Revising and Optimizing Iso-Yield Curves for the Diverse Agro-Climatic Zones of Sri Lanka

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***Abstract*— The most recent nationwide Iso-Yield curves, which illustrate regional variations in crop productivity, were last updated in Sri Lanka in 1978. This lengthy gap in data is significant, especially given the considerable changes in climate, hydrology, and agricultural practices that have taken place over the past four decades. This study aims to update Sri Lanka's yield maps for its two primary monsoon-driven cultivation seasons: Maha (Northeast Monsoon) and Yala (Southwest Monsoon). To achieve this, an integrated approach is employed, combining river gauge data, records of reservoir operational inflows and outflows, and observed agricultural production statistics. Historical and contemporary hydrological datasets from key river basins were compiled and analyzed to estimate irrigation water availability patterns across districts. These hydrological indicators were statistically correlated with crop yield performance data derived from national agricultural statistics, facilitating the spatial interpolation of updated yield distributions. Advanced geospatial analysis techniques and GIS-based modeling were employed to delineate field zones characterized by homogeneous yield potential, resulting in the generation of updated Iso-Yield curves for both monsoon seasons. The findings indicate significant spatial shifts in high- and low-yield zones compared to the 1978 maps, reflecting the combined effects of climate variability, alterations in reservoir operations, and evolving irrigation practices. The updated Iso-Yield curves provide a more accurate representation of Sri Lanka's current agricultural productivity landscape, aiding in precise zoning for optimized agronomic decisions, targeted irrigation scheduling, and region-specific crop planning. This study offers a valuable decision-support tool for policymakers, irrigation managers, and farmers, while establishing a methodological framework for future yield mapping endeavors in monsoon-dependent agricultural systems.**

I. Introduction

Iso-yield maps, also referred to as iso-yield curves, are spatial representations that connect points of equal agricultural yield, serving as valuable visual tools for assessing productivity variations across different landscapes [1]. These maps enable researchers and practitioners to correlate agricultural output with underlying environmental and management factors. Functioning similarly to topographic contour maps, iso-yield maps emphasize areas that produce the same level of crop yield. They are widely employed in precision agriculture to identify patterns of productivity, optimize field management strategies, and enhance the efficiency of resource allocation [2].

The introduction of yield mapping in the 1990s, which integrated Global Positioning System (GPS) technology with yield sensors on harvesting equipment, revolutionized the measurement of spatial yield variability at more refined scales. Although this practice has historical roots, no comprehensive documents are available prior to 1993. In year 1993, Schnug et al. [1] pioneered the development of yield maps in the USA. Since then, numerous researchers have created yield maps for various crops across different countries [2], [3], [4], [5]. As highlighted by Blackmore et al. [4], "yield monitors, GPS receivers, and yield mapping software are now widely employed" to produce detailed maps of production patterns. However, accurately interpreting these maps requires the ability to differentiate between genuine variability and errors arising from sensor and GPS system inaccuracies. Raw yield map data often exhibits spatial inaccuracies, such as voids, GPS anomalies, and yield spikes, which can obscure actual patterns. Therefore, post-processing steps such as void detection, spatial interpolation, and error correction are crucial for generating reliable iso-yield maps. A contemporary approach focuses on identifying voids and spatial errors before interpolation to ensure the creation of high-quality contours [6].

Iso-yield maps are vital for identifying both high- and low-yield zones within agricultural fields, enabling targeted, site-specific management decisions. In the context of precision farming, these maps are crucial for determining where to apply variable-rate inputs, such as fertilizers or irrigation, ultimately enhancing profitability while promoting environmental sustainability [7]. Literature highlights that yield mapping allows farmers to "identify areas that may require more intensive irrigation or are yielding no crops whatsoever." Moreover, when paired with variability indices, yield maps can identify zones that consistently show low yields or significant variability areas that are prime candidates for management adjustments or interventions. Iso-yield curves further assist in delineating field zones characterized by uniform crop performance, supporting precise zoning for optimized agronomic decisions [8]. By integrating sensor technology, GIS, and spatial statistics, iso-yield maps provide invaluable insights into agricultural productivity. By visualizing yield variability, addressing data quality concerns, and enabling context-specific interventions, these maps significantly contribute to the evolution of precision agriculture.

In the context of Sri Lanka, yield mapping has primarily involved the creation of Iso-Yield curves by the Irrigation Department since 1989 [9]. These Iso-Yield curves are classified into two main agricultural seasons: the Maha Season (October to March) and the Yala Season (April to September) [10], [11]. The Iso-Yield Maps of Sri Lanka play a crucial role in analyzing water budgets and conducting operational studies of existing irrigation reservoirs and tanks, as well as supporting other agricultural water resource development initiatives in the country. Although the Iso-Yield curves were initially published in 1978, there is a recognized need for updating this information. The specific water yield is influenced not only by rainfall but also significantly by the geographical and land use patterns within the drainage areas. Rainfall patterns have changed considerably since 1978 due to climate change and various meteorological factors, and land use patterns in the country continue to evolve [12]. Consequently, the values for Specific Water Yield across the nation may have undergone significant shifts since 1978. Therefore, it is necessary to calculate these parameters at regular intervals and update them accordingly.

II. Data Used and Method of Analysis

The primary data used for the development of Iso-Yield Curves are obtained from streamflow measurements at hydrological gauging stations and inflow data calculated from the operational records of existing reservoirs and tanks [13]. Two main types of data can be effectively utilized for constructing Iso-Yield curves. The first type encompasses the streamflow data collected from hydrological gauging stations, while the second involves the comprehensive operational data from existing reservoirs and tanks. To achieve results that are both consistent and reliable, it is essential to gather a substantial amount of data for either of these types. A comprehensive dataset enables more precise analyses, minimizes the margin for error, and increases the overall reliability of the findings. In the absence of such a robust data foundation, the outcomes may be distorted or misleading, ultimately restricting their applicability and effectiveness in real-world situations.

A. Analysis of Stream Flow Data of Hydrological Stations

Flow data gathered from hydrological stations plays a vital role in determining the specific water yield of their respective drainage areas, as this data accurately captures both surface runoff and base flow components. The integration of base flow in the evaluation of Iso-Yield curves is widely accepted, particularly as the focus is on yields arising from natural hydrological processes.

This comprehensive analysis considers data from 29 strategically selected hydrological stations, each possessing a robust record of flow measurements over an extensive period, including the most recent data available up to 2020. However, a thorough examination of total monthly discharges and calculated specific yields leads to the systematic exclusion of four stations from the analysis due to the emergence of unrealistic results. These discrepancies are likely due to inaccuracies in the rating curves used to convert recorded water level data into discharge estimates.

Ultimately, the analysis centers on deriving monthly discharges and monthly specific yields, the latter calculated by dividing the total monthly discharges by the effective drainage area for each station. This methodology facilitates the averaging of data across 25 carefully vetted hydrological stations, providing a strong foundation for the preparation of Iso-Yield curves. For visual clarity and reference, the geographical distribution and significance of these selected hydrological stations are illustrated in Fig. 1.

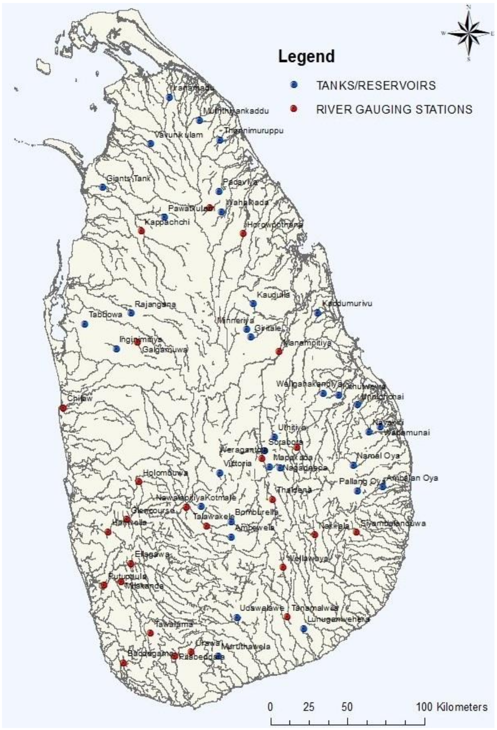

Figure 1. Hydrological Stations and Reservoirs/Tanks Selected for Yield Calculations (Adopted from [14]).

20....... .... මාසය සඳහා .... ගොවිජනසේවා නිකුත් කළ ජලය පිළිබඳ වාර්තාව

Report of issue of water from the Minneriya Tank sluice for the month of Sep 2014

Irrigation } 8

Name of the Tank	Minneriya	Head of water on the last day of the preceding month	23.2
Catchment Area	237.056 Sq.Km.	Head of water on the last day of the current month	22.7
Capacity at F.S.L.	110,000 Ac.ft	Capacity of the end of preceding month	37,621
F.S.L. Head	38.1 ft	Capacity of the end of the current month	35,590
Number of Spills: 1 .... 2 .... Nature of Spills	1: 200 ft; 2: 45 ft	Length	245 ft
Area under cultivation	9,099.19 Ha.	Monthly Algebraic Difference of Capacity	-2,031
Stage of cultivation	....	Date of first issue	Date of last issue of water ....

Sluice No.01: Width 2.8 ft, Height 4 ft, Diameter ....; Sluice No.02: Width 2.6 ft, Height 3 ft, Diameter ....; Sluice No.03: Width ...., Height ...., Diameter ....

Date	Head of Water At Sluice	Effective Head	Sluice No.01 Issue in Ac.Ft.	Sluice No.02 Issue in Ac.Ft.	Sluice No.03 Issue in Ac.Ft.	Rainfall in 24 Hours mm	Volume of Spilling over Crest Level (Ac.Ft.)	Inflow from Other Sources (Ac.ft)	Remarks (Diversions)
1	23.2	17.5	814.6	37.2		0	0	4138.2	
2	22.9	17.2	911.7	36.4		0	0	1003.9	
3	22.8	17.1	908.8	36.6		0	0	1051.6	
4	22.8	17.1	448.2	0.0		0	0	1104.3	
5	23.0	17.3	268.6	0.0		0	0	1203.0	
6	23.3	17.6	208.6	0.0		0	0	1446.8	
7	23.4	17.7	211.1	37.5		0	0	261.8	
8	23.4	17.7	733.4	0.0		0	0	0.0	
9	23.0	17.3	802.9	36.9		0	0	0.0	
10	22.7	17.0	795.4	36.5		0	0	0.0	
11	22.5	16.8	545.2	0.0		0	0	0.0	
12	22.3	16.6	202.5	0.0		0	0	0.0	
13	22.2	16.5	201.7	0.0		0	0	0.0	
14	22.1	16.4	201.0	0.0		0	0	0.0	
15	22.0	16.3	488.5	35.5		0	0	0.0	
16	22.0	16.3	0.0	0.0		0	0	0.0	
17	22.0	16.3	0.0	0.0		0	0	0.0	
18	22.0	16.3	488.5	0.0		0	0	0.0	
19	21.7	16.0	488.5	0.0		0	0	0.0	
20	21.5	15.8	260.4	0.0		0	0	0.0	
21	21.4	15.7	186.4	0.0		0	0	0.0	
22	21.4	15.7	194.3	0.0		20	0	0.0	
23	21.4	15.7	0.0	0.0		15	0	230.2	
24	21.5	15.8	0.0	0.0		21	0	106.2	
25	21.7	16.0	0.0	0.0		44	0	84.2	
26	22.5	16.8	0.0	0.0		14	0	0.0	
27	22.6	16.9	0.0	0.0		1	0	0.0	
28	22.7	17.0	0.0	0.0		6.6	0	0.0	
29	22.7	17.0	0.0	0.0		0	0	0.0	
30	22.7	17.0	0.0	0.0		0	0	26.9	
			9370.4	256.6		121.6	0	10637.0	

ISSUES: Sluice No 1 9370.4; Sluice No 2 256.6; Sluice No 3 0; Total Issues 9,627.08

Rate of consumption 0.416927653 Ac. Ft per Ac. /MCM; Rate of consumption 0.011418367 Ac. Ft per Ac. /MCM; Rate of consumption 0 Ac. Ft per Ac. /MCM; Average for the month 0.43 Ac. Ft per Ac. /MCM

+ (Total Issues) – (Monthly Algebraic difference in storage) + (Spillage) } = { + Yield from Catchment .... Ac. Ft or MCM; – Yield from diversion .... Ac. Ft or MCM; – Losses in Storage .... Ac. Ft or MCM

Yield = Total Issues – (Difference in storage) + Losses in Storage – Yield from other sources (Diversions) .... Ac. Ft or MCM

Difference in Storage = Storage at the end of the month - Storage at the end of previous month = -2031 Ac.ft

If there are more Rainfall stations in the catchment please specify below: Station 1 Name: Coordinates; Station 2 Name: Coordinates; Station 3 Name: Coordinates

Figure 2. The Daily Records of Operational Data in a Monthly Format (Adopted from [14]).

THE REPUBLIC OF SRI LANKA - DEPARTMENT OF IRRIGATION (HYDROLOGY DIVISION) ANNUAL STATEMENT OF RESERVOIR REPLENISHMENT AND BEHAVIOUR

Reservoir: Minneriya	Location G/16 (12.30 x 5.25)	Province North Central	
Cat. Area 237.1 Sqkm	Date of Last Contour Survey of Reservoir Bed__________		
Capacity 135.64 MCM	Area Of F.S.L. 2550 Ha.	Full Supply Depth 12 m	
	Statement for the Water Year Ending September 30, 2014		

1	2	3	4	5	6	7		8	9	10	11	12	13	14	15	16
Month	RF on Cat. mm	Yield From Cat. mm.	Yield From Cat. M.C.M	Issue From Sluices M.C.M	Discharge Over Spills M.C.M	Change In Reservoir Storage - M.C.M. + Increase	Change In Reservoir Storage - M.C.M. - Decrease	Evapo - Seepage Loss M.C.M.	Area Irrigated Ha	Duty In Metres col5 /col9*1 02	Mean Rate of Evapo-Seepage Loss mm Per Month	Reservoir Storage M.C.M.	Water Area Ha	Depth At Lowest Sluice m	A.M/P.M. on .... Maximum Spillage; Maximum Annual Flood =.......... Cumecs At......; Cuecs at......... a.m/p.m. Recorded...... Cumecs; Maximum Flood On.........	Diversion M.C.M.
October	61	0	0	10.75	0	7.03		1.79	9095	0.12	110	55.27	1581	7.62		58.8
November	139	3	0.72	34.44	0		21.44	1.22	9095	0.38	80	62.3	1677	8.08		13.5
December	117.4	107.1	25.4	21.73	0	35.57		1.3	9095	0.24	80	40.86	1376	6.71		33.2
January	232	12.9	3.07	33.44	0	3.81		1.51	9095	0.37	80	76.43	1865	9.05		35.69
February	99	1.4	0.34	13.86	0		13.08	1.46	9095	0.15	80	80.24	1915	9.24		1.9
March	0	1.9	0.44	3.61	0		4.42	1.88	9095	0.04	110	67.16	1742	8.41		0.63
April	60	5.9	1.41	4.21	0		3.98	1.66	9095	0.05	100	62.74	1683	8.11		0.47
May	69	0	0	9.3	0	8.84		2.03	9095	0.1	120	58.76	1630	7.83		21.41
June	0	0	0	15.39	0		18.33	2.43	9095	0.17	150	67.6	1747	8.44		7.22
July	0	0	0	17.62	0		15.92	2.07	9095	0.19	150	49.27	1497	7.25		8.47
August	45.3	8.4	2	12.45	0	12.92		1.9	9095	0.14	140	33.35	1262	6.16		25.27
September	121.6	17.4	4.13	11.5	0		2.49	1.87	9095	0.13	130	46.27	1455	7.07		6.75
Totals	944.3	158.2	37.5	188.29	0	68.17	79.66	21.12		2.07		43.78	1420	6.92		
					Difference		-11.49									

Worked by .... Checked by ....

Date .... Date ....

Figure 3. The Specimen Replenishment Sheet Calculated for a Water Year for Minneriya Reservoir (Adopted from [14])

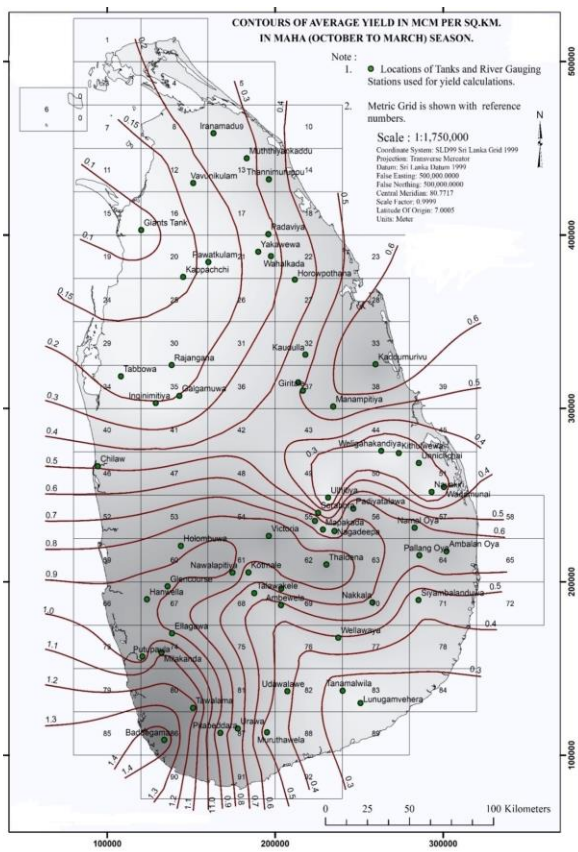

Figure 4. The Iso-Yield Curves for Maha Season (North East Monsoon) (Adopted from [14]).

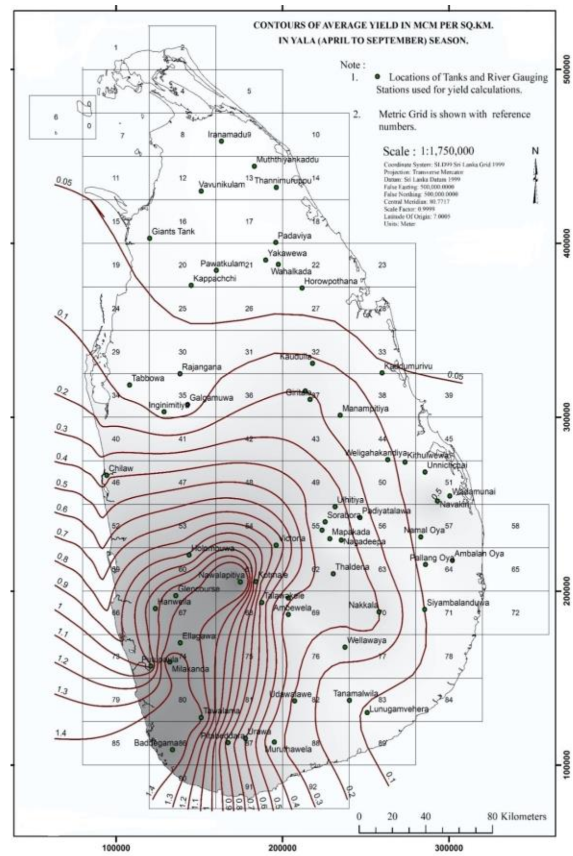

Figure 5. The Iso-Yield Curves for Yala Season (Southwest Monsoon) (Adopted from [14]).

B. Analysis of Operational Data of Irrigation Reservoirs/Tanks

The operational data of reservoirs and tanks can be effectively utilized to derive the total water yield from the drainage area, leading to the calculation of Specific Water Yields, provided that all relevant data is accurately recorded. Essential information includes daily water levels, which can be converted to daily storage volumes using Area-Capacity curves or tables, along with records of daily releases from all sluice gates, and comprehensive documentation of spills. discharges, and diversions to and from the reservoir or tank, as well as from and to its drainage area, are crucial data for the analysis. This data forms the basis for conducting a water balance study of the specific reservoir or tank, enabling the calculation of the total water yield from the catchment area.

It is preferable to select reservoirs or tanks that do not have significant upstream storage influences for this analysis. However, in light of the limited availability of such reservoirs, we have opted to include those with minimal upstream storage effects, which can be accurately quantified.

ID has implemented a systematic method for recording data and analyzing the water balance of tanks. The Engineer In-Charge of each reservoir or tank is responsible for recording all daily operational data in a monthly format designated as "Irrigation 8". An example of this format is provided as Fig. 2.

At the end of a water year, a complete set of these sheets was compiled and summarized in an Annual Replenishment sheet, a sample of which is included as Fig. 3. While the calculation procedures are not detailed in this document, the sheets are designed to be self-explanatory.

In this analysis, data from an initial 185 reservoirs and tanks were evaluated. However, a significant number were excluded primarily due to incomplete data and considerable gaps. The deficiencies identified in the data are outlined below, which may assist reservoir and tank managers in improving future records.

1. Spilling discharges are inaccurately recorded in several reservoirs and tanks.
2. In certain instances, while spill discharges from gated structures are correctly documented, discharges from natural spills are not.
3. Diversion inflows are recorded incorrectly in some cases.
4. Diversion outflows from the upper catchment are rarely recorded.
5. Sluice discharges are not calibrated accurately in some cases.
6. Area-capacity curves and tables are unavailable for certain reservoirs and tanks.

Initially examined data from 141 reservoirs and tanks. However, a detailed review revealed that a substantial portion of the data was compromised due to various issues, necessitating its exclusion from the study. Consequently, the focus was narrowed to data from 44 tanks for further calculations. Despite a meticulous preliminary screening process, results for 14 of these reservoirs and tanks were discarded due to the detection of irregularities that significantly deviated from expected outcomes. The discrepancies observed were likely due to human errors, which may encompass incorrect unit conversions, lapses in data entry, or other unidentified factors that warrant further investigation. Consequently, the final dataset comprised only 30 reservoirs and tanks, supplemented by data from 25 strategically chosen hydrological stations. This targeted strategy aims to enhance the reliability and accuracy of the Iso-Yield outcomes.

III. Results and Discussion

The monthly specific yields calculated for all hydrological stations, encompassing 25 individual stations, 30 reservoirs, and 30 tanks, were systematically aggregated to derive seasonal yields for both the Maha and Yala seasons at each location across all considered water years.

To facilitate further analysis, the average seasonal yields for each site were utilized to create detailed contour maps using the ArcGIS platform. These contour lines were subsequently refined through various smoothing techniques available within the software, resulting in the final yield curves illustrated in Figs. 4 and 5. These curves represent the seasonal yields measured in Million Cubic Meters (MCM) per square kilometer of catchment area, offering a crucial metric for assessing water availability.

Additionally, the comprehensive mapping was enhanced by incorporating a Coordinate Grid (SLD 99) and detailed Metric Topographical sheets at a 1:50,000 scale, covering the entire island. This mapping framework is designed to assist users in easily identifying specific Points of Interest.

While the data collection period for most hydrological stations extends beyond 20 years, a select few stations possess only approximately 5 years of data. Nevertheless, to address gaps in the dataset and ensure that extensive areas are not deprived of vital information, these shorter datasets were integrated into the analysis. The specific data points utilized are depicted in Figs. 4 and 5, which also prominently feature the names of the respective locations. This comprehensive approach aims to provide a thorough understanding of seasonal water yields across the studied regions.

IV. Recommendation

In light of the findings from the recent analysis, the following comprehensive recommendations have been proposed.

Utilization of Iso-Yield Curves: Stakeholders are strongly encouraged to employ the newly developed Iso-Yield curves for all relevant studies, planning initiatives, and design projects across the island. These curves are vital tools for understanding water yield variability and can significantly enhance water resource management practices.

Considering that the variables influencing water yields are continually impacted by factors such as climate variability, land use changes, and shifts in water demand, it is essential to schedule regular updates for these Iso-Yield curves. It is recommended to conduct these updates at least once every decade to ensure that the curves remain aligned with the most current data and conditions. To achieve optimal accuracy in future analyses, it is imperative to gather daily operational data from all reservoirs and water tanks throughout the region. The Irrigation Department of Sri Lanka has made strides in this area by updating the relevant data collection format, now designated as "Irrigation 8." This format is tailored to facilitate effective data recording and management.

It is urged that all reservoir managers within the country's agencies diligently monitor and record the operational data of their respective reservoirs and tanks. This information must be submitted promptly to the Hydrology and Disaster Management Division of the Irrigation Department. Hence, this data will significantly enhance the accuracy and reliability of future Iso-Yield curve analyses. By implementing these recommendations, we can improve our understanding of water resource dynamics and strengthen the overall effectiveness of water management strategies on the island.

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