02

An Attempt Classification of Reservoir Cascade Systems

JMSB Jayasundara[1]

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ජලාශ ප්‍රතිසංස්කරණය සඳහා ජලාශ එල්ලාංගා පද්ධති සංකල්පය භාවිතා කරන ලදුව ද ගංගානිම්න වල විශාල ජලස්කන්ධයක් තවමත් වැඩි ප්‍රයෝජනයකින් තොරව මුහුදට ගලා යයි. ගංගානිම්න වල පහළ කොටසේ ජලය භාවිත කිරීමට යොදාගත් පෙරරාජකීය ක්‍රමෝපායයන් ඉහළ කොටස්වලට වඩා වෙනස් වනවා මෙන්ම එම ක්‍රමෝපායයන් භාවිතා කිරීමට අදට ඇති විභවතාව ගවේෂණය කළයුතුව ඇත. මෙම අධ්‍යයනයේදී, ගංගානිම්න වල ස්වභාවික හා නිර්මිත ලක්ෂණ පදනම් කරගෙන ගංගා නිම්නයේ කොටස්වල කැපී පෙනෙන ලක්ෂණ වෙන්ව හඳුනා ගැනීම සඳහා වර්ගීකරණයක් කිරීමට උත්සහ දරා ඇත.

උප ජලාධාර 48ක විචලායයන් 18ක් සංඛ්‍යාන විශ්ලේෂණය කිරීම තුළින්, ස්වභාවික හා නිර්මිත ලක්ෂණ පදනම් කරගෙන ගංගා නිම්නවල කලාප වෙන්කර හඳුනාගත හැකි යැයි යන උපකල්පනය තහවුරු වී ඇත. විචලතා උපරිම කරන මූලික සාධක විශ්ලේෂණ ක්‍රමය පදනම් කරගෙන ද්විතීයික සාධක වල මධ්‍යන්‍ය Z අගය කලාප 03 ක් සඳහා පැහැදිලි වෙනස් කමක් පෙන්වයි. ප්‍රධාන වාරිමාර්ග තාක්ෂණ පෙන්නුම් කරමින් මෙම කලාප 03 වෙන්කෙරෙන සංකල්පීය රූප සටහනක් ගොඩනගා ඇත. ගංගානිම්නයේ ඉහළ කොටසේ ප්‍රතිලෝම දුරාවලී ක්‍රමයෙන් එල්ලාංගා නිර්මාණයට වඩා ජලය ප්‍රයෝජනයට ගැනීමේ විභවතාවක් පහළ කොටසේ අනුලෝම දුරාවලී ක්‍රමයෙන් හැකිවන බව හඳුනාගෙන ඇත.

යොමු වචන: ජලාශ එල්ලාංග පද්ධති, ශ්‍රී ලංකාව, ගංගා නිම්න වර්ගීකරණ

Introduction

Construction of cascade of Wewa (Reservoir with its ecosystem) has been identified as the major strategy for efficient water management system of the "hydraulic civilization" sustained for centuries in Sri Lanka.
"In the realm that is subject to me there are, apart from many strips of country where the harvest flourishes mainly by rain water, but few fields which are dependent on rivers with permanent flow of on great reservoirs.

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[1]Dr. JMSB Jayasundara, Senior Lecturer, Department of Social Sciences, Faculty of Social Sciences & Humanities, Rajarata University of Sri Lanka, jmsb161@yahoo.com

Also by many mountains, by thick jungle, and by widespread swamps my kingdom is much straitened.

Truly in such a country not even a little water that comes from the rain must flow into the ocean without being made useful to man.

Except at the mines where there are precious stones, gold and the like, in all other places the laying out of fields must be taken in hand" made by King Parakramabahu (1153 – 1186 AD), demonstrates the philosophy behind the concept. (Paranavitana, 1960)

However, even now much of the water drains to sea without any productive use particularly during the rainy season. Moreover, with the increased rainfall intensity associated with climate change the water has become a source of hazard, flooding the lower sections of river basins. Estimated total annual runoff from the dry zone consists 20,661,000 Acre feet (Arumugam, 1969). As this estimate was made just before the major changes in climate, actual amount would be higher. Though modern development projects were able to capture some of the water by rehabilitation of ancient large and small reservoirs, the situation could be much improved.

When one goes through the work of R. L. Brohier (1934) it seems that not only the cascade system of Wewa established in the upper parts of the river basin that enabled to collect increasing amounts of water in the sequence of downstream and canals diverting water, but also there was a cascade system diverting water from large rivers, storing and distributing in the downstream. These systems seem to have had different environmental, hydraulic and management strategies. This is much prevalent in the North Western and Eastern section of the country.

Obviously a question appears: is arises as to whether there a difference in the irrigation technology used in the upper portions of the river basin and downstream? Much the scientific investigation at present focused on the Wewa cascade system of the upper portion of basins. Therefore, it is justifiable to identify variations of different natural and man-made features along a river basin in order to establish a pattern.

Objectives

General objective of this study is to identify variations of natural and man-made features within a river basin in the sequence of flow from watershed to river mouth in order to recognize any pattern if exists. The specific objectives are to: identify variations of the features, to construct

a conceptual scheme of major irrigation technologies and to classify the basin based on the variations.

Hypothesis

Primary hypothesis of this study is that there is a variation in the complex of natural and manmade characteristics with the sequence of a watershed.

Methodology

Following variables were selected for the study based on the research conducted earlier: shape of valley, type of stream network, stream network density, velocity, bed erosion, bank erosion, soil erosion, discharge, evapo-transpiration, land cover, average size of Wewa, intensity of human activities, water quality, level of land and water pollution, potential problems, hydrological function, geomorphologic function and dominant geographic feature. Data was collected from 48 sub watersheds along Yan Oya and Mi Oya river basins in the Eastern and Western sections of the dry zone of Sri Lanka respectively. Further, these data sets were separated according to the comparative location, making three sections in the sequence of the basin. Data was collected by measuring, reading maps and by observations.

Data were graded using scales following the method developed by White (1974) and analyzed calculating mean values of each variable in three sections. Further, weighted means of each variable was calculated by giving a weight for suitability of the selected sub-watersheds in terms of each variable. For example, Shape of valley was given highest value (03) as it is an important factor in determining the suitability of construction of irrigation structures.

Further, hierarchical factor analysis was conducted in order to reduce factors facilitating zonal separation applying the method adopted by Onex (2000). Principle component analysis with rotation of variance maximization and further rotation of oblique factoring were conducted. The mean values of secondary factor were used to explain the three zones.

Results

The obtained F statistic is less than the F-table statistic and the p value is lower than the alpha level of significance, which enables the researcher to accept the primary null hypothesis.. (If the F-statistics computed in the ANOVA table is less than the F-table statistics or the P-value if greater

than the alpha level of significance, then there is no reason to reject the null hypothesis that all the means are the same: www.pindling.org, 2011). Observations indicate a spatial variation, the analysis conducted with the use of discharge, land cover and potential problems revealed that there is a definite spatial separation (Table 1).

Table 1 Model summary

Model Summary

Mode l	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000ª	1.000	1.000	.000

a. Predictors: (Constant), Potential problems, Lancover, Discharge

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	32.000	3	10.667	7.418E15	.000ª
	Residual	.000	43	.000		
	Total	32.000	46			

a. Predictors: (Constant), Potential problems, Lancover, Discharge
b. Dependent Variable: threezon

Distribution of the values of selected variables within the watershed represents the three zones: Upper, Middle and Lower sections. There is no uniformity in distribution. Some variables show higher values in the upper section while others show higher values in the middle or even lower section. Both natural and man-made features behave with the same pattern (Table 2).The scale is likert type three level

Table 2. Mean zonal values of variables

Variables	Zonal mean Units			Variables	Zonal mean Units		
	Upper	Middle	Lower		Upper	Middle	Lower
Shape of valley	2.8	2.3	1.6	Average size of Wewa	2.6	2.4	1.4
Dominant geographic features	2.6	2.8	1.1	Land cover	2.4	1.8	2.5
Geomophological function	2.3	2.0	1.3	Evapo-transpiration	1.5	1.9	2.6
Hydrological function	1.2	1.8	2.8	Discharge	1.3	2.3	2.9
Potential problems	1.0	1.8	2.9	Soil erosion	2.2	1.9	1.7
Level of pollution	1.3	1.5	2.9	Bank erosion	1.5	2.0	2.2
Water quality	2.0	1.5	1.4	Bed erosion	3.8	2.6	1.8
Intensity of human activities	1.9	1.4	2.2	Velocity	1.5	2.2	2.6
Type of stream network	2.6	1.5	1.2	Stream network density	1.6	2.4	2.8

Weighted mean values do not provide any significant variation among the three sections. The total values vary in close proximity being 77, 77 and

74 out of total possible amount 162 (18 X 3 X 3) in upper, middle and lower sections respectively. Due to various reasons all three sections are almost equally suitable for construction of irrigation structures as average values are :4.31, 4.28 and 4.14 of Upper, Middle and Lower sections respectively (Table 3). In the upper section, where small Wewa cascade system dominates, prominent variables are *dominant geographic*

Table 3 Weighted mean values of variables in three zones

Variable	Upper	Middle	Lower
Shape of valley	8.40	6.90	4.80
Dominant geographic features	7.80	8.40	3.30
Geomophological function	6.90	6.00	3.90
Hydrological function	3.60	5.40	8.40
Potential problems	0.33	0.60	0.97
Level of pollution	0.43	0.50	0.97
Water quality	1.00	0.75	0.70
Intensity of human activities	5.70	4.20	6.60
Type of stream network	7.80	4.50	3.60
Average size of Wewa	5.20	4.80	2.80
Land cover	2.40	1.80	2.50
Evapo-transpiration	1.50	1.90	2.60
Discharge	3.90	6.90	8.70
Soil erosion	4.40	3.80	3.40
Bank erosion	3.00	4.00	4.40
Bed erosion	7.60	5.20	3.60
Velocity	4.50	6.60	7.80
Stream network density	3.20	4.80	5.60
Total values	77.67	77.05	74.63
Average values	*4.31*	*4.28*	*4.14*

features (7.8), *types of stream network* (7.8) and *bed erosion* (7.6).

In the given weights, the first two variables play a positive role and the remaining one – a negative role. Only *dominant geographic features* play an important role in the middle section (8.4). High discharge and low velocity have contributed to improve suitability in the lower section being their values 8.7 and 7.8 correspondingly. As it is indicated by the

above factors, cascade system is highly interlinked as it has been already identified in the literature.

Principle component analysis with rotation of variance maximization produced distinct three factors with Kaiser Normalization, selection of components with Eigen value more than one, out of 48 variables which explain cumulative Eigen value of 99% of the variation. Score coefficients of the three components show that the variables 'potential problems', 'hydrological function' and ' 'discharge' have higher values in the first component and indicate that the 'component can be named as *'water and problems'*. The second component with higher values of 'level of land and water pollution', 'stream network density' and 'bank erosion' can be named as *'resource degradation'*. The third component where 'bed erosion' and 'land cover' have higher values suggest the name of *'vegetation and bed erosion'*. Accordingly, these are the components that determined the variations among the three zones.

Secondary factor analysis with the principle component analysis with no rotation was conducted for the three former factor scores to generate one secondary factor. *Three zones show a distinct separation on the basis of the mean values of the secondary factor. Zone one having 0.44 mean value of the secondary factor, -1.40 the same in the Zone two and 0.89in the third zone. (This fact justifies the zonation of cascade systems.)*

Table 4 Factor analysis
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	10.778	59.877	59.877	10.778	59.877	59.877	10.43;	57.990	57.990
2	4.974	27.633	87.510	4.974	27.633	87.510	4.329	24.048	82.038
3	2.212	12.289	99.799	2.212	12.289	99.799	3.197	17.761	99.799
4	.036	.201	100.000						
5	2.851E-15	1.584E-14	100.000						
6	2.012E-15	1.118E-14	100.000						
7	1.714E-15	9.521E-15	100.000						
8	1.100E-15	6.112E-15	100.000						
9	7.206E-16	4.004E-15	100.000						
10	5.533E-16	3.074E-15	100.000						
11	2.763E-16	1.535E-15	100.000						
12	7.199E-18	3.999E-17	100.000						
13	-4.915E-16	-2.731E-15	100.000						
14	-8.597E-16	-4.776E-15	100.000						
15	-1.439E-15	-7.995E-15	100.000						
16	-2.168E-15	-1.204E-14	100.000						
17	-2.331E-15	-1.295E-14	100.000						
18	-4.308E-15	-2.393E-14	100.000						

Extraction Method: Principal Component Analysis

Table 5 Component Score Coefficient Matrix

	Component		
	1	**2**	**3**
Shape of valley	-.063	.145	.067
Type of stream network	.084	.075	-.024
Stream network density	.016	.205	-.032
Velocity	-.062	.094	.123
Bed erosion	.056	-.012	.306
Bank erosion	.001	.250	.096
Soil erosion	-.043	.163	.154
Discharge	.121	.062	.198
Evapo-transpiration	-.045	.013	.180
Lancover	.042	.066	.348
Average size of Wewa	.095	-.054	.037
Intensity of human activities	-.009	.182	-.085
Water quality	.094	.018	-.005
Level of land & water pollution	.076	.202	.070
Potential problems	.117	.063	.141
Hudrological function	.107	.016	.073
Dominant geograpgical features	.093	.028	-.009
Geomophological function	.098	.045	.021

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Component Scores.

a.   Classification of river basin based on the spatial variation of natural and man-made features

Amalgamation of map analysis, observations and field data collection provided the basis for construction of a conceptual scheme to represent major feature of irrigation network of the ancient hydraulic civilization consisting three sections, namely: Upper section (I), Middle section (II) and Lower section (III). Chart 1 demonstrates its major features.

Upper section (I)

The main feature of the upper section is small Wewa cascades, collecting water, amount of which increases in the sequence downstream and simultaneously the size of Wewa increases. This represents *inverse hierarchical pattern*. The second feature is canals feeding upper parts of

the stream from other river basins, distributing water throughout the basin and discharge water to other basins to feed them. The dams are straight lines and there are some very small Wewa without a command area. Well established ecosystem after construction of Wewa may call for a term *"analogue natural ecosystem".*

Middle section (II)

Large Wewa with sophisticated hydraulic engineering dominates in the middle section, where large amount of water is stored in order to use in the dry season and to assure irrigation. Canals in different sizes distribute water throughout the command area. In this section natural ecosystems are modified and large command area and settlements are been established. With the home gardens, highland farming areas, Wewa and the command area together make a classical *"agro-ecosystem".*

Lower section (III)

Diversion of water from a large river by different kinds of anicut and distribute through a canal and Wewa (Kulam) system is the major characteristics of the lower section. There is a mixter of large and small Wewa where larger Wewa provide water to small Wewa in the needy times. This represents a kind of *proper hierarchical pattern.* Due to low gradient the dams of Wewa are been constructed crescent shape unlike in the upper and middle sections. This section is less attended in recent literature. Some of the canals and Wewa in this section has paid the way to takeoff the hydraulic civilization technology (Brohier, 1934).
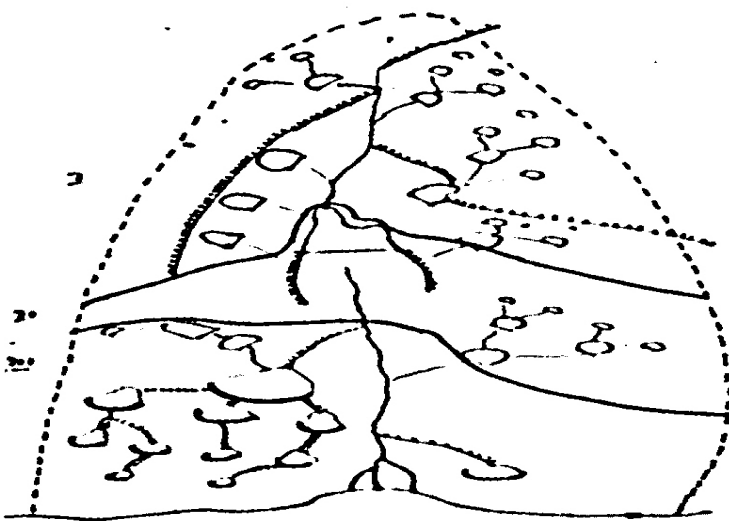

Chart 1. Schematic representation of the result of zonal separation

Conclusion

Though the constructed model does not reject the null hypothesis, further analysis of mean and weighted mean values do to show much difference in the values and suitability of the three sections of river basin. Prominent features of cascade system classification are dominant geographic features, types of stream network, bed erosion, discharge and velocity. Further, hierarchical factor analysis show that *water and problems, resource degradation and vegetation and bed erosion* are the major components separating the zones. The sections are interlinked and planning must be based on this integrated links of the whole system. There is a large potential in the lower section with the application of "proper hierarchical system of cascades for capturing water from large rivers in their downstream, which otherwise drains to the sea. In addition, lower sections are less studied and need more scientific investigations.

References

Arumugam, S. (1969). Water Resources of Ceylon. Colombo: Water Resource Board.

Brohier, R. (1934). Ancient Irrigation Works in Ceylon. Colombo: Ceylon Government Press.

_____ *(2006). The story of water management in Sri Lanka down the ages. Colombo: Soorya publishers.*

Jayasena, H. A. (2009). Thousand Years of Hydraulic Civilization Some Socio-technical Aspects of Water Management. World Woter Forum Report (pp. 225 - 262). Istanbul: World Water Forum.

Maddumabandara.C. (2009). Village Tank Cascade Systems of Sri Lanka: A Traditional Technology of Drought and Water Management.Third annual workshop on Disaster Reduction Hyperbase. Tokyo, Japan.

Mahatantila, K. ,. (2008). Spatial & temporal changes of hydrogeochemistry in ancient Tank Cascade Systems (TCS) in Sri Lanka: evidence for a constructed wetland. Water Environment , 22 (1), 17 - 24.

Matsuno, Y. ,. (2003). Analysis of returnflow in a tank cascade system in Sri Lanka. PADDY AND WATER , 1 (4), 173 - 181.

Onex, J. a. (2000). Measuring Social Capital in Five Communities. Journal of Applied Behavioral Science , 23 - 42.

Paranavitana, S. (1960). Civilization of the Polonnaru period: political.economic and social conditions. In H. C. Ray, History of Ceylon (Vol. I Part II, p. 555). Colombo: Ceylon University Press.