Bacteriological Contamination Vulnerability Assessment of shallow aquifer ground water: A case study of Thalakulathur Grama Panchayath, Kerala State, and Republic India.

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KEYWORDS
Sustainable Development, Ground Water, Arc GIS, Bacteriological Contamination, Vulnerability Assessment

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ABSTRACT

The natural resources vulnerability assessment is the first step for formulating strategies for sustainable development..Thalakulathur is one among the developing Panchayaths in Kerala State. Republic of India. The Panchayath is located at 11^0 20' and 11^0 24' North latitudes and 750 44' and 75^0 49' East longitudes with an elevation ranging from 0 to 156 M above MSL. Though the Panchayath is surrounded by water bodies on two sides, the Panchayath faces acute shortage of drinking water, especially during the summer season. Bacteriological contamination threat, in the available shallow aquifer dug well water is one among the major issues which the panchayath has to be addressed.

A *geodatabase* was created with feature dataset including feature classes for water table, land use, soil series, density of drinking water sources and density of septic tanks. Geographic features from rectified images were *vectorized* in the form of point, line and polygon and were saved in different feature classes with the help of active window in Arc GIS Map. The attributed values of various map layers Depth of water table, Effluent from onsite Water treatment, Soil Media ,Topography & Land Use, Out let water, Conductivity and Aquifer media (DESTOCA) were then classified by equally dividing the range of values between the maximum and minimum in 1 to 10 ranks. The pumping rate is another factor which may influence and was ascertained before giving the final weightage.

A Site specific, realistic methodology DESTOCA has been developed and revealed that approximately 10 to 15% (175 to 260 Hectares) of the Panchayath is highly vulnerable in bacteriological contamination of shallow aquifer groundwater. The study concluded with specific, appropriate Strategies can be adopted to overcome the bacteriological contamination issue in the affected area.

1. INTRODUCTION

"Dharmo rakshati Rakshitaha" the vision kept in every breath of ancient Indian is very powerful not only to sustain life but also to maintain required Jeevamritham *for each and every organism* in the earth. By utilising direct energy from the sun, the hydraulic cycle showers to mother earth about 505,000 cubic kilometers (wikipedia.org) of distilled water every year. Natural self purification is taking place in the environment from the point at which water particle touches the earth by various processes like disinfection by ultra violet rays, aeration, absorption, adsorption and also preserves a certain percentage of surface water into underground for future use. In the case of artesian well, water shoots up without any artificial energy. Impact of unabated anthropogenic activities with very short sightedness imbalance the whole ecosystem which leads to contamination of resources like water, which will not only affect human but even flora and fauna. In accordance with the World Health Organization, about 2.6 billion people, half of the developing world lack even a simple 'improved' latrine and 1.1 billion people has no access to any type of improved drinking source of water. About 1.6 million people die each year from water borne diseases; the figure may go up further as imbalance of demand and supply of potable water increases with time.(WHO).In India health burden of poor water quality is enormous. It is estimated that around 37.7 million Indians are affected by waterborne diseases annually and 73 million working days are lost due to waterborne disease each year. The resulting economic burden is estimated at $600 million a year.(Water aid).Protection of groundwater resources is always better than remediation and restoration of the aquifer. In most cases, restoration of a polluted aquifer back to shape is very near to an impossible task. The groundwater system responds slowly to contamination events and the travel times to reach the groundwater zone are often long. Moreover, finding alternative sources for water supply is not always possible (Asghari Moghaddam, 2009)***.***

Kerala is one among the States in India which receives a high amount of rainfall. This may become more evident when one compares its rainfall (3060mm) with the National average (1100mm). But many other factors like population density, hydrogeology, and ineffective management of water and allied resources, make it difficult for the State to keep up its earlier high public health status which the State had achieved through clean and healthy environment. In this context, a success story from the adjacent state makes a positive spirit. For the people of Tamil Nadu the traditional Ooranis or ponds have truly proved to be a blessing. The Ooranis were developed as the main water supply systems in Tamil Nadu centuries back. Recently 360 Ooranis have been rejuvenated in several districts with the combined efforts of the Government, the community, technical expertise from the Anna University and NGO participation. Recharging of Ooranis also is arranged from surface/ harvested rain water. Water shortages have now become a thing of the past in these areas, From this it is very clear that the combined use of groundwater, surface water and roof top rain water harvesting system is to be encouraged as means of improving sustainability and drinking water security (Planning Commission, GOI 2007)

2. BACK GROUND OF THE STUDY

Based on a sample study conducted by Kerala Water Authority (KWA) in 2007, there were about 45 lakhs of Kinar (Masonry lined Dug wells to withdraw water from shallow aquifer) in the state. The present cost of total private investment done in this area will come to about Rs 25000 crores. Later many of these wells were abandoned due to many reasons including steep falling of water table and deterioration of quality of water due to unplanned urbanization. However it is expected that, about 30 lakhs of those are still functioning. Based on a sample case study conducted by KWA, it is understood that non sustainable approaches prevailing in the state, reduced the number of perennial & water quality reliable *Kinar* to a few thousands.. From the literature and sample case studies it is clear that at least a simplified Geographical Information System (GIS) based modeling of vulnerability to contamination is essential to protect Dug Wells of the state. Major Concern of Shallow Aquifer Water (SAW) and requirement of interference is given in Table.1.

Table.1. Major Concerns and Interference

Sl.No	Major Concern of Shallow Aquifer Water	Requirement of Interference
1	Water quality status represented by a single water sample varies horizontally, vertically, and temporally without any reliability. I.e. temporal and spatial variability.	scientific assessment and sustainable development.
2	Wells may be constructed with various construction material and many different ways with various casing diameters and screen depths.	Standardization of sanitary well construction methods and its early implementation.
3	Apart from the topography and geology, the quantity and quality of waste water discharged from soak pits in the catchment area, Rate of Pumping of water from the water source etc will also affect contamination.	The Existing water quality modeling methodologies like 'DRASTIC' should properly be modified to suit site condition.
4	Lack of sewerage system in urban system will make the urban shallow aquifer become an "anaerobic reactor" which will affect the foundation including piles of multistoried buildings and underground utilities.	At least secondary treatment assured before disposal of waste water or totally corrosion resistant material should only be used for foundations and underground utilities.
5	Improper assessment leads to either under utilization or over exploitation.	Sustainable Developmental approaches to be assured.

3. GIS IN WATER RESOURCE MANAGEMENT

Recent advances in geographical information and mapping technologies have created new opportunities for public health administrators to enhance planning, analysis, monitoring and management of water resources. The word geographic in GIS carries two meanings: Earth and geographic Space. The term Earth indicates that all data in system are pertaining to earth's features and resources covered by it. Geographic space implies that the commonality of both the data and the systems are developed to solve geography, i.e., the location is defined with geographical reference.

3.1 Application of GIS

The concept and development of GIS has brought about a dramatic philosophical and technological revolution. Now GIS has already evolved as a gateway for accessing and integrating geographical data at global and local levels. GIS has become an indispensable tool for government officials to manage land and natural resources, monitor the environment, formulate economical and community development strategies, enforce law and order and deliver the social services.

A typical GIS comprises an organized collection of computer hardware, software, geographical data and personnel, designed to efficiently capture, store, update, analyze and display all forms of geographically referenced information. Each piece of information is related in the system through specific geographical coordinates (e.g. latitude and longitude) to a geographical entity (e.g. health centre, school, dam, drainage, village or state). In the case of control and prevention of pollution from domestic and industrial sector, GIS has an extra-ordinary role to play, as it attributes change in a large manner with respect to space and time. Selection of opt methodology which can utilize the GIS based data base is the next major task. To assess the aquifer vulnerability three methodologies are referred to: (a) DRASTIC vulnerability index (Aller et al,1987 (b) USGS Methodology (developed for the State of North Carolina), an overlay and index method based on the definition of an unsaturated zone rating (Eimers et al., 2000). In the case of pollution vulnerability the DRASTIC methodology can be used for getting a reasonable solution.

$$\text{Drastic Index} = D_rD_w+R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w \qquad (1)$$

DRASTIC Parameters given in Equation (1) are Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and hydraulic Conductivity of the aquifer

Where, w = weight 1 to 5 r = rank 1 to 10

As the above methodologies are well established and time tested, it will give strong base for formulation of any new methodologies in the field.

The initial phase of an aquifer vulnerability assessment project comprises acquisition, development and attribution of various GIS data representing natural hydro geologic conditions for use as input into the model. The input data chosen during this phase determines the level of detail, accuracy, and confidence of final model output (FAVA Project, 2009). Vulnerability mapping identifies areas with high pollution potential, and in turn, prioritises for monitoring. A geo statistics methodology is then used to interpret the obtained data and to examine the spatial distribution of monitored parameters at different sites (Husam Baalousha, 2010)

4. CASE STUDY

Risk of pollution is determined not only by the intrinsic characteristics of the aquifer, which are relatively static and hardly changeable, but also on the existence of potentially polluting activities, which are dynamic factors which can in principle be changed and controlled. The Intrinsic characteristic is termed as vulnerability, based on that one can predict the risk due to certain polluting waste applied on the area.

4.1. Objectives of the study

The objective of the study is further classified as general and specific objective.

4.1.1 General Objective
The Shallow Aquifer Water quality fluctuation is a highly dynamic phenomenon. The selection of significant parameters, fixing weightage and rank are mammoth task in the formulation of reliable index to assess vulnerability. In the case of shallow aquifer the fluctuation in bacteriological quality will be much more due to many reasons. Hence creation of a local site based cost effective and reliable methodology to assess Bacteriological Contamination Vulnerability of SAW is the general Objective of this study.

4.1.1. Specific objective
The specific objective of this study is to use a GIS based, specific methodology to assess the complex Bacteriological contamination vulnerability of SAW in Thalakulathur Grama Panchayath and suggest remedial measures to overcome the contamination problem.

4.2. Description of the Study Area

Thalakulathur Grama Panchayath is situated near the northern boundary of Kozhikode district. The Panchayath lies between 11^{0} 20’ and 11^{0} 24’ North latitudes and 75^{0} 44’ and 75^{0} 49’ East longitudes.
The index map showing Thalakulathur Grama Panchayath is given in Fig .4.1.

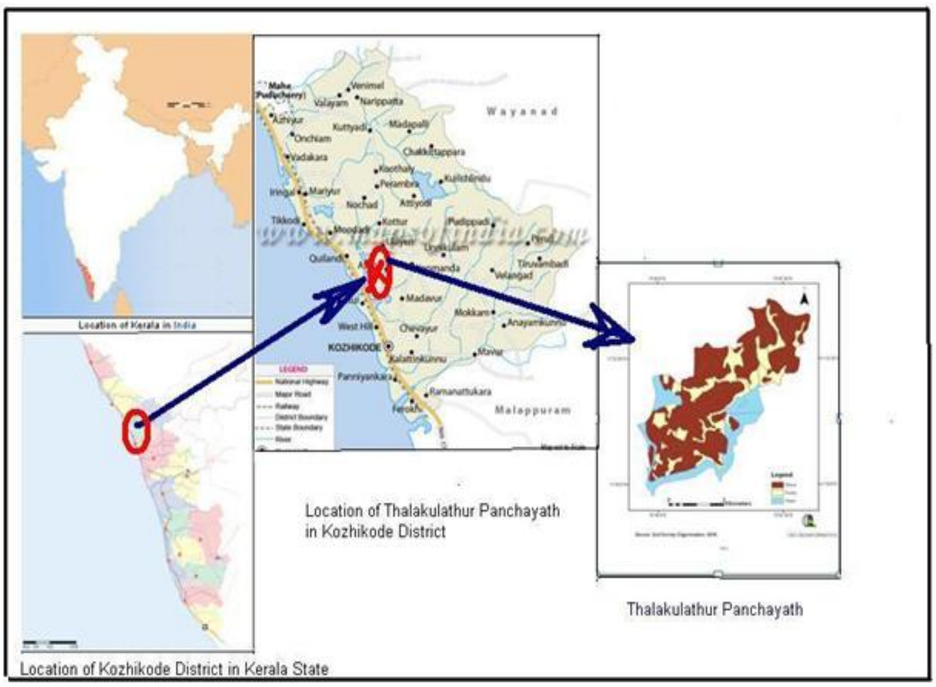

Fig 4.1. Index Map showing Thalakulathur Panchayath.

The Panachayath has 13 wards, namely Andikode, Mathilakam, Annasseri, Edakara, Kochamvalli, Pattarpalam, Paraparapavayal, Mukkamkadavu, Pukkattiri, Poozhiyil, Palora and Parambath. Thalakulathur Grama Panchayath which lies near the northern boundary of Kozhikode Thaluk in Kozhikode District is located 12 km away from Kozhikode City. The total population of the Panchayath as per the 2001 Census is 26687 with an average population density of 1528/sq km. There are 5468 households in the Panchayath which are distributed in its 13 wards.

4.3. Formulation of methodology to make vulnerability Assessment

It is well established that factors like water table, soil type, topography, aquifer media and conductivity are highly influencing parameters in the case of Bacteriological contamination vulnerability. In most of the cases land use is decided by topography, soil media and water table. Hence land use is a dominating parameter to assess the vulnerability. In the case of point pollution source like soak pit, the quantity, quality, rate of discharge ,vertical distance with water table media are also to be considered. When pumps are used to withdraw water from dug well, rate of pumping also becomes an incremental factor for the vulnerability. In the case of Thalakulathur Panchayath, all the above factors are seriously

considered for obtaining a realistic model. After deciding the major influencing parameters, determining the weightage of each parameter is the next major task. Even within one type of parameter, there can be sub group which may make significant differences in the vulnerability. Hence a sub-type of each parameter is ranked based on a thorough analysis.
Here in the case of Thalakualthur Panchayath, aquifer media is Laterite Stone in the entire area. The main influencing factors are finally identified as the Depth to Water table, Effluent of point waste sources (Density of soak pit),Soil media, Topography , Outlet water points (Density of Dug well) Conductivity and Aquifer Media. Hence vulnerability index can be termed as DESTOCA index

DESTOCA Index = DrDw+ErEw+SrSw+TrTw+OrOw + CrCw + ArAw (2)
Where, w = weigh r = rank . The methodology of analysis by using DESTOCA is Shown in Fig. 5.2

Table 3. Parameters & individual Weightage

Parameter	Description	Relative Weightage Percentage
Depth of water	It is depth from ground to water table, deeper the water table lesser will be the chances of pollutants to interact with ground water. It is assessed that during the rainy season depth of water will reduce and vice versa. Very critical parameter towards the vulnerability	20
Effluent from onsite Latrine pits	Here the disposed waste is 99.99 % liquid waste, hence contamination is taking place without recharge.. Also assumed that recharge is indirectly promotional to depth of water	15
Soil media	Soil media is weathered part of the ground, soil cover from top to water table level excluding surface texture As the waste Water discharging point is one meter below the soil media is considered combined vadose zone	10
Topography & Land use	Land use is also related the Topography of the area. Surface texture of the soil is also included in this parameter, besides slope	25
Out let water (Density of Dug well)	It is assumed that rate of pumping will increase the conductivity of the common media hence Also proper lining with effective curtain length will interfere in conductivity but reduce the Vulnerability in a greater level	15
Conductivity	Common media in the entire Panchayath hence relative weigtage is not making any variation.	10
Aquifer media	This parameter is Also represented through Topography and Land use.	5

4.4. Creation of Data Base

Every parameter in the model has a fixed weight indicating the comparative influence of the parameter in transporting contaminants to the Ground Water. The factors D, E, S, T,O ,C and A have been assigned one value per range. In the case of Thalakulathur, Aquifer is Laterite in the entire area and hence value of C and A are constant. Thalakulathur Grama Panchayath comprises of low mid and high land portion of Kozhikode district, with an elevation ranging from 0 to 156 M above MSL.The tract, in general, is moderately drained, and extensively drained in certain areas, where the slope is steep. Major rock type seen in the panchayath is the charnockite group of Preambrian crystallines. Migmatte covers large areas of the Panchayath. The region, in general, has a humid tropical climate. About 60 to 70% of the rain fall is contributed by south west monsoon. The average rainfall in the Panchayath is about 3060 mm. The Soil Survey Organization, a wing of Agriculture Department, Government of Kerala has carried out a detailed soil survey of Thalakulathur Grama Panchayath by using a cadastral map of scale 1:4000. Details of soil and their occurrence in the Panchyath, their potential and limitation, land-use in the Panchayath etc are obtained from the Panchayth and incorporated in the report. The mean maximum temperature is 30.8^0C and mean minimum temperature is 27^0 C. The water table of the area varies from 0 to 6 meter.
The KWA maintains a Water Supply Schemes in the Panchayath, namely RWSS Thalakulathur and Elathur which covers only 20 to 30% of the Panchayath. It is also observed that there are 4100 latrine pits in the Panchayath. Properly constructed septic tanks are rare. Normally a pit is used for primary treatment of toilet waste. In some cases kitchen waste water is being utilized for house yard gardening/vegetables/ coconut plantation. There are about 3800 dug wells in the panchayath. Most of them are lined carelessly by laterite masonry. For Pumping water from dug well, 0.5 to 1HP pumps

are generally used. Average pumping is about 1000 liters per day per dug well. All the information collected from the area are incorporated for creation of data base for each layer i.e. Topography and land use, Soil Media, Density of Septic Tank, Density of dug wells etc
Description of individual parameter, Description and Weigtage of individual parameters of DESTOCA model is given in Table.3. The design and implementation of specific GIS project include many considerations. Building of geodatabase is the first step of any project. Geodatabase represents geographic features and attributes as objects and is hosted inside a Relational Database Management System. Geo databases are supported in Arc GIS was used for this study. Feature datasets exist in the geo database to define a scope for a particular spatial reference. All feature classes that participate in topological relationships with one another must have the same spatial reference

Feature datasets are a way to group feature classes with the same spatial references so that they can participate in topological relationships with each other. They also have a natural organizational quality, much like a folder on a file system. The following series of logical steps were adopted in the present study.

4.4.1 Preparation of vectorized maps and attributing data
The base maps collected from the Soil Survey Organization, Department of Agriculture, and Government of Kerala were geo referenced using geo referencing options in Arc GIS. The rectified images were then used for vectorization. A geodatabase was created with feature dataset including feature classes for water table, land use, soil series, density of drinking water sources and density of septic tanks. Geographic features from rectified images were vectorized in the form of point, line and polygon and were saved in different feature classes with the help of active window in Arc Map. The attribute data were entered during the vectorization process.

4.4.2 Topology Building and Editing
After completing the vectorization process, topology was built including all the feature classes. This topology tool is adopted to trace the vectorization error and to make all the feature classes error free. The topological rules are applied for different feature classes. The important topological rules applied for the polygon feature classes are to be free from overlaps gaps. The errors were detected through error inspector and were validated using topology toolbar in Arc Map after validating the entire topology, the feature classes were projected for further analysis.

4.4.3 Map Projection
All the features which were edited using topology were projected to WGS 1984 UTM 43 N by using projection tool. The maps generated from these data are shown in Fig. 5. (1).

4.4.4 Application of spatial analyst
The Geo statistical analyst of ArcGIS was used to create voronoi maps. The objective is to determine various chemical parameter for premonsoon and post monsoon to find whether water quality suitable in the study area and compare with pre-monsoon and post-monsoon (S. Prabaharan et al,2011) Raster based analyzing is used for this study as it gives reasonably good results in overlay analysis.

4.4.5 Conversion to raster format
The projected data set were converted to raster format using conversion tools and this raster was used for the vulnerability assessment.

4.5 Reclassification of Dataset

The attributed values of various map layers were then classified by equally dividing the range of values between the maximum and minimum in 1 to 10 ranks. The database of each layer is incorporated in the preparation of map of each layer. Data layer Maps of Land Use, Soil type Dug Well and Latrine Pit Density are shown in fig 5(1). As Laterite is the only one aquifer in the entire Panchayath, Ranking is not required for this parameter about their attributes.

4.5.1 Vulnerability Assessment by using raster calculator
The weightage given in the raster-calculation along with the methodology adopted is given in the final map which generated is shown in Fig.5 (2) through the raster-calculator is renamed as vulnerability map. The vulnerability map gives an outlook of bacteriological contamination threat prevailing in the Panchayath.

5. RESULTS AND DISCUSSION

The Fig 5.2 displays the bacteriological vulnerability of the aquifer of Thalakulathur Grama Panchayath. The present study is a preliminary step to assess the vulnerability, and will provide a path for sustainable developmental approach. The Validity of methodology has been done in both nitrate distribution map and fecal coli form distribution map. It is observed that the methodology is more or less matching with both of the above distribution maps.

In any case presence of fecal coli form was not less than that of the assessment. It may be due to direct intrusion of waste water also. Hence real validity of the methodology can only be done after controlling direct waste water intrusion through impermeable Platform etc/ falling fecal waste of birds into well etc. However, after considering above facts, it is seen that vulnerability index and presence of Fecal Coli form in the panchayath is proportional to DESTOCA assessment . From the present study, it is revealed that approximately 10 to 15% (175 to 260 Hectares) of the Panchayath is highly vulnerable zone for bacteriological contamination of SAW. This zone i.e. DESTOCA index above 8.5 can be considered as ZONE 1. The areas surrounded by paddy field are found with higher vulnerability in compared to hilly and middle land areas. This is mainly due to the impact of shallow water table, high density of dug wells and latrine pits prevailing in the areas.

About 20 to 25% (350 to 435 Hectares) of the total area of the Panchayath is moderately vulnerable.(DESTOCA Index above 7 and below 8.5) can be grouped as Zone 2. About 20 to 25 % of the panchayath area found lightly vulnerable (DESTOCA Index above 5.5 and below 7) can be termed as Zone 3. 35 to 50% of the Panchayath area is very low vulnerable(ZONE 4) .After a detailed study following creation of first hand data base, the zones of vulnerability should be Published. Usage of SAW in the zone 1 without effective treatment to be de motivated. License for hotel/Restaurant in zone 1 should only be given after ensuring on site water treatment facilities. Usage of SAW for non domestic usage like gardening, growing vegetables, and car washing after simple filtration can only be motivated in zone 1.
In the case of Zone IV, water can be used for domestic purpose. But Sustainable Developmental approach to be ensured while making further development to avoid pollution threat. From field experience, it is realized that involvement of grass root level stakeholders is necessary for a reliable and updated database, rather than engaging commercial agencies for this task. At the same time, expert agencies can be effectively utilized for creating a reliable technical environment, thus the vulnerability can be controlled to be within permissible limits. The information can be displayed in the form of maps, graphs, charts and tables. Despite the tremendous potential of GIS, the water sector in India has not been fully exploited. A majority of the Public Health Engineering Departments in India does not have the hardware, software or trained staff that would enable them to apply GIS technology. In addition to making a separate wing for GIS, the whole department should be synchronized with the idea of GIS based Data Base Management. It is the initial requirement for creation of GIS Based Data Base Management. The work will be much effective if it is collaborated with Local Self Government Department (LSGD). The Data Collection Data Entry Assessment of model etc can be done through mass participation including Higher Secondary Schools and Colleges. Now many of the Engineering colleges already initiated to teach GIS. This will be an added advantage for implementation of GIS Based Data Base Management System (DBMS). Much change can be made through making a difference on developmental approach. Effective treatment of waste water/Solid Waste Disposal of the Panchayath.

It is true that Lack of sewerage system in urban system will make the urban shallow aquifer become an “anaerobic reactor” which will affect the foundation including piles of multistoried buildings and underground utilities. Hence the situation demand monitoring SAW even there is no sewerage system in order to safe guard foundation of structures and underground utilities from aggressive environment. A separate agency to monitor, plan to mitigate adverse impact on shallow aquifer at the vicinity of critical structure is a need of the hour.

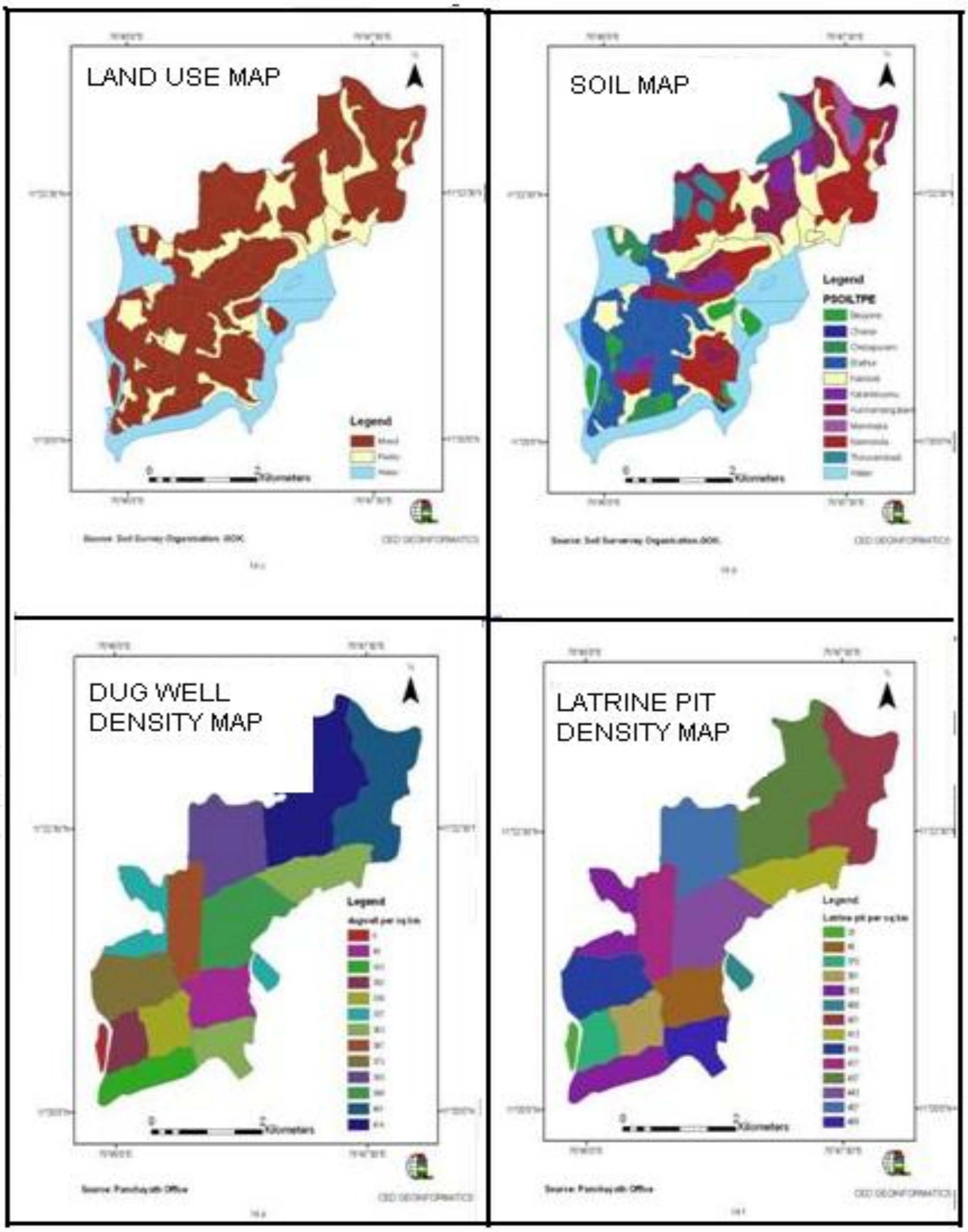

Fig 5.1. Data layer Maps of Land Use, Soil type Dug Well and Latrine Pit Density

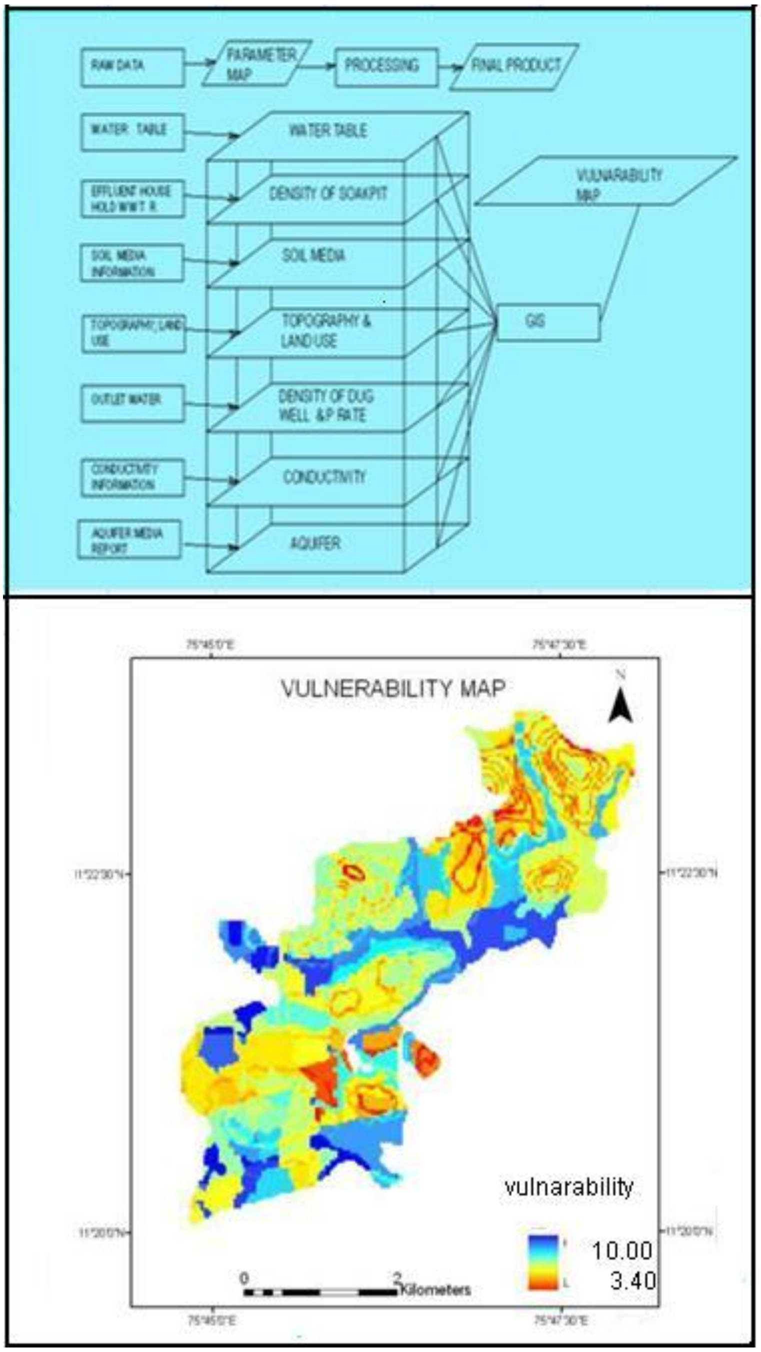

Fig. 5.2 Methodology of analysis and vulnarability Map

6 . CONCLUSIONS

It is observed that the newly formulated DESTOCA methodology to assess GIS based bacteriological vulnerability of ground water in Thalakulathur Grama Panchayath is performing satisfactorily. Based on the DESTOCA assessment, following strategies are suggested for Risk Management.

(a) As the present study is based on academic interest, the DESTOCA Index may be further stream lined through stringent field study of actual pollution and its impact on SAW by using latest technology including isotope hydrology based Environmental Impact Assessment.

(b) Full fledged GIS Based DBMS may be created with collaboration of LSGD. Local Science/Engineering/Technology institution may be introduced in a massive way to prepare GIS based DBMS, which will be mutually beneficial for both government as well as the institute.

(c) SAW usage in highly vulnerable area to be strictly restricted to non potable use. Any commercial food/restaurant industry Agencies tries to utilise SAW from this highly vulnerable zone, shall be insisted to have their own Water Treatment facilities and must be certified by an accredited agency. Stringent legislation is to be introduced in this regard and implemented on National/State level to avoid any catastrophe. General public is to be educated on the seriousness of the issue.
(d) Standards for Lining including platform & covering etc to be formulated based on detailed technical discussion and concerned local self government may be entrusted to issue approval of Sanitary Certificate based on assessment by using DESTOCA or similar real site based methodology for all wells which are expected to be used as source of water for domestic use.
(e). Instead of latrine pit, well designed septic tank cum soak pit is to be introduced in all zones to control pollution threat.
(f) In urban areas where there is no sewerage system, shallow aquifer is to be monitored and controlled by an accredited & independed agency to safe guard the foundation of critical structures from aggressive/ corrosive environment.
The renewable resources like water are nature's gift and hence, development should be achieved without its deterioration and imbalance in the ecological system.

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