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Hydrogeochemical Behavior in the Central Mahaweli Basin of Sri Lanka.

Rajapakse, R.R.G.R., Suhail, M.N.M., Balasooriya, N.W.B. and Jayasena, H.A.H.

Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka.

The chemical behavior of natural waters within the Central Mahaweli basin is examined. Water samples, 49 in 1996 and 46 in 1997, were collected from rivers, surface streams, ponds, dug wells and tube wells in the area for two different seasons and analyzed for number of chemical parameters. Major cations (Na^+, Ca^{2+}, K^+, Mg^{2+}) and anions (SO_4^{2-}, CO_3^{2-}, HCO_3^-, Cl^-), total Fe, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Total Hardness (TH) were measured and plotted in several classification diagrams. The geographic distribution of pH in ground and surface waters varies between 5.65 to 8.00 in the dry season and 5.41 to 8.98 for the wet season. EC varies from 20 to 880 μs/cm. Ground water shows higher EC than the surface water specially in the dry season. However, there is no such relation in the wet season. TDS vary between 12 to 608 ppm in the dry season and 19 to 1280 ppm in the wet season. Low TDS may result due to lack of soluble materials in the crystalline hard rock terrain. Semi-logarithmic plots of $Na^+/(Na^++Ca^{2+})$ vs. TDS and $Cl^-/(Cl^-+HCO_3^-)$ vs. TDS for the water samples show high abundance of Ca^{2+} and HCO_3^-. The analytical results show following types of water. During the wet season Ca^{2+} + Mg^{2+} and HCO_3^- dominant and during the dry season Na^++K^+ and HCO_3^- dominant. Sulfate content in the dry zone (0 - 54 ppm) is higher than that in the wet zone (0 - 20 ppm), and this may result due to high evaporation. Logarithmic plot of Mg vs. Ca show samples collected in the wet season fall within the range of Mg/Ca = 0.1 to 1.0 however, in the dry season, they fall within Mg/Ca = 0.1 to 10.0. The waters in the region can be classified as low salinity - low sodium and medium salinity - low sodium categories. Total hardness varies between 11 to 811 ppm. However, based on the carbonate hardness, 30 % of the samples collected in the wet zone are fallen into very hard water type, while in the dry zone most fallen into moderate soft type.

INTRODUCTION

Analysis of chemical behavior of waters in a region is very important in assessing and understanding the available water quality and in implementing water supply programs. A number of studies related to hydrochemistry of ground and surface waters in the Kandy district have been completed (Dissanayake and Hapugaskumbura, 1980; Weerasooriya and Dissanayake, 1986). However, the effects of different water bodies on the hydrochemical regime have not been investigated. Since, these effects may provide significant indications, which can be used to maintain the total environmental balance of a region, we carry out this study, during the period between 1996 June to 1998 March, to examine the relation.

The study comprises field, laboratory and desktop studies, and aims to discuss the hydrochemical behavior of water in the central Mahaweli Region of Sri Lanka. The study area is characterized by extremely complex and variable patterns of relief. Even though intermittent agricultural land-use is noted, forest cover mainly underlies the study area. This study includes chemical analysis of water samples from six catchments (micro basins and inter basins) which cover an area of about 150 km² (about 58 mile²) within the central part of the country. The study area is located within the coordinates 7° 05′ to 7° 22′ N and 80° 37′ to 80° 61′ E (*Fig. 1*).

CONCISE ANALYSIS OF OVERALL HYDROLOGY

Rainfall Pattern and Distribution

The Central Mahaweli region lies in the rain shadow of the Knuckles Range and the main mass of the hill country. This area comprises a greater part of the intermediate climatic zone of Sri Lanka. This section provides an analysis of the total hydrological cycle and its overall behavior both in "Time" and "Space". The data were collected from the Meteorology department, Mahaweli Authority and Upper Mahaweli Forest Conservation Division of Sri Lanka.

The precipitation, controlled by ITCZ (Intra Tropical Convergence Zone) and orographic effects, show distinct bimodal distribution with peaks from December to February (northeast monsoon) and from May to September (southwest monsoon). The distribution shows a tendency to decrease the rainfall from south to north and northeast (*Fig 2*). The highest rainfall usually receive during the northeast monsoon and preceded inter monsoon convection rains. The average annual rainfall for these areas vary between 2000 to 3400 mm and generally increases northwards in many of the catchments. The average annual temperatures vary between 20.0° and 22.5° C. It decreases towards the Central Highlands with the increase of the altitude.

The sunshine hours are also significant mainly to assess the humidity, evapotranspiration etc. It is noted that the sunshine hours are in the range of 9-10 hrs and may vary in the rainy season some time being very low due to cloud cover. Deciduous, broad leaf trees are common within the wet regions and which replaced by thorny bushes in the northeastern dry part of the project area. This vegetation cover directly affects the amounts of evapotranspiration. However, after the introduction of by laws and the vigorous forestry program, it is noted that the ET is maintained close to potential value. As has been noted that the Kandy has fairly high Potential Evapotranpiration of 1578.63 mm (Dharmasena, 1990), the above factors should be thoroughly examined. In general discharging zones close to lower reaches of small and large stream segments provide water with high EC.

Streams, Perennial and Seasonal

Except Uma Oya, other basins in the study region represented by up to 4th and 5th order streams (based on Strahler, 1957). Most of them flow along the valleys formed by prominent geological structures such as joints, fracture zones, lineaments, and geologically weak rocks such as marble, khondalite and biotite gneiss layers. Development of different morphological features within the area is related to the underlain geology and the prevailing geological structures. Streams belonging to 1st and 2nd orders are either intermittent or depend on seasonal rainfall. Certain 3rd order streams draining within smaller catchment areas or those belong to the dry or the intermediate zone may have seasonal discharges. However, certain 1st and 2nd order streams in the wet highlands have perennial discharges (Suhail, 1997). Based on point discharge observation, the following ranges of values have been obtained for Uma Oya, Kurundu Oya and Belihul Oya basins during the dry season (March to end of September). However, they represent only point values and one may have to select suitable control to obtain more realistic measurements.

1st order	-	2.5 m^3/s
2nd order	-	20 m^3/s
3rd order	-	200-250 m^3/s

In the rainy season (November to February end), the discharge values are very much different and vary with the precipitation intensity and increase by several folds. The measurements as collected by the Upper Mahaweli Forest Conservation Division indicate an annual discharge value of $56*10^6$ m^3 for the Uma Oya catchment. The flood plain deposits are good for crop vegetation. Therefore, number of cash crops or paddy lands are associated with them. The soil moisture is fairly high in the clay rich overburden. The thickness, soil type, soil moisture and cropping pattern within the drainage basins may be changed with the perennial and seasonal streams.

PHYSICAL SETTING

Land use

Several distinctive land-use areas have been identified in the Central Mahaweli Region. The permanently cultivated lands are largely confined to the western end and strips of land occupying the wetter, higher areas on the southern slopes of the Knuckles Range and the northern slopes of the main hill country.

Soil types

Major soil groups in the region are Red Brown Earth (RBE) and Low Humic Gley (LHG). However, some areas consist of Red Yellow Podzolic (RYP) soils (Panabokke, 1996). In general the flood plains have five to nine meters thick alluvial soils which are tapering off close to the adjacent residual soils or rock outcrops. Colluvial soils are also found in certain parts, which usually formed uniform slopes, while hummocky and carved topography occurred in the eroded regions (Suhail, 1997).

Geology and structure

This area occupied high-grade, lithologically and isotopically distinct, Proterozoic metamorphic rocks, which belongs to the Highland Complex of Sri Lanka (Cooray, 1984; Kröner et. al., 1991). Major rock types of this area are:

1. Quartzite and quartz schist
2. Charnockitic Gneisses
3. Garnet-Biotite-Sillimanite Gneiss ± Graphite
4. Undifferentiated charnockitic biotite gneiss
5. Marble (crystalline limestone)

The general strike of these units aligned in the north-south direction. In general most of the highest order streams usually follow the same trend. Poly-metamorphic structures are common in the area, where Palugama antiform is one major fold with the axis having a same trend as above. Several major lineaments

showing different orientations intersect the study area. A number of pegmatite bodies are also found along the left and right banks of the Randenigala reservoir.

Vegetation

Intermediate dry evergreen forests are present in the study area (Gunathilleke and Gunathilleke, 1990). Since, many parts of the area being degraded by various man made practices, such as chena cultivation and forest fires, secondary forests have been later occupied the region. This sparsely distributed forests show open canopy with savannah grasslands at places, which may quite significant in terms of hydrologic analysis. Riverine vegetation is associated with the streams and rivers.

METHODS OF STUDY

Background Materials

The aerial photographs (1:40,000), topographic and orographic maps (Kandy and Rangala 1 inch sheets) were used to identify major structures, fault zones, geomorphological variations and drainage patterns. The water divide for the drainage basin were later demarcated and several micro and inter basins were identified. Basic geologic analyses were carried out to obtain the overall geologic information.

Water sampling procedure

First batch of sampling was carried out during the dry June/July period, and subsequently second batch of sampling was completed in the wet Nov/Dec period in 1996. These samples were collected from different water bodies, either artificial or natural. In addition, another set of samples was collected with in the more wet areas close to Kandy in the year 1997. The first batch was collected again in the dry June/July and the second batch in Nov/Dec, 1997. In these sampling programs the following water bodies were selected; viz.; the rivers, streams, springs, shallow dug wells, tube wells and major reservoirs. The sampling locations were presented in *fig 1*.

Storage and Preservation

Proper storage and preservation minimizes contamination risk and destabilization of the chemical elements in the water. Hence actual chemical quality of the samples will retain within the range of acceptable accuracy. Analyses for chemical constituents were carried out within a week of sampling. Sample bottles were thoroughly cleaned by soaking overnight in 2-5 N HCl acid and rinsed out. In addition, they were washed out by respective water during sampling operation. Filtration of the samples was preceded using a filter with pores having diameter of 0.45 μm. Since, pH and EC values are fluctuated with temperature; they were measured as "insitu" tests. For bicarbonate and chloride, samples were acidified with Ultra R grade HCl of 3 ml/l.

Analytical Techniques and Methods

American Standard Testing Methods (ASTM) were adopted to determine the chemical constituents and related parameters. Methods used are given below briefly. EC and pH were measured at the sampling site. EC was measured with a portable conductivity meter (HORIBA-DS-7), which has a facility of adjusting the temperature at desired levels. HANNA-HI 8519-Membrane pH meter with digital display was used to obtain pH. The temperature of the sample was measured using a thermometer having accuracy up to 0.1°C.

Calcium, Magnesium, Sodium, Potassium and Total Ferrous

Major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and Minor cations (Total Fe) were determined using high sensitive atomic absorption spectro-photometer (AAS) – Buck SCIENTIFIC 200-A. The calibration curve of concentration vs. absorption is plotted for known standard solutions of a particular element using the AAS. Absorption value of the sample is measured and corresponding concentration to the sample is obtained using the above calibration curve. If the samples contain high concentration of a particular element, the dilution is preceded before the analysis until the elemental concentration lies within the optimum range.

Sulfate (SO_4^{2-})

Sulfate was determined by turbidimetric method using spectrophotometer. Sulfate ions are precipitated in a HCl / Glycerin medium with $BaCl_2$ as uniform size of Barium Sulfate ($BaSO_4$) crystals. The absorbency of this suspension solution is measured spectro-photometrically at 420nm.

Chloride (Cl⁻)

MODEL EE-Cl Iron selective electronic method used in chloride determination. Electric potential of the sample is obtained with respect to chloride concentration, after addition of buffer solution CH_3COOH: CH3COOCH3 of 1:1 ratio. Concentration of the sample can be obtained with the calibration curve plotted for known standard of chlorides.

Bicarbonate (HCO₃⁻)

Titrimetric method was used to analyze the bicarbonate concentration of the samples. The sample is titrated electrometrically with 0.01 M Sulfuric acid while pH being monitored through out using a digital pH meter (CD-740). The inflection point of the drawn curve for the titration, in the region of pH 4.5 is taken as end point volume. Following equation gives the bicarbonate concentration in mg/l.

$(HCO_3^-) = (2440/S)(V2 - V1)$
where,
S = Volume of sample in ml.
V2 = ml of HCl required for titration to pH 8.3.
V2 = ml of HCl required for titration (pH 8.3 - 4.5)

Total Dissolved Solids and Hardness (TDS and TH)

Standard formulae were used to obtain TDS and TH as given below.

TDS (in ppm) = 0.64 EC (μs/cm)
TH (in ppm) = 2.497 Ca (in ppm) + 4.115 Mg (in ppm)

Sodium Adsorption Ratio

SAR is calculated using the following formulae.
SAR= Na / √ {(Ca+Na)/2}, where, Na and Ca are in milli-equivalents per liter.

Accuracy and Precision of Analytical method

Accuracy and Precision of the complete analysis for the major ions have been estimated by checking the Electronutrality (Powell, 1964).

Electronutrality = $\frac{\text{(Sum of cations) + (-Sum of anions)}}{\text{(Sum of cations) + (-Sum of anions)}}$ x 100

For the above equations, the concentration are given in meq/l and if electronutrality is less than 5.0 %, analysis is considered to be correct and if it is less than 2.0 % it is excellent.

RESULTS AND DISCUSSION

Chemical quality of the water

The analytical results of water samples collected in two seasons for 1996 and 1997 were shown (Appendices I, II, III and IV). The following chemical parameter variations are provided for the interpretations.

Variation of pH in the area

Many natural chemical reactions, such as oxidation, hydrolysis, hydration and carbonation are controlled by the H^+ concentrations in the aqueous media (Hem et al., 1967; Hem, 1985). The chemical and physical quality of water strongly affects the solubility of substances such as iron, aluminum, manganese, which becomes more soluble at different pH values. For instance at pH 6.00 Mn become insoluble and at 8.50 Fe become insoluble (Driscoll, 1986). Soluble iron present in the soil and in river water at pH between 6.5-7.5 will precipitate when it reaches to the sea. The geographic distribution of pH in ground and surface waters varies between 5.65 to 8.00 in the dry season and 5.41 to 8.98 for the wet season.

Table: 1 pH ranges for different seasons and water bodies

Season	Reservoirs	Springs	GW bodies	SW bodies
June/July 1996	7.30-7.80	6.20-7.50	6.50-6.90	6.20-8.00
Nov/Dec 1996	7.53-8.98	7.40-7.96	6.72-8.15	6.20-8.16
June/July 1997	5.65-7.60	6.77-7.28	5.90-7.07	5.65-7.60
Nov/Dec 1997	5.41-8.31	*	5.41-6.84	6.66-8.31

* Springs were not sampled

The above table indicates that the pH range for the wet season collection shows higher values, which indicates the presence of alkaline materials within the system. On the other hand, the groundwater sources for both the years show that the highest value within the range is always lower than that of the surface waters. This may represent the near neutral conditions for the groundwater. Considering the variation of water samples in both seasons, the waters in the Central Mahaweli Region is slight acidic-neutral-slight alkaline type with in the acceptable limits for drinking (WHO, 1984) and irrigation purposes (U.S. Salinity Laboratory, 1954).

The variation of EC

Electrical Conductivity (EC) is a measure of dissolved ions in water. EC varies from 20 to 880 µs/cm, except few anomalous samples that show 1000 □s/cm for a spring and 2000 □s/cm for dug well. Generally ground water shows higher EC than the surface water bodies such as streams and rivers. This is quite significant in the dry season. However, in the wet season, there is no such relation. The EC of samples collected from Kimbulantota where marble rock was found closer to the locations show general higher values. In addition the Ca contents are also higher in these samples. Therefore, it can be concluded that the dissolution of marble has contributed for the high EC in such areas. Samples collected from same locations but with different sources show different EC values. The high EC values in the stagnant bodies or ground water may attribute to the fact that these sources show accumulation of chemical constituents with in the system than the flowing water.

Distribution of TDS

Physical and chemical properties of water mainly depend on TDS content. If TDS is greater than 1000 ppm, the water is not acceptable for drinking. In irrigation practices, the TDS is extremely important and sensitive to crop patterns. TDS in water of Central Mahaweli Region is relatively low. This may be due to the fact that lack of soluble material in the crystalline hard rock terrain or due to rapid runoff along the drainage network.

TDS content mainly dependent on evaporation rate and precipitation. In general, waters from quartzite and marble pose fairly low TDS content whereas basic and ultrabasic rocks have high TDS. The composition of groundwater naturally reflects the underlying geology and the residence time where the water in contact with the rock through the flow path.

TDS varies from 12.8 to 457.6 for the samples collected in June/July while it varies from 20.61-1280.0 for the samples collected during Nov/Dec. Since, the EC is closely related to TDS, The localities, which pose the higher EC, show the higher TDS. The semi-logarithmic plots of TDS vs. $Na^+/(Na^++Ca^{2+})$ and TDS vs. $Cl^-/(Cl^-+HCO_3^-)$ for all the water samples collected from different sources are shown in the *Figures 3a, 3b, 3c and 3d.*

Gibbs, 1970, stated that if the ratios of $Na^+/(Na^++Ca^{2+})$ and $Cl^-/(Cl^-+HCO_3^-)$ for the water are close to 1.0 or the TDS content is close to 10 ppm, the chemical constituents in natural waters usually reflect the chemistry of atmospheric precipitation. However, streams having higher TDS (70-300 ppm) or have the above ratios of 0.5 or less show the maximum influence of interaction with rock or the results of evaporation and precipitation of $CaCO_3$ from the solution. These figures (Corbett, 1979) show that the analytical results for water samples are highly skewed towards the TDS axis indicating high concentration of HCO_3^- with respect to Cl^-.

Piper Trilinear diagram

The piper diagram is a multiple-trilinear diagram for graphical representation of the major chemical constituents of water. It sufficiently portrays analytical data of dissolved constituents also used to classify a sample as a water type. Major cation and anion distributions in the Central Mahaweli Region are illustrated in *figures 4a, 4b, 4c and 4d* for the dry and wet seasons during 1996 and 1997. The prominent fact shown by the diagrams is that the SO_4^{2-}, content in the water samples is very low, especially in Nov/Dec season. Ca^{2+} and Mg^{2+} correlate very closely with HCO_3^-, and the greater proportion of $CaHCO_3^-$ reflects the influence of reaction with the geologic terrain.

According to the Piper (1944) diagram the waters can be classified as Ca dominant type, Na^++K^+ dominant or Mg dominant type with cation concentration, $CO_3^{-2} + HCO_3^-$ type or non-dominant $SO_4^{2-} + Cl^-$ type with the anion concentration. The waters in the Central Mahaweli Region can classify as Ca and Mg dominant type with $CO_3^{-2}+ HCO_3^-$. This is clearly shown in *Fig. 4b and 4d* for the Nov/Dec season. However, about 40% of the samples collected for June/July season are shown that they are Na^++K^+ dominant types with mainly $CO_3^{-2}+ HCO_3^-$ (*Fig. 4a and 4c*).

Quality class ratings of water for Drinking and Irrigation purposes

As shown in the Na - Salinity hazard diagrams (U.S. Salinity laboratory Staff, 1954) samples for all locations have fallen into Low-Salinity Low–Sodium (C1-S1) and Medium-Salinity Low-sodium (C2-S1) categories. There is one sample falls into C3-S1 category where it was collected during Nov/Dec 1996 (*Figs.5a, 5b, 5c and 5d*). The sample collected from a marshy land where no irrigation is taking place.

However, the adjacent lands have been irrigated through good water management and by proper drainage systems, which control the salinity.

Lithology that is in contact with water will add inorganic chemical constituents to the waters (Jayasena and Dissanayake, 1995). However, the wet climate in the region may dilute these constituents and control the salinity producing good quality water for drinking and irrigation purposes (WHO, 1984).

Distribution of Hardness

Hardness in water is primarily the result of interaction between water and geological formations. Water either flowing through or over the bedrock may provide the necessary elements for the hardness. Carbonate (CO_3^-) equilibrium in the water system greatly controls the abundance of Ca and the value of pH in water. Hardness is calculated in many ways,

(1) CO_3^- Hardness [(CO_3^{-2}+ HCO_3^-) ppm]
(2) (Ca+Mg) Hardness

Carbonate Hardness

Carbonate hardness is varies from 10.90 to 811.30 ppm in the Central Mahaweli Region. Observing the data, 30% of the samples are fallen into very hard water type. 50% - 60% of the samples are of soft to moderately soft water. In the Nov/Dec period, the CO abundance is quite higher than the June/July period.

Total Hardness

Total hardness is mainly depending on the presence of alkaline elements of Ca and Mg. Other elements such as Sr, Ba, Fe, Mn and Al, though present, are not normally detectable at sufficient quantities to affect the hardness.

Total hardness is calculated from Mg and Ca concentration. In the Central Mahaweli Region, the TH is varying within 17.80 - 156.0 ppm for June/July period and 9.13 - 611.37 for Nov/Dec. The maximum desirable level is 250.0 ppm as CaCO3 and maximum permissible level is 600.0 ppm (SLS is 614 in 1983). Except several samples, most are within the maximum desirable level. But the L6 is a shallow dug well directly overlies on CO deposit soil layer, which shows 611.37 ppm.

Log-Log plot of Mg vs. Ca (*Figs. 6a, 6b, 6c and 6d*) shows the Mg/Ca ratio and relative positions of water samples. All the samples collected except few springs in Nov/Dec season

are fallen into Mg/Ca = 0.1 to 1.0. This indicates higher Ca content than Mg in the wet season. However, for June/July season more samples within the Mg/Ca = 1 to 10. Therefore, during the dry period, Mg existence or accumulation may pronounce.

Sulfate (SO_4^{2-})

Sulfate SO_4^{2-} content of water samples is not quite considerable. High amounts are expected where water draining areas are underlain by volcanic rocks or the oxidized zones of sulfide ore deposits such as Sphlerite (ZnS), Galena (PbS) and specially Pyrite (FeS). The study area though underlain by Precambrian metamorphic rocks, intermittent sulfide enrichments associated with pegmatite bodies are noted. It is well seen that the SO_4^{2-} content in the groundwater is fairly low, however, in several locations in the wet region, it has significant concentrations. It has been observed in the other parts of the world that SO_4^{2-} is not significant in the surface waters and ground waters (Hem, 1985).

CONCLUSION

The present study examined an area covering six major basins, within which sampling for two different seasons were performed. It is noted that certain specific ion enrichments present within different water bodies of the region have direct relationship to the season and the rock types. It is very clear that HCO_3^- >>Cl^-> SO_4^{2-}. The lather relation is obliterated when water collected from the wet zone. For cations Ca^{2+} > Mg^{2+}>> Na^+ however, in certain location and Mg^2 may have higher vales than Ca^2. Abundant Ca^{2+} and Mg^2 C in the water directly related to the marble and secondary calcite formation. Calcite is more soluble under earth surface conditions and produced Ca^{2+} and HCO_3^- into 1:1 equivalent ratio by the following equation.

$$CaCO_3 + H_2O + CO_2 \leftrightarrows Ca2^+ + 2HCO_3^-$$
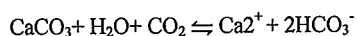
On the other hand Na^+>>K^+ indicating that the Na^+ bearing mineral percentage than the K^+ bearing ones. The abundant charnockite and biotite gneiss may produce the necessary Na^+, while the K-Feldspar may provide the K^+. EC, TDS and TH show linear relationship. Based on the salinity diagram waters can be used for agricultural purposes. However, for more realistic interpretations, we proposed to carry out a detailed investigation supported by a controlled sampling program.

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APPENDIX I - CHEMICAL ANALYTICAL DATA OF WATER SAMPLES COLLECTED IN JUNE-JULY 1996

Sam-no	Temp	PH	EC	TDS	HCO	CL	SO	Ca	Mg	Na	K	Fe	T.H	SAR
S1	25.5	6.7	205	131	99.02	10	5.5	2.75	19	9.1	1.08	0.2	84.78	0.431
S2	25.6	7.2	180	115	66.26	5	5.55	2.53	11.6	8.5	0.34	0.2	53.89	0.493
S3	25	7.5	295	119	113.06	3.9	5.6	4.05	18.85	8.8	3.28	0.7	87.41	0.407
S4	25	8	350	224	13024	4.2	4.1	2.75	1.9	2.7	2.34	1.5	14.67	0.308
S5	25.4	7.8	275	176	16.41	4.4	8	2.7	3.3	2.92	2.34	0.3	20.28	0.282
H1	26.2	6.2	670	426	45.64	4.4	10	9.45	3.92	8.4	2.03	0.1	39.69	0.629
T2	25.5	7.3	90	58	41.67	3.4	10.6	4.7	4.89	8.08	2.26	2	31.8	0.629
WF2	24.5	7.5	90	57	2.25	3.8	2.02	0.55	0.35	2.8	0.46	2	2.81	0.718
WF4	25.4	7.5	145	93	2.92	4.2	10.6	0.5	0.3	3.15	0.26	0	2.48	0.856
BA1	26	7.5	430	275	72.91	7	7.02	5	12.1	7.72	2.76	5	62.11	0.425
HA1	26	7.5	920	589	39.66	3	7	4.4	6.05	5.12	1.64	0	35.8	0.372
RB3	25.6	6.5	520	333	101.89	4.6	4.6	7.55	13.5	8.32	2.04	2.5	74.23	0.421
RB2	26	7.6	400	256	98.31	2.1	3.2	15.57	11.32	3.44	2.1	0	85.34	0.162
RB1	25.5	6.5	900	576	173.65	7	10.75	45.78	10.78	3.55	2.4	0	158.65	0.123
WF3	25.5	7.8	240	154	60.31	5.64	2.1	13.45	5.23	3.21	2.1	0	55.07	0.188
K1	26.5	7.8	180	115	63.72	4.2	11.91	15.67	6.25	2.31	2.3	0.2	64.8	0.125
ME1	25.5	7	120	77	53.64	3.2	11.91	11.9	4.56	5.63	2.1	0	48.45	0.352
ME2	25.6	6.5	90	58	73	4.75	14.81	14.78	8.32	4.62	2.6	0	71.06	0.238
ME3	25.6	6.5	85	54	66.14	4.75	3.2	10.78	5.21	6.53	2.1	2	48.31	0.409
ME4	26	6.5	84	54	51.83	4.77	5.2	9.67	4.36	4.56	2.3	0	42.05	0.306
ME5	25.6	7	40	26	42.23	2.31	4.2	5.98	5.25	2.22	2.5	0	36.48	0.161
SU1	26.5	6.9	300	192	86.38	8.45	22.41	20.89	9.32	6.23	2.3	2	90.44	0.285
SU2	25.6	6.7	360	230	105	9.4	20.41	25.67	11.23	4.52	3.4	0	110.22	0.187
H2	25.5	6.5	950	608	168.52	9.87	23.71	45.78	12.36	6.12	8.1	0	165.13	0.207
T1	26.5	6.2	110	70	37.72	8.45	13.17	13.89	4.23	2.11	2.33	0	52.07	0.127

APPENDIX II - CHEMICAL ANALYTICAL DATA OF WATER SAMPLES COLLECTED IN NOV-DEC 1997

Sam-no	Temp	PH	EC	TDS	HCO	CL	SO	Ca	Mg	Na	K	Fe	T.H	SAR
L1	22	7.57	41.6	27	12.99	2.56	4.56	2.4	1.52	2.4	1.3	0.02	18.23	0.298
L2	25.6	7.66	56.6	36	22.76	4.75	3.64	6	1.68	2.4	1.9	0	21.89	0.223
L3	23.6	7.55	148.7	95	37.11	1.15	8.18	4.4	4.88	3.1	2.5	0.02	31.01	0.242
L4	23.7	8.16	162.5	104	22.78	4.41	15.94	4.8	5.08	3	2.05	0.02	32.83	0.227
L5	22.6	7.21	47.4	30	11.9	2.89	0.7	2	0.88	2.5	0.3	0.07	8.61	0.371
L6	21.6	7.88	63.1	40	16.1	4.13	5.13	4	1.56	2.45	2	0.02	16.4	0.263
L7	21.9	7.56	29.8	19	8.82	1.42	1.82	1.2	0.92	1.7	0.6	0.02	6.77	0.284
L8	24	7.72	63	40	12.34	4.83	2.43	3.6	1.08	2.45	0.9	0	13.43	0.291
L9	24.5	6.2	39.5	25	10.55	0.55	0.35	1.2	1	2.45	0.4	0.02	7.1	0.4
L10A	26.5	6.72	391	250	144.97	4.79	9.08	37.76	8.8	2.8	1.65	0.02	130.48	0.106
L10B	26.4	7.96	340	218	172.2	8.34	14.52	37.6	15.88	2.8	2.65	0	159.48	0.096
L11	25	7.77	184.5	118	44.06	5.8	3.7	8.8	4.4	2.9	1.75	0.02	40.04	0.199
L12	25.6	8.15	525	336	222.64	5.69	9.63	49.6	17	2.8	2.05	0.02	196.16	0.087
L13	25.6	7.51	490	314	210.43	5.82	23.66	57.6	12.8	2.8	2.3	0.02	196.48	0.086
L14	25.6	7.4	259	166	82.36	5.04	13.65	20	4.4	2.8	2.6	0.02	84.44	0.133
L15	27.5	7.53	79.5	51	19.79	0.9	7.55	4	2.08	2.2	1.95	0.07	18.53	0.223
L16	27.3	7.82	264	169	61.66	9.82	16.44	17	6.12	2.8	6.2	0.07	67.59	0.148
L17	27.6	8.98	89.4	57	21.68	3.26	10.11	6	2.64	2.3	1.9	0.07	25.82	0.2
L18	23.6	7.7	63.4	41	10.18	3.81	4.63	2	1.68	2.65	0.75	0.02	11.89	0.334
L19	23.7	7.86	103.3	66	23.09	7.32	4.96	6.4	2.68	2.4	1.75	0	26.99	0.2
L20	25.8	6.92	438	280	71.09	11.26	55.96	16	21.92	2.85	0.95	0	129.87	0.108
L21	24.6	8	136.9	88	43.55	4.63	1.25	8.8	3.56	2.45	1.4	0	36.6	0.176
S11	25.4	7.22	71	45	9.74	4.02	7.6	2	2.32	2.3	1.45	0.01	14.51	0.262
S22	25.4	6.42	69	44	9.79	6.11	3.28	2.4	1.36	2.5	2.25	0.07	11.58	0.319
S33	25.4	7.41	49.4	32	5.86	4.89	3.17	1.2	1.16	2.5	1.3	0.1	7.76	0.39

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APPENDIX III - CHEMICAL ANALYTICAL DATA OF WATER SAMPLES COLLECTED IN JUNE-JULY 1997

Sam-no	Temp	PH	EC	TDS	HCO	Cl	SO	Ca	Mg	Na	K	Fe	T.H	SAR
DWL1	23	6.11	125	80	70.92	7.7	0	3.65	17.37	6.92	0.87	0.1	80.58	0.612
STL2	22.8	7.39	215	137.6	225.41	5.15	0.1	21.37	7.69	7.55	3.3	0.1	85	0.393
STL3	22.4	5.65	20	12.8	13.72	1.78	8	0.67	3.92	2.27	1.5	0	17.8	0.384
TWL4	23.7	6.88	275	176	162.13	5.48	0	20.65	9.8	6.3	3.92	0	91.89	0.059
OYL5	22.8	6.28	30	19.2	10.9	5.15	0.1	1.12	4.73	3.4	2.01	0	22.26	0.463
STL6	22	6.64	35	22.4	38.27	4.76	0.3	1.01	2.01	3.4	1.15	0.9	10.79	0.47
DW7	24.5	5.9	125	80	64.75	2.71	0.1	2.66	6.24	7.02	0.43	0	28.17	0.652
CAL8	27	6.98	135	86.4	78.79	2.74	0	10.23	3.89	4.37	1.83	0	41.55	0.321
TWL9	26.9	6.37	470	300.8	242.56	18.4	6	27.28	21.06	15.97	2.05	0.1	154.78	0.685
TWL10	27	6.77	715	457.6	272.79	22.1	0	32.01	15.65	33.6	3.95	0	144.32	1.182
CAL11	25.9	6.85	370	236.8	222.6	21	20	27.5	21.35	14.95	3.98	0	156.52	0.647
TWL12	27	7.07	520	332.8	119.7	16.6	18	30.3	4.72	32.4	1.43	0	95.08	1.166
DWL13	26	6.24	275	176	136.52	15.25	6	17.87	10.67	9.4	1.64	0	88.53	0.507
TWL14	25	6.89	180	115.2	253.26	24.3	0.1	57.33	4.62	13.72	4.14	0	162.16	0.454
SPL15	24	6.77	175	112	92.24	6.62	0.4	3.38	8.89	7.2	1.78	1.56	46.15	0.238
SPL16	24.6	7.28	75	48	34.86	13	0	2.48	2.88	5.9	1.92	1	18.04	0.588
REL17	24.4	6.62	100	64	40.4	9.03	0.2	6.69	4.26	4.01	2.5	0	34.23	0.346
TWL18	25.5	6.47	320	204.8	219.2	19.8	1	26.23	3.75	31.15	8.58	0	80.93	1.174
STL19	25.2	7.6	315	201.6	166.18	12.15	0	23.44	11.97	11.97	3.22	0	107.79	0.566
OYL20	25.7	7.15	60	38.4	22.32	4.01	0.1	2.97	4.24	6.92	1.15	0	24.86	0.635
OYL21	25	6.82	210	134.4	94.64	10.02	6.25	3.76	17.52	8.72	1.73	0.2	81.48	0.712
DWL22	24.6	6.06	160	102.4	37.65	4.7	5.63	8.03	4.7	3.27	0.85	0.1	39.39	0.457
OYL23	25.1	6.27	98	62.72	69.92	12.6	11.72	4.24	5.21	0.67	1.72	0.1	32.03	0.06
STL24	26.3	6.75	120	76.8	42.63	8.93	12.02	16.92	4.65	2.71	3	0.5	61.38	0.17
REL25	25.8	7.26	93	59.52	54.25	4.76	10.93	8.65	3.73	3.47	1.93	2.7	36.95	0.28

APPENDIX IV - CHEMICAL ANALYTICAL DATA OF WATER SAMPLES COLLECTED IN NOV-DEC 1997

Sam-no	Temp	PH	EC	TDS	HCO	CL	SO	Ca	Mg	Na	K	Fe	T.H	SAR
DWL1	24.5	6.63	880	204.82	544.42	19.2	12.6	34.62	11.94	19.86	3.01	0.1	563.2	3.804
STL2	24	7.57	415	114.41	262.3	24.12	3	28.63	10.43	20.53	1.69	0.1	265.6	4.141
STL3	23	7.2	370	93.4	179.95	16.93	0	18.38	7.65	17.7	3.21	0	236.8	4.167
STL4	24	7.34	240	71.48	162.56	16.05	2.3	19.35	5.63	15.32	2.63	0.1	153.6	3.688
TWL5	25	5.98	465	156.02	268.4	24.25	0	36	16.07	23.05	1.94	0	297.6	4.242
DWL6	25	6.84	2000	611.37	811.3	90.9	20.6	134	67.26	35.01	12.01	1.9	1280	8.89
STL7	24.7	7.28	645	187.96	411.75	29.61	4	43.37	19.36	22.3	2.75	0	412.8	3.892
OYL8	23	7.42	345	85.65	122	15.5	0.9	23.11	6.8	17.9	1.58	0	220.8	3.953
DWL9	23.5	6.47	400	82.69	207.4	18.01	0.7	25.6	4.56	15.06	6.01	0.1	256	3.34
DWL10	24.2	6.77	76.2	129.6	455.97	14.32	0	29.9	13.35	20.3	3.2	0.1	48.77	4.052
DWL11	24	6.7	450	118.04	267.23	24.12	0.4	34.65	7.66	23.16	4.27	0	288	4.308
STL12	24.6	7.39	255	70.63	154.02	13.9	0.2	19.27	5.47	12.46	2.01	0.3	163.2	3.128
STL13	23	7.01	130	45.93	76.25	6.25	0.1	11.44	4.2	9.65	1.38	0	83.2	2.972
STL14	24	8.31	59	19.64	42.7	0.93	0	6.4	0.89	1.08	0.24	0.1	37.76	0.558
STL15	21	6.66	37	9.13	19.82	0.42	0	2.98	0.41	0.17	0.1	0.1	23.68	0.135
STL16	24	7.22	120	26.22	59.65	5.4	0.3	8.95	40.94	3.21	0.2	0.2	76.8	1.302
STL17	24.2	6.68	32.2	9.59	21.3	0.41	0	3.2	0.94	0.26	0.04	0	20.61	0.047
DWL18	24.1	5.41	115	39.38	51.85	5.12	0.2	7.78	0.39	1.25	0.62	0	73.6	0.588
DWL19	23.7	5.54	110	28.28	59.47	1.5	0.7	8.92	4.85	0.9	0.17	0.1	70.4	0.406
STL20	22.1	6.88	57.5	17.11	38.12	0.7	0.1	5.7	1.46	0.4	0.26	0	36.8	0.229
STL21	23.1	6.7	35	13.47	31.1	0.46	0	4.67	0.7	0.1	0.15	0	22.4	0.664

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Fig. 1. Location Map of the study area.

Samples Collected in June July 1996
Samples Collected in Nov Dec 1996
Samples Collected in June July 1997
Samples Collected in Nov Dec 1997

Monthly normal average rainfall - Kirimetiya
30 years average

Rainfall (mm)

300
200
100
0

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

(a)

Monthly normal average rainfall - Kandeketiya
30 year average

Rainfall (mm)

400
300
200
100
0

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

(b)

Fig.2. Normal rainfall distribution for a). Kirimetiya in the wet zone, b).Kandeketiya in the dry zone
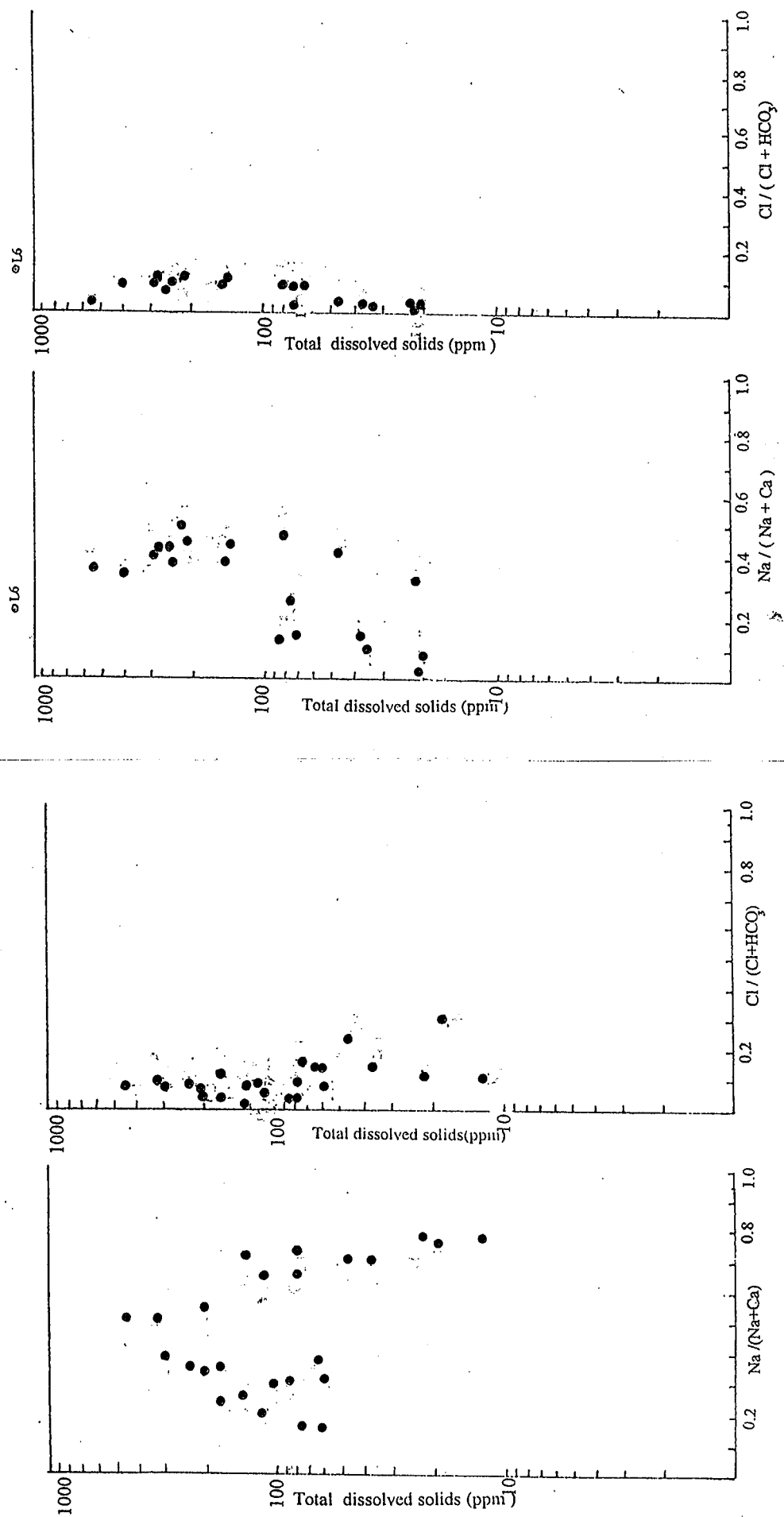
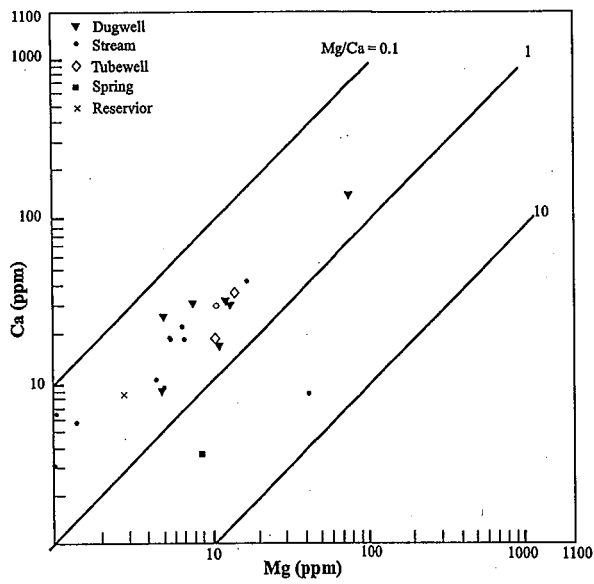Fig 3. Graphs for the TDS vs. Na/(Na+Ca) and TDS vs. Cl/(Cl+HCO₃); (c). June July 1997 (d). Nov Dec 1997.
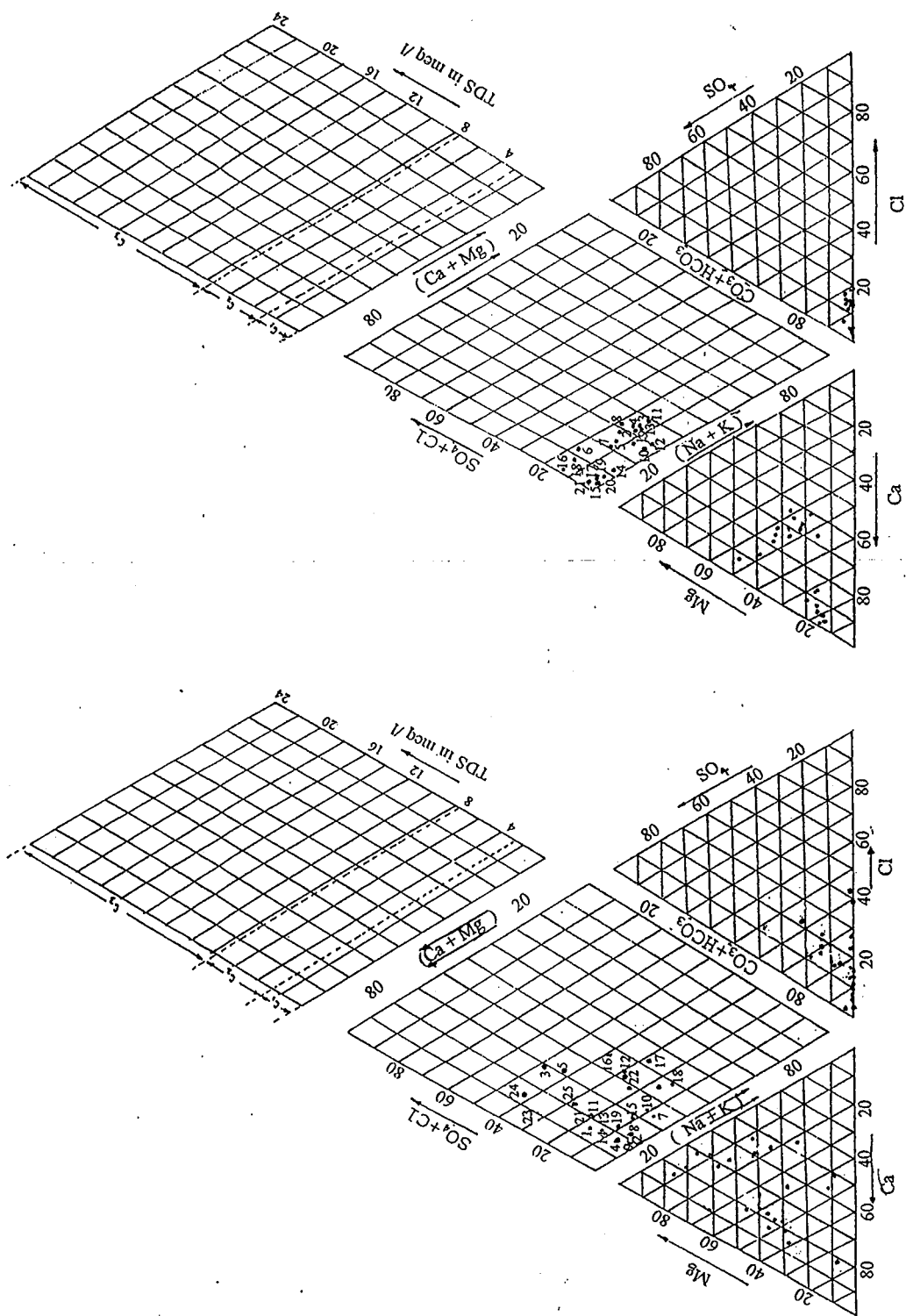
Fig 4. Piper Diagram representing major cations and anions distribution of water samples; (c). June July 1997 (d). Nov Dec 1997.
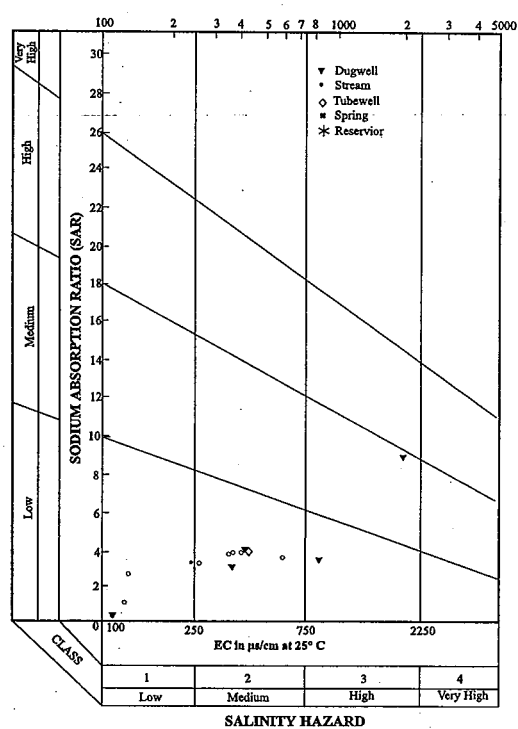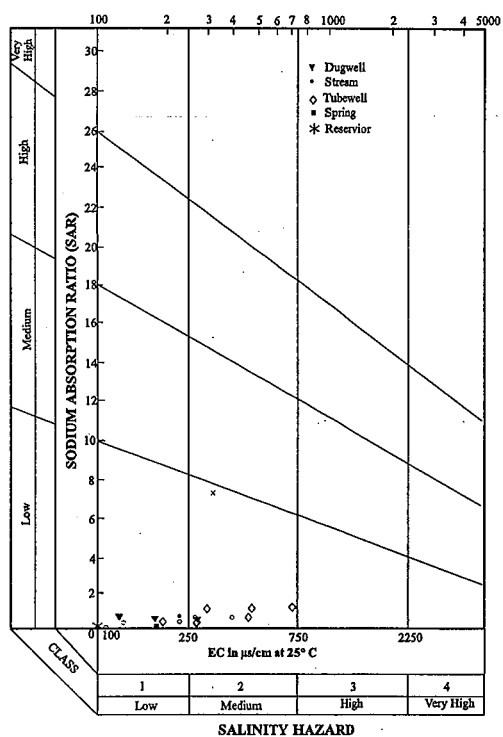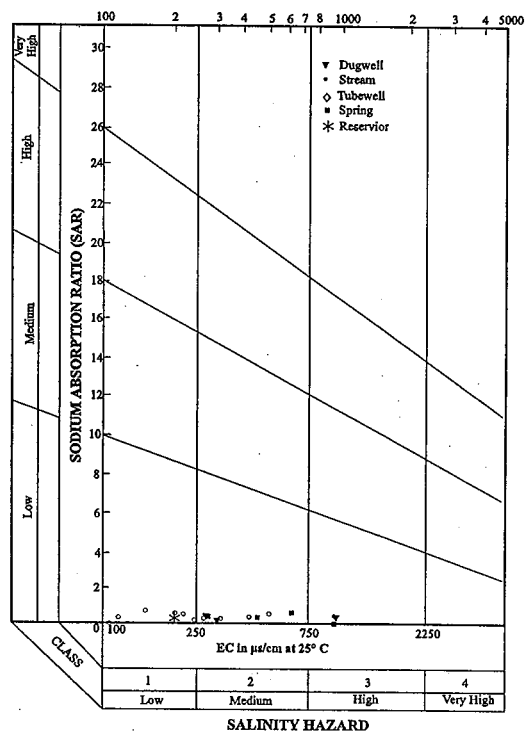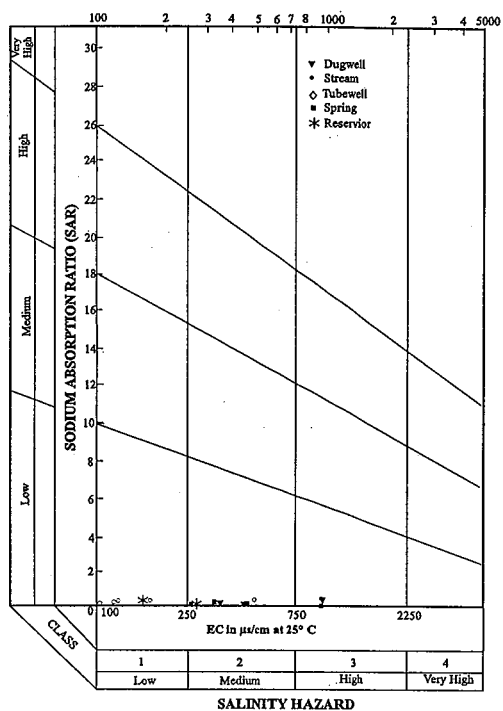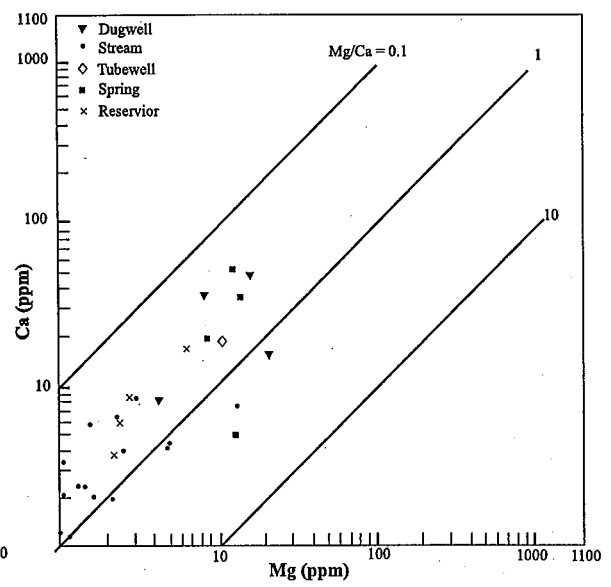
Fig. 5: Na- Salinity Hazard Diagrams
(a) June July 1996 (b) Nov Dec 1996 (c) June July 1997 (d) Nov Dec 1997
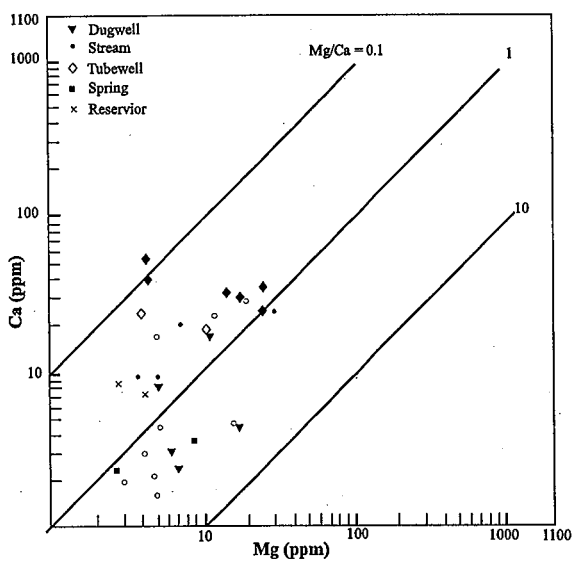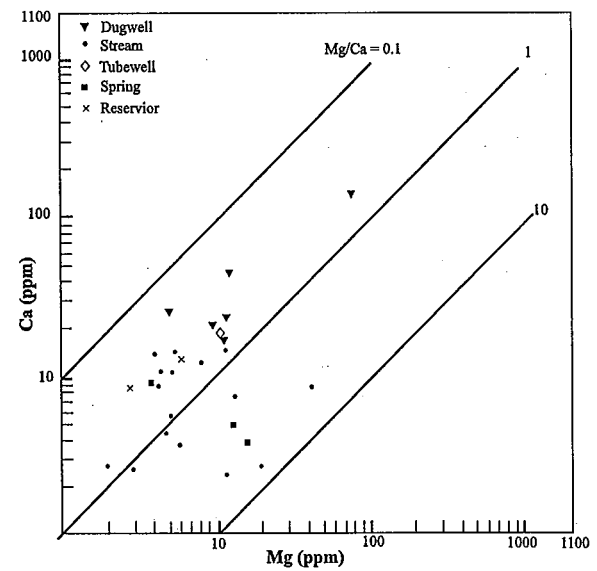
Fig. 6: Log-Log Plots of Mg vs Ca Distribution for Different Seasons.
(a) June July 1996 (b) Nov Dec 1996 (c) June July 1997 (d) Nov Dec 1997

SOME SUGGESTIONS TO DEVELOP THE GROUNDWATER MANAGEMENT IN SRI LANKA

U.de S.Jayawardena (Department of Civil Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya, Sri Lanka)

ABSTRACT

The author has published a few research papers since 1979 to date. The objective of this paper is to combine all conclusions and recommendations together. Research based on groundwater evaluation, changes of the chemical quality of groundwater. attitude of rural people, maximum drilling depth, actual hand force to be applied, maximum pumping period and minimum recovery period, the affect to the environment due to long term extraction and the different management systems in Sri Lanka are discussed here.

INTRODUCTION

Water is perhaps the most basic resource. It is an extremely scarce and hence a most valuable resource in many parts of the world. Because of this the period from 1981 to 1990 was declared as the International Decade for Water Supply and Sanitation. Generally in Sri Lanka the people living in major cities and urban areas get water from the delivery pipes under the government drinking water supply schemes. People living in other areas use water in open dug wells, irrigation channels, reservoirs, tanks, lakes, natural springs, rivers, streams, or by collecting rain water. This had been a practice before the introduction of the deep well concept to Sri Lanka in 1978.

After commenced the deep well concept in Sri Lanka, a number of foreign organizations have started to tap deep groundwater resources in the fractured crystalline rocks. The hydrogeological investigations under different projects in different administrative districts were carried out for domestic water supply for the rural areas as well as for the close by towns and urban areas to satisfy the water deficit problem.

The deep wells have been categorized into hand pump borehole wells and production borehole wells. Hand pumps were installed for the low yielding wells and electric pumps were installed for production wells for distributing of water through delivery pipes after pumping to a storage tank. Before use the water each well is subjected to evaluate the quantity and quality of water of source.

OBJECTIVE

The author carried out a number of surveys, research and investigations in different areas on groundwater resources and published many research papers after introducing the deepwell concept to this country since 1978 to date. The objective of this paper is highlight the conclusions and recommendations mentioned in his papers.

METHODS OF SURVEY

At the beginning, the scientific investigations for groundwater resources in hard rock terrains were initiated by a state enterprise. The aim of these studies was to yield economic quantities of groundwater. Then the demand for tube wells increased drastically and as a result of this, several government, semi government, private institutions and foreign firms were authorized to carry out investigations in Sri Lanka. The author visited different localities to observe the ongoing groundwater programs which have been managed by different institutions in various administrative districts in Sri Lanka. The author collected more data specially from the Kandy District Water Supply and Sanitation Project and carried out more research in various themes which are given below.

(a) Groundwater Evaluation

A groundwater evaluation for the Andella Oya basin in Ampara district was carried out using the available data of precipitation, evapotranspiration and runoff. The net recharge from the precipitation was found from these data but the result is not the actual groundwater storage in the basin.

(b) Chemical Quality of Groundwater

The water quality variation of different low yielding wells (hand pump wells) and high yielding wells (production wells or piped water schemes) were found. Analysis were done for the samples obtained before pumping, with continuos time intervals while pumping and after the completion of pump test. The changes of the variations of all elements while pumping were found.

(c) Attitude of People

Some villagers are thinking that water in open dug wells are more pure than the closed wells such as hand pump wells. To find the truth of this traditional thinking of people water samples were collected from open dug wells, closed dug wells and closed hand pumped wells and analyzed chemically.

(d) Maximum drilling depth

The reports of borehole wells and the location maps were collected to study the subsurface fracture systems of crystalline hard rocks in three electorate of Kandy district. This study was based on the borehole reports of production wells only. The major information taken from the borehole reports were mean sea level at drilling point, subsurface rock types, penetration rates, of rock drilling, groundwater discharge levels and the variation of the changes of flushing yields while pumping. From all of these data only the flushing yields of various depths were considered to understand the subsurface fracture

patterns. The number of fractures at every five meters compared with the flushing yields and then used these data for statistical analysis.

(e) Impact to the environment

A survey was carried out around Ampitiya, Kandy to investigate the land subsidence and the other environmental impacts due to groundwater extraction from hard rocky areas. The hydrogeological setting, groundwater pumping, water level declines etc. was found.

(f) Maximum hand pump force

Some hand pumps which are used to lift groundwater from low yielding wells are not easy to operate. Even for a adult needs a very high force to get groundwater. There may be several factors to be considered before the installation of all the parts of pump. A survey was carried to determine the suitable conditions for pump installation and easy operation conditions. The relationship among the theoretical force, dynamic water level and the pump installation depth for a particular hand pump (INDIA MARK II) were found.

(g) Groundwater management and research

There are many problems associated with the groundwater development programs or tube wells construction program in Sri Lanka. Problems in data collection, problems arising during the filed work, technical problems while drilling, well design and construction etc. and nontechnical problems. Groundwater investigations in Sri Lanka are conducted by several organizations either governmental or nongovernmental or foreign organizations. All institution s face number of problems though they have their own development program. The author found that all of these institutions are not under one administration.

DISCUSSION

(a) The general factors affecting to the groundwater circulation are climate, geology and water bearing properties of rocks, geomorphology, drainage and sea water levels. Occurrence of groundwater in an area varies with the climatic condition such as rainfall, temperature, humidity and evapotranspiration. Groundwater recharge take from streams, natural reservoirs and lakes, and swamps in addition to the seepage from the surface by direct precipitation. The artificial surface water supply schemes such as reservoir for hydropower and water supply, irrigation channels, agricultural fields etc. contribute to change the general groundwater level. Seepage from these water bodies may take place into the basins. Therefore the groundwater circulation and storage is different in different basins. This shows that the exploitation of groundwater quantity depend on the net groundwater recharge and storage in the basin.

There are more irrigation water tanks and canals which supply the surface water for paddy cultivations in the ANDELLA OYA water basin. Water may recharge into the ground from these schemes also. The source of these surface water bodies may not be only from this basin and may be from other basins. Therefore the total groundwater recharge is not only from the precipitation. This implies a groundwater balance study should be carried out for each water basin in the country. This gives the total recharge, discharge and storage in each basin. The amount to be extracted can be calculated after this evaluation. This is very important for future development programs.

(b) In most hand pumped wells all the elements tested were within the permissible limits or less than the WHO safe limit standards and therefore no harm to the human health. But a few wells contained more iron and fluorides. For these a iron and fluoride removal plants should be introduced among the people.

Chemical analysis of production wells indicated that the continuous pumping of bedrock groundwater also may create adverse effects to the human health if there is no procedure to monitor the their quality frequently. Some elements may increase and some may decrease while continuous pumping for piped water supply scheme. Therefore it is necessary to establish a well planned sampling program to determine if any trend occur in the future. For example, if groundwater is becoming acidified, plans must be developed to deal with the health and treatment implications.

The deep wells should be constructed carefully along the coastal regions because water from fractured rocks may be mixed with saline water.

(c) The results indicated that the water quality of closed wells and hand pump wells are much better than the open dug wells. It proved that the traditional thinking of the people on the effect of sun light is wrong and it is not a factor for change the quality of water. Therefore the people must educated to use the hand pump wells.

(d) From the analysis , it was found that the drilling beyond 70 meters below the surface level would not be beneficial and might be an unnecessary expenditure except very few locations. The well sites should be selected only in the valley or basins or along lineaments.

(e) The ground surface surrounding the production well has gone down about one meter due to the extraction of groundwater.. Some cracks and holes were able to seen along the road crossing the area. Some houses close to the pumping wells also affected by this land subsidence and cracks have been developed on the walls and foundations. The paddy field are drying out and no water at all in some dug wells after commenced this project.

The total groundwater withdrawal amount has increased for the second year than the first year after commenced the distribution without any reason. This may be due to the increase of demand for drinking water. But the withdrawal per day should be constant because a minimum recovery period is needed for the aquifer before start the next day pumping. If

the pumping period is not maintaining the damage to the surrounding environment will be very high in the future. This is very important factor to be considered to save the aquifer.

Another investigation was carried out at Pathadumbara production well sites. The pumping tests data used to find the storage, recovery and the maximum pumping yield of aquifer and then recommended a minimum of 8 hours period per day for recovery. Decreasing of this recommended period will be harmful to the aquifer as well as to the surrounding environment. And also recommended the maximum pumping rate per day.

(f) This survey indicated that the hand force sometimes not enough to operate the well. Some hand pumps are not from the same manufacturer. In a village not only the adults but also small children are coming to collect water from the wells. If a child cannot operate a hand pump, or his force is not enough to operate the handle of the pump, then the objective of this project may not be successful. for a particular pump the maximum dynamic water level and the maximum pump installation depth from the ground surface must be found for easy operation.

(g) Groundwater is a renewable resource. It would last for ever with good management and proper development system. Investigations for groundwater in Sri Lanka are very easy because of the limited land area which is surrounded by the sea with no geographical boundaries with other countries. Good management and skilled planning are needed to maintain the amount of consumption below the lower limit of recharge.

Existing programs are conducted by different government organization under different ministries, private local organizations, foreign organizations with the permission of the government or as non-governmental organizations. The aim of all the organizations is to provide safe groundwater for the people. Most of these programs are funded by foreign organizations such as NORAD, WORLD BANK, ADB, UNICEF etc. Though they are giving funds for the development of groundwater the targets, objectives and managements are not similar. Due to this different administration all of these investigations are only for short term solutions. There are no long term solutions for the next generations under this situations. To avoid this problem an institute must be responsible for the data collections, investigations and research and those should be the main objectives the institution. All other construction should be carried out under the instruction and supervision of that institute. It create one administration for groundwater extraction for the people living in the country for a longer period.

CONCLUSION

To develop the various sections of groundwater programs, all groundwater projects must be under single management. Therefore it is necessary to establish a GROUNDWATER RESEARCH INSTITUTE in Sri Lanka. Successful groundwater programs in the future will involve a team of experts including social and political scientists and economists under a single managements. The technical and nontechnical research teams will find the answers for the real problems.

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Sustainable use of the precious groundwater resources in Sri Lanka through systematic research approach

Dr (Ms) C.Shanthi de Silva
Senior Lecturer in Agricultural Engineering
Faculty of Engineering Technology
The Open University
Nawala, Nugegoda

ABSTRACT

Agrowells have been introduced to use the precious groundwater resource to overcome the problem of water shortage in the dry and intermediate zones of Sri Lanka. Due to the underlying crystalline hard rock formations, which have very low storage and transmissivity, the groundwater resources in these areas are limited. However, haphazard development of agrowells without recourse to scientific investigations have caused serious problems such as drying of wells in the mid season, low recovery of well after long pumping and interference between neighbouring well.

Therefore a study has been carried out in North Western Province of Sri Lanka, to study the recharge, well performance for short and long term pumping, recovery of the wells after pumping and aquifer flow mechanisms. Based on the study results a methodology was developed to regulate groundwater resources in agrowell systems by proper designing of well dimensions. Through this methodology, a set of nomographs is developed for the particular case study area. It is possible to identify the safe volume of water that could be abstracted from known dimensions of a well. Extent of cultivation could be decided according to the crop water requirement of the crops selected for cultivation with the safe volume of water available per well.

Policy makers and the organisations involved in agrowell constructions could adopt these findings in the policy development. And also educate farmers based on these nomographs about the safe volume of water that could be abstracted from his own well. Optimum well dimension could be decided if a farmer is constructing a new well, and crop water requirements, so that the farmer himself can regulate his own groundwater resources to avoid over-exploitation. Similar nomograph is also developed for Huruluwewa watershed and could be developed for any part of Sri Lanka with the basic data available using the methodology introduced in this study.

INTRODUCTION

The mean annual rainfall in dry and intermediate zones of Sri Lanka ranges from 800 mm to 1500 mm. More than 90% of the annual rainfall is received during the wet season (from October to December). In most years precipitation is insufficient to meet the crop water requirements for 7 to 8 months during the dry season (from January to September).

Rapid development of the country and increase in rural population places a high demand in water. Water is extensively used by industries and agriculture in addition to the domestic purposes. More intensive and successful agriculture practices are largely dependent on the availability of assured water resources. Fluctuating weather conditions changed the rainfall patterns and the usual amount of seasonal rainfall was not received during the last few years. Hydro-power became scarce due to insufficient storage in the hydro-catchments. At this state of affairs, groundwater is the only source if there is a severe water shortage.

In Sri Lanka nearly 90% of the land area is occupied by metamorphic crystalline rocks, called "hard rocks". Therefore the groundwater potential in dry and intermediate zones is limited due to low storage and transmissivity of the underlying aquifer formations. Except in the Jaffna Peninsular in the extreme north of the island, where the rich aquifers are associated with Miocene limestone and sand aquifers in coastal areas like Kalpitiya, ground water has never been used on large scale in dry and intermediate zones till late eighties. The Government of Sri Lanka implemented a nation-wide agrowell programme for supplementary irrigation in dry and intermediate zones in late eighties.

However, the development of agrowells has taken place in a haphazard way without proper assessment of the hydrogeological properties, spacing of wells, safe yield, recharge and a rational siting of wells. Farmers are not guided enough to use the national groundwater resources efficiently. Usually farmers use more water than the requirement to irrigate their crop (De Silva, 1995). The density of wells per unit area has increased without proper spacing between wells. As a result, there is evidence of salinity problems, interference between wells and drying of wells in mid season (De Silva, 1993; De Silva and Weatherhead, 1994). Further, indiscriminate opening of new agrowells may lead to serious problems in the future.

Therefore, supplementary irrigation using agrowells in the hard rock aquifers of Sri Lanka should be carefully planned through a systematic research approach with respect to hydraulics of groundwater aquifer and recharge. Groundwater must be regulated so that establishing well dimensions can regulate the rights of water under individual lands. The objective of this paper is to introduce the methodology developed through a systematic research approach for groundwater regulation in hard rock aquifer.

CASE STUDY AREA

In order to fulfil the objective, a case study was conducted in a typical agrowell system in Kobeigana in North-Western Province of Sri Lanka. Farmers in this study have never had large schemes for irrigation. During late eighties, agrowells were introduced to these areas. An agrowells in this area is 6m in depth and 6m in diameter; walls are lined with brick from bottom to top of the well. After the construction of large diameter wells (agrowells) they cultivate paddy during the wet season (rainfed) and vegetable and cash crops during the dry season in both up lands and low lands with

agrowell irrigation. Farmer normally irrigates using a 50 mm pump with portable hose pipes leading directly to short furrows (10 to 20 m long) or small basins (25 to 100 m²). The well storage allows the pump to be used at its optimum rate. The well is then left to refill slowly before the next irrigation.

The study considered thirty (30) wells with the farm associated with it in several villages of Kobeigana were taken up. These agrowell sites were intensively equipped with observation boreholes, raingauges and evaporation pans. Daily field monitoring was carried out on groundwater levels, changes in groundwater levels due to pumping, pumping rates for 21 months along with the rainfall and evaporation data. Several pumping tests were conducted during early and late dry seasons to study the aquifer parameters and flow mechanisms. Investigations were also made of the properties of the aquifer to understand the hard rock formation in the study area.

METHODOLOGY FOR GROUNDWATER REGULATION

The methodology developed for the groundwater regulation through a systematic research approach is presented in Figure 1. This methodology was developed after studying the agrowell systems in hard rock aquifer in detail and understanding the aquifer flow mechanisms and the agrowell performance during dry and wet seasons. This methodology could be used with the basic data available in any agrowell system. But the accuracy depends on the validity of the data.

Step 1: Basically two computer models are used in this methodology. The first model is a radial flow model (De Silva and Rushton, 1996) which simulates radial flow towards the agrowell.

The radial flow model is used with the features of seepage face, well storage, varying saturated depth and varying outer boundary (no- flow or rechargeable boundary) to analyse the pumping test and estimate the aquifer transmissivity and specific yield (De Silva, 1995). By analysing pumping test it is possible to calibrate the model for a particular study area (short-term calibration).

Step 2: Second is a soil moisture balance method based computer model named IWR (Irrigation Water Requirement), which runs on historic weather data with crop and soil information (Hess, 1990). In the soil moisture balance method a daily estimate of the soil moisture balance is made with an input of precipitation plus irrigation minus run-off and losses due to actual evapotranspiration and drainage which may include aquifer recharge. When the soil moisture deficit is zero, water can pass through the soil zone to the aquifer provided that the aquifer can accept water. The IWR computer model could be used to estimate the annual average actual aquifer recharge for several years depending on the availability of reliable data.

Once the specific yield is estimated in the Step 1, it is also possible to estimate the approximate annual average aquifer recharge by multiplying the overall groundwater drop per year (if known) by the specific yield, which will give the estimate

of the annual average aquifer recharge. This could be checked with the results obtained from the IWR model.

Step 3: The radial flow model could be used for analysing different scenarios of well dimensions after calibrating for the long-term behaviour of the agrowell. The calibration of long term behaviour could be done only when detailed groundwater level monitoring is available for a long period (preferably daily data for a complete year).

Step 4: The model calibrated for long term behaviour is then used for simulations. Different well radii, well depth and distance to outer boundary could be tested. The distance to the outer boundary is an important parameter in agrowell systems. The existence of a number of agrowells in an area means that an area of aquifer is associated with each well. This can be represented adequately as a circular aquifer with an equivalent outer radius on which a condition of no flow crossing the boundary is enforced (De Silva, 1995).

For simulations the abstraction is increased by factors until the well supply water for abstraction without reaching the excessive draw down limit of 90% of the saturated depth within the growing season. This procedure could be repeated for different well radii, depth and distance to the outer boundary. The results obtained in the simulation could be developed into nomographs. For sustainable irrigation the abstraction should be less than the recharge. The recharge available for the area associated with the well could be calculated from the distance to the outer boundary. Then the area associated with the well could be multiplied by the average annual recharge estimated in step 2 to calculate the volume of recharge available for abstraction. The amount of abstraction equal to or less than the 50% of recharge could be used for irrigation. Cultivated extent could be decided based on the cropping pattern, crop water requirement and the amount of water available for irrigation from the well.

APPLICATION OF THE METHODOLOGY

The methodology developed was applied to the case study area to develop a set of nomographs for groundwater regulation. Results obtained are discussed below.

The radial flow model was used to analyse the pumping tests conducted in the study area. The model results were compared with the draw down in the pumped well and also in the observation bore hole at 13 m and 43 m from the well centre respectively. A range of parameter values were tried and the satisfactory agreement between the field and model results were obtained. The estimated average horizontal hydraulic conductivity and specific yield were 6.0 m/d and 0.07 respectively.

Actual recharge of the study area was calculated using IWR model. Ten-year average annual recharge for the study area was 250 mm. The typical cropping pattern used by the farmers in the field was considered for this calculation. This cropping pattern consists only 60% of land with brinjals, chilli, long bean, cucumber and paddy. Rest of the land is grass comprising small and large trees.

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The well no 1 dimensions and the growing season (210 days) of the study period from February to September was taken as an example to calibrate the long term behaviour of the agrowells in the study area. It is assumed that the well is fully penetrating the aquifer and aquifer is fully recharged. The maximum pumped draw down in the model was set as 90% of the saturated depth so that there will always be 10% of the saturated depth of the water in the bottom of the well. When this draw down was reached in the simulation, the pump was automatically switched off and the well supply was regarded as having failed. To obtain a satisfactory agreement the tall tree evaporation from ground water table was introduced to the model (De Silva and Rushton, 1996).

The radial flow model calibrated for the long-term behaviour of the study area then carried out the simulations. Well radii from 1 to 8 and well depth from 3 to 10 were tested with four different distances to the outer boundary (No-flow boundary). Results obtained were developed into nomographs showed in Figure 2. These nomographs indicate the volume of water that could be abstracted from an agrowell with increased well radius and well depths (De Silva et al 1996; De Silva and Weatherhead, 1996). But the more important inference is sustainability of these wells. It is not possible to abstract all the water that is available at a well. Instead, it should be checked with recharge during the previous wet season to calculate the volume of recharge available for a well of that particular well radius, well depth and well spacing.

The safe yield of water that could be abstracted from the well did not increase beyond 180 m well spacing. It shows that at larger well spacing the ability of the well to draw water from the distant parts of the aquifer is limited. However, closer spacing of the wells may lead to reduce yields and restriction of the area under cropping, thus jeopardising the economic interests of the farmers who venture into groundwater irrigation. Further it may negate the positive aspects of the agrowell program.

For an example, the agrowell of 6m depth and 4 m radius with the distance to the no-flow boundary of 101 m, which is equal to an average spacing between two nearby wells of 180 m, is considered. The area associated with each well is 32400m². The average recharge for that year was 250 mm. Therefore, the recharge available per well is 8000 m³. If the volume of water available for abstraction is 50% of the total volume of recharge per well is 4000 m³. From the nomograph, the maximum water that could be abstracted by the same well is 15340 m³. Therefore it does not imply that is possible to abstract all 15340 m³. Considering the recharge it is possible to abstract only 4000m³. If the farmer exceeds this amount there will be over exploitation and interference with near by wells. In addition, if the farmer is abstracting only 4000 m³ per growing season then a well of 1.5m radius is more than enough to supply the same volume of water. By this the farmer could avoid the unnecessary cost of constructing a 4m radius well. The author has already adopted this methodology successfully and nomographs have been developed for Huruluwewa watershed (De Silva et al, 1998) and the nomograph for Trippane Tank Cascade System is on progress.

GROUNDWATER REGULATION

The organisations responsible for constructing these agrowells and policy makers for funding agrowell construction are playing a major role in implementing this methodology to regulate groundwater. Similar nomographs could be developed for areas where the agrowells are being intensively used in Sri Lanka by adopting the methodology given in this paper. These nomographs could be used to identify the safe yield of water that could be abstracted without over-exploitation for respective well radii, depth and spacing. In addition, it is also possible to identify the well radius for a given aquifer depth and spacing. By this it would be possible to cut down the unnecessary cost involved in construction of large agrowells.

Further, it is necessary to educate farmers about the safe yield of water that could be abstracted from their well according to the well dimensions to avoid over exploitation. The land area that could be cultivated in each farmer's field using agrowell water is decided by the cropping pattern and the crop water requirements. Crop water requirements could be calculated by using CROPWAT computer model and farmers could be advised based on their selection of crops. High-value crops with low water requirements should receive sufficient attention. Vegetable cultivation under agrowell irrigation can be easily adjusted to coincide with the periods of high demand owing to shortage of supply.

Since the ultimate objective of all these changes to give the maximum benefit to the farming community, strategies should be evolved to seek the active participation of the farmers. Farmer representation in local-level committees pertaining to groundwater development will be a significant step forward as the beneficiaries will thus be involved in the decision-making process. Effective farmer training in crop water requirement, selection of high value crops with and low water requirement, irrigation methods, groundwater resources and safe yield should be developed to enable the farmers to regulate the groundwater resources on their own.

CONCLUSIONS

The methodology developed under this study enables the regulation of groundwater resources without over-exploitation. Further, a set of nomographs could be developed for the respective areas using basic data available and the radial flow model. The study results indicated that the groundwater resources in hard rock aquifers could be regulated through proper designing of agrowell dimensions and farmer training on crop water requirements, groundwater resources and safe yield. These nomographs are useful to identify the amount of water that could be abstracted safely during a growing season based on the well radius, depth and spacing. It is also possible to identify the well radius for a given aquifer depth and spacing to minimise the construction cost.

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RECOMMENDATIONS

* Develop nomographs for the areas where intensive agrowell construction and irrigation is practised.

* Identify the safe yield of water that could be abstracted from a well of given well radius, depth and spacing, considering the recharge from the nomographs and advise the farmers accordingly.

* Advise farmers to keep a record of the amount of water that they abstract for irrigation by measuring the drop in water table in the well multiplied by the plan area of the well each day.

* Identify the crops cultivated by interviewing farmers to calculate the crop water requirement in order to advise the farmers on the extent of cultivation based on the volume of water that could be abstracted safely.

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Figure 1
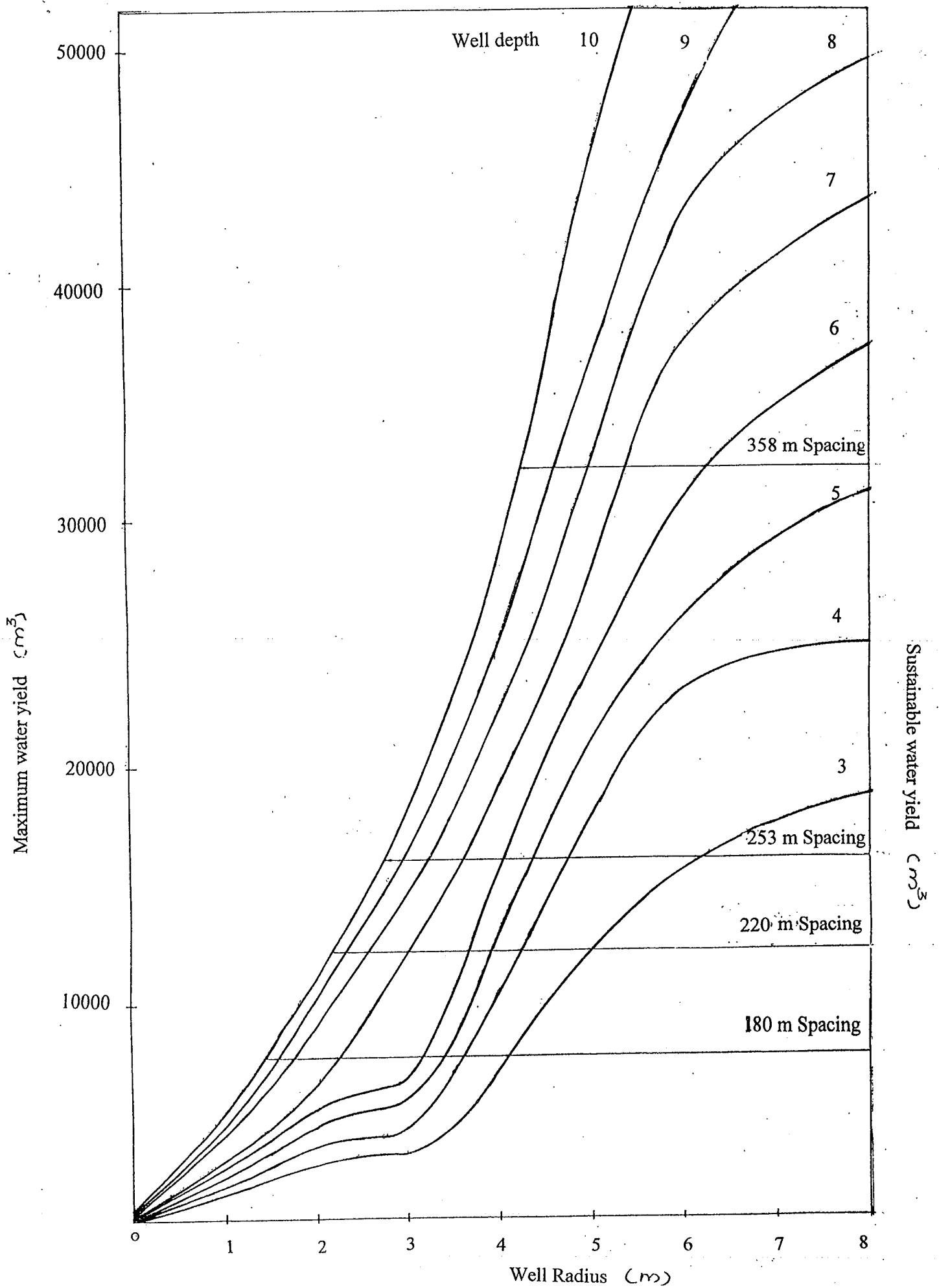
Figure 1 Flow chart of the methodology developed in this study.

8
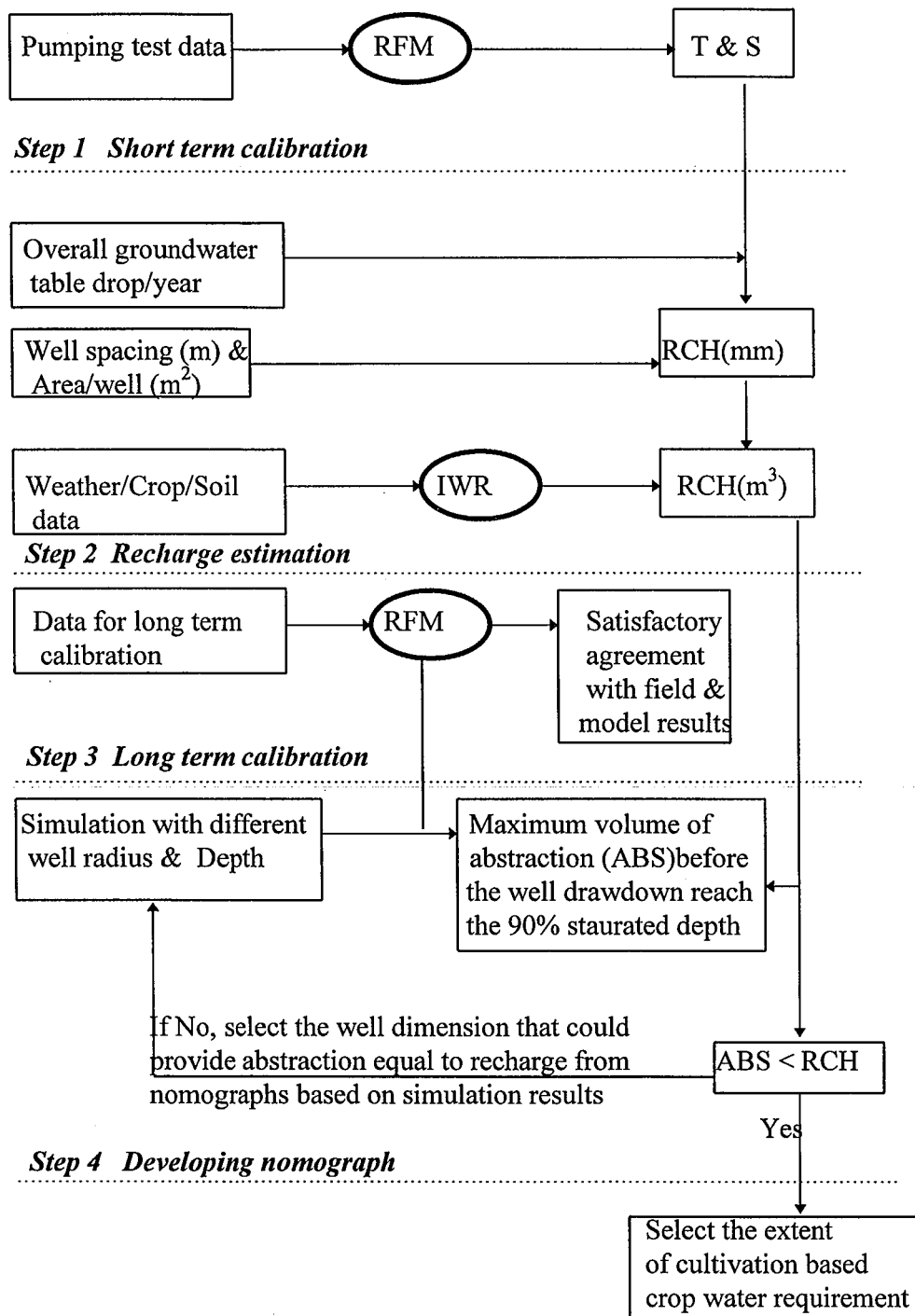
Figure 2 Nomographs of agrowell design for groundwater regulation.

HYDROGEOLOGICAL INVESTIGATION AND EXPLOITATION
OF GROUND WATER IN SPRING ZONE

A. A. KOPDIPPILI

GROUNDWATER SECTION
NATIONAL WATER SUPPLY AND DRAINAGE BOARD
RATMALANA

H023551

HYDROGEOLOGICAL INVESTIGATON AND EXPLOITATION OF GROUNDWATER IN SPRING ZONE

A. A. KODIPPILI. **National Water Supply and drainage Board, Ratmalana**

ABSTRACT

A hydrogeological investigation program was carried out to assess the potential sustainable yields of ground water associated with natural springs geographically distributed 80 km sq. in Beliatta area of southern Sri Lanka.

Investigation program aimed to establish the interaction between natural springs and the local hydrological cycle and also to find impacts of groundwater abstraction on the health of groundwater dependent Eco-systems including modification of spring flow and base flow of Sinmodara oya, when groundwater is pumped from the spring zone for Beliatta Water Supply Scheme.

The area studied lies between 80^0, 38' and 6^0, 05' and 80^0, 47' and 6^0, 58' and is situated in Hambantota district (see Fig. 1) and falls into the intermediate zone with the average annual rainfall of 1675 mm

The community of the spring area insisted that groundwater is important for their paddy cultivation. But the community who does not have access to potable water reported that drinking water is a paramount problem. Therefore, Hydrogeological investigation of this area was performed in order to design tube wells as the water sources, in such a way that impact resulting from groundwater abstraction through tube wells on the environment is negligible while ensuring cost effectiveness. In the process of investigation, it was not limited only to find sources and also extended to delineate aquifers and identification of probable recharge. As high productive aquifer is fractured hard rock aquifer, much emphasis was laid to find areas, which have high degree of fracture intensity, interconnections, lengthy extensions with good recharge, to abstract substantial amount of groundwater.

High productive groundwater potential is limited to the North - West geological fault zone, along side of which most of springs emerge and Siniomodara oya flows. Perennial springs that have occurred through fractured hard rock feed the Sinimodara oya from the start to the end. Further, productivity of springs depend on various factors such as degree of fracture intensity, width of fracture opening, their interconnections, water saturation, and the ground water storage of regollith of hard rock, etc. Recharges of springs are probably from the mountain regions of Godawelaknda and Wawulugalakanda with substantial thickness of regolith through geological lineaments.

LOCATION MAP OF THE STUDY AREA

Scale = 1 : 63,360

LEGEND

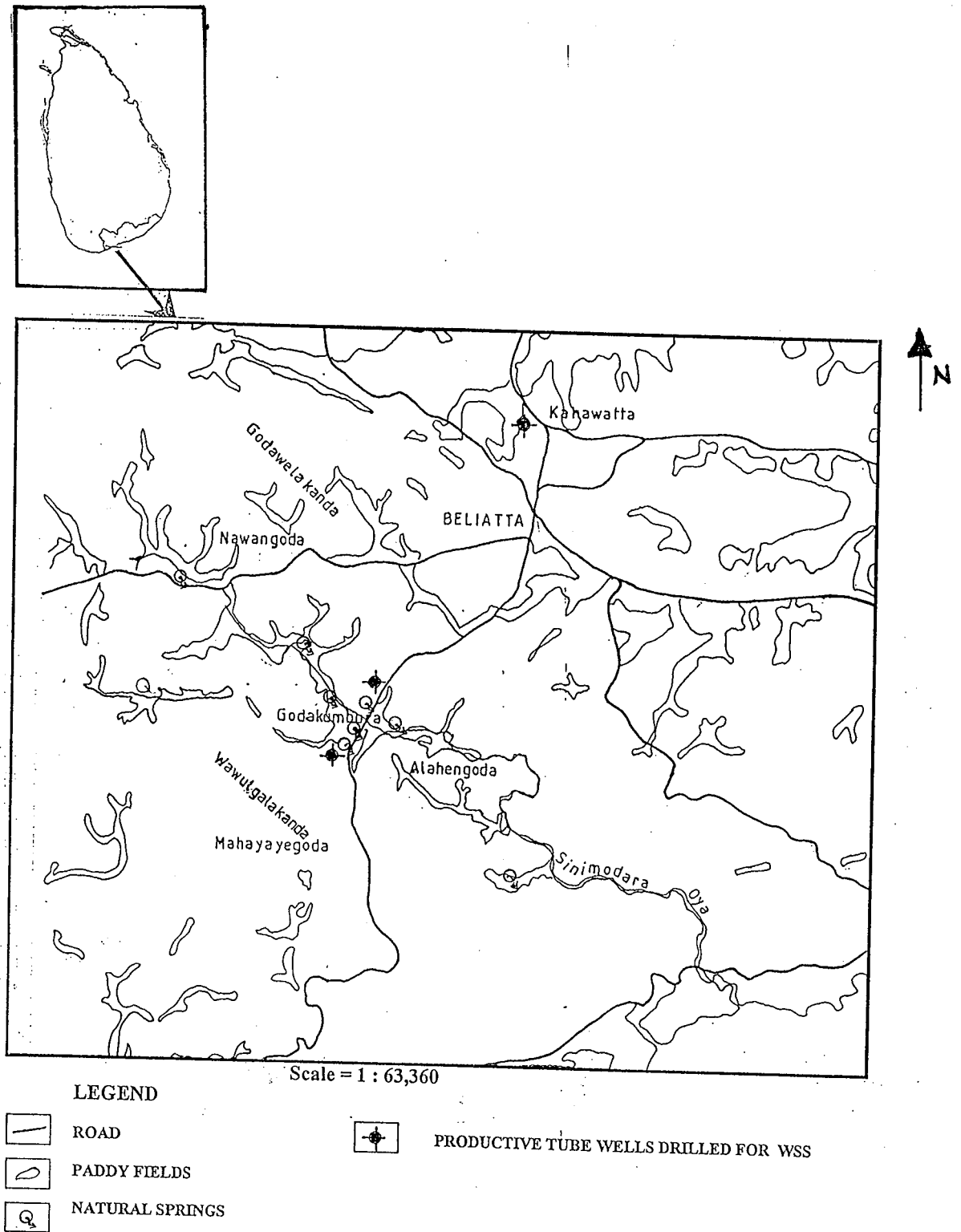|	
—	ROAD
⌒	PADDY FIELDS
Q	NATURAL SPRINGS

PRODUCTIVE TUBE WELLS DRILLED FOR WSS

Fig.1

1.0 INTRODUCTION

The groundwater in the spring zone of Sinimodara oya basin is a significant community asset, being generally of high quality, and productivity. It provides water predominantly for irrigation activity especially paddy cultivation through natural springs and in addition for drinking and other activities through dug wells and tube wells.

In early 1960s, Beliatta Town Water Supply Scheme was implemented using a natural spring as a source, also used by farmers. It was reported that at the beginning there had not been any complaints on shortage of water for irrigation. As time passed with the development of the area, farmers were affected by shortage of water for paddy cultivation. The main cause highlighted for shortage of water for paddy cultivation was the usage of spring for town water supply.

At present, this spring is pumped for 10 hours a day and is allowed to free flow to the channel for the irrigation purposes. The total daily abstraction from the spring for town supply is about 570 m3/day. But the present demand is estimated to be 1500 m3/day for the 8000 people. Due to the objection from farmers against the use of spring for augmentation of Beliatta Water Supply Scheme, it is essential to find new sources.

As there is no perennial and reliable surface water source in the vicinity of Beliatta town and the groundwater was found to be the only reliable and economical source, it was proposed to abstract groundwater through tube wells, which seemed to be the most appropriate. Locations for tube wells were earmarked in the vicinity of spring zone.

Residents who lives in the area where natural springs occur do not favor the locations of tube wells in their territory, on the ground that such large abstraction might exhaust their exiting water resources with time. It was decided to construct several tube wells in high productive zones with a substantial distant apart and no influence on each other.

Subjected to the result of hydrogeological investigation and also the views of the community, productive tube wells were constructed at the most promising zones. The wells were subjected to long term pumping test during the drought with a view to understand groundwater scenarios and to evaluate the aquifers. Even though each tube well has sufficient capacity to meet the demand of Beliatta W.S. S, three tube wells were constructed at different locations with the controlled rate of abstractions subjected to the results of pumping test in order to have negligible impact on environment.
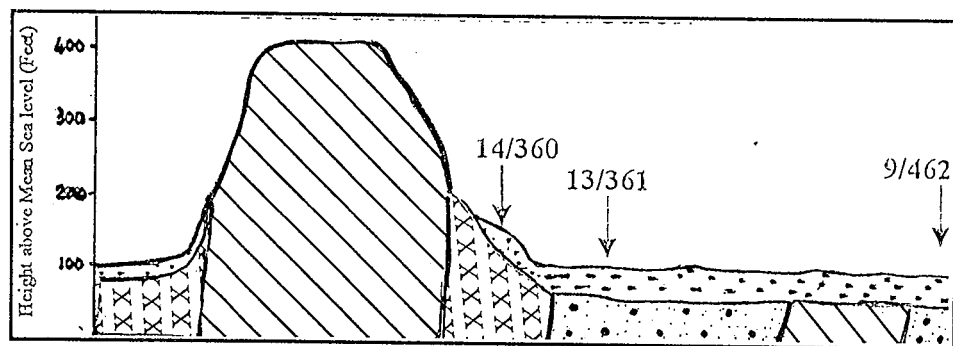
As hard rock fracture aquifer is more productive, more emphasis was given to the study of tectonic pattern to locate tube well sites. At the sametime, geological structures and lithologies were also studied through interpretation of aerial photographs.

GEOLOGY MAP OF THE STUDY AREA
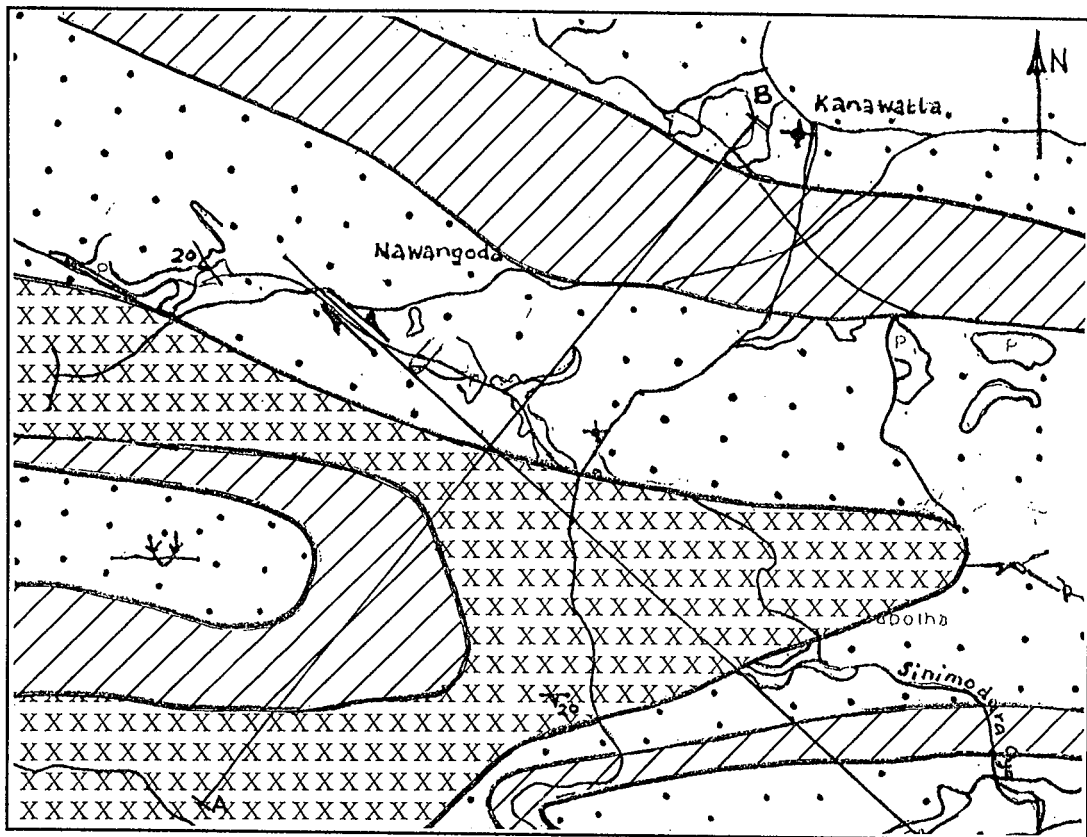
SCALE 1:63,360

GEOLOGICAL CROSS SECTION ALONG LINE "AB"

LEGEND

Garnet Sillimanaite Gneiss		Regolith		Overturned Syncline		
Undifferentiated Meta-Sediments		Fault		Geological Boundary		
Charnockite		Foliation Direction				

Fig. 2

2.0   BACKGROUND

2.1   Topography

The study area is mainly in the coastal peneplain of Sri Lanka with an elevation below 200 meters and shows "undulating topography" with a few isolated hills. Low mountains range namely "Wawulugalakanda" and "Godawela kanda" lay trending in the direction more or less in the North-West with few peaks. Main dranage in the study area, Sinimodara oya flows in between these two mountains. Kirama oya flows north of Godawala kanda.

2.1   Geology

The study area occupies charnockite, garnet sillimanite gneiss, undifferentiated meta-sediments (garnet granulite and garnet biotite gneiss) and intrusive rock such as granite and pegmatite. Overturned syncline and anticline are trending in East – West direction and plunging towards West (see Fig. 2). Regional trend of rock is in East-West direction and dipping towards South. Rock dipping varies and ranges from 20^0 to 50^0. Regional geological faults extend in Northwest direction. While geological lineaments exist extending in various directions with more or less vertical dipping.

Thickness of soil cover of hard rock varies from place to place. They are thicker on garnet sillimanite gneiss whereas thinner on charnockite. Alluvium is developed along lower reaches of Sinmodra oya alongside geological fault. Thickens of alluvium cover is generally shallow.

2.3   Climate

The study area falls into intermediate zone bordering the wet zone from the West and dry zone from the East. According to monthly mean rainfall of past thirty years, highest rain prevails during October to November while dry weather prevails in Januray to March. The mean annual rainfall is 1675mm (see Fig 3).

Fig. 3   MEAN MONTHLY RAIN FALL
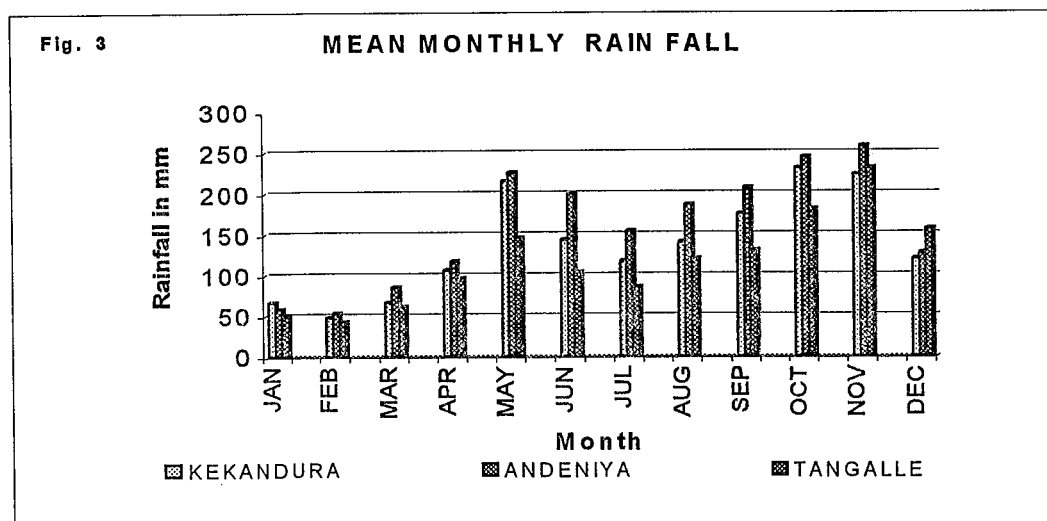
2.4   Drainage

The study area drain water mainly through Sinimodara oya and minor portion through Kirama oya. Sinimodara oya is seasonal stream and catchment of the Sinimodara oya is 38 Sq.Km. It carries substantial amount of water to the sea during rainy season and it is estimated to be 82 cum x10 ^{6}, 35% of precipitation (National Atlas). Interesting feature of Sinimodara oya is that perennial natural springs fed the stream from start to nearing to the sea.

NATURAL SPRINGS

There are seven major springs and many number of small springs found in thick clay cover and hard rock areas. Out of these springs, the highest yield is recorded from Eldeniya spring and its yield is 800 lpm during the dry season in 1986. The quantity fed to the stream by measurable springs is about minimum of 3500 lpm (1.8 cumx 10^6 annually).

3.0   HYDROGEOLOGY

Hydrogeology of the study area is very closely related to the lithology, tectonic, geologic structure, topography, vegetation and the climate. According to the occurrence of groundwater, aquifers can be categorized into three main groups;

1. Regolith of Hard rock
2. Weathered rock
3. Fractured hard rock.

These aquifers can be further subdivided into three main groups according to hydrostatic pressure namely unconfined aquifer, leaky aquifer and confined aquifer. Generally regolith and weathered rock aquifers show unconfined condition. They are seasonal and limited to where regolith cover is less. Water from the unconfined aquifer which exists in the strike ridges and flows downward through regolith cover as well as hard rock fissures. Water which flows through hard rock fissures and emerge at lower reaches as springs

3.1   Regolith Aquifer

Regolith aquifer of hard rock, unconsolidated deposit over the hard rock is of important for domestic water supply by means of shallow dug wells. This aquifer spreads all over the study area and it is seasonal to areas wherever hard rock encounters at shallow depths. The yield of regolith aquifer is low and estimated to be in the rang of 5 to 100 lpm. The important factors of this aquifer are thickness of aquifer, hydraulic conductivity and the storage. Thickness of regolith cover varies from 0 to 22 m and it is thick over the garnet sillimanite gneiss rock. It is shallow along the path of Sinimodra oya and wherever charnockite rock and granite occur.

3.2   Weathered rock aquifer

This aquifer is little important because it is thin and it lies between the regolith and the fresh hard rock.

3.2   Fractured Hard rock aquifer

This aquifer is important for all the activities such as irrigation through natural springs, drinking and other purposes through tube wells. This aquifer has a characteristic of high permeability wherever fracture has substantial width of fracture opening, extend widely depending on the degree of the post-tectonic involvement. It is also important in carrying water from far distant along major lineament. Natural spring found in the study area is fed through hard rock fractures that exist in prominent lineament patterns. The yield of this aquifer varies drastically, 1 to 3500 lpm, depending on the degree of opening of fracture, and infilling of fractures by weathered products of fracture plane. Local fractures exist generally just below the weathered portion of rock and the yield is moderate (1 to 50 lpm). Tube well, which encounters only this fracture system, is not reliable since it is attributed to limited extension of the aquifer. According to results of 109 no. of tube wells drilled in the area for various reasons, air flushing yield on fracture depths were studied and variation of air flushing yield is shown in 4a. Frequency of occurrence of tube wells by air flushing yield in the study area is shown in Fig. 4b.
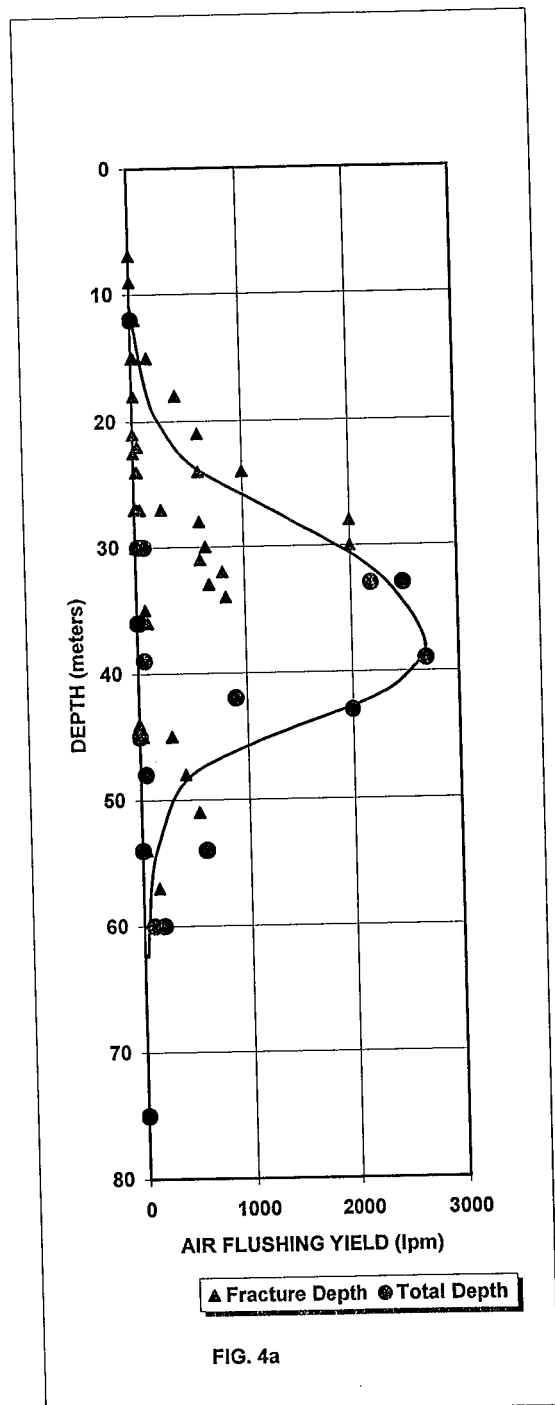
3.3   Ground water quality

Water quality of regolith aquifer is of acceptable in almost all the areas studied, except southeastern part. Electrical conductivity of water in Northwestern hilly terrain is low 90 micro mho/cm while in southeastern part it rises to 1000 micro mho/cm. However, in fractured hard rock aquifer, it is very high, as much as 10000 micro mho/cm, in southeastern part.

4.0   PROCESS OF INVESTIGATION

Hydrogeological investigation includes chemical quality surveys, preparation of tectonic maps with the aid of interpretation of aerial photographs, geo-electrical soundings, hydro-geological mapping, drilling of tube wells and performing of pumping tests in the study area. In the process of hydrogeological investigation, much emphasis of was laid on identification of possible impacts on the spring zone, due to abstraction of water for the above town water scheme.

Ground water information data such as tube well information, geologaical map of the area, aerial photographs, and data of previous works etc, also were collected. Tectonic map prepared through interpretation of aerial photographs was superimposed on geological maps and topographic map. Exact location of major predominant geological

VARIATION OF AIR FLUSHING YIELDS WITH FRACTURE DEPTHS

FREQUENCY OF OCCURRENCE OF TUBE WELLS BY AIRF LUSHING YIELDS

AIR FLUSHING YIELD (lpm)

▲ Fracture Depth ● Total Depth

FIG. 4a

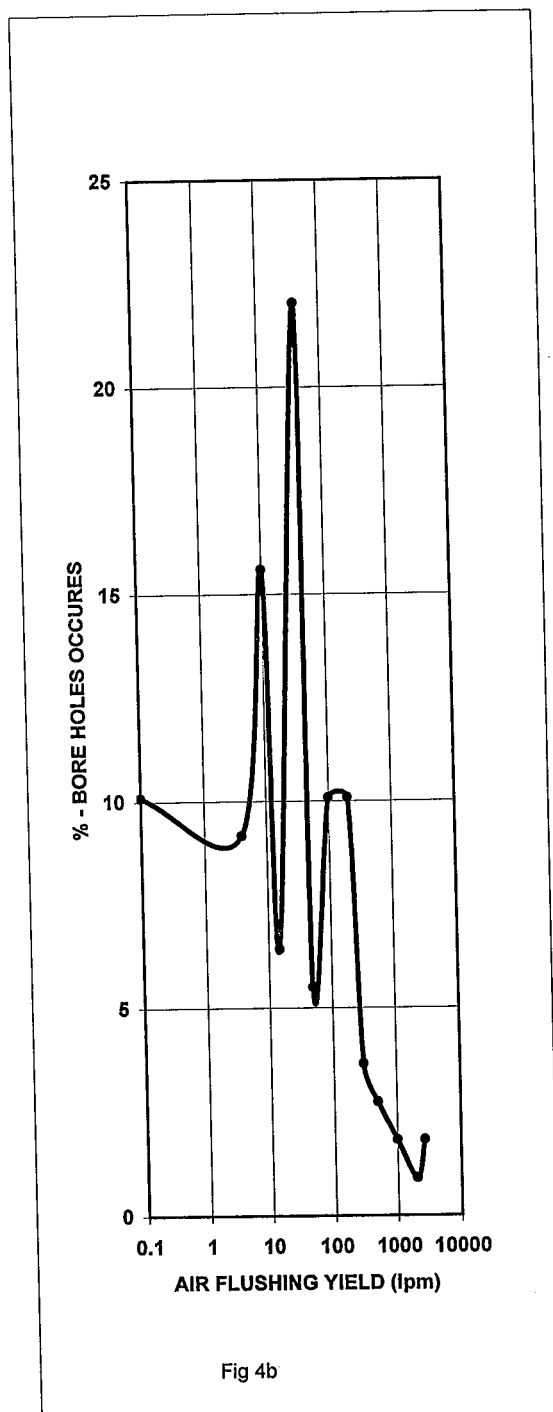AIR FLUSHING YIELD (lpm)

Fig 4b

Fig 4

lineaments, which were identified through the study of geological maps and aerial photographs, were located in the field running electrical resistively profiling. The possible locations were further studied by electrical soundings using sclumberger array.

Water samples collected from shallow dug wells, of which temperature and electrical conductivity were measured in the filed. The samples were analyzed chemically in the laboratory in order to find clues to delineate aquifers.

Locations for drilling sites were selected in consultation with the community in the spring area to avoid disputes among users. After construction of tube wells, they were subjected to perform pumping test for 3 days following step draw down tests. Prior to the pumping tests, water level of tube wells were monitored fixing auto recorders for few weeks to understand the pattern of water table fluctuations. During the process of pumping tests, pumping water level, water levels of wells in the vicinity of pumping well were monitored and springs were also gauged.

The pumping test data were analyzed using numerical model for two zone layered aquifers formulated by Prof. K. S. Rathod and K. R. Rushton. After calibration of model for feeding well and aquifer data, the curve was extrapolated to six months to obtain desired drawdowns at given rates.

Finally pumping rates were recommended to abstract groundwater from the fractured hard rock aquifer so that impacts on springs and nearby shallow well due to groundwater pumping are to be insignificant. In order to meet the demand of Beliatta water supply scheme, two tube wells in Sinimodara oya basin and one in Kirama oya basin were constructed.

5.0   NATURAL SPRING AND HYDROLOGIC CYCLE

Natural springs situated in this area are recharged locally. Schematic diagram of occurrence of springs and recharge is shown in the fig 5.

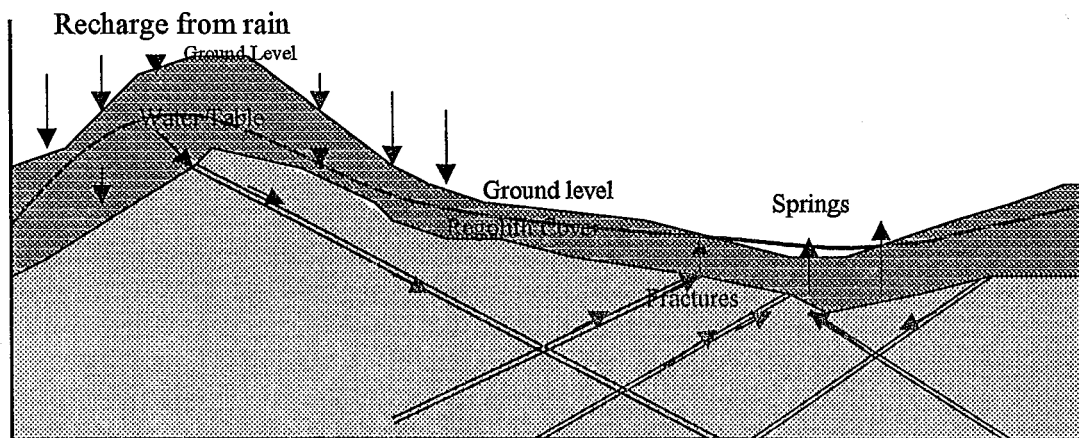Fig. 5   Shematic diagram of Occurrence of spring and probable way of recharge

ISOLINE MAP OF AIR FLUSHING YIELD OF TUBE WELLS IN THE STUDY AREA

NO 0F TUBE WELLS STUDIED   = 75

Origin of Metric Scale is 200 Km South and 200 Km West of Pidurutalagala

Fig. 6

When the groundwater potential is concerned, groundwater scenario must be visualized and it is also needed to establish water balance in the study area. The catchment of water balance could be represented in following equation.

Precipitation of Rain = Evapotranspiration + Surface Run-off + Change in soil moisture content + Ground water withdrawal + change in Ground water storage + Under flow to other regimes + Under flow to the sea + Etc.

Change in ground water storage = Recharge from Rain – (Evapotranspiration + Surface Run-off + change in Soil moisture content + Ground water withdrawal + Under flow to other regimes + Under flow to the sea + Etc.)

The above equation shows that change in groundwater storage is a function of man made activities, such as land degradation and groundwater withdrawal through wells, and the natural phenomenon of hydrological cycle. Ground water withdrawal to meet the demand of the development process, whenever it is more economical and reliable, is inevitable to control the abstraction. However, groundwater loss due to increasing of paved areas, soil erosion, etc. could be minimized through implementation of community awareness Programme.

CONCLUSION

Productivity of hard rock aquifers could be approximated by the air-flushing yield during the process of well construction. When air-flushing yields of tube wells are plotted and contoured, it shows a pattern. High yielding tube wells are concentrated in direction of Northwest and Southwest directions parallel to the predominant lineaments (See Fig. 6). In addition, they are also situated in adjacent to prominent major geological lineament. Tube wells in the Northwest fault zone is the most productive zone in the studied area.

Based on the results of hydrogeological investigations, a map was prepared according to hydrogeological characteristics of aquifers (see Fig 7). Seasonal regolith aquifer confines to charnockite and undifferentiated metasediment rock with shallow overburden.

Non pumping water levels on productive tube wells show two lows and highs per day to be suggested to have a relationship with the sea tides.

Temperatures on all spring waters remain consistent and were 26^0 Celsius, which is 1^0-2^0 higher than in shallow dug wells in recharge zone. Temperature in dug wells with stagnant water show high values attributed to dosage of solar energy.

# HYDROGEOLOGICAL MAP OF THE STUDY AREA
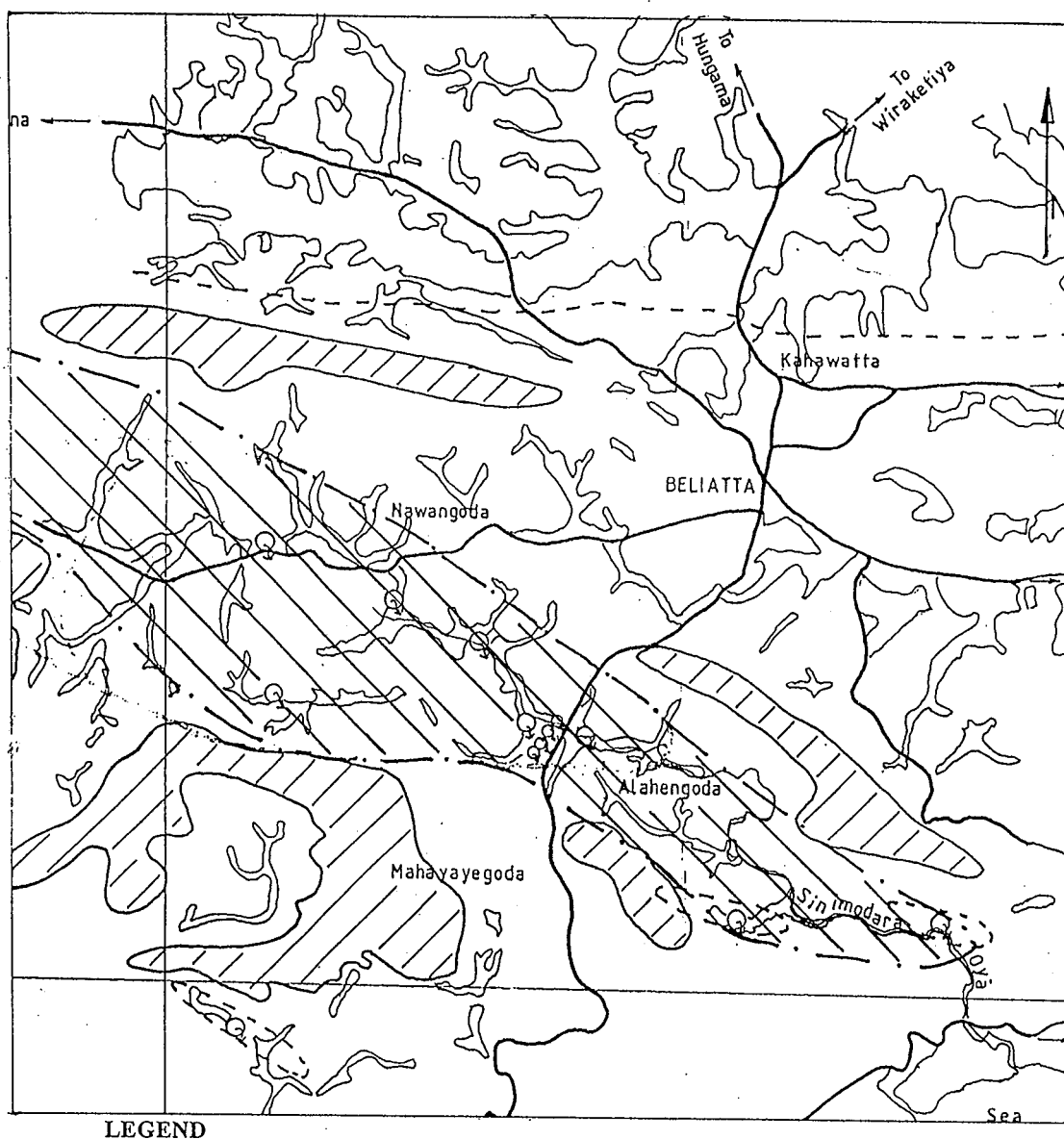
LEGEND

▨ Seasonal Unconfined Aquifer		▱	Paddy Fields
◩ Leaky / Confined Aquifer		▭ Q	Natural Springs
▭ Unconfined Aquifer		╱	Road

Fig. 7

Each tube well constructed for the said water supply scheme has a capacity to pump the demand. But to minimize the impacts to other users three wells were constructed too apart from each other.

It was observed that earlier forest cover has been removing by people settling in higher reaches. This cause lands degradation and in turns reducing contribution from rainfall to groundwater by increasing of runoff. This phenomenon plays a main role in reducing water in springs other than ground water withdrawal for various purposes. This could be corrected through the community awareness program to grow vegetative cover to minimize the run off.

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RESEARCH PAPERS PRESENTED

Session No.20 6 November 1998 *9:00 a.m.*

Water Management Challenges

Paper No.26
Wijayaratne, L.K.W.
De Zoysa, Mangala
Socio-Economic Achievements Of The Lunugamvehera Irrigation Settlement In Sri Lanka: A Comparative Study

Paper No.52
Bakker, Margaretha
Multiple Uses Of Water in the Kirindi Oya System, Sri Lanka

Paper No.72
Barker, Randolph
Samad, M.
Food Security And Irrigation Development In Sri Lanka: Past Achievements And Future Prospects

SOCIO-ECONOMIC ACHIEVEMENTS OF THE LUNUGAMVEHERA IRRIGATION SETTLEMENT: A COMPARATIVE STUDY

by

L. K. W. Wijayaratne and Mangala De Zoysa
Department of Agric. Economics
Faculty of Agriculture
University of Ruhuna
Mapalana

ABSTRACT

Irrigation settlements in Sri Lanka draws thousands years of history with glory and prosperity of the nation based on agriculture. Those settlements were established with due consideration of availability of water, natural environment and topography in addition to the socio-economic requirements of the settlers. The Lunugamvehera settlement under the Kirindi Oya Irrigation Settlement Project was commenced in 1979 with the aim of sustainable food supply, generation of employment and equity distribution of income among the land less poor. Nearly after two decades, a comparative analysis of socio-economic status of the settlement with a nearby traditional village has become a practical significant in order to evaluate the success of the settlement.

In addition to the secondary data, primary data were collected for the study through an in-depth field survey of informants randomly selected from Lunugamvehera settlement and the adjoining Koholankala traditional village. The paper examines the existing institutional setting in the settlement that attempts to uplift the socio-economic status of the settlers. Empirical evidence revealed the facts that there are significant differences of socio-economic status in terms of Education, Health, Agriculture, Employment, and Income and income distribution between the two locations. Further, the main factors particularly irrigation policy that influenced for those discrepancies are discussed.

BACKGROUND

From the time the human civilization occurred, there had been gathering of people as social units. History of Sri Lanka provides information on settlements established under irrigation networks centered on large man-made water reservoirs, which claims a prominent place of the amalgamation of people particularly in the dry zone. In Sri Lanka, the Kirindi Oya Irrigation & Settlement Project (KOISP) which commenced in 1979 implemented a large scheme for settlement of the people in the southern region. The project emphasized the generation of employment, sustainable food supply and equity distribution of income among the poor settlers (Wanasighe, et. al., 1984).

The KOISP was initiated with constructing Lunugamvehera reservoir by crossing the Kirindi Oya, which begins, from Rawana Ella near Wellawaya. The capacity of the reservoir is 1,86,000 acre-feet that sufficient to provide water for the area of 455 square miles (11,174 square meters). Reservoir covers about 7,438 acres (3,011 hectares) of

1

agricultural lands and the dam is 3.25 miles (5.2 km.) in length. Crest level of the reservoir is 191 feet(57.3 meters) above the sea level. To release the water in excess, when the reservoir is full, there are 6 sluices each 50 × 16 ft. (15 x 4.8 meters) in dimension. Right Bank Canal (of Lunugamvehera reservoir is 22 miles (35.2 km.) whereas Left Bank Canal (LBC) is 16 miles (25.6 meters). The land under cultivation using the water distributed by the reservoir is estimated as 25,826 acres (10,455 hectares) (ARTI, 1994).

The present study has been conducted nearly after two decades of the commencement of the KOISP. In fact, it is quite meaningful and is of practical significance for such a study to be conducted to investigate the merits and demerits of the project and at the same time to propose suitable solutions in order to avoid the shortcomings, if any, on behalf of the settlers.

To understand the socio-economic achievements of the settlement project, a comparison of the data and information was done with a traditional border village that was not subjected to the settlement. The selected village: Koholankala where the population is around 1136 belongs to 315 families. The population in Lunugamvehera is 28,353 which is very large compared to that in Koholankala. Hence, disproportionate stratified random sampling technique was adopted for field data collection. Secondary data were also collected from many institutes and organizations such as Divisional Secretary's offices at Lunugamvehera and Hambantota; schools, resident project manager's office of Irrigation Management Division at Lunugamvehera, Grama Niladari officers, etc.

The study is indeed a comparison of socio-economic achievements as the impacts of different water management strategies in the settlement and a traditional village. During the study it was projected that almost all the problems in Lunugamvehera settlement area were based on some kind of problems related to water. The paper attempts to discuss these problems as found through the empirical study.

AGRICULTURAL DEVELOPMENT

The settlers in Lunugamvehera are predominantly paddy farmers. Almost all of them (88%) cultivate paddy on the land holdings larger than 2 acres (0.81 hectares). Further, 90% of the settlers also cultivate upland crops on the land holdings less than 1 acre (0.40 hectares) that were distributed by the project among the each settler. The lands cultivated by 96% settlers are their own lands while only 4% are tenants. Type of possession of land is almost the same both in Lunugamvehera and Koholankala where farmers having the land of their own. Land tenancy is experienced in Lunugamvehera while land encroachment could be observed in Koholankala, at very low levels. In Koholankala, 88% of the villagers have their own lands inherited from their parents. The rest 12% of the villagers have encroached lands form the government forest. Holding sizes larger than 2 acres (0.81 hectares) are cultivated with paddy by 56% of the villagers while 44% cultivate paddy on smallholdings less than 1 acre (0.40 hectares). In addition to paddy 86% of the villagers cultivate upland crops on more than 1 acre (0.40 hectares) of lands that are larger in extent compared to Lunugamvehera.

Under the low rainfall conditions prevailing in the area, the farmers in both Lunugamvehera and Koholankala cultivate paddy only for one season per year. Hence, the land used efficiency is very low in Lunugamvehera compared to Koholankala where there are large extent lands are cultivated with paddy under irrigation water supplied from Lunugamvehera reservoir. Paddy farmers in Koholankala are mainly depend on the seasonal rainfall except the few farmers who receive some water from Maha Aluthgam Ara. Evidently, the inappropriate water management policies and strategies of the settlement have further resulted with low productivity and low incomes from their paddy lands. In the occasions of not having sufficient water, water is first supplied to the Tissa area as it was promised and then supplies the water either to left or right-bank depending on the availability. If the water is supplied to the left bank, canals of right-bank are closed and same as for the supply of water to the right-bank. In some areas under the KOISP, sugar cane cultivation is prominent. In these cases, motors are operated throughout 24 hrs to obtain water illegally from the water channels. Even the reservation areas and riverbanks which are under the sugarcane cultivation could be observed in the area. Therefore the duty of water received form the Lunugamvehera reservoir is lower than it was predicted. Apparently, the duty of water in Lunugamvehera reservoir is not sufficient to irrigate the KOISP where 26,058 acres (10,550 hectares) of paddy lands and other field crops are cultivated.

The government policy direct towards the rehabilitation and improvement of irrigation schemes through cropping intensities (IIMI, 1995). It has been proved that the possibility of growing other field crops successfully in large potion of KOISP even during the low rainfall seasons (Weerakoon, 1993). The average cropping intensity of irrigation schemes in Sri Lanka has been estimated as 130%. Even though the KOISP is highly vulnerable for water deficit conditions, only 10% of the farmers have adopted both crop diversification and crop rotation, 20% have adopted only crop diversification and 10% have adopted only crop rotation as the remedial measures. The "Samurdhi Program" has constructed Agro-wells with 1.5 –3.5 meters in diameter and 3-6 meters in depth at different locations of the settlement to provide the farmers with water for their field crops. In addition to the traditional paddy cultivation, farmers in Koholankala are intensively cultivating their highland with wide range of field crops. As they have considerable extent of highlands, they are equally concerned about both paddy and field crops in order to secure their stable income flows. Crop diversification and crop rotation in upland cultivation are seen higher in Koholankala than in Lunugamvehera. According to the respondents, 36% of the farmers have adopted both crop diversification and crop rotation while 42% have adopted only crop diversification keeping their incomes comparatively at higher level. These conditions have paved the way for better condition in Koholankala, especially in relation to agriculture and economy, than in Lunugamvehera. Unlike in Lunugamvehera, home gardening is also popular in Koholankala.

It is noteworthy that 16% of the settlers in Lunugamvehera utilize only their family labor while a considerable number of families (24%) utilize only paid labor for their agricultural activities. As an attempt to reduce the cost of production and to cope with

diverse requirements, 32% of the families in Koholankala utilize only their family labor for the agricultural purposes. Only a very few families (8%) utilize only the paid labor for the purpose.

Occasionally the settlers in Lunugamvehera are engaged in rearing of buffaloes. Apart from paddy cultivation, few settlers have adopted upland crops such as banana, sugar cane, chilies, green-gram, cowpea, groundnut, maize, red-onion and vegetable. Indeed, the upland cultivation has become an appropriate solution for the deficiency of water for paddy cultivation. Considering the duty of water needed for one acre (0.40 hectares) to be cultivated, evidently, upland crop cultivation needs even less than half of the amount required by a paddy. Further, they are reluctant to cultivate field crops due to their failure to protect the crops while residing at a distance average of 1 km.

EMPLOYMENT OPPORTUNITIES

Almost all the people in both Lunugamvehera and Koholankala are farmers as their main source of income. Especially settlers in Lunugamvehera are farmers purposively selected for agricultural settlement. Hardly find any settlers who are engaged in other occupation except a very few (5%) as unskilled daily paid labors working in agriculture within the settlement. Though the people in Koholankala are engage in farming, 18% have some other employment opportunities as main occupations. Some of them are employed in the government and private sector as teachers, staff officers, clerks, mechanics etc. in the village and nearby urban centers. Others such as merchants, masons, carpenters etc. are working in the village and outside the village as well.

On the contrary, the villages in Lunugamvehera are strictly dependents on paddy cultivation. Therefore, as usual, when there is a shortage or lack of water, a crop failure is approached and consequently there appears a want in income. Indeed, it is very hard for them to find even labor works as the problem is common to a very large number of settlers. In most instances, the government has to provide them with aids and subsidies merely for their survival.

Throughout the generations, the villagers in Koholankala have upgraded their educational level and have exposed to the societies outside their village. Many better-off villagers usually send their children to the reputed schools in urban cities for the higher studies. Therefore, even though there are no enough employment opportunities available in the village, they have the opportunities to find employment in the else where particularly in the urban centers through the personal contacts. However, the settlers in Lunugamvehera are farmers and land-less labors selected from the poor families about 20 years ago. They have not yet being able to upgrade their educational level or skills to find employment other than farming. On the other hand, with the rapid increase of population, fragmentation of lands and worsening of land man ratio, a category of land-less labor are being gradually emerged within the settlement. Lack of agro-based industries or any vocational training programs within the settlement may further leads to the unrest particularly among the youth of the settlement.

INCOME AND INCOME DISTRIBUTIONS

Income levels of farmers and their families can also be taken into account in determining the socio-economic condition of the settlement scheme. Majority 56% of the farm families in Lunugamvehera settlement earn around Rs. 5,000 ~ 20,000; 20% earn less than Rs. 5,000 and only 24% of the settlers are able to earn more than Rs. 20,000 per annum. Most of the settlers (82%) are frustrated that their total incomes are equal or less than the total requirement for annual expenditure. On the other hand, 32% of the respondents are experiencing with fluctuating incomes, 42% are experiencing with decreasing incomes while only 26% are experiencing with increasing income through the successive years. As the settlers in Lunugamvehera are mainly depend on subsistence agriculture, they are not in a position to reinvest in their agriculture. Therefore, it is hard to see any improvement of their income levels through the successive years. Fragile farming systems dominating by paddy cultivation is highly dependent on the supply of water. Lack of water and problems of water management in the settlement directly affect not only the income but also the survival of a large number of settlers. Hence, the government very often has to bear a burden of providing the settlers in Lunugamvehera with drought relief subsidies.

Compared to the Lunugamvehera settlement, villagers in Koholankala have favorable incomes and also an equitable income distribution. According to the study, 78% of the farm families are earning more than Rs. 20,000 per annum. Under the rural setting, the total expenditures of 64% of the villagers are less than their total incomes. They have different sources of income from farming and non-farm occupations as well. Therefore, they are fewer dependents on agriculture to some extent and also less susceptible for the adverse farming conditions emerged through water management problems. Further, the adoption of diversified farming systems by farmers and availability of supporting services established for long period in Koholankala have attributed to the higher incomes and stable income flows. Moreover, 74% of the villagers in Koholankala are experiencing with increasing in incomes through success years. In response to the higher incomes and household savings, the farmers are intended to reinvest in their farming as a profitable enterprise.

EDUCATIONAL STATUS

As it was found during the study, people in Lunugamvehera is lower in educational level than those of Koholankala. The settlers selected for Lunugamvehera were mainly farmers and land-less labors who have invariably with low educational levels. Only 52% of the respondents have secondary education while 12% are illiterate. There are 20 primary schools and 5 secondary schools in Lunugamvehera project area. According Wanasinghe et. al, (1983), the literacy rate in the settlement has been increased from 85.5 percent in 1981 to 95.7 percent in 1994 also narrowing the gap of educational levels between male and female. However, the study revealed that 6.4% of their family member are still illiterate and 50% are school droppers from the primary level. Among the many reasons, poor family income, family labor requirement for agriculture and lack of family counseling to encourage the children to go to schools have become prominent. Low

facilities available at schools and the facilities being not in the standard for higher education as expected by the students is also discourage their higher education. As a solution, some of the children are attending the schools outside Lunugamvehera. Commonly, lack of employment opportunities in government or private sector at their vicinity has not created a favorable environment for the children to continue their studies.

Koholankala as an traditional village for centuries has developed social and economic status that encourage their younger generations to moves together with socio-economic advances of the country. Not only the 78% of the farmers, 88% of their family members are having high educational qualifications above the secondary level. The favorable income levels of the families have influenced the parents greatly to send their children for higher studies at reputed schools in nearby urban cities. The school children are not allowed to work in their farms during the school hours. Further, the educated parents in the village make effort and wish that their children become salary earners in government or private sector employment other than become a farmer.

HEALTH AND NUTRITIONAL CONDITIONS

The number of families earns income sufficient to secure their health and nutritional conditions are lower in Lunugamvehera than that of Koholankala. About 60% of the farm families responded in Koholankala earn income from agriculture and other occupations sufficient to provide nutrition requirements of their families. However the settlers in Lunugamvehera have no other alternative but agriculture which provide sufficient income only for 38% of the farm families to cater their nutritional requirements. It has been revealed that 14% of the families in Lunugamvehera are presently suffering from nutritional deficiencies. The government has launched a social welfare program to distribute "Three Posha" a nutritious food among those families with free of charge. It could be observed that the poor educational levels particularly of mothers have further aggravated the nutrient deficiencies among the children. Many mothers interrogated have no enough knowledge about the minimum nutritional requirement for their children.

There is no much difference regarding the health conditions in both Lunugamvehera and Koholankala. After commencement of the KOISP, 1 hospital and 2 dispensaries have been established to improve the health facilities of the settlers in Lunugamvehera settlement. They can easily reach the hospital within the distance of average 5-km. As there is no hospital, the villagers in Koholankala have to travel average of 10 km. to reach a hospital in Hambantota. Occasional outbreaks especially of malaria is experienced in 22% of the families in Lunugamvehera which is little more (18%) than that in Koholankala.

Evidently, in addition to the hospital many investments have been done by the government and non-government organizations to improve the health and sanitary facilities in Lunugamvehera. With the irrigation difficulties, lack of drinking water in the area also has become a severe problem face by the settlers. From the settlers 98% receive drinking water through pie-bone water supply schemes. The Water Resource Board together with World Vision Aid Program have constructed more than 200 tube wells to

provide potable water especially in Mattala, Ranawaranawa & in right bank areas. Poor quality of the water obtain from tube-wells are not utilized as potable water but utilized for other household purposes. The KOISP has constructed 37 dug wells and also supplied pipe-born water for selected areas to solve the problems related to drinking water. The settlers however, utilize the drinking water for other purposes particularly agriculture. Supply of drinking water is not being considered as a problem in Koholankala. As an equal source, 46% of the families obtain their drinking water from wells that are considered as uncontaminated and protected sources by the villagers.

Existing lavatory facilities which is an another key factor indicate the hygiene, is in poor condition in Lunugamvehera. Lavatory facilities mainly water-sealed toilets are available for 86 percent farm families in Koholankala. In Lunugamvehera, 44 percent of the settlers still use poorly constructed and unhygienic pit toilets, which required a little amount of water. Unhygienic lavatory facilities and poor quality drinking water supply are the main causal factors for epidemic of infectious diseases in the settlement.

INFRASTRUCTURE DEVELOPMENT

Post-harvesting problems such as fungal and insect pest damages are common in both Lunugamvehera and Koholankala. However the post harvest problems and marketing problems are prevailing in Lunugamvehera are much more severe and complicated than in Koholankala. Evidently, comparative low income from their agricultural products in Lunugamvehera is mainly caused by post harvest problems and marketing problems. The establishment of 25 co-operative shops and sales center (weekly fairs) by the KOISP emphasized the provision of marketing facilities for the products of the settlers. The study revealed that 48% of the respondents in Lunugamvehera face the problems related to the marketing of their products. On the other hand, almost all the farmers produce homogeneous products that are abundantly supply to the market during the harvesting season. Amount and frequency of supplying irrigation water in the settlement is the key determinant of the agricultural production. Therefore, the existing inefficient and poorly developed marketing structure with traditional marketing technologies has no sufficient capacity to absorb their products effectively. Further malpractices unfair transactions of the traders have also led to poor performances of the marketing system. In Koholankala, only 22% of the farmers face problems related to marketing of their products. Long-term experiences and diversity and stability of their product supply have developed market led production systems.

To minimize the risk and uncertainty in farming 32% of the farmers in Lunugamvehera have obtain crop insurance policy from the Crop Insurance Board. According to them, the main risk and uncertainty prevailing in the area is the amount and frequency of distribution of water throughout the settlement by the KOISP authorities. Additionally, 16% of the settlers have obtained input subsidies from government aid programs. The farmers in Koholankala are neither crop insurance holders nor the recipients of government aid programs. They invest their own resources in agriculture at own risk and uncertainty with the aim of promoting their agriculture.

Percentage of farmers obtains formal credit facilities for cultivation is negligible in Lunugamvehera. The reasons they pointed out were the difficulty in repaying, risk of low income in case of crop failure, low enthusiasm and unfamiliar circular procedures. In fact, the main reason for inability of obtaining loans is resulting of the negligence of repaying their previous formal loans. Even the farmers in Koholankala are reluctant to obtain formal credits because they consider it as an extra burden.

Condition of roads, bus service, communication facilities, electricity and conditions of houses, all are found to be at a lower level in Lunugamvehera compared to the respective of Koholankala. According to Wanasighe et. Al (1983), road network consisting homestead roads, feeder roads and linking roads have been constructed and improved in Lunugamvehera by the project. Presently, 96.3 percent of the households are accessible by a vehicle. Other infrastructure facilities such as transportation, electricity, communication etc. have yet to be developed in Lunugamvehera compared to Koholankala.

FARMER ORGANIZATIONS

The Kirindi Oya Management Committee comprised of 22 government officers and 30 farmer representatives selected from the settlement. Further, each Sub Project Committee (SPC) under the management committee is comprised of Distributory Canal (DC) organizations, farmer representatives and the government officers. Field canal organizations and farmers where the Field Canals (FC) that are nurtured by Distributory Canals (DC), are belonged to the sector which lies under Sub Project Committee (SPC).

When the water in the Lunugamvehera reservoir is at a low level, Distributory Canal (DC) is closed. From the distributory canals many Field Canals (FC) are fed. These field canals have been typically designed to discharge 28 liters of water per second (IIMI, 1994). As a result, it has been found that there are conveyance losses in distributing water through these field canals. Further the water distribution through the distributory canals is also not that satisfactory according to the farmers. Hence, the farmers have got use to obtain water from some other canals which leads to many quarrels among the settlers.

According to the respondents, 86% of the farmers in Lunugamvehera are members of the farmer organizations. However, they are not satisfied with the role that the organization is playing to perform its functions and responsibilities. Cultural and social disparities among the settles who came to the settlement form different locations often hinder their mutual understanding and the cooperation. Many landowners are not residing in the settlement. They mainly do farming through hired labor or the tenant farmers (De Zoysa, 1998). Although the farmer participation in the organizations is comparatively low (52%) in Koholankala, their strong cooperation could be observed. They are working together with mutual understanding to share water resources in faire manner as they have strong social obligations developed through generations.

Farmer organizations have not yet being developed to cater their supporting services such as marketing, credit, communication etc. both in settlement and the adjoining traditional village.

CONCLUTIONS

The socio-economic achievements of the Lunugamvehera settlement are far below compared to the achievements in the adjoining traditional village Koholankala.

Lack of sufficient water and poor water management policies have paved the way for almost all the socio-economic problems, which are encountered in the settlement.

The farmers in Koholankala, through their experiences over generations, have adopted farming systems and cropping patterns to cope with the prevailing conditions particularly the availability of water and agro-climatic environment. Further, their market led diversed production systems maximize their incomes from the agriculture.

In appropriate irrigation policies and inflexible attitudes of the settlers to adjust their cropping pattern suitable for the availability of water have resulted with uncertainty of production and poor income from their farming

Unlike in Koholankala, no opportunities have been developed in Lunugamvehera for other occupations other than farming. As the farming in occupation, the settlers have no skills or experiences for other occupations.

Low-income levels of the farm families that obtain from agriculture bound with water supply have paid poor attention by the settlers for the education, health and nutritional status of their families.

Social and cultural disparities and poor motivation of the settlers still prevent them taking collective decisions for sustainable resource management.

POLICY IMPLECATIONS

Attitudes and behaviors of the settlers have to be changed through multi-disciplinary extension and educational approach to adopt them farming systems with profitable cropping patterns compatible with the prevailing water availability and agro-climatic conditions.

Market driven production systems have to be established by encouraging the private sector involvement with efficient and faire marketing strategies.

The farmers have to be empowered through local institutional development to manage their own local resources particularly the water and land with environmental and social harmony.

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Promotion of agro-based industries in the settlement may facilitate not only the value addition to their products but also the absorption of excess labor in farming, equitable distribution of income and prevent the land fragmentation due to the rapidly increase of the population.

Establishment of government sponsored social services and counseling program would play and immense role to educate and train the settlers and their families to upgrade their educational, hygienic and nutritional status.

ACKNOWLEDGEMENT

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Multiple Uses of Water in the Kirindi Oya Irrigation System, Sri Lanka

Margaretha Bakker

International Water Management Institute
PO Box 2075
Colombo
Sri Lanka
Email: m.bakker@cgiar.org

Abstract

As water scarcity intensifies, there will be an increasing pressure to transfer water from agricultural uses to municipal and industrial uses. It is not possible to predict the full impact of such actions with our current base of knowledge. Researchers, policy-makers, and agency staff involved with water resources have too long focused on only one water use, either irrigation or domestic use when in fact, people have been using water in irrigation systems for many purposes. The study in Kirindi Oya showed that the water is not only used for irrigating the field crop but also for livestock, fisheries, homegarden cultivation, domestic uses, industries and the environment. Agriculture, particularly paddy, is the largest consumer of water. Many other uses like fishing or bathing do not consume water, while others such as drinking and curd pot making consume relatively small amounts of water. Because they draw their water directly from the irrigation system (canals and tanks) or indirectly (wells through groundwater recharge), there is thus a complementarity between these uses and field irrigation. However, when water becomes scarce there interdependence increase and so does competition and conflict over water. This interdependence makes it very important to recognize the full spectrum of uses of water in an irrigation system. Going beyond the sectoral boundaries will change our picture of irrigation systems and has important implications for the management of water within the irrigation system, and also for broader water resource policy.

Multiple Uses of Water in the Kirindi Oya Irrigation System, Sri Lanka[1]

Margaretha Bakker

Introduction

Priorities for water resource allocation and development have been changing during the last decade. Irrigation, which was once seen as essential to ensure food security, is now seen as a "low-value" use of water compared to municipal, industrial, and even environmental uses. Often, irrigation does no longer receive priority in the allocation of water or in funds for project development. In a growing number of cases all over the world, water is being transferred out of agriculture to meet the growing demand in other sectors like industry, often without agreement of or compensation to farmers with irrigated land and water rights. The main reason to transfer water out of irrigated agriculture is the relatively low output per unit of water combined with the fact that it is the biggest consumer of fresh water. On global level irrigation comprises 72% of the average per capita water diversions, with industrial and domestic uses accounting for 19% and 9% respectively (Seckler *et al.*1998). However, there is a general failure to recognize that irrigation systems supply water not only for the main fields, but also for homegarden cultivation, trees, and other permanent vegetation. Other productive uses include livestock, fishing, harvesting of aquatic plants, and a variety of (small-scale) enterprises like brick making. In addition, irrigation systems are generally a major source of domestic water supply, and can have important functions in supporting biodiversity in plants, birds, and wildlife. It is therefore misleading to equate irrigation with agricultural water use.

In the ongoing management of irrigation systems the other uses and users are generally not taken into account. One of the reasons is that most agencies dealing with water resources have only sectoral responsibilities. They deal with irrigation or drinking water or environment. The government as a whole has responsibility for overall water use, but the implementing agencies do not have the mandate nor the incentive to balance the needs of various users (Yoder 1981; IIMI 1995).

This paper argues that to ensure efficient, equitable and sustainable water use (to reduce poverty and improve well being) irrigation and water resources policies need to take into account all uses and users of water within the irrigation system. The multiple uses of water in the Kirindi Oya irrigation system are examined in this paper. Especially attention is paid to household water uses, competition, conflicts and complementarities within and among the different uses and the policy implications when multiple uses of water in irrigation systems are recognized. The information presented in this paper relates to findings from a household water survey among 156 families in the study area. The survey was carried out from May to November 1997. It was essential to supplement the survey data with key informant interviews, focus group discussions, field observations and secondary data sources because of the difficulty obtaining accurate information from respondents and the need to understand the nature of competition and conflicts in the area.

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[1] This paper is based on SWIM paper: 'Multiple Uses of Water in Irrigated Areas: a Case Study from Sri Lanka'. Forthcoming. Edited by Margaretha Bakker, Randolph Barker, Ruth Meinzen-Dick and Flemming Konradsen.

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Site description

The Kirindi Oya irrigation system is located in the southeastern dry zone of Sri Lanka, about 260 km from Colombo. Nearly constant year-round temperatures (26°C to 28°C) characterize the climate of the area. Mean annual rainfall is 1,000 mm. About 75% of the rainfall is received in the Maha season (October to April), and 25% in the Yala season (April to October). Evaporation is uniform throughout the year, with an annual average approximating 2,100 mm.

The irrigation system consists of an old and a new irrigated area (see Figure 1). The five tanks under the old Ellagala system have been built over a thousand years ago. In 1987 the Lunugamwehera reservoir was constructed and the irrigable area was expanded by 5,400 ha of newly developed lands. Besides water for the new area, the reservoir provides irrigation water to 4,200 ha of land under the old Ellagala system and 850 ha of land under the Badigiriya irrigation system.

There are approximately 87,750 people living in the study area, of which about 30% live in the new area. The household size estimated from the field surveys is 4.8 persons per household in the old area and 5.1 persons in the new area. The settlements in the old area are already existing for centuries and the area is more urbanized. In the new area, a total of 5,200 families were settled during the 1980s. About 55% of the residents in the new area acquired land because of being displaced from old holdings *(alternate settlers)* the other 45% of the settlers came under the government program to allocate new irrigated land to the landless from other parts of the country *(open settlers)*. In additions to the 0.2 ha highland, each settler was to be allocated 1 ha of irrigated land[2] (Stanbury 1989).

Literacy rates are quite high: 97.7 percent for men and 94.5 percent for women in the old area, and 96.7 percent for men and 93.4 percent for women in the new area. In both areas, there has been a declining trend in dependency on agriculture and rise in salaried employment like factory worker, trader, armed forces or police.

Uses and users of water in the irrigation system

This section describes the different uses and users of water in the Kirindi Oya irrigation system. At the end of the section a distinction is made between irrigation and non-irrigation water sources and their different uses.

Field crop production

The most important and biggest water user is irrigated agriculture, which mainly consist of paddy cultivation. Farmers will grow other field crops (OFCs) such as chilies, onions, groundnuts, bananas etc. when there is insufficient water for paddy cultivation. The old areas are having priority in water allocation and they receive sufficient water to cultivate 100% of the command area with paddy during Maha and 70% of the command area during Yala. Any surplus water is issued to the new areas, according to an agreed rotation between three demarcated zones. The main irrigation source is the Lunugamwehera reservoir and

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[2] With the intention of providing as much land as possible to the most number of landless, the size of individual allotments has decreased to 1 ha in Mahaweli and other recent settlement schemes. One hectare is generally considered adequate for cultivation using family labor.

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approximately 300 to 400 agrowells provide supplementary water for cultivating mainly OFCs and sometimes rice as well.

Homegarden

Because most residents of the old area have been settled in the area for generations they have landscaped homegardens with fruit trees and other permanent vegetation, plus gardens producing vegetables unlike settlers in the new area. In the old area homesteads cover a fairly large area, in total up to 20% of the land in the old area (IIMI 1995). Rainfall, wells, and wastewater from domestic uses provide the main source of water for homegarden cultivation. It should be recognized that both recharge for wells and domestic water originates from the irrigation system.

Livestock

The study site is a traditional buffalo and cattle raising area and is well known for its curd industry. After construction of the Lunugamwehera reservoir the traditional pasture areas of the cattle and buffaloes were taken over for crop production. This resulted in conflicts between farmers and herdsmen, due to increasing crop damage by cattle, which had traditionally grazed in the same area. The main water source for livestock to drink and bathe are small tanks that obtain their water mainly from rainfall. In dry periods these sources dry up, and the animals are brought back to the irrigation system area mainly to meet their water requirements from the major tanks in the area and for grazing on the paddy stubble. There are no specific water sources or scheduled diversions for livestock.

Fisheries

In all major tanks and in the Lunugamwehera reservoir inland fisheries is undertaken. In the two smaller tanks, Deberawewa and Pannagamuwawewa, fishing is mainly done for home consumption because the water surfaces of these tanks are almost completely covered with lotus and other vegetation. The fish catch is high when the water levels of the tanks and reservoir go down. Fish gets concentrated in the shallow water and is easier to catch. There are no scheduled water diversions for fisheries. Only the water remaining after the irrigation requirements are met can be used as habitat for fish.

Domestic

Domestic uses include drinking & cooking, bathing, laundering, sanitation and washing of utensils. Drinking and cooking do not need large quantities of water but they require high quality water. With bathing and laundry it is just the other way around. Because these activities are often done instream a large quantity of water should be available. This water can be of some inferior quality. In the new area a piped water supply system was constructed to supply the people with good quality drinking water . The water is taken from the Lunugamwehera reservoir and is treated (chlorination or aerosion and sandfiltration) before it is distributed to the standpipes and some private household connections. The old area also has a piped water supply system, which distributes treated ground- and river water, with fewer standpipes than the system in the new area. For their drinking water, people in the old area depend more on wells.

During the dry period, when no water is issued for irrigation, once in the 14 days water is especially issued through the canals for bathing and laundry purposes.

Environment

The wetland system of the Bundala National Park receives drainage water from the Right Bank area and the Badagiriya system. This inflow of drainage water has upset the salinity balance in the lagoons and has caused, among other things, a dramatic reduction in the shrimp population, which in turn affected 200 families who were completely dependent on shrimp farming to make a living (key informant interviews 1997). At this moment there are no regulations about the amount of water to be drained into the Bundala National Park.

Other uses

Other users of water in the area include an army site, a textile factory, and a number of tourist hotels. In addition, there are a number of household enterprises that depend on water from the irrigation system like brick making. And as a consequence of the milk based curd industry, there are also a lot of curd pot making enterprises. Mud from the tank beds is used to make these pots.

Irrigation and non-irrigation water uses

Data from the household water survey were used to assess the importance of irrigation water compared with non-irrigation water as sources for different uses. Irrigation water is defined as water from the reservoir, tanks and irrigation or drainage canals. Non-irrigation water comes from homestead wells, the piped water supply system, the Kirindi Oya river and rainfall. It should be acknowledged, as mentioned before, that a large proportion of the well water is in fact seepage water from the irrigation system. Also, part of the water distributed through the piped water system has its origin at the Lunugamwehera reservoir. However, the water no longer flows through irrigation structures and is treated and therefore classified as non-irrigation water.

The first priority water sources for different uses are showed in Table 1. Rice and OFC cultivation obtains water almost exclusively from the irrigation system. Precipitation was the only source of water for chena cultivation. Regularly, those chena areas are in the highland parts and far away from the irrigation canals and tanks. Homegarden cultivation mainly depends on rainfall. Livestock is more or less equally dependent on irrigation water and non-irrigation water sources such as wells for drinking and bathing. The small number of families involved in inland fisheries completely depends upon the irrigation sources. More than half of the households prefer or depend upon irrigation water as a source for washing of laundry, bathing or recreational uses. Hardly any household makes use of irrigation water for drinking, cooking, sanitation and washing of utensils. Families involved in home industries are almost equally divided between families dependent on irrigation and non-irrigation water sources.

Competition, conflicts and complementarity

In the Kirindi Oya irrigation system water is used for more purposes than only irrigating the field crops. Many of the other uses such as fishing or bathing are non-consumptive, while others such as drinking, and brick-making consume relatively small amounts of water compared to field irrigation. Because they draw their water directly from the irrigation system (canals and tanks) or indirectly (wells through groundwater recharge), there is a complementarity between these uses and field irrigation. When water is available in the tanks and canals for paddy fields, it is also available for other uses like fishing, bathing, and curd pot making. On the other hand, when there is no water for irrigation, wells will dry up

and no water is available for domestic uses from the tanks and canals.

There is more competition and even conflict over water when water becomes scarce. From a system perspective, the different types of uses compete. However, from the household perspective, this competition is not so much between the different uses but more between different members, because all households are engaged in more than one activity involving water use. Because the household members have different responsibilities related to water use, some members may be more affected by shortages (or benefit from abundance) of water for certain uses than others.

The major types of complementarities, competition, and conflict within and between different uses are summarized in Table 2. Because irrigation of field crops holds the strongest water rights and is the main water consumer, the relationship of each use to irrigated crop production is the most important form of interaction. Table 2 is based on this relationship.

The most important kind of competition and conflict over water is not between different types of uses but between irrigating the fields in the old and new area. There is an ongoing tension between the demand of farmers in the old area for full paddy cultivation in two seasons, based on their historical claim to water, and those of different parts in the new area to receive water for paddy in at least one season. Although priorities have been set, fluctuating water availability through changing rainfall require re-negotiation of how much water each area receive every season. Even within the old or new areas, there may be competition between fields to receive water for irrigation, especially when water supplies are short.

In the old area, where wells (seepage from irrigation) provide the main source of drinking water, there is a complementarity between irrigation and drinking water. In dry years however, these uses compete for water. The biggest conflict is over the water right of the National Water Supply and Drainage Board to keep the water in the reservoir at a certain level to guarantee domestic water needs via the piped water system. During Yala 1992 irrigation water issues were stopped to protect domestic water needs. This resulted in serious conflicts and politicians became involved to settle the disputes (Brewer forthcoming). In 1995 and 1997 these conflicts occurred again. There are also potential conflicts between irrigation and drinking uses of water when it comes to water quality issues. Due to agrochemical runoff and mineral leaching, mainly salts, from paddy fields both surface and groundwater sources have been contaminated. Many wells in the old area contain water which is actually unsuitable for drinking purposes.

Another domain of complementarity and conflict over water use is between irrigation and environment. The availability of water in the irrigation system has provided a habitat for birds, especially in the Weerawila tank. Despite negative predictions, the bird population has increased since expansion of the irrigation system. On the contrary, the water quality of the downstream located Bundala National Park is negatively effected by enlargement of the irrigation project. Two brackish lagoons have been converted into fresh water lakes due to drainage water inflow. This has had a negative impact on the number of birds and the diversity of species. Moreover, hundreds of families engaged in lagoon prawn fishing lost their main source of livelihood and had to look for other sources of income. Besides this there are also euthropication problems with excessive growth of algae because of livestock dung and upstream fertilizer use.

Policy implications and conclusions & recommendations

Where resources that sustain livelihoods are scarce, their interdependence increases, but so does competition. From this perspective it is particularly important to recognize the full spectrum of uses of water in an irrigation system and the interaction between these different uses and users. Recognition of the various uses and users of water is an important first step towards managing the system to accommodate all needs. Moreover, water management decisions often only take into account water quantity issues. Considering multiple uses of water and their interactions brings to the surface the significance of water quality, which is especially important for domestic uses, fisheries, and the environment.

Up till now municipal and industrial uses of water have not been major competitors for water with irrigation because the Kirindi Oya irrigation system is quite far from urban centers. However, there are plans to build an oil refinery on the coast, which would require a lot of water from the Kirindi Oya system. A rudimentary analysis might suggest that the water requirements for the oil refinery could be met by improving irrigation efficiency[3], changing from paddy to other crops for cultivation or a combination of these two. However, a more comprehensive view would recognize that changing the quantity and timing of water deliveries in order to supply the oil refinery would affect more than the system managers and the farmers who possibly have to switch crops. It would affect the whole system. Groundwater levels, which indirectly depend on irrigation water supply, would decline and affect water availability for homegardens, drinking & cooking, and other domestic uses. Water levels in the tank would decline and affect fish production, runoff and hence concentration of agro-chemicals entering the wetlands among other factors. This example illustrates that recognizing multiple uses of water in irrigation systems changes the analysis of intersectoral water allocation, especially for reallocation out of irrigation.

While the exact uses and users of water and their relative importance will vary from one irrigation system to another, the issues identified in this study have broader implications for water management policies in Sri Lanka and elsewhere. These relate among other things to the allocation of water and financial resources between irrigation and other sectors; measures of water quality and efficiency of use; and mechanisms to involve stakeholders in negotiations over water use.

If irrigation systems are observed from a multiple use of water perspective we see that men and women use water several times over. This would certainly increase the value of water use, and needs to be taken into account when irrigation system output is evaluated and when water management decisions are to be made. This especially counts for decisions related to the transfer of water out of irrigation systems. Recognizing the interactions between the uses and users may also provide scope to better accommodate the various uses, thereby increasing water use efficiency. To increase the total value of productive and non-productive uses in irrigation systems attention to water quality issues is required. However, as it is difficult to develop accurate empirical measures of quantitative efficiency, it is even more difficult to measure and incorporate measures of water quality. Moreover, on the output side it is very difficult to put a quantitative value on the uses that are especially sensitive to water quality like domestic (drinking) and environmental uses. Valuing water for non-productive uses, remains an important area for future research. More case studies on multiple uses of water in

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[3] Canal lining, sprinkler or drip application systems and rotational irrigation schedules are common means to increase the proportion of water in a system that is used for crop evapotranspiration and thus increase irrigation efficiency.

irrigation systems should provide decision-makers with more substantial data, and help in the design of efficient, equitable and sustainable water management.

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Map labels (as visible):

N

Study Area

LUNUGAMWEHERA
RESERVOIR

LB MAIN CANAL

ELLAGALA
ANICUT

PANNAGAMUWA
WEWA

DEBERA
WEWA   TISSA
              WEWA

WEERAWILA
WEWA

YODA
WEWA

RB MAIN CANAL

KIRINDI OYA

BADAGIRIYA
TANK

Indian Ocean

EMBILIKALA BUNDALA LEWAYA
KALAPUWA

MAHALAN
LEWAYA

BUNDALA NATIONAL PARK

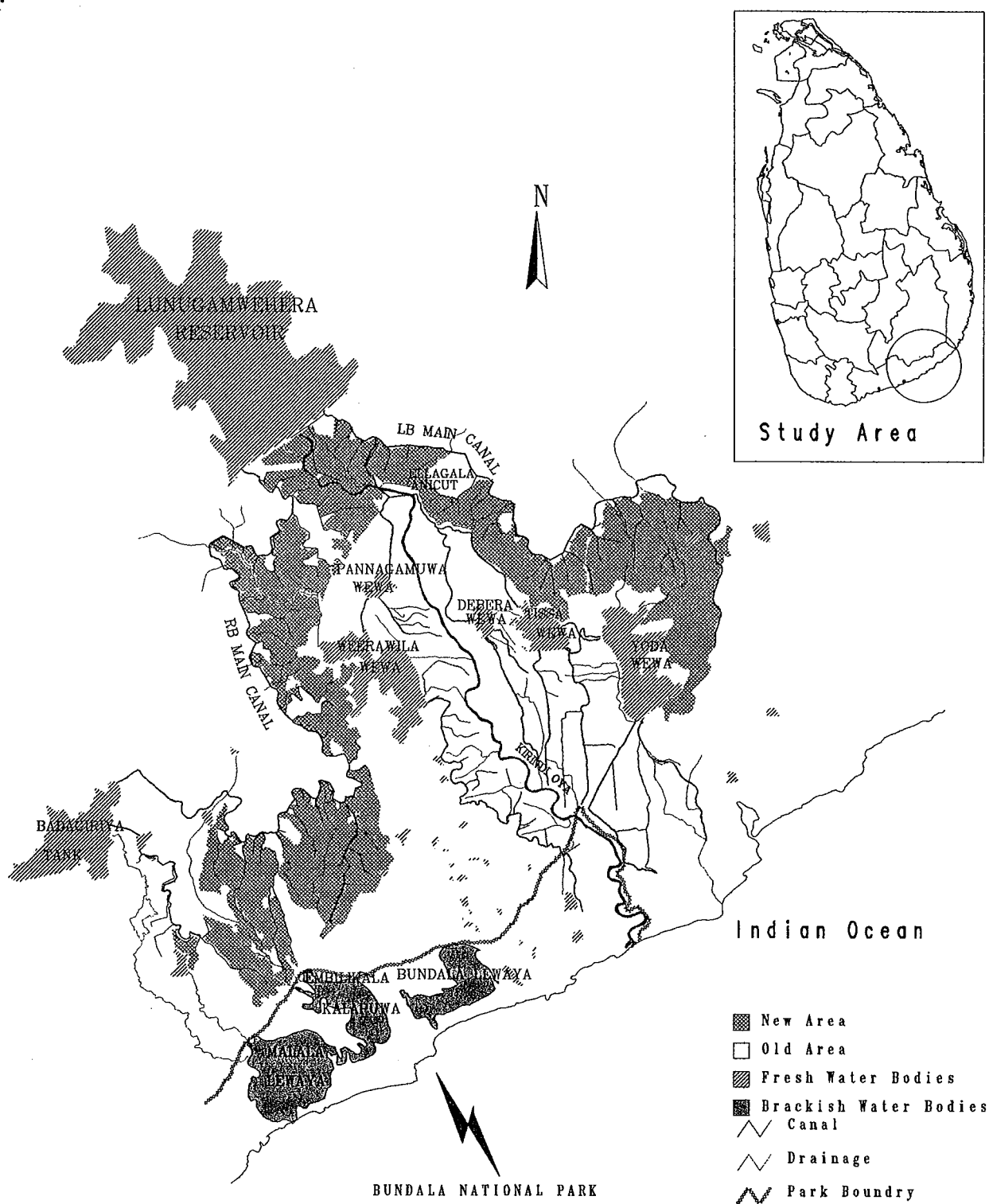|	
▨	New Area
☐	Old Area
▧	Fresh Water Bodies
▦	Brackish Water Bodies
∧/	Canal
∧/	Drainage
∿	Park Boundry

Figure 1 - Map of the study area

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Table 1: The importance of irrigation water in comparison to other sources for a variety of uses (first priority water source)

Uses	No. of respondents	Use of different sources in %	
		Non-irrigation water	Irrigation water
Agriculture			
• rice	93	0	100
• other field crops (e.g. onions)	17	0	100
• shifting cultivation	30	100*	0
Homegarden	54	87*	13
Cattle, buffaloes and goats	20	45	55
Inland fisheries	9	0	100
Domestic uses			
• drinking, cooking, sanitation and washing utensils	156	96	4
• bathing, laundering and recreation	156	53	47
Home industry	17	41	59

* including water from rainfall

Table 2: Conflicts, competition, and complementarity of water use in Kirindi Oya

	Irrigated crops	Live-stock	Fishing	Laundry & bathing	Drinking	Home industry	Home gardens	Environ-ment
Irrigated crops	-							
Live-stock	-/+	x						
Fishing	-/+	-	x					
Drinking	-	x	x	-	-			
Laundry & bathing	+	-	x	x				
Home industry	-/+	x	x	x	-/+	x		
Home gardens	-/+	x	x	x	-	x	x	
Environ-ment	-/+	-	x	x	x	x	x	-

- = conflicts and competition
x = no conflicts and competition
+ = complementarity

FOOD SECURITY AND IRRIGATION DEVELOPMENT IN SRI LANKA: PAST ACHIEVEMENTS AND FUTURE PROSPECTS

Randolph Barker and M. Samad[1]

(Paper Presented At the National Conference on the Status and Future Directions of Water Research in Sri Lanka, 4-6 November 1998, Colombo Sri Lanka)

INTRODUCTION

Sri Lanka, historically, has placed a high value of *basic human needs*. This policy has resulted in one of the highest levels of human welfare among low income countries (UNDP 1994). With a priority on food security, all segments of society have had access to basic food staples at a reasonable cost. Food security, poverty alleviation, and other welfare goals have been achieved by expanding irrigation and introducing new technologies to increase rice yields. By the mid-1980s most of the potential for further growth in yield and expansion of irrigation had been exhausted. There is mounting evidence that over the past decade, the food production sector has remained stagnant. This has caused growing concern to the Government in terms of its implications for rural poverty and national food security objectives.

The Report of the National Development Council Working Group on Agricultural Policy (1996, p. 1) states that: "Sri Lanka's non-plantation agricultural sector has lost its momentum over the past 10-15 years. This is reflected in the key indicators such as, per acre yield of crops, total annual output, intensity of the use of irrigated lands, farm family income and employment." A recent report of the World Bank (1996, p.2) argues that, "the current level of 'food security was purchased at a high cost through investment in very capital-intensive irrigation schemes to produce a low-valued commodity" (i.e. rice). The continued focus on rice self-sufficiency inevitably constrains the performance of the agricultural sector.

This paper reviews the achievements and limitations of the welfarist strategy adopted in the past, particularly the role played by irrigation development to achieve food security and promote growth. It is argued that major irrigation schemes will continue to provide the foundation for the nation's food security, but ways must be found to produce more food with less water. The paper contends that improved management of irrigation and water resources is essential for maintenance of food security

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[1] Senior Advisor and Research Associate Respectively, IWMI, Sri Lanka.

BASIC NEEDS, FOOD SECURITY, AND THE ROLE OF IRRIGATION

Sri Lanka's experience in the field of public provision of basic needs is well documented (Isenman, 1980; Sen, 1981; Bhalla and Glewwe, 1986; Bhalla, Bhalla, 1991; Anand and Kanbur, 1995; World Bank, 1995). For example, Anand and Kanbur (1995), analyzing time series data from 1951-82 period, concluded that systematic and direct government intervention played an important role in enhancing the quality of life in relation to health, education, and nutrition. Sri Lanka's achievements in some areas of human welfare, such as health and education, have been described as remarkable for a country with a low per capita income level (UNDP, 1994). Welfare indicators such as life expectancy at birth of about 71 years, infant mortality rates of 24 per 1000 are similar to those for Malaysia with three times the per capita income and Thailand with twice the per capita income.

From the mid-1950s to the end of the 1970s, welfare expenditures accounted for 30 to 40 percent of total government expenditures (Osmani, 1994). Beginning in 1977, the new government initiated economic liberalization, reduced social expenditures, and replaced universal food subsidies with a targeted food subsidy program aimed at reaching the economically vulnerable groups. The share of GDP for total welfare expenditures fell steadily from 12 percent in 1970 to 8 percent in 1977 and 3 percent in 1985.

The impact of reduced spending on welfare has been a matter of considerable debate. For example, studies by Sahn (1986) and by Anand and Kanbur (1995) suggest that a cut in the food subsidy expenditures after 1977 caused an increase in malnutrition and a reduction in social equity. However, Bhalla (1991) concludes that there is some direct evidence to support the view that welfare of the poor has improved since liberalization. A more recent assessment of poverty in Sri Lanka conducted by the World Bank (1995) supports the conclusion of Bhalla. Osmani (1994, p. 419) undertook a comprehensive review of the evidence to determine whether there was a conflict between growth and welfare? He concludes as follows:

"The general lesson that one can draw from Sri Lanka's experience is that even a poor country can bring about rapid improvement in the living standards of its people by adopting a judiciously designed welfare strategy ...But there is another dimension of the Sri Lankan experience which offers no less valuable a lesson. It shows how important it is to maintain a satisfactory rate of economic growth for the sake of welfare itself."
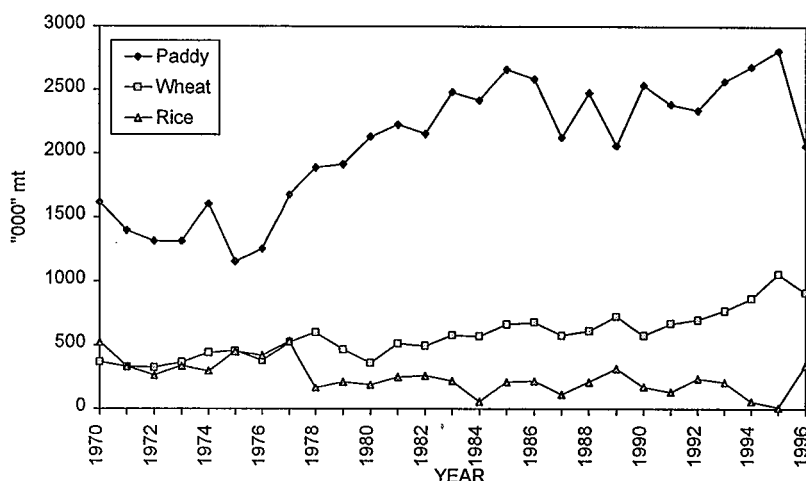
Food Security

Rice accounts for 75 percent of the total cereal consumption and 45 percent of calorie intake. Irrigated paddy accounts for two-thirds of the harvested area under paddy and provides around three-fourths of the total output of paddy in the country.

The National Agriculture, Food, and Nutrition Strategy (NAFNS) of the government of Sri Lanka published in 1984 states, self-sufficiency in basic foods, rice, milk, sugar, fish and pulses is one of four objectives. According to the 1993 Report of the Presidential Tariff Commission, "rice in any case is a staple diet and for strategic reasons the country should rely on its own production." The National Policy Framework for Agriculture, Lands and Forestry (1995) emphasizes self-sufficiency in rice as a major national objective. This objective is combined with the aim of saving foreign exchange by substituting domestic for imported rice, employment creation, and satisfying the nutritional needs of the population. Recently the objective of food security has been redefined as "rice self-sufficiency at affordable cost" (as quoted in World Bank, 1996).

According to the World Bank report (1996, p.2) this "affordable cost approach does not appear to be working. The opportunity cost of defining 'food security' in terms of 'physical self-sufficiency' may actually be unaffordably high in terms of sectoral growth foregone." Public investment in irrigation is seen as the main factor contributing to the unaffordably high cost. The major investment in new irrigation construction in the past two decades was for the World Bank supported Mahaweli Development Project which from the mid-1970s to the mid-1990s accounted for 90 percent of total irrigation investments.

The government strategy for food security in Sri Lanka involves more than "rice self-sufficiency" and must take into account the growing importance of wheat in the Sri Lankan diet. Between the mid-1960s and mid-1980s rice production grew at close to 4 percent per annum (Figure 2). Per capita consumption in this period ranged from 105 to 115 kg. per annum, with no apparent trend. Since 1977 imports have averaged about 200 thousand mt per annum and ranged from 7 to 15 percent of apparent consumption. Meanwhile, government subsidies for wheat have encouraged growth in wheat consumption and imports making it possible to avoid heavy imports of rice even when growth in production stagnated over the past decade. Annual per capita wheat consumption has risen from less than 20 kg. in the early 1960s to approximately 50 kg in the mid 1990s . Annual imports have risen to 700 to 800 thousand mt per annum. Thus, government food security is based on maintaining rice production at 85 to 90 percent of domestic needs, but encouraging a substitution of wheat for rice in the diet to take advantage of the substantially lower price paid for wheat vs. rice imports.

Figure 2
SRI LANKA-PADDY PRODUCTION AND
RICE/WHEAT IMPORTS 1970 - 1996

Irrigation Development

The development of irrigation has been a major element and one of the largest costs in the Government's food security program. In the early 1950s, investments in irrigation accounted for about one third of total public investments. It declined to 15% in the mid-1960s and then rose to as high as 25 percent in the 1980s.

From the mid-1960s to the mid-1980s area irrigated grew from about 300 to 500 thousand hectares. Most of the growth was in major irrigation schemes in the dry zone, principally under the multi-purpose Mahaweli Development Program initiated in the early 1970s, which provided over 100,000 ha of land with improved irrigation. (World Bank Appendix 2 p. 14?).[2]

Irrigation development coupled with the introduction of new technology played a pivotal role in increasing rice production in the country and realizing the national policy objective of self-sufficiency in rice. At present about half of the national rice output is produced in the major irrigation schemes which provide irrigation principally to the Dry Zone districts where high levels of solar energy have permitted more rapid growth in yields. Between 1952 and 1985 the area planted to rice in the major irrigation schemes grew at 4 percent, where as the area under minor irrigation and rainfed rice grew at 2 percent and 1.5 percent respectively.

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[2] Major irrigation schemes are those with command areas of 200 ha. Or more. Minor irrigation schemes are those with command areas of less than 200 ha.

Fig. 2 shows the close correlation between the expansion of the area under major irrigation schemes and the move toward rice self-sufficiency. [3] We have estimated that without the investments in major irrigation schemes, rice self-sufficiency in 1994 would have been 78% as against the 94% realized in 1994.

The Mahaweli Development Project has been the center piece of irrigation development in the last two decades, and at the center of some controversy. Following the food and energy crisis of the mid-1970s and the apparent uncertain outlook for both food and energy prices, Mahaweli looked like an attractive investment from the point of view of both the Sri Lankan Government and the World Bank. However, Aluwihare and Kikuchi (1991, p. 24) show that the benefit-cost ratios for new irrigation construction which were well above 1 in the 1960s and 70s fell below 1 in the 1980s as construction prices rose and rice prices fell. This gives rise to the conclusion of the World Bank Report (1996) that "rice self-sufficiency has been costly to achieve as has its efforts to alleviate poverty through large-scale irrigation development." The right question to ask, however, is: "What would the international price of cereal grains have been if the World Bank and other donors had not financed the construction of large-scale irrigation systems such as

Figure 2   Rice self-sufficiency and the expansion of the irrigated area (1950-94)
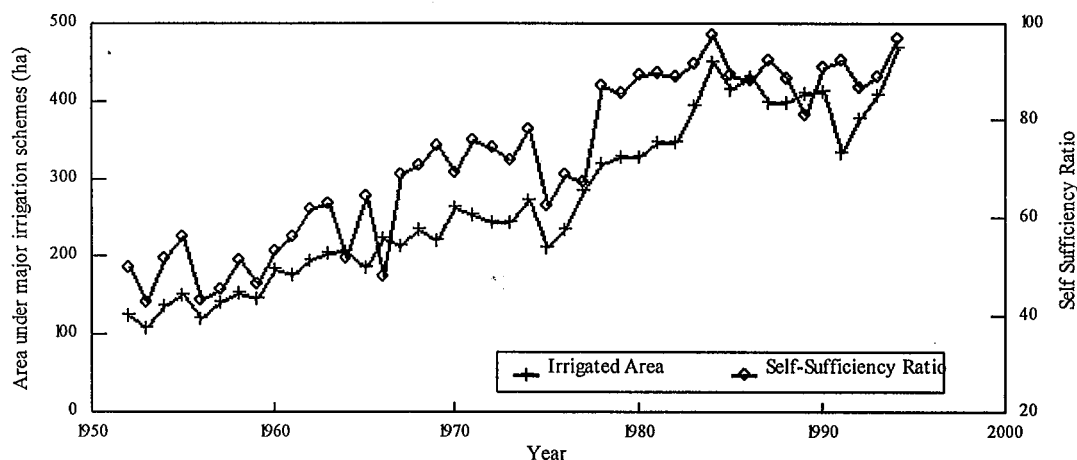
Mahaweli in the 1970s and 80s?" Most observers would agree that the global and domestic food security and agricultural surpluses achieved by these investments was well

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[3] Degree of self-sufficiency is defined as the ratio of locally produced rice to the total supply (locally produced plus imports).

worth the cost. Todays low benefit-cost ratios reflect a large measure of success in achieving global food security.

Furthermore, the benefits of irrigation investments include more than the value of the physical commodities produced. The development of Dry Zone irrigation also has led to major population resettlement and employment creation. Between 1946 and 1981 the population in the Dry Zone, which accounts for 62 percent of the countries land area, increased from 1.2 to 3.8 million or from 12 to 26 percent of the total population of Sri Lanka (Statistical Abstracts, 1995). A majority of the new settlers have been landless persons from the Wet Zone who were resettled in the irrigation schemes and provided with employment opportunities in farming. Investments in irrigation and the development of the dry zone discouraged rural-urban migration and reduced the social costs associated with overpopulation in the cities. Also overlooked in benefit-cost calculations, are the many other uses of water in irrigation systems such as fish, livestock, and garden production as well as domestic uses.

The process of resettlement has had its problems. For example, some critics of the Mahaweli Development Project have pointed to the strong engineering bias in the planning and execution of the project (Muller and Hettige, 1995). It is argued that this bias has resulted in inadequate attention to the provision of social services and lack of planning for the second generation of settlers.

In sum, rice self-sufficiency has been a major objective of the Sri Lankan Government's food security program. This goal has been achieved through investment in major irrigation schemes. The benefits from crop production have been lower and the irrigation construction and crop production costs higher than originally anticipated. Lower than expected benefits are the consequence of a similar strategy implemented successfully by countries throughout Asia which has led to lower rice prices. However, the benefits of irrigation investments cannot be confined to food security alone. Irrigation water is used for a multitude of purposes and irrigation investments have created employment for new settlers and fostered growth in the relatively less populated Dry Zone of Sri Lanka. However, the benefits and costs of food security policies need to be carefully reevaluated in the light of today's economic conditions and government financial constraints.

THE STAGNATION OF AGRICULTURE: RESOLVING THE DILEMMA

The World Bank Report (1996) identifies what it sees as the key constraints to agricultural development and the Report of the National Development Council (1996) offers a comprehensive action plan for getting agriculture moving. While these two reports differ in the details, the general recommendations are similar, and the key recommendations can be summarized as follows.

- Move towards a market oriented agricultural economy which provides farmers with greater incentives and control over their resources.

- Introduce land tenure reform and create a land market to promote investment in large scale commercial agriculture.

- Diversify agriculture and create an internationally competitive exportable surplus of quality agricultural products.

- Provide farmer organizations with greater responsibility and legal authority for the operation and management of public irrigation schemes.

We will examine the reasons for the stagnation, and then access the likely impact of the first three recommended policy reforms.

Growth and stagnation. As previously noted, Sri Lanka has pursued a policy of increasing domestic food production and enhancing the welfare of the population. This growth-equity strategy proved very successful from the mid-1960s until the mid-1980s. The main sources of growth were the new seed-fertilizer technologies in rice and the expansion of irrigation. The success of this growth strategy pursued by Sri Lanka and most Asian countries has led to a what economists refer to as a "cost-price squeeze." While the price of rice and other crops has fallen the costs of many of the cash inputs and irrigation construction have steadily risen (National Development Council, 1996). The dual emphasis on welfare and growth meant that the government subsidies associated with this growth have been heavier than in other countries following the same growth strategy.

The 4 percent agricultural growth based on irrigation expansion and new seed-fertilizer technology was not sustainable. Efforts to date to maintain growth in output through crop diversification have not been successful. The subsidies associated with agriculture have become an increasing drain on government financial resources.

There is evidence of a potentially high degree of complementarity between agricultural and industrial growth in the early stages of economic development (Johnston and Mellor, 1960). Satisfactory growth in one sector depends on delivery of inputs from the other. Grain, raw materials, and labor flow from agriculture to industry and in return consumption goods and modern farm inputs are supplied by industry to agriculture. The growth of industries linked to agriculture, such as food and raw material processing and equipment repair, initially facilitate this two-way flow. As the economic transformation proceeds, agriculture as a percentage of the total economy shrinks.

Table 1 shows the change in the percentage distribution of *gross domestic product* (GDP) between 1970 and 1993 for Sri Lanka and four neighboring Asian economies. The economic transformation has been most rapid in Thailand and Indonesia and slowest in

the Philippines and Sri Lanka. One quarter of the GDP and approximately 50 percent of the labor force remains in agriculture in Sri Lanka and labor productivity remains low. The Philippines and Sri Lanka also export a significant portion of their "surplus" labor to other parts of the world. Thus, in Sri Lanka the potential complementarity between agricultural and industrial growth seems to have been lost; the slow growth of the non-agricultural sector has become a major constraint to the further development of the agricultural sector.

Table 1. Percentage Distribution of GDP

Country	Agriculture		Industry		Services	
	1970	1995	1970	1995	1970	1995
Sri Lanka	28	23	24	25	48	52
Bangladesh	55	30	9	18	37	52
Indonesia	45	17	19	42	36	41
Philippines	30	22	32	32	39	46
Thailand	26	11	25	40	36	49

Source: World Bank: World Development Report, 1995 and 1997

Market Oriented Agricultural Economy: The basic thrust of the recommendations in this area is to allow market prices to allocate resources, to remove the subsidies on inputs and the wheat flour subsidy, and to shift protection from imports to a tariff basis so that they are more transparent. The role of the government should be to create the environment and provide the incentives which will allow both input and product markets to perform effectively and allow private sector activities and investments to expand in the rural areas.

Land tenure reform, farm size, and efficiency. Sri Lanka's land tenure policy in the irrigated settlement schemes since the inception of the program in the late 1930s has been guided by the country's emphasis on basic needs. The size of the holdings alienated varies from 8 acres per family in the irrigated settlement schemes established in the 1950s (e.g. Galoya) to 2.5 acre holdings alienated under the Mahaweli Development Project. The land is alienated under the concept of "protected holdings with restrictions on transactions in land."

The concept of protected holding was initially to prevent land fragmentation. Despite legal restrictions, informal fragmentation and transactions are widespread in the irrigated settlements. The provision of tradable (and mortgageable) land tenure rights should encourage more private investment in land improvements. But whether privatizing land would lead to an increase in farm size and productivity as suggested in the World Bank

Report (1996) is a matter of debate. For example, studies conducted in several countries show that in the production of rice and other vegetables, there are no economies of size (Lau and Yotopaulus, 1971). The evidence in Sri Lanka also suggests that large farms are no more efficient than small farms in terms of unit cost of production.

The National Development Council Report (1996, p.4) correctly observes that expansion of farm size will depend not only on a well functioning land market but also on alternative investment and employment opportunities in the non-agricultural sectors that pull labor out of agriculture and raise the productivity of farm labor. Without such opportunities, the unemployed or underemployed landless laborers will increase. Given the limited opportunities existing for non-farm employment, the common practice of dividing the rural household labor force between farm and non-farm activities is an appropriate solution for maximizing the productivity of household labor and one commonly practiced in many parts of Asia.

Issue related to farm size and land tenure need to be considered carefully in developing land tenure policy. Given the uncertain employment opportunities, the Government in the short run would like to avoid a situation leading to concolidation of land into large holdings and displacement of labor..

Crop diversification: The Sri Lankan Government has promoted crop diversification as one alternative to raise farm incomes. Wijayaratna et. al. (1996) studied crop diversification in Sri Lanka over a ten year period - 1982-93. All crops were analyzed as import substitutes and the results clearly showed that rice and all other field crops (OFCs) analyzed except green gram, had a comparative advantage for local production. Edirisinghe (1991) estimating domestic resource cost (DRC) also concluded that Sri Lanka has a comparative advantage in rice production. By contrast, using the same methodology, the World Bank Report (1996, p. i) concluded that "overall, Sri Lanka shows no comparative advantage in the production of rice or OFCs in either major or minor irrigated or rainfed agriculture." The different conclusions seem to rest principally on different assumptions regarding the cost of labor and of irrigation in crop production. Given the fact that rice is almost the only crop that can be grown on puddled land in the wet season, and that non-farm employment opportunities are extremely limited, for most rural families producing rice provides the highest return to their labor and other owned inputs. In addition, farmers like to ensure food security by producing their own subsistence.

OFCs are more suitably grown under irrigation in the dry season. However, depending on the soil conditions, the cost of serving individual fields and of switching back and forth from wet season rice to dry season upland crops may be so high as to make the practice uneconomical (World Bank, 1985). In addition, domestic demand is relatively low and prices very volitle. Wijayaratna et.al. (1996, p. xiii) conclude that the opportunities for continued expansion of production of traditional OFCs - chili, onion, green gram, black gram, and vegetables - are limited. There has been a declining trend in the profitability of all OFCs related to the narrowing gap between demand and local production as well as

the increase in the cost of production. Thus, more attention needs to be paid to searching for special crops for special markets and to increase the agribusiness opportunities for added value and for exports.

In summary, the rapid growth in nonplantation agriculture from the mid-1960s to the mid-1970s is no longer sustainable since the potentials offered by the new seed-fertilizer technologies and the development of new irrigated areas have now been almost fully exploited. A major constraint to agricultural development lies in the slow growth of the non-agricultural sector and lack of non-farm job opportunities.

Another emerging constraint is the growing scarcity and competition for water for both agricultural and non-agricultural purposes. Since food security in Sri Lanka still relies heavily on the irrigation sector, we now turn to examine issues related to the growing competition for water and the potentials for improving water use efficiency through the recommended privatization of irrigation schemes.

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RESEARCH PAPERS PRESENTED

Session No.21 6 November 1998 *9:00 a.m.*

Crop Water Use

Paper No.12
Sanmuganathan, K.
Rajapakse, T.B.J.
Dissanayake, D.M.P.
Advances In Irrigation Of Sugarcane In Sri Lanka

Paper No.28
Keerthiratna, G.B.
Determination Of Water Use And Crop Yield Production Functions For Soyabean Using Drainage Iysimeters

Paper No.111
Weerasinghe, K.D.N.
Attanayake, W.S.
Sabatier, J.L.
Water Balance And The Irrigation Need Of Rice In Different Agro-Ecological Regions Of Sri Lanka

Advances in Irrigation of Sugarcane in Sri Lanka

By

K. Sanmuganathan, T.B.J. Rajapakse and D.M.P. Dissanayake

Sugarcane Research Institute, Uda Walawe, Sri Lanka

The conventional system of irrigating sugarcane (*saccharum officinarum*) in Sri Lanka is furrow irrigation. In this system, water is diverted manually to one or more furrows in turn from unlined field channels that receives water from the main unlined channel.

An evaluation of this system showed that the water conveying efficiency was only 40 to 50% and the water application efficiency range from 30 to 50%. The low water application efficiency was mainly due to non uniform furrow slopes range from 0.5 to 3% and high and non uniform flow rates to the furrows range from 2.8 to 4.2 l/sec.

An experiment was carried out at Sevanagala Sugar Project, Embilipitiya to evaluate and to improve the existing system of irrigation. It was found that, counter furrow system with a gradient range from 0.3 to 0.5 % with a volume flow rate of 2.1 l/sec into furrow length range from 45 to 60 meters will give a water distribution efficiency of 70 to 80% for Reddish Brown Soils.

Based on the above results the traditional system practiced was modified to a siphon furrow irrigation system. In this system plastic (PVC) siphon tubes of 50 mm diameter were used in transferring a measured quantity of water from lined field channels into individual furrows of 65 meters having an average slope 0.5 to 0.7. Six to seven siphons were used at a time. The field channel received water from a lined main channel. With the introduction of the cut back, application efficiency of 64% with a distribution uniformity of 80% could be achieved. It was also found that the maximum non erosive furrow stream for Reddish Brown Soil with an average slope range from 0.5 to 0.7 was nearly 3.4 l/sec.

Now this system is practiced by nearly two thousand small holder sugarcane farmers at Sevanagala Sugar Project with satisfactory efficiency. The main problem in maintaining the irrigation efficiency is due to the poor repair and maintenance of the channel system and lack of knowledge on irrigation by farmers. Education and training at all levels are

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necessary to get the maximum benefit from the system.

Water is becoming a very scarce resource in Sri Lanka and more efficient systems like sprinkler and drip irrigation need to be tried out to optimize this scare resource. However, now the cost of these systems does not justify the benefit from these systems. This is because the cost of irrigation water is small when compared with the other inputs. Eventually inefficient irrigation systems are not only wasting water but also reducing the yield and quality of cane harvested and reducing the land available for sugarcane cultivation by causing ill drain condition. As Such, there is a need to rehabilitate the irrigation system with improved water management methods.

1. INTRODUCTION

The annual domestic demand of sugar in Sri Lanka is nearly 500,000 metric tons at per capita consumption of 25 kg. Only 10 to 12 percent of the annual demand is produced locally from 14,000 hectares of which nearly half the area is under irrigation and rest under rainfed cultivation.

In the dry zone, where the sugarcane is cultivated, receives nearly 1500 mm of rain fall per annum. The annual rainfall distribution exhibits a distinctive seasonality. The rainfall follows a well expressed a bimodal pattern in most of the years as showed below:

- a long rainy season (three months) begins in early October and ends in late December (Maha rains)
- a short dry season (two months) covers the months of January and February
- a long dry season (five months) begins in May and ends in late September
- a short rainy season (two months) lasts for two months of March and April (Yala rains)

Though the rainfall is sufficient to compensate for evaporation in some years, due to poor distribution of monthly and annual rainfall, the crop produced are seldom equal to the crop produced under irrigation. The rainfed yield is nearly half the irrigated yield.

The supplementary irrigation will not only increase the yield but also stabilize the production per unit time and increase the efficiency of land use.

Two methods of irrigation, surface and overhead, are used in Sri Lanka to irrigate sugarcane. However, the overhead system was confined to sugarcane nurseries only due to the capital cost involved in setting up the system. Surface irrigation was the only method practiced in the commercial plantation. Now, the area under surface irrigation is nearly three thousand hectares. Water is conveyed to the field by series of open unlined canals and finally diverted either to a cane furrow or to an inter-row under gravity. There is rarely any device for control or meter how much water applied per unit area. Overall,

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the frequency varies from 10 to 14 days depending on the water availability and weather conditions. Though it is a furrow irrigation system, the furrows are not open in time and often fields are flooded.

This method of irrigation is simple and needs less capital but it is labour intensive requiring nearly four man days per hectare. Now, this irrigation practice is very inefficient having an efficiency of 30 to 50 percent.

2.   MATERIALS AND METHODS

An experiment was conducted to evaluate the performance of the surface irrigation system for sugarcane. The purpose of this study was to:
- to determine the efficiency of the system as it is being used.
- to determine how effectively the system can be operated and whether it could be improved
- to obtain information that will assist in designing the other systems
- to provide guidance for the management to continue the existing practices or to improve the system

An experiment was undertaken in a block of one hectare at Sevanagala Sugar Project, Embilipitiya, Sri Lanka. This project is on the left bank channel of the Uda Walawe reservoir in the dry zone of Sri Lanka. The soil type in this area is Reddish Brown Earth (Alfisol), which is the predominant type for the cane production. The soil is sandy clay loam with 25-30% clay, 10-20% silt and dry bulk density are from 1.4 to 1.6 g/cm^3 with a field capacity of 20%.

Ten furrows with a length of 70 meters were selected at random. Levels were taken at every 18 meter interval along each furrow and stations were marked by planting wooden pegs. Average gradients of each furrows were calculated. Three furrows out of ten having approximately equal average gradients were selected as an experimental furrow. Each experimental furrow was provided with two guard rows on either side.

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Infiltration measurements were taken just before irrigation by a double ring infiltrometer to find the intake rate of the soil (Figure 1). Tensiometers were installed to find the moisture tension of the soil before and after irrigation. The tensiometer reading at field capacity and 50% depletion level of available soil moisture were recorded (Figure 2). Various combinations of siphons were operated to find the maximum allowable stream size in the experimental furrow, and in the mean time the guard furrows were wetted to field capacity. Tensiometer readings were taken every day after first wetting of the soil and the second irrigation was made at 50% depletion level.

3. RESULTS AND DISCUSSIONS

The maximum non erosive furrow stream was 1.4 l/s with furrows having an average slope between 0.7 and 0.9%. The length of furrows in the sample field was 70 meters. According to Criddle (1956), to achieve high uniformity of wetting the stream front should reach the lower end of the furrow within one-fourth of the total time needed to refill the soil moisture reservoir. One-fourth of the irrigation time calculated under this study was 15 minutes. With this time, even the maximum allowable furrow stream advances only about 40 meters along the tested furrows. Constructing furrows with uniform length is not practicable in the field, so furrows range between 50 and 60 meters are acceptable for practical purposes that will give a satisfactory water distribution uniformity.

To obtain best results, using combinations of siphons with different diameters to get the required volume flow rate is advisable. Though they gave acceptable results, the problem is to use them in the field. Therefore, a siphon with a diameter of 50 mm was selected for the field use.

Cutback system was tried out with two siphons one with 40 mm and the other with 50 mm and then the 50 mm was removed after the water reaches the tail end of the furrow. Though this system increases the efficiency by nearly 10%, now, this is not recommended due to the practical problems associated with the system.
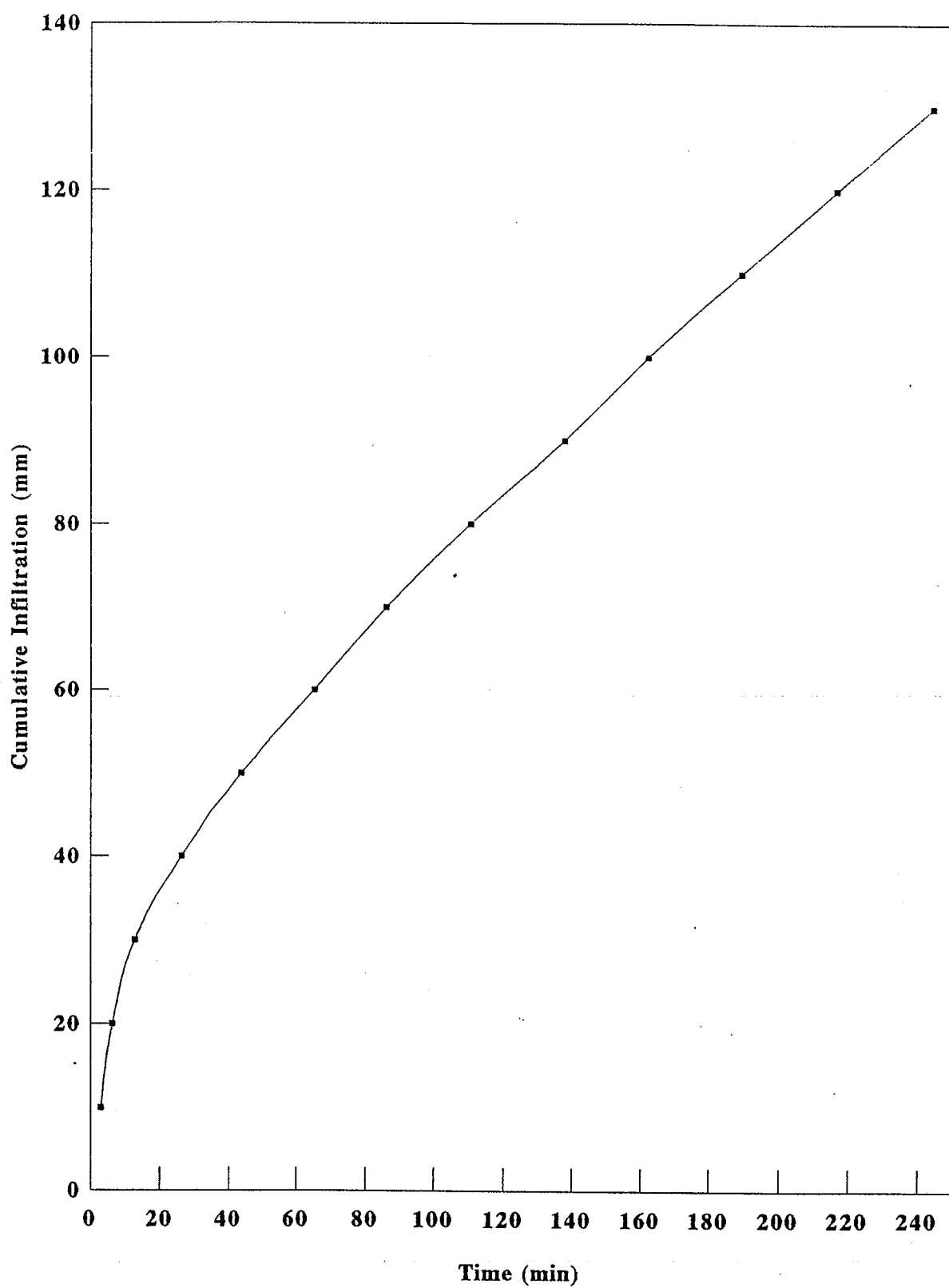
Figure 01. Cumulative infiltration graph for Sevanagala Reddish Brown Earth
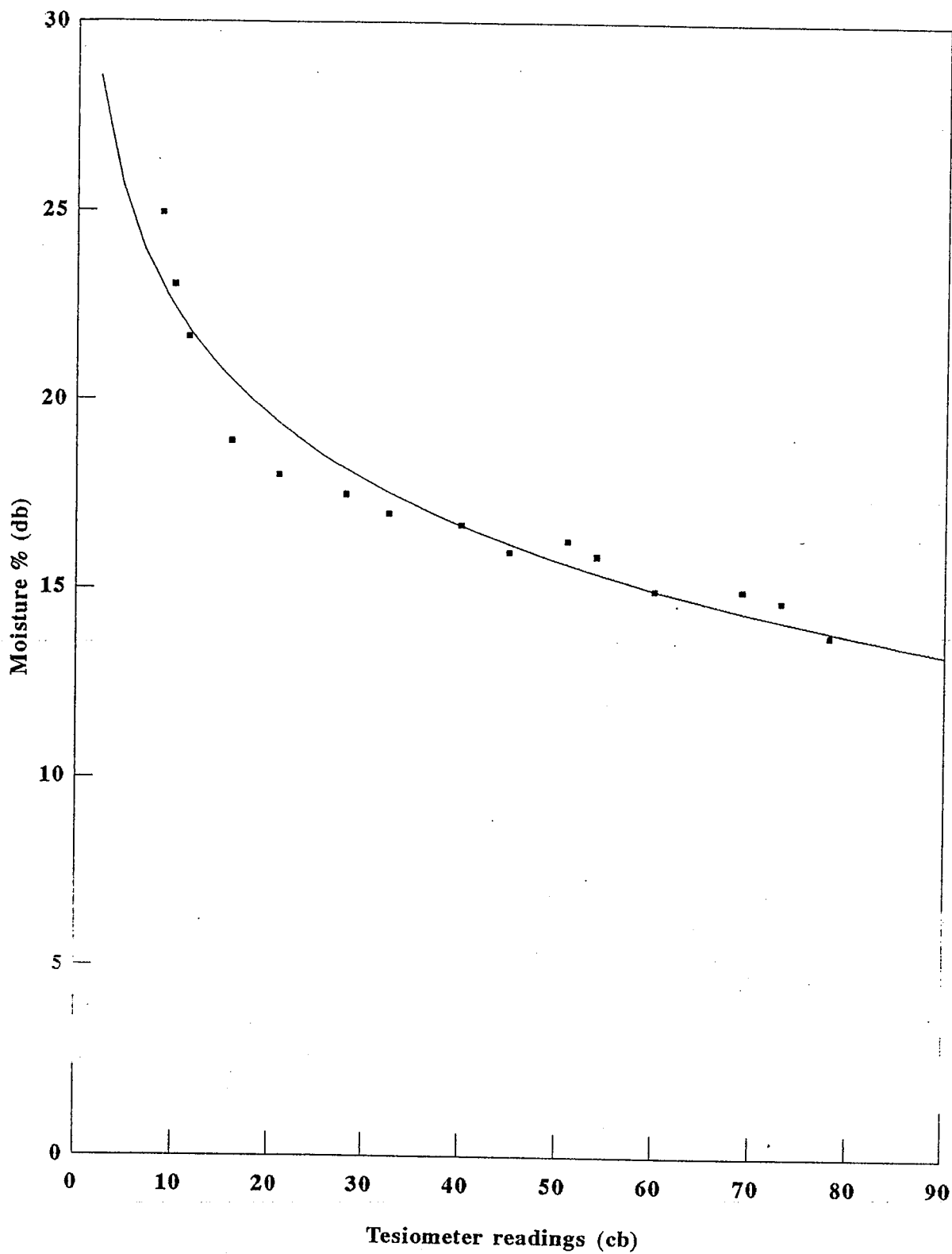
Figure 02. Tensiometer calibration curve for Sevanagala Reddish Brown Earth

To obtain the best results from the study:

Land should be prepared to a pre calculated contour grade to assure uniform slopes as possible. The average slopes of these furrows must be 0.7 to 0.9% but it should not exceed 1%. It was found that more than 1% slopes causes soil erosion.

The following factors were found to contribute to the loss of efficiency
- poor repair and maintenance of the channel system
- vandalism by farmers
- insufficient knowledge on irrigation, drainage and soil conservation by farmers
- soil compaction and gradual reduction of infiltration rate of the soil

Water is becoming a very scarce resource in Sri Lanka and more efficient systems needs to be tried out to optimize this resource. This is more important if water is lifted for irrigation. Now cost of water is low when compared with the other inputs for the production of sugarcane and efficient systems will not justify the cost incurred. However, inefficient irrigation systems are not only wasting water but also reduce the yield and quality of cane harvested. This is causing an ill-drained condition and reducing the land availability for sugarcane cultivation.

The following recommendations were given to improve the irrigation efficiency for sugarcane
- direct research activities to invent low cost irrigation equipment with materials available in the local market.
- training should be conducted at all levels from farmers to managers in irrigation, drainage and soil conservation.
- a routine maintenance programme should be done to keep the channel net - work in proper condition
- at national level policy should be formulated to encourage the sugarcane farmers to use efficient profitable system of irrigation by giving subsidy for installing irrigation equipment.

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Determination of water use and crop yield production functions for Soyabean using drainage lysimeters.

Keerthiratna,G.B.

Natural resources management centre,

Department of Agriculture,

Peradeniya.

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" The status and future directions of Water Research in Srilanka"

Abstract

Conservation is the key to proper Water Resource Management.Proper water policies
should be based on the principle of profit maximization with least waste of this
valuable natural resource,

"WATER".

Need of the availability of country specific and location specific data on the crop
water requirement for most profitable yield level has initiated this study.It has
been revealed from the results that,in the dryzone of Srilanka higher total yield
levels could be reached with adequate water issues in the dryseason than in the wet
season especially with respect to non rice annuals like Soyabean(Glycine max).

Allocation of the wright quantity in the wright season has to be
stressed as a viable policy for Water managers,Decision makers,and the Polititions.

Introduction

Water and yield (input-output) analysis is the key to the understanding relationships between water and yield .At what moisture status should irrigation be applied in order to obtain maximum yield or what would be the yield loss if water applications are inadequate. For many if not all crops in a given climate dry-matter production is proportionate to the amount of transpiration.

Literature review

Heady and Dillon(1961) described the production function as a concept of physiological and biological sciences. Kentsch(1959)used multiple regression to obtain a quadratic equation for yield for water variables for periods within the growing season.

Hall and Butcher(1968) developed a dynamic programming model for the optimal allocation of irrigation in quantity and time. Yaron(1971) distinguished between two types of water yield relationships.One was the total water input with fixed intraseasonal water distribution and the second relationship for flexible water inputs or dated water input.The curves for various years tended to be parallel.

Yield water use functional relationships.

A considerable amount of evidence has accumulated to indicate that upto a minimum amount of actual evapotranspiration (AET) producing near maximum yield, the relationship between yield and ET is nearly linear.The correlation is even higher when total drymatter is considerd as compared to grain yield .Yet two basic inconsistancies remain to be revealed.

1)To explain the results of those studies that obtained a curvilinear relation between yield and water use.

2)To show how unique relationship between yield and actual evapotranspiration can hold when it is known the same AET deficits can give different yields if imposed at different times or conversly how the same yield can be obtained for different values of ET.

The relationship between yield and seasonal ET is quite well represented by a straight line function for Corn and Sorghum.If the upper bound of yield is related to the depth of water applied,rather than ET,a curvilinear relationship will result.

Critical moisture sensitive stages of crops .

A number of research had shown that the yield response to moisture deficit at a particular growth stage may not be a function of that growth stage alone,but may be affected by the degree of stress in earlier growth stages.There may be a tendency for stress imposed at any one growth stage to harden the plant against damage from stress at a later stage as far as grain yield is concerned.

Nevertheless critical growth stages of different crops are still important.

Critical moisture sensitive stages for selected crops

Crop	Critical moisture sensitive stage	Reference
Snapbean	During flowering and pod development	Kattan and Fleming(1956)
Pea	At the start of flowering and when the pods are swelling.	Salter(1962,63)
Soybean	Period of major vegetative growth and blooming.	Runge and Odell (1960).

Experimental production functions

The following section present experimentally determined water yield production functions for the major economic crops.

Wheat:

The relationship between total amount of water (X) to the estimate of relative grain yield (Y) for northern Negan and Lakhish region may be described by the following linear equation

$$Y = -10.7 + 0.208\,X\;; \qquad r^2 = 0.767$$

In Jordhan Rift and the Betshean vally following equation was given.

$$Y = -58.3 + 0.268\,X\,; \qquad r^2 = 0.933$$

Materials and methods

Lysimeter tanks were made using galvanized iron sheets with the top open and bottom closed.In the middle of the tank bottom a two inch diameter hole was made and a same diameter elbow joint was welded to it from outside.S-loan tubes of the required length were connected to the elbow joint so that there would not be any leaking of water.These tanks were buried in pits of the same dimention from where soil wasremoved for placement of the tanks.Only 7.5cm of the tanks were kept above ground level and 90 cm thick soil monolith from the soil surface was repacked toapproximate original bulk density .

This was done by taking 5cm layers seperately from the surface up to 90cm and by keeping these eighteen layers seperately before packing.Later these were packed back to the original bulk density by placing all the soil taken from 5cm deep layer of the profile in a 5cm deep layer in the tank in the same sequence as was found in the soil profile.

Four tanks were arranged to drain into one collecting pit with four separate outlets for the purpose of drainage measurement independantly from each tank. These four tanks were treated as one block and three such blocks were constructed for each experiment for the Soyabean crop which was grown in 2.44mx2.44mx1.22m tanks.Each of those four tanks in one block carried one of the four chosen treatments.Thus the experiment consisted of 4 treatments and 3 replications in a randomized complete block design.

Following four soil moisture depletion patterns were maintained till 2 weeks before harvest as four treatments.Namely first one at field capacity T1,second one till the soil moisture content in the root zone reaches 25% of the available moisture depletion level T2,third one till the soil moisture content in the rootzone reaches 50% of the available moisture depletion level T3,and the last one till the soil moisture content in the rootzone reaches 75% of the available moisture depletion level T4.

Approximate depletion rates were determined using the neutron probe.Three calibration curves were obtained one for the first 15cm layer,the other for the next 30cm layer and last one for the balance 45cm layer.

Best fit was given by a qudratic equation.
Three equations obtained are given below.

Equation for 0-15 cm layer   Eqn (1).
$$Y = -0.029 + 0.417X - 0.059 X^2 \qquad (R = 0.98ns).$$
Equation for 15 – 45 cm layer   Eqn (2).
$$Y = -0.006 + 0.287X + 0.005 X^2 \qquad (R = 0.68ns).$$
Equation for 45 –90 cm layer   Eqn (3).
$$Y = 0.118 + 0.173 X + 0.0003X^2 \qquad (R = 0.604ns)$$

Where Y is the volumetric water content in cms of water per cm depth of soil and X is the count ratio which indicates the ratio of average count in soil to average standard count.

Note: Eventhough above three equations are not significant at 0.5% and 0.1% level they are significant at 1% level. Since 90%correlation between X and Y is justified for decision making in agriculture sector,I used the above three relationships.

Procedure used in obtaining the moisture content of the profile is given in appendix 1.Relation between actual moisture content,calculated moisture content,and the error are given below for the three equations.

Equation 1.

Actual moisture content cm water/cm depth of soil.	Calculated moisture content cm water/cm depth of soil.	Error (actual-calculated)
0.162	0.183	-0.021
0.165	0.200	-0.035
0.078	0.091	-0.031
0.129	0.115	0.014
0.221	0.190	0.031
0.211	0.189	0.022

Equation II

Actual moisture content cm water per cm soil depth.	Calculated moisture content cm water per cm soil depth.	Error
0.187	0.172	0.015
0.199	0.173	0.026
0.287	0.217	0.070
0.196	0.205	-0.009
0.222	0.208	0.014
0.243	0.214	0.029
0.245	0.227	0.018

Equation III

Actual moisture content cm water cm depth of soil	Calculated moisture content cm water cm depth of soil.	Error
0.205	0.225	-0.020
0.243	0.231	0.012
0.284	0.254	0.030
0.221	0.254	-0.033
0.217	0.220	-0.005
0.257	0.266	-0.009
0.263	0.243	0.020

Above values are reported since there was a slight disparity between the equations derived from the computer and the reported equation which was derived manually.

All the drainages were collected from each tank independently and were converted to a linear measurement by dividing from the surface area of the tank.Irrigations were given as indicated in appendix II.

A simple water balance equation was used to determine evapotranspiration values.

$$\text{ie } W1\text{-}W2 = S = E + d - (I + R)$$

Where W1 is the profile storage in day 1,W2 is the profile storage in day 2, S is the change in storage,E the crop evapotranspiration ,d the drainage,In the irrigation and R is the precipitation (All rainfall values = or < 7.5cm taken).

From stage by stage ET values seasonal ET values were estimated.From stage by stage ET + P values seasonal ET + P values are calculated. Total seasonal water supply was taken from seasonal irrigation + rainfall.These were correlated with grain yield during 1984,85,86 Yala season and 85/86 Maha season. These were also correlated to relative yield as a percentage.

Results and Discussion

Seasonal evapotranspiration values were correlated with mean grain yield (from three reps) obtained from the lysimeter tank and the borders seperately.

Inside tank results.

1984 Yala season

$Y = 0.002X + 1.274$ $r^2 = 0.875$ (where Y = mean grain yield at 12% moisture in mt/ha, X = seasonal ET).

1985 Yala season

$Y = 0.002X + 1.025$ $r^2 = 0.781$

1985/86 Maha season

$Y = 0.003X + 0.217$ $r^2 = 0.34$

1986 Yala season

$Y = 0.002X - 0.246$ $r^2 = 0.942$

Seasonal evapotranspiration plus percolation values were also correlated to grain yield as above.

Inside tank results

1985 Yala season

$Y = 0.0005X` + 1.528$ $r^2 = 0.8$

1985/86 Maha

$Y = 0.001X` + 1.263$ $r^2 = 0.17$

1986 Yala

$Y = 0.002X` - 0.245$ $r^2 = 0.93$

Where X` = Seasonal ET + Percolation

Since there were year to year variation in grain yield this parameter was expressed as a relative yield making maximum value as 100.

Correation between relative yield and seasonal ET(mm) are given below.

Inside tank

1984 Yala season

$Y = 0.064X + 41.367$ $r^2 = 0.87$

1985 Yala season

$Y = 0.087X + 46.936$ $r^ = 0.78$

1985/86 Yala season

$Y = 0.152X + 9.725$ $r^ = 0.34$

1986 Yala season

$Y = 0.23X - 32.37$ $r^2 = 0.94$

Seasonal ET + P was also correlated to relative grain yield .

Inside tank

1985 Yala

$$Y = 0.022X + 71.03 \qquad r^2 = 0.80$$

1985/86 Maha

$$Y = -0.04X + 56.66 \qquad r^2 = 0.17$$

1986 Yala

$$Y = 0.221X - 32.201 \qquad r^2 = 0.93$$

Conclusion

Theoretically there shold be a negative intercept on the Y-axis.This was very clearly seen in the year 1986 dry season.Overall reduction in yield during this year was due to heavy lodging and a pest incidence but the ideallistic theoretical trend remained unaffected.Varied response in other years could possibly be due to confounding effects of various other factors like weed control,plant population and perhaps many more climatic parameters.

In addition to substantiating the form of the functional relationship between yield and water use,the results of various studies other than Srilankan work allow some observations to be made regarding the most efficient use of irrigation.

A major effect was the severe depression of yield caused by stress during "critical growth stages" of various crops.Crops vary in their tolerence to water stress and excessive water supply therefore ,differential effects may be observed in different crops.

If a crop is supplied with seasonal quantity of water less than its potential requirements severe yield reduction could occur if this deficit occurs during the period of such sensitivity.

An important result found in many cases is that the maximum ETof a crop does not necessarily correspond to the maximum yield. The application of water more than PET(potential evapotranspiration) requirements may increase the total yield of some crops such as sugarcane.

Considerable scatter in data obtained by many researchers when plotting crop yield versus water use,largely results from the time of occurance of water deficits in relation to the stages of growth.

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Appendix I

Proceedure in calculating water content in the profile is given below.

Three equations given below were used in the calculations.

0-15cm layer,

$$Y = -0.029 + 0.417X - 0.059X^2 \qquad R = 0.98 \text{ ns}$$

For 15 – 45 cm layer,

$$Y = -0.006 + 0.287X - 0.005X^2 \qquad R = 0.68 \text{ ns}$$

For 45-90 cm layer,

$$Y = 0.118 + 0.173X - 0.003X^2 \qquad R = 0.604 \text{ ns}$$

Where Y is the volumetric water content and X is the count ratio.

A sample calculation.

Depth of reading	counts	count ratio	volumetric water content. cm water/cm soil.	layer factor	water content in each layer.
Surface(7.5cm)	633,633	0.635	0.212	15	3.18
20 cm	633,633	0.635	0.178	10	1.78
30 cm	714,731	0.724	0.204	10	2.04
40 cm	735,714	0.751	0.212	10	2.12
50 cm	769,745	0.759	0.251	10	2.51
60 cm	758,767	0.764	0.252	10	2.52
70 cm	792,772	0.786	0.256	25	6.40

Total water content in 90cm profile = 20.55 cm

Note: Though F-test was not significant in both linear and qudratic fit ,when more data were added to previous Maha calibration data, qudratic fit showed an improvement over the linear fit since a higher percentage of variability in Y was explained by the qudratic fit than the linear one.So I used that form in this exercise.

Appendix II

When the rootzone reaches the indicated deficits given below full profile deficits were given as an irrigation.

From 07/06 to 22/06 is taken as stage I where,

$T1 = S(15) = 0.000$ where $S(15)$ is the change in total soil moisture storage in the first 15 cm soil layer from the surface.

$T2 = S(15) = 0.525$

$T3 = S(15) = 1.050$

$T4 = S(15) = 1.575$

From 22/06 to 17/07 is taken as stage II where,

$T1 = S(60) = 0.000$ cm

$T2 = S(60) = 1.875$cm

$T3 = S(60) = 3.750$ cm

$T4 = S(60) = 5.625$ cm

From 17/07 to 21/08 is taken as stage III where,

$T1 = S(90) = 0.000$cm

$T2 = S(90) = 2.850$cm

$T3 = S(90) = 5.700$ cm

$T4 = S(90) = 8.550$ cm.

During the growth stage IV no irrigations were given for all treatments.

WATER BALANCE AND THE IRRIGATION NEED OF RICE IN DIFFERENT AGRO ECOLOGICAL REGIONS OF SRI LANKA

K.D.N.Weerasinghe
W.S.Attanayake
J.L.Sabatier

Department of Agricultural Engineering,
Faculty of Agriculture,
University of Ruhuna,
Mapalana,
Kamburupitiya

WATER BALANCE AND THE IRRIGATION NEED OF RICE IN DIFFERENT AGRO ECOLOGICAL REGIONS OF SRI LANKA

K.D.N.Weerasinghe[1]
W.S.Attanayake[1]
J.L.Sabatier[2]

INTRODUCTION

Sri Lanka is a tropical island with an area of 65610 sq. Km , where the double cropping of rice is practiced for centuries using the rainfall of north-east and south-west monsoons. The monsoon regime demarcates two distinct seasons for cropping practices namely "Maha (major) and "Yala" (minor) seasons..

The minor season doesn't carry sufficient moisture for a pure rain fed crop in many part of the island. Thus in respect to the rainfall distribution pattern Sri Lanka is divided in to wet , intermediate, and dry zones which are further sub divided in to 21 agro ecological zones. Accordingly eleven agro ecological regions have been identified for the wet zone, four in intermediate zone and six in the dry zone (National atlas of Sri Lanka)

The wet zone covers 1. 54 mln ha, where annual precipitation ranges from 2300-5100 mm. The intermediate zone is spread over 0.85 mln ha, where annual rainfall is 1600- 2300 mm . The major part of the island is covered by the dry zone (4.17 mln ha) where annual rainfall ranges from 900- 1500 mm.

Present agricultural policies of the government is geared to settle the farmers in north central and eastern dry zones with the aim of intensifying paddy cultivation by means of irrigation in the additional land of 364200 ha and 60000 ha in north central and south eastern dry zone respectively . It is also envisaged to increase the rice production up to 4.5 t/ha in the long term basis by expanding water management programs (National policy frame work, 1995). Therefore the realistic estimates of the water need for rice irrigation, suited to Agro-Pedo-Climatological potential of dry areas is of paramount need to meet the future challenges in rice intensification programs.

Correct assessment of water need, onset and duration of the season, risk associated with dry and wet spells are important aspects in this regard.

The objective of the present paper is to assess the moisture availability and the agro climatological risk in different agro ecological regions for rice farming. An attempt was made to identify the different hydrological regions of the country based on water balance.

[1] Dept. of Agric. Engineering, Faculty of Agriculture, University of Ruhuna, Mapalana,Kamburupitiya
[2]. IRAT/CIRAD, Montpellier, France

MATERIALS AND METHODS

Daily rainfall and pan evaporation of 21 locations in the dry, intermediate and wet zone, which represent all agro ecological regions of Sri Lanka were used for the present analysis. The geographical locations, annual rainfall and pan evaporation of the selected locations are given in the table 1.

TABLE 1

Annual rainfall (1950-1990) and the respective Agro Ecological Zones of the Selected stations.

Station	Long	Latitude	Rainfall (mm)	Agroecological zone*
1.Anuradhapura	80.38	8.35	1282	DL1
2.Apelessa	80.90	6.15	1092	DL1
3.Badulla	81.05	6.99	2384	IM1
4.Batticaloa	81.70	7.72	1765	DL2
5.Charley Mount	80.28	6.00	2761	WL4
6.Colombo	79.86	6.90	2345	WL4
7.Dandeniya	80.39	6.00	1724	WL2
8.Denagama	80.79	6.06	1903	IL1
9.Hambantota	81.13	6.12	1041	DL5
10Jaffna	80.02	9.65	1213	DL4
11 Kalawewa		8.	1120	DL1
12Maha Iluppallama	80.47	8.12	1379	DL1
13Mannar	79.92	8.95	958	DL3
14Mapalana	80.57	6.07	2354	WL2
15 Mawarella	80.36	6.11	3067	WL1
16Nuwara Eliya	80.77	6.97	2328	WU3
17Polonnaruwa	81.00	7.93	1669	DL1
18Puttalam	79.83	8.03	1226	DL3
19Thihagoda	80.34	6.01	1830	WL4
10Trincomalee	81.21	8,58	1522	DL1
21Vavuniya	80.50	8.75	1420	DL1
22Watawala	80.60	6.95	5241	WU1

A computer program " first" was created (Weerasinghe , Sabatier Grandgean Luc, 1990) to assess the rainfall probabilities and statistics at a desired level in monthly, weekly ten day or five day periods. The rainfall probability of the period is calculated by the ranking order method. The program, allows probability levels to be selected by the user. Probability of rains in monthly and weekly intervals at 75% probability were taken as the assured rains in the present study.

In the program Markov chain procedure is employed to analyze dry and wet spells; the method of backward and forward accumulation described by Morris and Zandstra, 1979 is incorporated to calculate onset and termination of the rainy season . By choosing a certain date during the calendar year, usually the peak of the dry season, the rainfall of the selected period could be summed forward or backward until certain amount is accumulated. This process is repeated for the entire years of the data file and the probability of having received given amount of rain can be given for each time interval chosen.

summed forward or backward until certain amount is accumulated. This process is repeated for the entire years of the data file and the probability of having received given amount of rain can be given for each time interval chosen.

As suggested by Morris and Zandrsta (1979) 75mm accumulation of rainfall at the 75 % probability was taken as the onset time for the growing season for dry seeded crops, and 200mm accumulation for wetland preparation of rice.

The termination of the wet season is determined by the backward summing of rainfall data. According to Morris and Zandstra (1979) 500mm of accumulated rains after the planting would be sufficient to raise wetland rice. This criteria is used by Oldemen and Frere (1982), to determine the onset and termination of rice growing seasons in south east Asian countries.

In the present work forward and backward moisture accumulation curves were employed to decide upon the crop establishment period and the satisfaction of the rainfall to meet crop water demand. The probability level at which two curves of a given crop is bisected is considered to be the probability at which the particular crop could be raised (crop performance probability).

Forward accumulation of 200 mm rains from the 1 st march for Yala and, 1 st September for Maha seasons, and the backward accumulation of 500 mm rains from 1 st July and 31 September for two respective seasons were computed and based on which crop performance probability of the rice was assessed.

Water balance of the localities were assessed using the Hargreav's Moisture availability index (MAI) . The Program CROPWAT was used to estimate irrigation need to eliminate the climate risk in both Yala and Maha seasons. Irrigation requirement of rice for the different locations were simulated considering the transplanted paddy in LHG soils. GIS program UNIMAP was used to plot the rainfall, evaporation, water balance, Crop performance probability and irrigation need maps.

RESULTS AND DISCUSSION

The rainfall map clearly demonstrate that Sri Lanka has number of rainfall zones. Central mountainous region against the south west winds during the wet monsoon makes a clear climatic divide. High precipitation areas are found along the windward slope of the south west monsoon . The sharp contrast to the leeward side is clear. Most arid regions lie in north eastern and south western boundaries of the country (fig. 1).The highest evaporation 2400 -2500 is observed in Trincomalee. The other parts of the dry zone have an annual evaporation over 2100 mm.

The number of consecutive months with Moisture Availability Index (MAI) above 0.34 in the annual cycle and in the Yala and Maha seasons are given in fig 2, 3 and 4 (Weerasinghe, 1991) According to annual MAI, part of the dry and intermediate zone of Sri Lanka could considered to be in moderately deficient moisture regions. How ever Jaffna. Mannar Puttalam, Trincomalee, Amparai and Hambantota areas have less moisture availability, compare to other moisture deficient regions.

From the stand point of the water balance approach for Yala and Maha seasons two hydrologic regions, namely humid and semi arid regions are identified for the Maha season (fig. 3) and three hydrological regions viz. Humid, Semi arid, and Arid regions, in Yala season. The entire dry zone remains arid in the Yala season (Fig. 4)

The selection of proper sowing dates constitutes the central strategy in the optimum exploitation of the rainfall resources. According to Panabokke and Walgama (1974), the main strategy in selection of cropping season is to tailor the crops to rainfall, and adjust their management to available sequence of soil moisture.

Farmers cropping strategies are influenced by the variability they have experienced in the onset of the cropping season. This could be examined by judging the forward rainfall accumulation probabilities from the date of the commencement of the rainy season.

Dates of the forward accumulation of 25 to 200 mm rains from the beginning of the Yala and Maha seasons (from 1st March and 1st September) at ten selected stations of the dry areas of the country is at 75% probability level are given in the figures 5 and 6.

In three out of four years, 200 mm rainfall accumulation which is needed for wetland preparation in Maha could be expected in 42nd 43 rd weeks in all locations except Hambantota and Mannar where accumulation is delayed by about two weeks (fig 5). Accumulation of 75 mm rainfall for dry land crops in Maha could be expected in Trincomalee and Vavuniya on 41st week which is about one week earlier to Anuradhapura, Polonnaruwa , Kalawewa, Jaffna and Batticaloa, and two weeks earlier to Hambantota and Mannar. This agrees with the earlier findings of Panabokke and Walgama (1974), where authors have identified the sowing dates for southern wet zone around the 41 St. week and for the area around Hambantota and Thissamaharama approximately 7 to 10 days later.

In our earlier work we have shown that in the sufficient moisture regions for wetland rice the forward and backward moisture accumulation curves of 200 and 500 mm meet at a level above 75% probability . Where rainfall is inadequate the two curves meet at a low probability level (Weerasinghe 1990). Further more in order to achieve the possible probability, the crop has to be sown prior to the date indicated at the meeting point of the two curves. Table 2 indicate the crop performance probabilities and latest date of crop commencement at different locations of the dry areas. Probability map of the Maha and Yala rice are given in fig 8 and 9.

Table 2.

The performance probability of the rain fed Maha rice in Dry Areas

Location	Probability of Maha crop	Last date of Crop Commencement (Week)
1.Batticaloa	75	45
2. Trincomalee	75	43
3.Polonnaruwa	70	44
4.Jaffna	70	43
5.Kalawewa	65	43
6 Vavuniya	60	43
7.Anuradhapura	55	42
8. Mannar	40	43
9. Puttalam	40	42
10 Hambantota	18	42

It is evident that the Probability of Maha rainfed rice exceeds 75 % in Galle , Colombo, Kandy, N,Eliya And Rathnapura areas. Analogicaly Sucsess is above 70% in Kurunegala, Polonnaruwa, Trincomalee and Batticaloa areas. In rest of the Country performance probability of rice seems to be lie around 50 % except Hambantota and Puttalam which are the driest areas of the country (Fig 8).

The Irrigation Requirement of Rice as calculated by the program "Cropwat " is varies from 1200-1500 mm in Yala season and 597- 1000 mm in Maha season except Hambantota where the irrigation demand is around 1200-1300 mm (fig 9,10). It is clear that Maha irrigation need is much less in north east and north central dry zones compare to other dry areas. Low irrigation need in many locations on November, December period coincides with the availability of sufficient amount of rainfall from the North east monsoon. How ever irrigation need in Hambantota is more than doubled that of Batticaloa and Polonnaruwa in Maha season. This associates with the comparatively high dryness in Hambantota even in during the Maha season.

Present analysis indicate the high water need and risk associated in rice production in Hambantota,Mannar, and Puttalam areas where the irrigation systems may have to supply more water during the Maha season. The rehabilitation of abandoned tanks, proper water management, and adaptation of timely crop practices, water conservation by minimizing the wastage are some of the practical measures to be taken to minimize the high irrigation need in different locations.

Conclusions

Dry zone of Sri Lanka can differentiate into two distinct hydrological regions according to the Hargreave's MIA namely, "Moderately deficient " and some what deficient moisture regions. Form the stand point of the water balance approach for Yala and Maha seasons two hydrological regions, namely humid and semi arid regions can be identified for the Maha season, and three hydrological regions viz. Humid, Semi arid, and Arid regions, in Yala season. The entire dry zone remains arid in the Yala season.

In most locations of the dry zone , forward accumulation of 200 mm rains for the commencement of the wetland rice in Maha at 75 % probability level could be expected on 42-43 weeks, with an exception of Puttalam and Hambantota areas.

The highest irrigation need in "Maha" seems to be in Hambantota(1000-1200 mm) district followed by Puttalam and Mannar. The irrigation requirement at "Yala" accounts for 1200- 1500 mm in Northern dry zone and 900- 1000 mm in North central dry zone.

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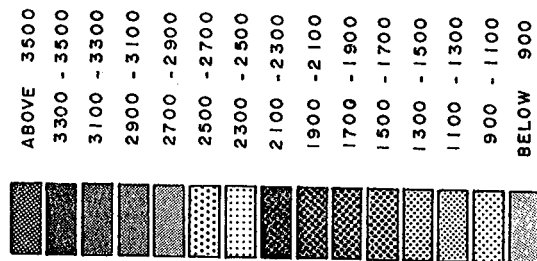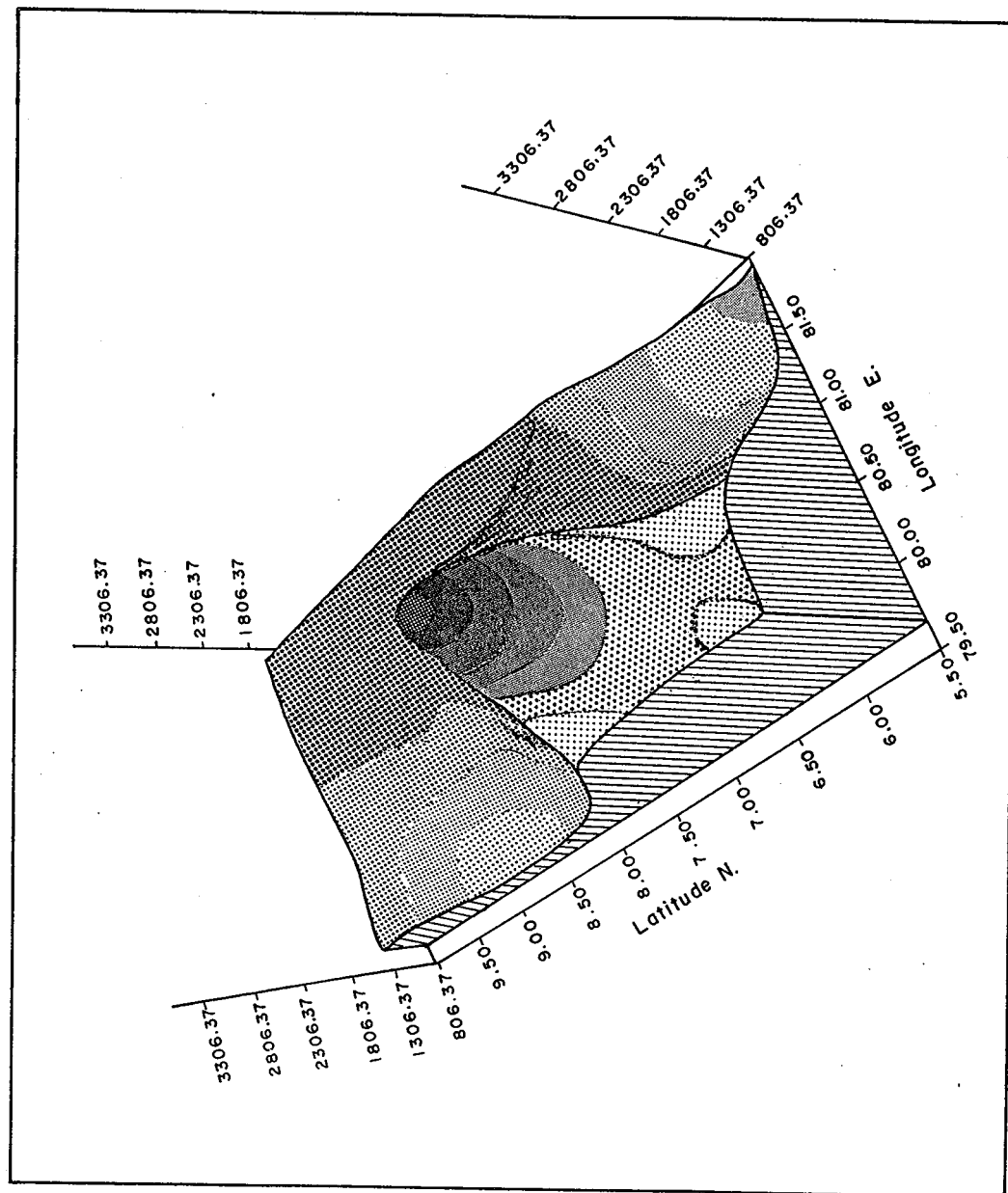Fig.1. ANNUAL RAINFALL – SRI LANKA (mm)

Legend:
ABOVE 3500
3300 – 3500
3100 – 3300
2900 – 3100
2700 – 2900
2500 – 2700
2300 – 2500
2100 – 2300
1900 – 2100
1700 – 1900
1500 – 1700
1300 – 1500
1100 – 1300
900 – 1100
BELOW 900

Fig. 2. Annual Moisture Availability Indices (MAI), Sri Lanka
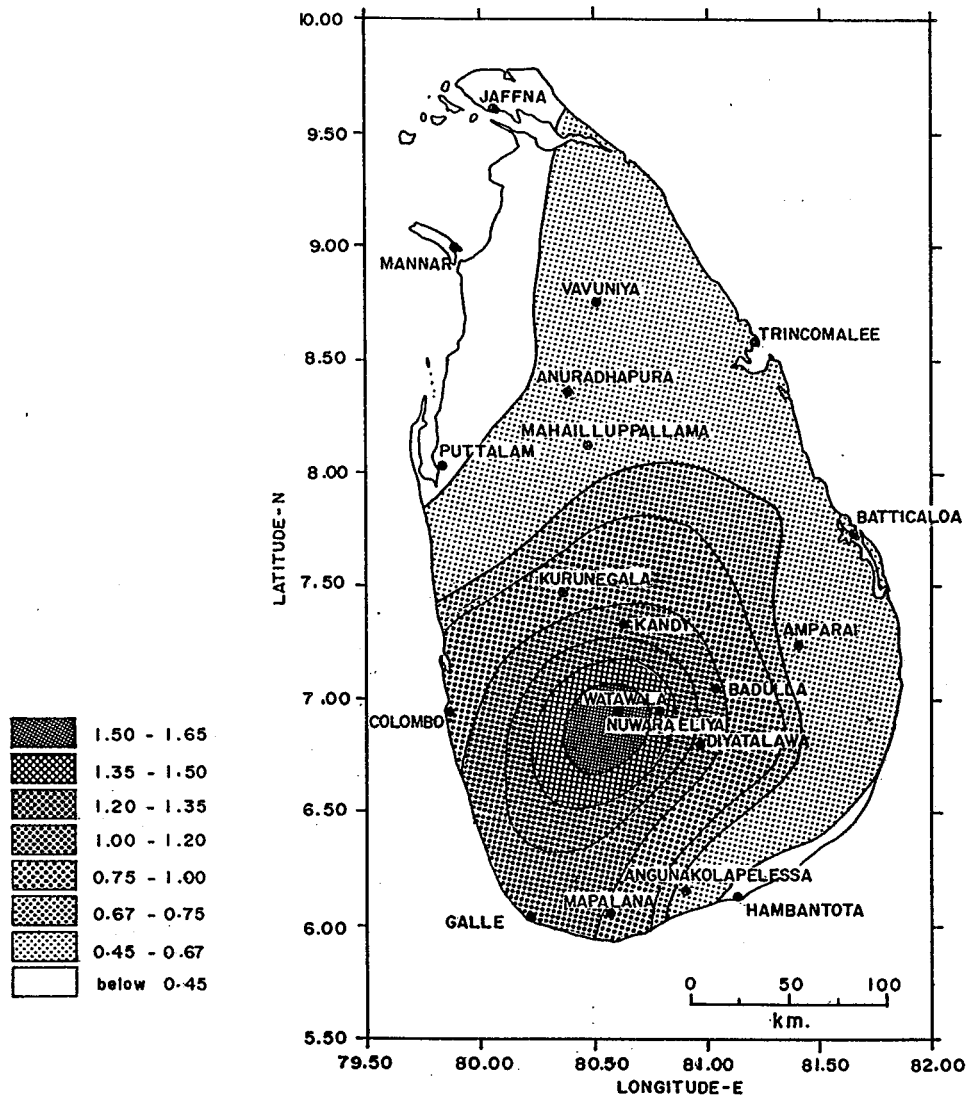according to Hargreave's Classification.

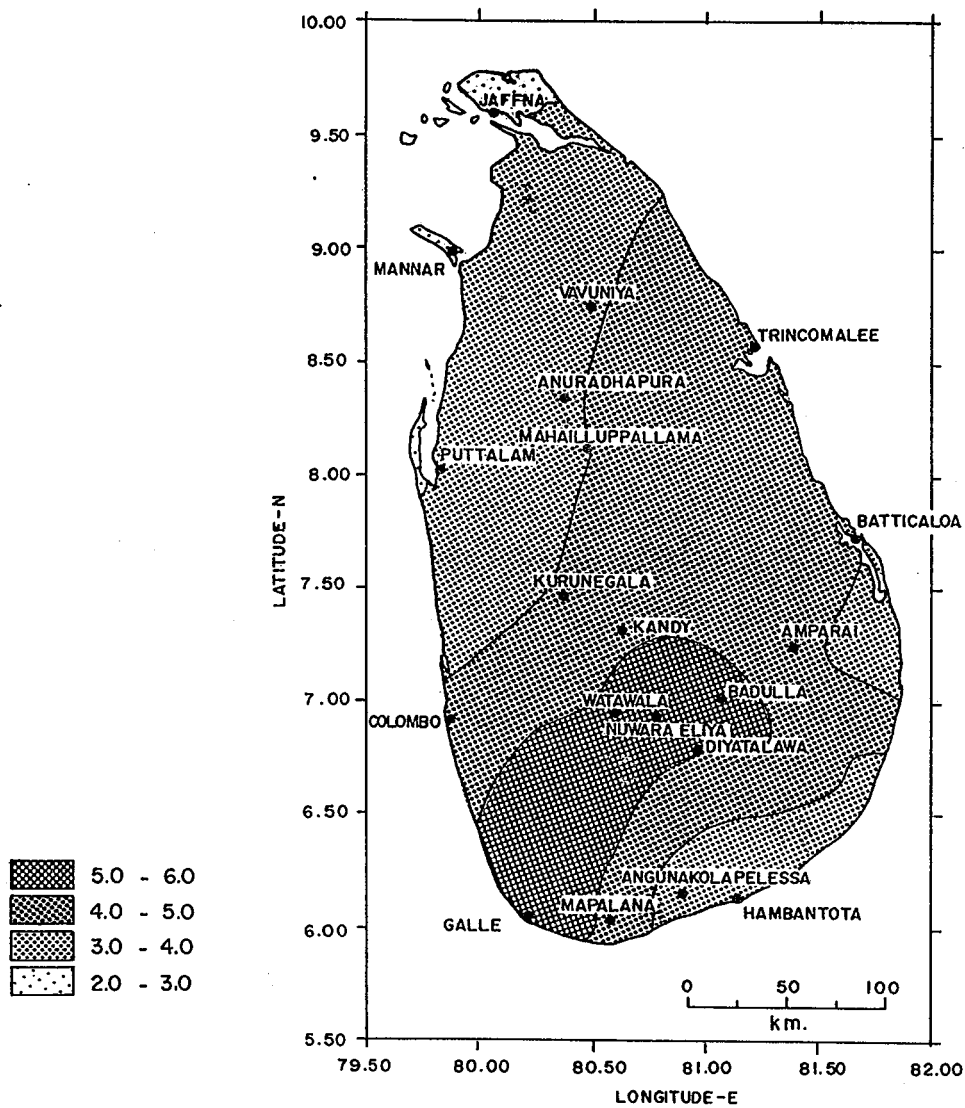# Fig. 3. Number of Consecutive Months with 'MAI' above 0.34 in Maha Season

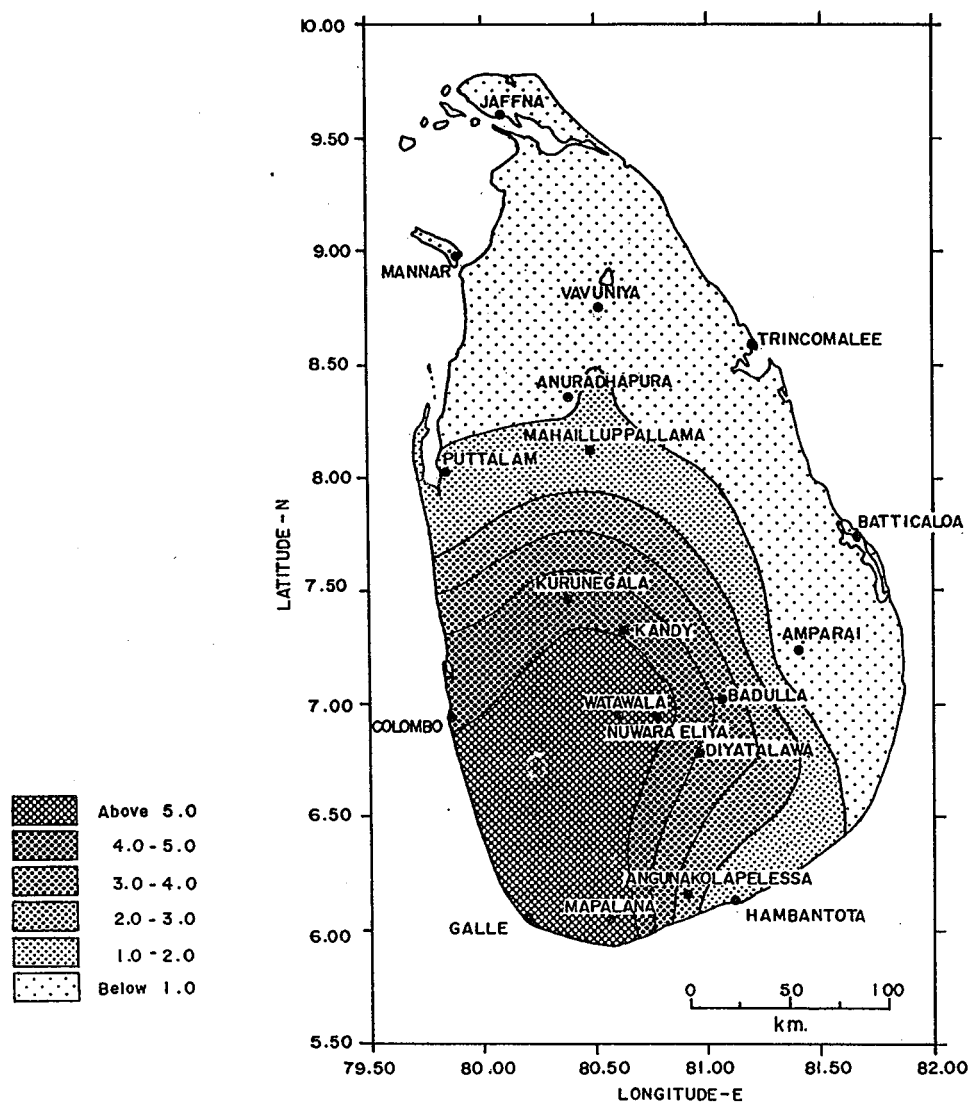Fig. 4. Number of Consecutive Months with 'MAI' above 0·34 in Yala Season

FIG 5

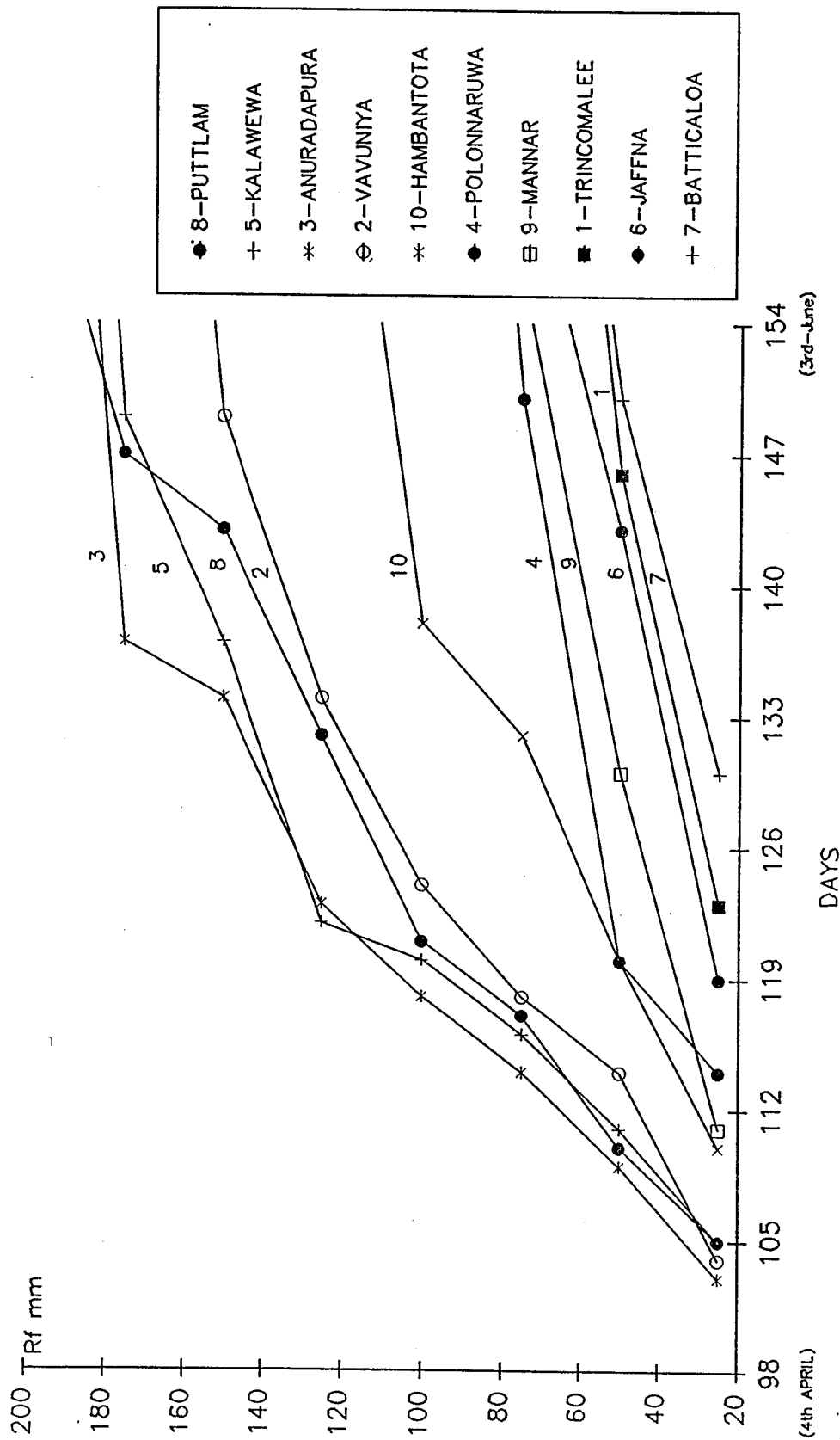FORWARD ACCUMULATION OF RAINFALL AT THE BEGINING OF 'YALA' SEASON IN 3 OUT OF 4 YEARS(.75P)

8-PUTTLAM
5-KALAWEWA
3-ANURADAPURA
2-VAVUNIYA
10-HAMBANTOTA
4-POLONNARUWA
9-MANNAR
1-TRINCOMALEE
6-JAFFNA
7-BATTICALOA

32.

FIG. 6

RAINFALL ACCUMULATION AT THE BEGINING OF MAHA SEASON IN THREE OUT OF FOUR
YEARS (75% probability)

FIG. 7

PROBABILITY MAP OF THE 'MAHA' RICE CROP

ABOVE   90.0
80.0 — 90.0
75.0 — 80.0
70.0 — 75.0
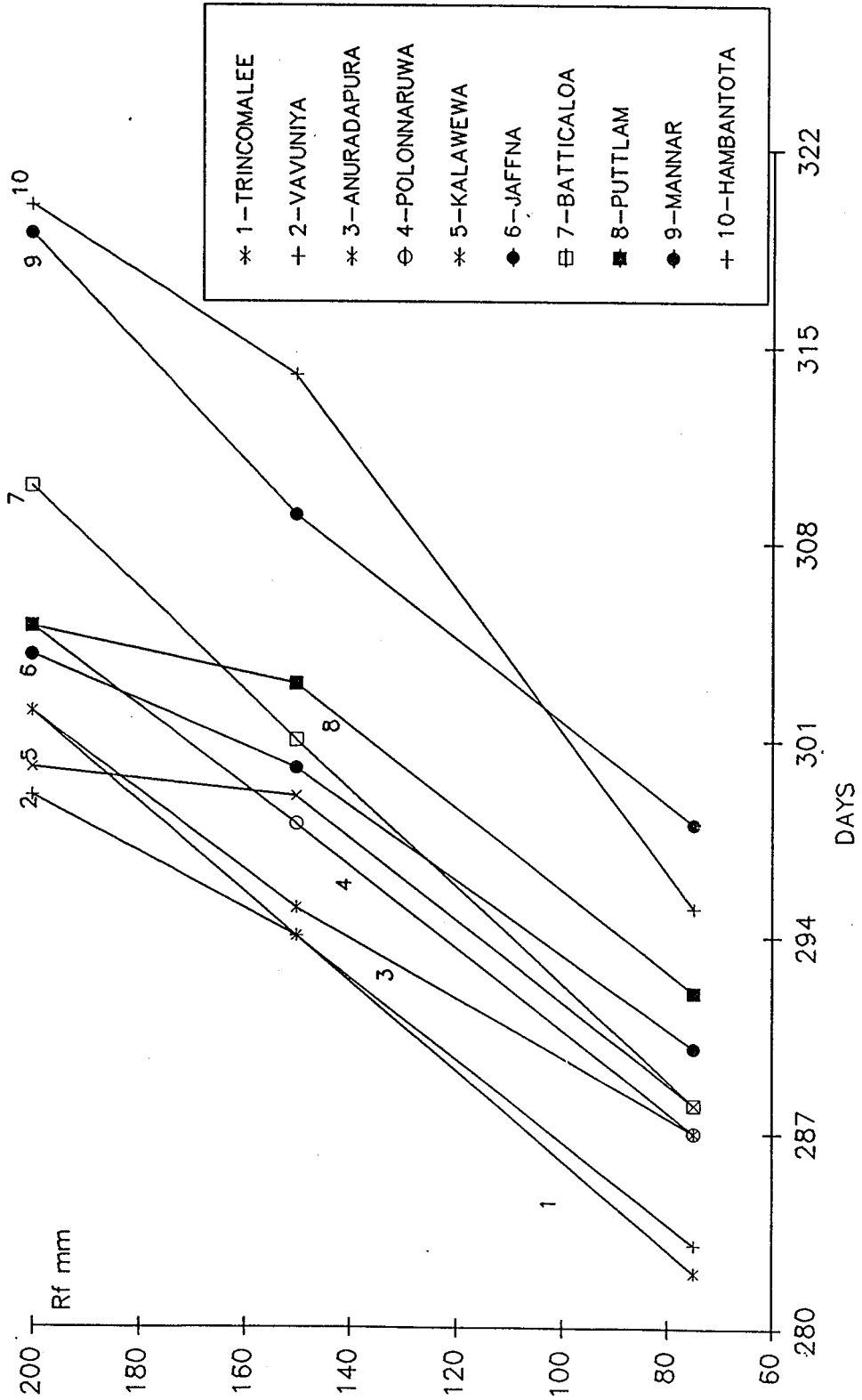60.0 — 70.0
50.0 — 60.0
40.0 — 50.0
20.0 — 40.0
BELOW   20.0
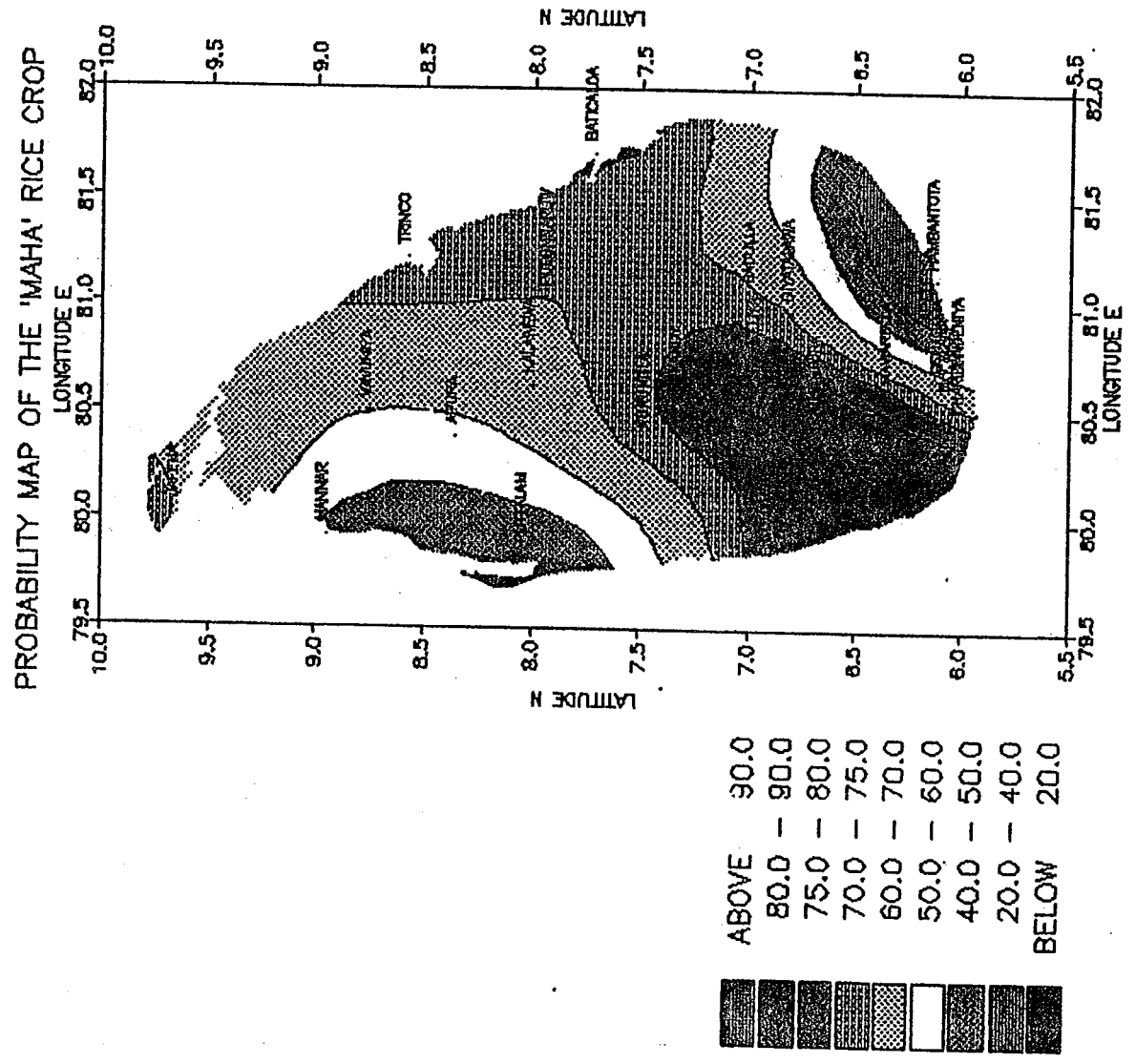
FIG. 8

IRRIGATION NEED OF THE 'MAHA' RICE IN NORMAL YEARS
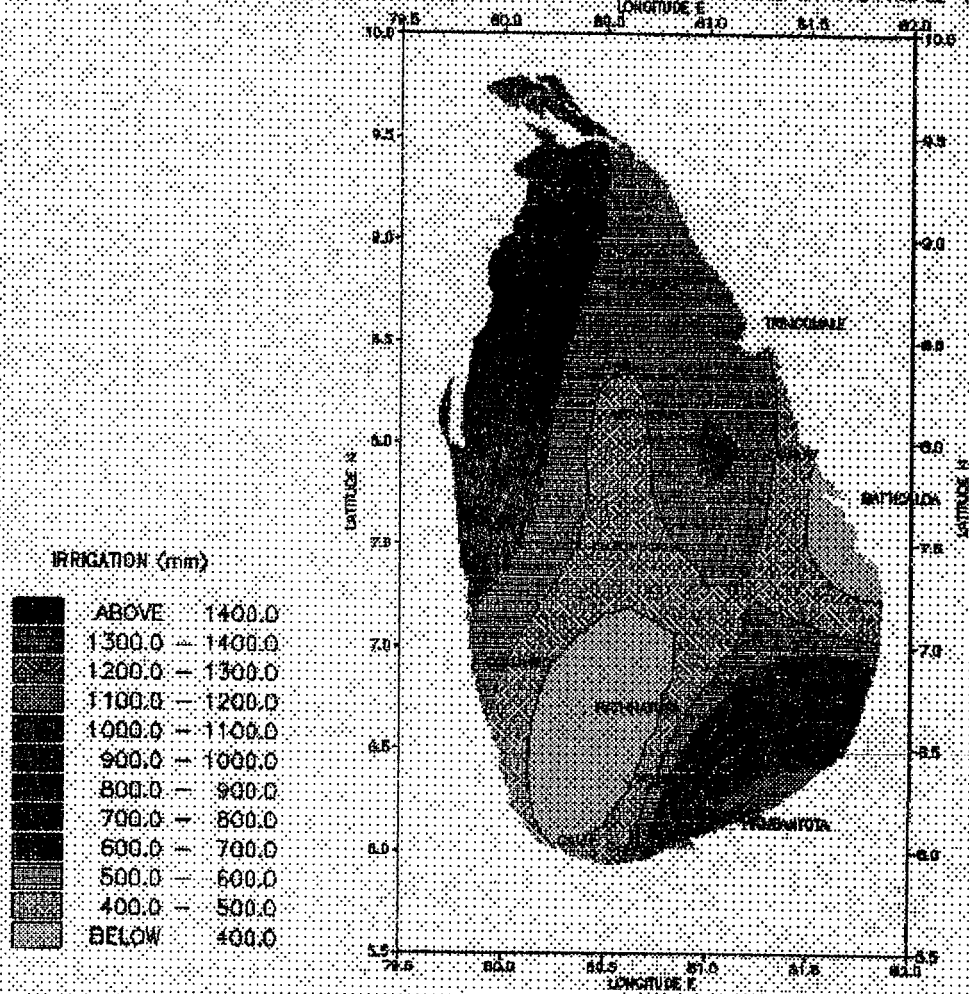
FIG.9 IRRIGATION NEED OF THE 'YALA' RICE IN NORMAL YEARS

IRRIGATION (mm)

ABOVE	1300.0
1200.0 —	1300.0
1100.0 —	1200.0
1000.0 —	1100.0
900.0 —	1000.0
800.0 —	900.0
700.0 —	800.0
600.0 —	700.0
500.0 —	600.0
400.0 —	500.0
300.0 —	400.0
BELOW	300.0