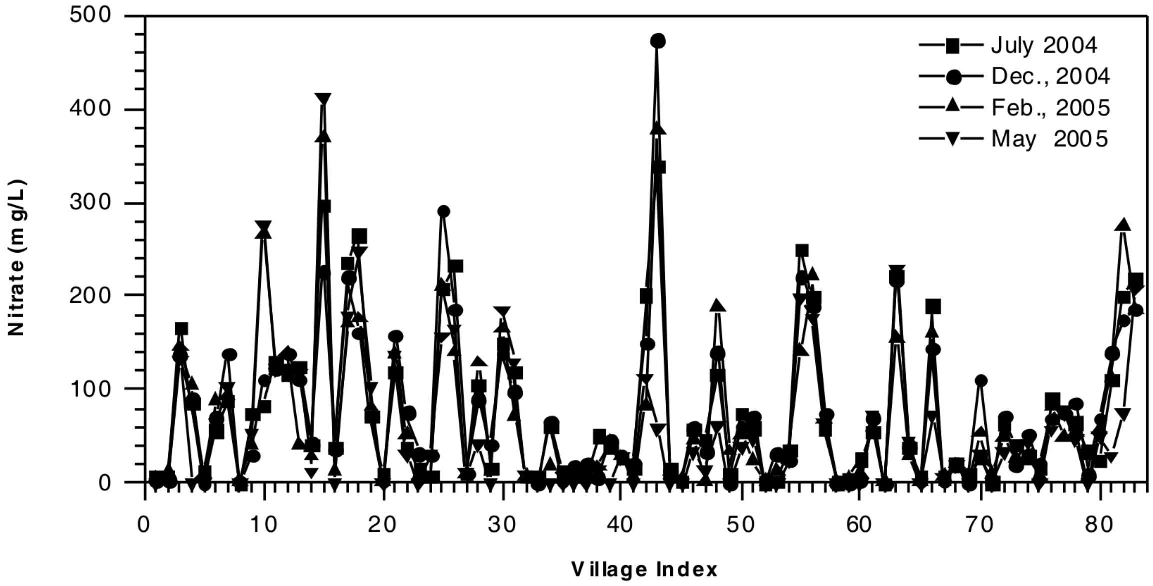

Figure 7: Nitrate variations in each polygon (village/town) during four field surveys in the study area.

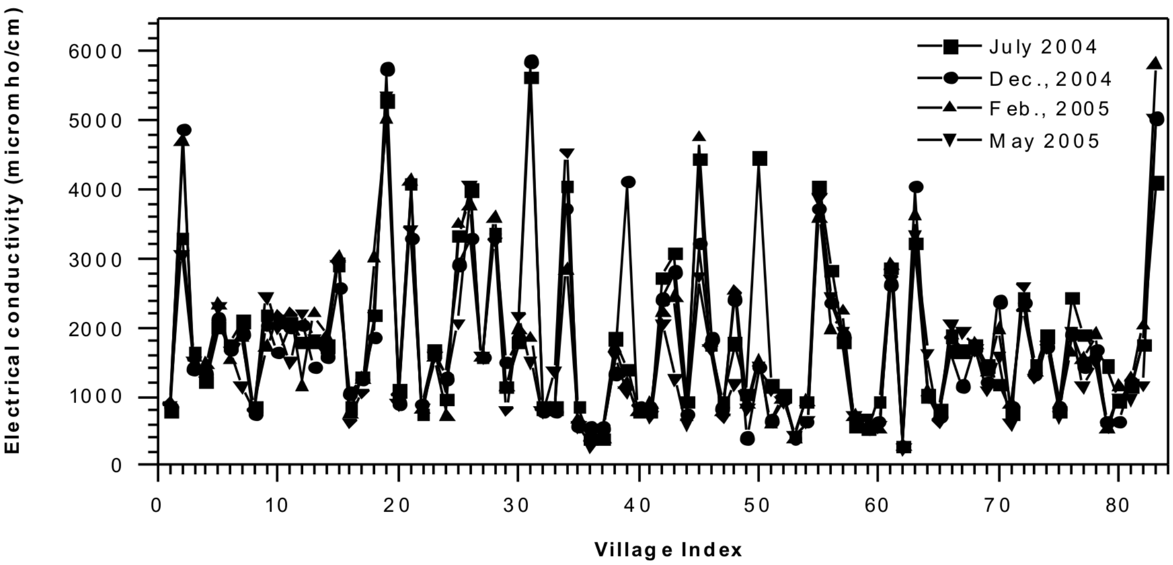

Figure 8: Electrical conductivity variations in each polygon (village/town) in the study area.

Table 2: Annual average nitrogen-loading zones (low, medium and high) and groundwater quality (NO_3)

Nirtogen class (Number of villages)	*Total geographical area (km^2)*	*Average nitrogen load (kg/yr)*		*Average NO_3 (mg/L)*			
		1991	*2004*	*July 2004*	*Dec., 2004*	*Feb., 2005*	*May 2005*
Low (46)	152.80	1194	1248	42	65	68	54
Medium (31)	189.40	5357	5633	71	82	77	86
High (6)	72.71	51385	54828	112	115	118	107

Table 3: Annual average nitrogen-loading zones (low, medium and high) and groundwater quality (EC)

		Average electrical conductivity (EC) (micromho/cm)			
Nitrogen class (Number of villages)	*Percentage of agricultural area*	*Jul., 2004*	*Dec., 2004*	*Feb., 2005*	*May 2005*
Low (46)	56	1850	1707	1629	1506
Medium (31)	59	1830	1805	1812	1691
High (6)	25	1998	2264	2485	2269

indexes are 53, 37 and 10 respectively. The percentage of low, medium and high phosphorus fertility indexes are 49, 34 and 17 respectively in the study area. Similarly, the percentage of low, medium and high potassium fertility indexes are 1, 19 and 80 respectively in the study area. This analysis also revealed that due to less percentage of soil nitrogen fertility indexes in the study area, the contribution of nitrate to the groundwater from agricultural activity is less than the non-agricultural activities. The high percentage of soil potassium fertility index up to 80% in the study area indicates that the dominant nutrient from agricultural activities is potassium. Therefore, the present methodology adopted to estimate nitrogen load from septic system along with 2D FCM clustering technique is suitable for assessment of nitrogen loading from septic system in the coastal plains. It is evident from the above discussion that groundwater contamination is significant especially in coastal towns and nearby areas in terms of nitrate concentrations. The groundwater quality may further deteriorate as the prevailing anthropogenic conditions continue in the study area.

Therefore, suitable controlling measures i.e. separate sewerage system may be initiated and public awareness on maintenance of septic-soak pit systems has to be increased by stating that the present groundwater nitrate contamination is mainly due to non-agricultural activities and unsewered conditions in the study area.

Conclusions

The nitrogen loading in each polygon (village or town) from septic systems is estimated for the years 1991 and 2004. Using these two years loading patterns, the study area is classified into low, medium and high zones of nitrogen using 2-D FCM technique. The comparison of nitrogen loading zones and its corresponding average shallow groundwater nitrate and EC indicated that the shallow groundwater nitrate contamination is mainly due to high density of septic systems and unsewered conditions in the study area. The analysis of soil fertility indexes between NPK in the study area indicated that percentage of high nitrogen index is limited to 10% only in the study area whereas phosphorus and potassium high fertility indexes are 80% and 17% respectively. It indicates that the agricultural activities are not major sources of present nitrate contamination in the coastal plains. The methodology adopted for estimating nitrogen loading from septic systems is more useful for assessing impact of non-agricultural activities in the coastal plains.

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