Indices and Indicators for Measuring Groundwater Condition and Vulnerability with Respect to Quantity and Quality in the Ruhuna Basin

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Ground water is the main source of drinking water in the Ruhunu basin. Seventy percent of the population relies on ground water. As such the ground water resource is very significant in the overall management of the fresh water resources in the basin for its sustainable use. The scope of this paper is to evaluate the condition and vulnerability as a first step towards the development of management strategies for sustainable use of the fresh water resource. The UN World Water Assessment Programme (WWAP) has developed a series of indicators and indices to represent the condition and vulnerability of ground water in a region (Gangopadhyay, 2001) and these indices and indicators are used in this paper to benchmark the condition and vulnerability of this basin. Keeping in mind that these indices and indicators developed by WWAP are for a general region; they are examined here for its relevance to the Ruhuna basin and improvements deemed necessary are also suggested. In the development of values for indices and indicators for the basin, the availability, reliability and representative ness of the data significantly effects the outcome and therefore the data used for the study is also examined for its significance and improvement in the future. The sources of data used for the development of indices and indicators are those available from previous studies, explorations and borehole logs as detailed under references. As an outcome of this study this paper also discusses the direction of future studies for the more accurate development of the indices and indicators and for the development of the ground water resources of the basin in general for its sustainable use.

1. Significance of the Ground Water Resource

It is estimated that over 70% of the population of about one million inhabitants in this basin uses ground water as the source of drinking water. 70% of this population can be assumed to use ground water for purposes of bathing and washing. Figures 1 show the distribution of the sources of drinking water in the district of Monaragala in 1994 (JICA, 2001). Various studies done on a few villages in the basin have shown that the per capita consumption of water for drinking and washing varies with socio-economic standard of the population. Assuming the average consumption per person to be 51.3 and 101.5 liters/day for drinking and washing respectively the current annual ground water demand can be estimated at 31 MCM.

The mean annual rainfall of the basin is 1,574 mm. Although some studies show a decline in the annual rain fall in the country over the last few years, in the long term no significant change in the annual rainfall patterns in this basin have been observed (Silva, 1984; NSF, 2000). The mean annual rainfall distribution within the basin in the short term shows large variations with some areas of the basin recording annual rainfall as low as 723 mm (De Silva, 1998). The monthly rainfall patterns have also shown considerable variation over the years. The lowest consecutive six-month rainfall of 148.4 mm was recorded in the Kirindi Oya and Malala Oya basins in 2001. These areas experienced a serious shortage of ground water during this time. Although the mean annual rainfall and the consequent recharge of aquifer within the basin is reasonably good, some

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areas of the basin have experienced severe water shortages of catastrophic proportions in the recent past causing immense hardship to the inhabitants of these areas.

The present use of groundwater for irrigation is not very significant as discussed elsewhere under the Ruhuna Basin Case Study. The viability of the planned industrial and infrastructure development identified as essential for the socio economic sustainability of the region would depend a lot on the availability of groundwater. Therefore the availability of groundwater of acceptable quality would be a key factor for the sustenance of the population and for the socio economic stability of the region.

2. Characteristics of the Aquifers

2.1 Hydro-geology

The geological characteristics of the basin have been discussed elsewhere in this Sri Lanka Case Study. Considering the hydrogeology of the basin the ground water yielding aquifers can be identified in to two main groups, the shallow 'regolith' aquifer which is about 10m thick overlaying the basement rock and the deep fractured zones in the basement rock below 40m. The shallow aquifer slopes gradually towards the southern coastline as shown by the contour map of the basement rock in figure 2. Therefore the shallow aquifer continuously drains out to the sea under a positive hydraulic gradient. On average at approximately 15 km inland from the coast the basement rock rises above the mean sea level. Therefore the loss of fresh groundwater to the sea is significant and virtually uncontrollable. As such the storage capacity of the aquifer is limited. Another significant feature of this basin is the well-distributed network of streams and rivers encouraging the quick inflows to them from the surface run-off and the base flow. As such the inherent storage capacity of the aquifer is further reduced.

2.2 Groundwater Recharge

Although the annual potential evapotranspiration (PET) varies from 1400 mm in the upper reaches to 2000 mm in the lower reaches, different studies have estimated the annual evapotranspiration by indirect methods of computation to be between 900 mm and 1200 mm. However more accurate models with data from representative regions would have to be made to make an accurate estimate. Similar studies have estimated the average annual recharge from rainfall to ground water to be 20mm to 125 mm. An average value of 100mm is taken for computations in this paper. It should also be noted that a very significant recharge occurs from surface water bodies and return flows. This recharge needs to be estimated and included in the assessment of the groundwater condition indices and also be considered in the management of the groundwater resource.

2.3 Water Quality

Studies in the southern district of Hambantota in the Ruhuna basin have concluded that about 60% of the wells are contaminated with saline water (Silva, 1984). Excessive depth of dug wells and over exploitation of wells may have contributed to the high salinity. Due to geological composition the occurrence of fluoride in ground water is high (Dissanayake, 1985). Analysis of data from limited studies of tube wells in selected areas of the basin have shown that only 21% of the wells have acceptable levels of electric conductivity and fluoride to current Sri Lanka standards for potable water (SLS 614: 1983 Parts 1 & 2). The water quality distribution of WRB tube wells is shown in figure 3. More significant is that of these wells 32% of the high yielding wells with over 100 lpm have acceptable levels of electric conductivity and fluoride as shown in figure 4. However, studies on shallow wells have recorded a much higher number of wells of acceptable water quality as shown in figure 5.

2.4 Groundwater Yield

Most well yield studies have been carried out on tube wells. These wells exploit the deep aquifer. The distribution of yield rates recorded for the 384 Water Resources Board (WRB) wells are shown in Figure 6. Records of yield rates for the wells in the shallow aquifer are not available. Due to the wide fluctuation of the water table observed over the year, the potential yield will vary significantly with the seasons. Potential yield from the shallow aquifer could be estimated from the records of the temporal variation of the water table. However such records of not been made for this basin.

3. Data on the Groundwater Condition

Data collection done to exploit the ground water resource in this basin have been limited to the collection of data for the purpose of finding locations where good quality groundwater is available to meet the immediate needs of the inhabitants in the area. Aerial photographs have been studied to establish areas having geological characteristics most likely to have groundwater sources. Limited surveys of dug wells and information on tube wells including pumping test data obtained during their construction are available. Landsat imagery has been used to a limited extent to obtain geomorphologic and geological data, lineament and bedding interpretation. Geophysical explorations have also been done in selected areas. Hydro meteorological data required for water management such as the monitoring of rainfall, potential evapotranspiration, river discharge records in a few stations, are continuously obtained on a monthly basis. Chemical analyses of water samples have also been done to a very limited extent. Apart from using some of this data for the location of tube wells, data have not been made available as useful information for the management or improvement of the groundwater resources of the basin. By this some data perhaps is not available for beneficial groundwater improvement programs and in other cases lost or duplicated by other studies. Under an on going study (JICA, 2001) it has been proposed to collate all available data and present them in a GIS environment for some areas of this basin.

The current status of data availability is summarized in Table 1.

4. Groundwater Indicators and Indices for the Basin

The indicator and indices computed for the Ruhuna basin from limited information available this basin is given in Table 2. Some areas of the basin undergo severe shortage of ground water during certain periods of drought years. This is not clearly reflected in the computed indices and therefore the indicators computed are not representative of the groundwater condition and vulnerability of these areas. Further refinement of these indices is required. This can be done by improving the quality and distribution of data as well as by modifying the indices to suit the character of the aquifers in this basin.

The benefit of a well-developed set of indices and indicators for the basin should not be under estimated, as it is an important tool to forecast the sustainability of the groundwater resource, to guide the development of a groundwater policy and to monitor remedial measures to sustain this resource.

The changes to the groundwater resource and the environment as a whole occur gradually and become apparent over a long period of time, sometimes causing irreparable damage. As such early identification would be very beneficial. The change in the forest cover of Sri Lanka from 1965 to 1992 is shown in figure 7 as an example of the gradual effects of anthropogenic and natural activity occurring in the country. The development of indicators may be able to identify such changes early. The recent shortages of water may also be due to the changes to the policy of water management. Figure 8 shows the number of abandoned ancient tanks in one part of the basin due to the emphasis on large irrigation schemes in the recent years. Some indicators are required to identify the effects and benefits of such changes. It is clear that a well-distributed system of small tanks would have contributed to a gradual recharge of the groundwater off setting the inherent weakness of regolith aquifer.

5. Conclusions & Recommendations

1. The validity of indices and indicators developed in this study are limited by the spares availability of data and its quality. Since two distinct groundwater aquifers have been identified for this basin the indices and indicators developed must reflect representative values taking in to account the overall contribution of each these aquifers. The scope of this study however did not permit a systematic allocation of weights for the significance of each aquifer to the individual indices. Since the availability of data was limited and not distributed evenly for each aquifer such a detailed study is irrelevant for this basin at this stage. However, when these indices and indicators mentioned in this paper are considered these limitations have to be kept in mind.
2. The indicator values for Groundwater Reliance and Groundwater Depletion with respect to the groundwater condition, for the Ruhuna basin presented in this paper appear to be satisfactory. However, in the recent past some areas of the basin have experienced sever water shortages. This may be due to the fact that the indicators do not reflect the salient features of this basin. The significant character of this basin is that the phreatic aquifer (regolith) on which there is a high dependence is only about 10m deep sloping continuously towards the coastal boundary of the basin. As such the temporal distribution of groundwater recharge becomes very significant. Temporal distribution of recharge is affected by the temporal distribution of rainfall and the spatial distribution of surface water bodies. The influence of the temporal distribution of the rainfall to the groundwater condition can be clearly identified. Therefore in the assessment of vulnerability indices and its value as an indicator of the influence of mitigating programs that are required for the sustainable use of the groundwater resource in this basin, the influence of the temporal distribution of groundwater recharge must be considered for this basin.
3. In order to develop more meaningful indices it is important to collate all available data to a GIS platform.
4. Data collection needs to be improved to obtain useful targeted information. For the regolith aquifer continuous data is needed, as the temporal influences are very high.
5. With respect to the availability of data, the Ruhuna basin can be considered highly vulnerable, as there is no mechanism to regulate the use of water or to control pollution. The extent of the aquifer, the source of recharge and the quantity of recharge of the deep aquifers has not been investigated. As such the extent of vulnerability is not known. Therefore target studies are required to address these issues.
6. Computer based groundwater simulation models will be an effective economical tool for both short and long-term evaluation of the regolith aquifer, for the effective planning of further studies on the groundwater resource as well as to introduce regulations for the sustainability of this groundwater resource. An effective groundwater policy would have to be implemented

to ensure sustainability of the aquifers taking into consideration the dependence of all the rich diverse eco systems within the basin. A well-designed computer based groundwater model would be the best available tool for implementing and maintaining an effective groundwater policy.

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Figures and Tables

Table 1. Availability of Data for the Groundwater Resource of the Ruhuna Basin.

Physical Framework	
Topographic maps showing the stream drainage network, surface-water bodies, landforms, cultural feature, and locations of structures and activities related to water	Available. Should be implemented in GIS
Geological maps of surficial deposits and bedrock	Available. Should be implemented in GIS. Details of well logs also to be incorporated
Hydrogeologic maps showing extent and boundaries of aquifers and confining units	Not defined
Maps of tops and bottoms of aquifers and confining units	Not defined
Saturated-Thickness maps of unconfined (water-table) and confined aquifers	Temporal data not available
Average hydraulic conductivity maps for aquifers and confining units and transmissivity maps for aquifers	Should be implemented in GIS. Details of well logs also to be incorporated
Maps showing variations in storage coefficient for aquifers	Not available
Estimates of age of ground water at selected locations in aquifers	Not available

Hydrologic Budgets and Stresses	
Precipitation data	Available. Should be implemented in GIS
Evaporation data	Limited data available. Inadequate. Should be implemented in GIS
Streamflow data, including measurements of gain and loss of streamflow between gauging stations	Available. Inadequate to compute loss or gain. Should be implemented in GIS
Maps of the stream drainage network showing extent of normally perennial flow, normally dry channels, and normally seasonal flow.	Availability of temporal data not known
Estimates of total ground-water discharge to streams	Temporal data not available
Measurements of Spring discharge.	Not available
Measurements of surface water diversions and return flows	Available
Quantities and locations of inter basin diversions	Available
History and spatial distribution of pumping rates in aquifers	Temporal data not available
Amount of ground water consumed for each type of use and spatial distribution of return flows	Available. Inadequate. Should be implemented in GIS
Well hydrographs and historical head (water-level) maps for aquifers	Not available
Location of recharge areas (aerial recharge from precipitation, losing streams, irrigated areas, recharge basins, and recharge wells), and estimates of recharge	Available. Inadequate. Should be implemented in GIS

Table 1. Continued.

Chemical Framework	
Geotechnical characteristics of earth materials and naturally occurring ground water in aquifers and confining units	Available. Not well defined. Should be implemented in GIS
Spatial distribution of water quality in aquifers, both aerially and with depth	Available. Should be implemented in GIS
Temporal changes in water quality, particularly for contaminated or potentially vulnerable unconfined aquifers	Temporal information not available.
Sources and types of potential contaminants	Information not available
Chemical characteristics of artificially introduced waters or waste liquids	Information not available
Maps of land cover/land use at different scales depending on study needs	Available. Should be implemented in GIS
Stream flow quality, (water-quality sampling in space and time), particularly during periods of low flow	Temporal information not available

Table 2. Indicators & Indices for the Ruhuna Basin.

NAME	VARIABLE(S)	DATA	VALUE	INDICATOR VALUE/SUB INDEX	INDEX
Condition					
Ground Water Reliance	Annual average ground water withdrawals	Primary/Secondary	31 MCM	8 %	The values assigned are for the shallow sub surface aquifer. Most data for the deep fractured zone not available. Overall more serious problem in certain areas of the basin. (Kirindi Oya & Malala Oya areas in the Hambantota District)
	Annual average total withdrawals (surface and ground water)	Primary/Secondary	410 MCM		
Ground water depletion	Annual average ground water withdrawals	Primary/Secondary	3.1 MCM	6 %	
	Annual average baseflow	Secondary/Analyzed	559 MCM		
Encroachment Ratio	Horizontal displacement of salinity front from a reference point	Primary/Analyzed	No Data	According to Silva (WRB 1984) 60% of Hambantota district is covered by saline ground water	
	Distance of control point from the reference point	Primary/Secondary	No Data		
Subsidence Ratio	Maximum subsidence with respect to a chosen datum	Primary/Analyzed	Not observed	Since the surface aquifer is shallow, large settlements due to the consolidation of the clay layers can not be expected. Local settlement due to the collapse of unlined dug wells can occur.	
	Minimum elevation of land surface with respect to chosen datum	Primary/Secondary			

Table 2. Continued.

Vulnerability					
Ground Water level decline	Hydraulic diffusivity	Primary/Secondary/Analyzed	(1 to 10 m2/day)/0.5 say 2 to 20 m2/day	High vulnerability	High vulnerability
	Heterogeneity	Primary/Secondary/Analyzed	high		
	Annual Recharge	Primary/Secondary/Analyzed	559 MCM		
	Volume of Aquifer	Primary/Secondary/Analyzed	2795 MCM Highly variable		
Salt Water intrusion	Hydraulic Gradient	Primary/Secondary/Analyzed	0.0014	According to Silva (WRB 1984) 60% of Hambantota district is covered by saline ground water Vulnerability High	
	Permeability	Primary/Secondary/Analyzed	0.001 m/day		
	Effectiveness of hydraulic barriers	Primary/Secondary	Not known		
Land subsidence	Stratification of Aquifer	Primary/Secondary	Surface sandy clay	(not observed) Vulnerability low	
	Total Thickness of aquitards	Primary/Secondary	3 to 5 m		
	Compressibility of aquitards	Primary/Secondary/Analyzed	Very low		
Stabilization time	Hydraulic diffusivity	Primary/Secondary/Analyzed	(1 to 10 m2/day)/0.5 say 2 to 20 m2/day	Usually recovers within 1 to 3 years	
	Characteristic length of basin	Primary/Secondary			
	Basin Constant				

Figure 1. Distribution of the source of drinking water in the Monaragala District in 1994. (JICA,2001).

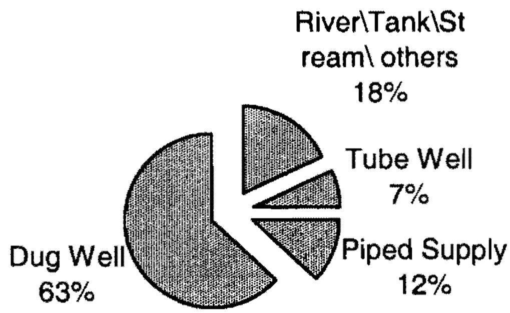

Figure 2. Topography of the Basement Rock in the Hambantota District in m.s.l.m. (Silva, 1984).

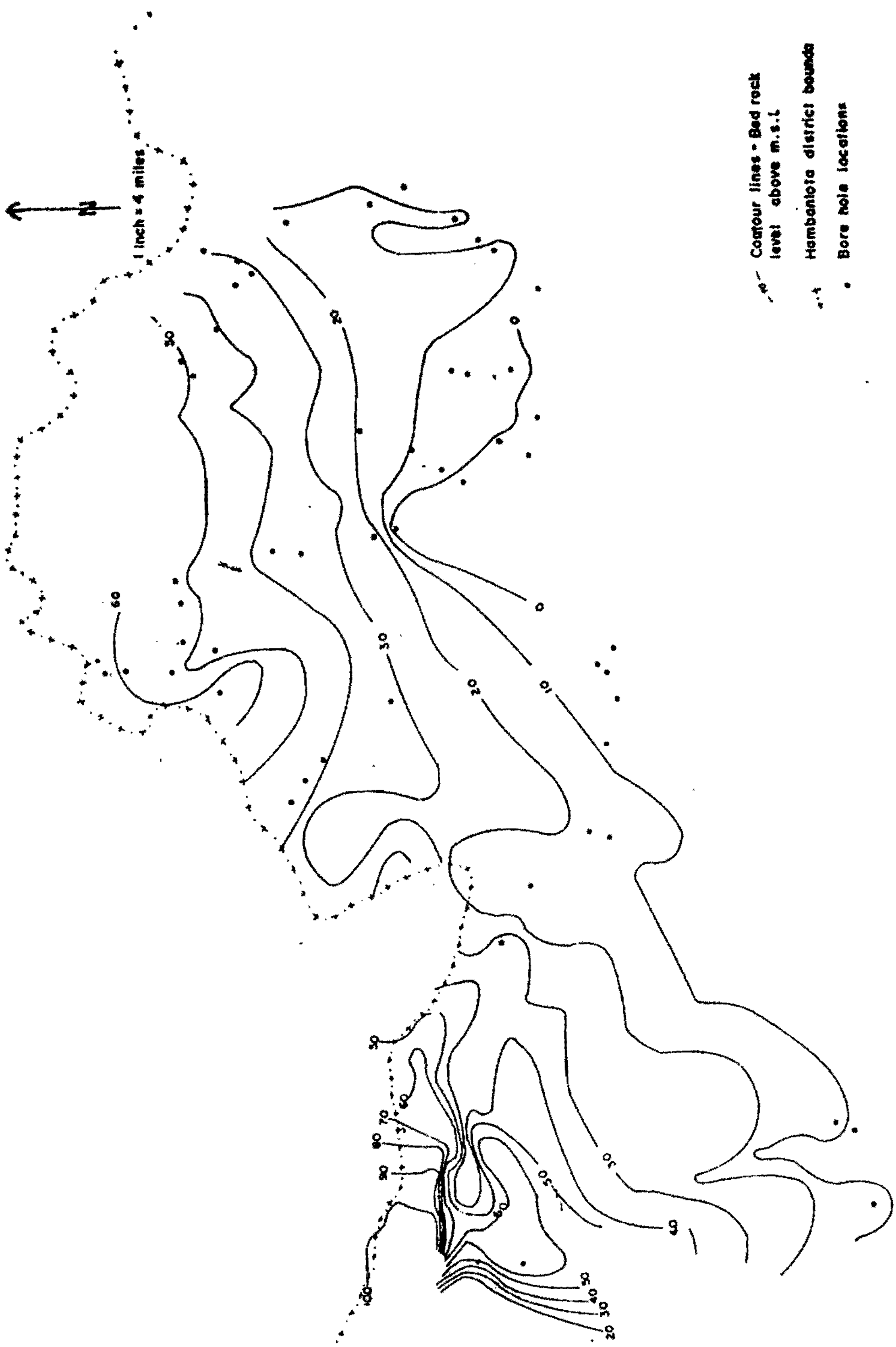

Figure 3. Distribution of Electrical Conductivity of 384 Tube Wells of WRB.

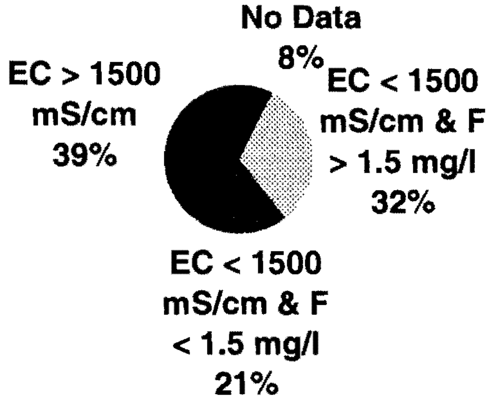

Figure 4. Distribution of Electrical Conductivity of 384 Tube Wells of WRB with yields over 100 lpm.

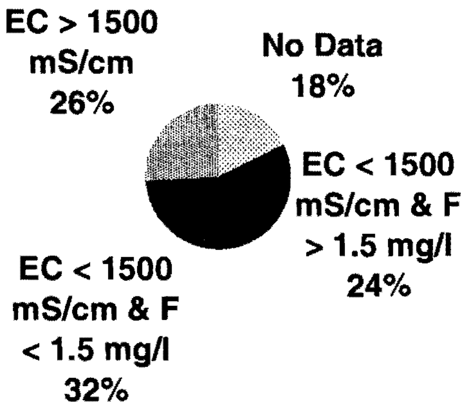

Figure 5. Distribution of Electrical Conductivity, Fluoride & Nitrate from well survey of 66 dug wells at Ridiyagama, Suriyawewa and Udawalawe (IWMI, 2001).

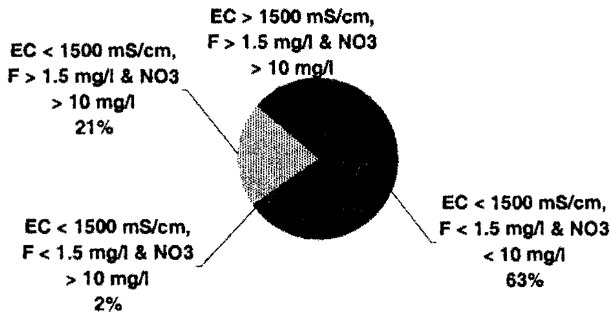

Figure 6. Distribution of Well Yields in the WRB tube wells.

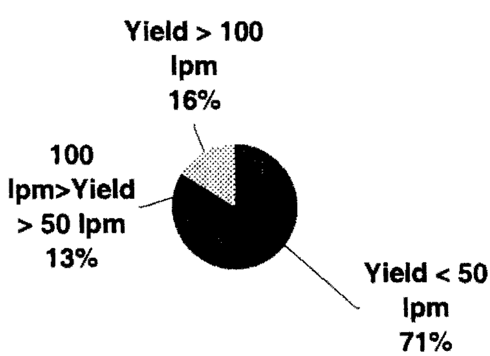

Figure 7. Sri Lanka's Forest Cover in 1965 (left) and 1992 (right).

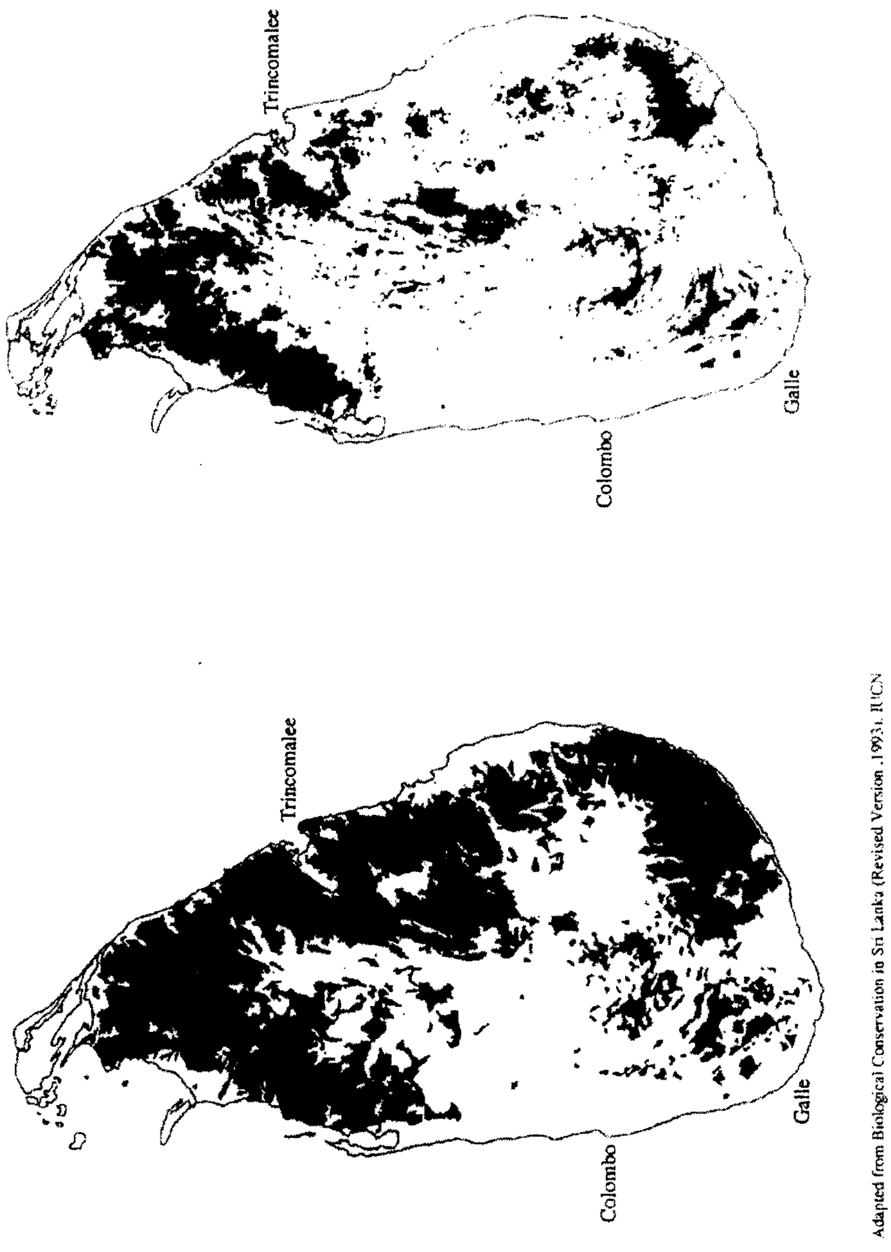

Figure 8. Abandoned Ancient Tanks (Silva, 1984).