The importance of the small-tank cascade system for the *sustainable production* of water in the dry zone of Sri Lanka

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ABSTRACT

Proper operation and maintenance of water resources in the dry zone of Sri Lanka is a pre-requisite to ensure sustainable development. Of particular concern in these regards is the case of the 'Rajarata' cascade system of interconnected small irrigation tanks which are spread all over the north central province and extend up-to the northernmost limits of the Vavuniya district. From a sustainable consumption and production perspective, these cascade systems function as recharging mechanisms that help to maintain sustainable and optimum stocks of fresh groundwater for human and agriculture utilization. This paper focuses on a case-study of the small-tank based cascade system in the Vavuniya Urban Council limits - where due to increases in human population, and subsequent disturbances that have occurred in such systems; the sustainable maintenance of the groundwater aquifer has become a critical management issue. A GIS based spatial modeling approach was adopted to understand the state of the small-tank cascade system at present. In these regards, terrain modelling and the modeling of the network of cascades within the Urban Council limits were done using the data acquired from Google Earth Pro services and field observations to assess the pattern and functioning of cascades for mapping the groundwater potential. This modeling approach provides the water resources manager with the facility to visualize, comprehend and simulate scenarios pertaining to management options for the system of concern. Results indicate that human-induced disturbances that have occurred in the cascades have reduced the sustainable production of water. It is suggested that an ecosystem based integrated water resource management method is the most effective option to enhance the water stock towards sustainable production of water resources in the dry zone of Sri Lanka.

[**Keywords:** sustainable production, management, cascade system, spatial modeling, scenarios, GIS = Geographical Information Systems]

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INTRODUCTION

Though freshwater resources are abundant on a global level, regional water scarcity and its effects on ecological integrity and socioeconomic development are well documented. The spirit of population growth and urbanization, threatens to exacerbate existing water crises, possibly leading to international conflict over transboundary water resources. On a local level, the lack of improved sanitation facilities and protected water supplies adversely affects the health and livelihood of millions of people worldwide. Therefore concern towards the sustainability of water resources must be realized by the mankind to ensure the ability of future generations to enjoy the same quality of life.

1.1 Cascade systems and sustainability of water resources

Focusing to the water resources of the dry zone of Sri Lanka, the Small Tank Cascade[†] Systems (STCS) and the unconfined groundwater aquifers are the available water resources for its regional development and for the livelihood of the village people. Initially the STCS were designed by the ancient kings during the Rajarata hydraulic civilization around North central province for the irrigation purposes. However some scholars still believe that they were operational but were not used entirely for irrigation but for maintaining the higher ground water levels (Maddumabandara, 1985).

This was supported by the historically event that – with the failing of Rajarata civilization occurred around the 12th century, (Maddumabandara, 1985), the villagers faced serious water scarcity issues and affected the agriculture and water supply because of the inefficient maintenance of cascades (Somarathna *et al*, 2004). Thus, in order to ensure the sustainability of water resources, it is imperative that keeping the cascades in its natural state is vital for the sustainable production of groundwater aquifers (Figure 1).

[†] A cascade is a connected series of tanks organized within the micro catchments of the dry zone landscape for storing, conveying and utilizing water from ephemeral rivulet (Maddumabandara, 1985) or series of small reservoirs that have been constructed in successive locations down one single common water course (Panabokke, 1996).

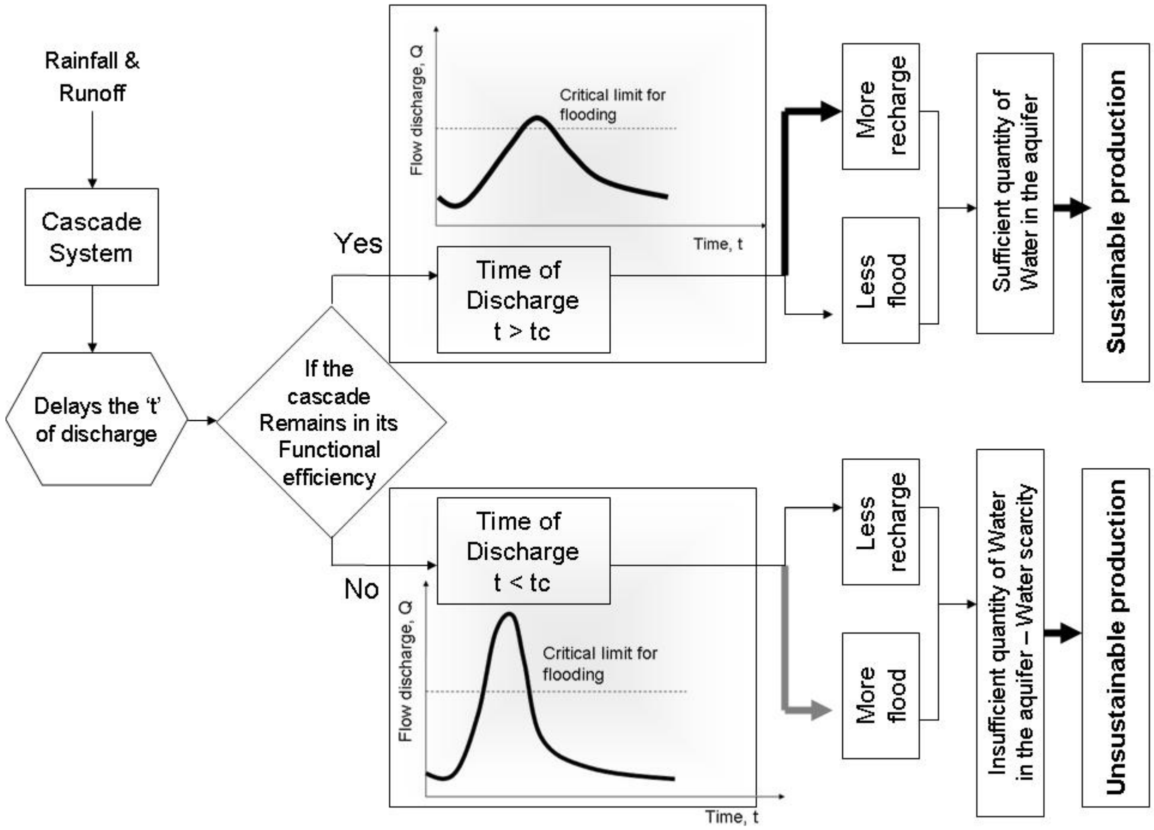


Figure 1: Different scenarios for the role of cascades on the sustainable production of groundwater resources (t – time of discharge; tc – critical time of flood)

Nevertheless the interactions of surface~groundwater processes have been commonly ignored in water management policies as they are difficult to observe and measure, (Winter *et al*, 1998). In view of the worth of groundwater resources especially in the dry zone (North, North-central province) of Sri Lanka, considering the surface water dynamics, especially the dynamics of STCS are mandatory to achieve a better integrated sustainable water management.

1.2 Case study – selected part of cascade in Vavuniya

According to this concept, this paper details the coupling/connection between surface~groundwater dynamics for a selected part of cascade system functions in the Vavuniya which too has been part of the Rajarata civilization and had benefited with the sensitively networked cascade system that contributes to the recharge of groundwater for the socio economic productivity of villagers.

As the Vavuniya urban area has been undergone rapid unplanned urbanization in the past two decades, have negatively altered the socio-environmental settings of this region – means some parts of the cascades i.e., a part of tank bed and paddy lands have been illegally encroached. This has reduced the functional efficacy of cascades in some parts of this Vavuniya urban area resulted to reduced groundwater potentials and ultimately ended with acute water shortages in the dry season (during the period of May/June – July/August every year).

In this instance, quantification of risk and uncertainty of water resource will increasingly be of major importance to ground-water management. Present trends in the use of models for water-resource management purposes include greater use of more sophisticated models that increasingly integrate the surface water components and its interactions with groundwater. Such models also capitalize on recent technological improvements with the development of graphical user interfaces and decision-support systems, taking advantage of the continuing development of Geographic Information Systems (GIS) and visualization technologies (Sophocleous, 2000).

In this regard, a case study of a selected transect of cascade in the Vavuniya Urban Council limits was embarked to arrive at a GIS based spatial model for describing the dynamics of the influences/s of the cascade system on the sustainable yield of (unconfined) groundwater aquifer.

Thus, the **aim** of this study is to assess/evaluate the potentiality of cascades on the sustainable production of groundwater resources in the dry zone of Vavuniya district. The research undertaken in this regard may be useful in the interests of socio-economic and environmental developments of a rapidly developing region like Vavuniya to achieve an effective ecologically integrated water resources management.

The **objectives** of this research can be stated as,

i. Assessing the degree of coupling between cascade~groundwater potentials
ii. Validating with field observations
iii. Quantifying the area affected by human induced changes
iv. Development of possible scenarios.

METHODOLOGY

The processes connected to the interaction of cascade-groundwater hydrological processes are complex and need to be visualized on the spatial domain for developing systems knowledge. Thus, a GIS based spatial modeling approach was developed to understand the state and the influence of STCS on the groundwater potential. A summary of the research methodological framework adopted for this investigation is given below (Figure 3).

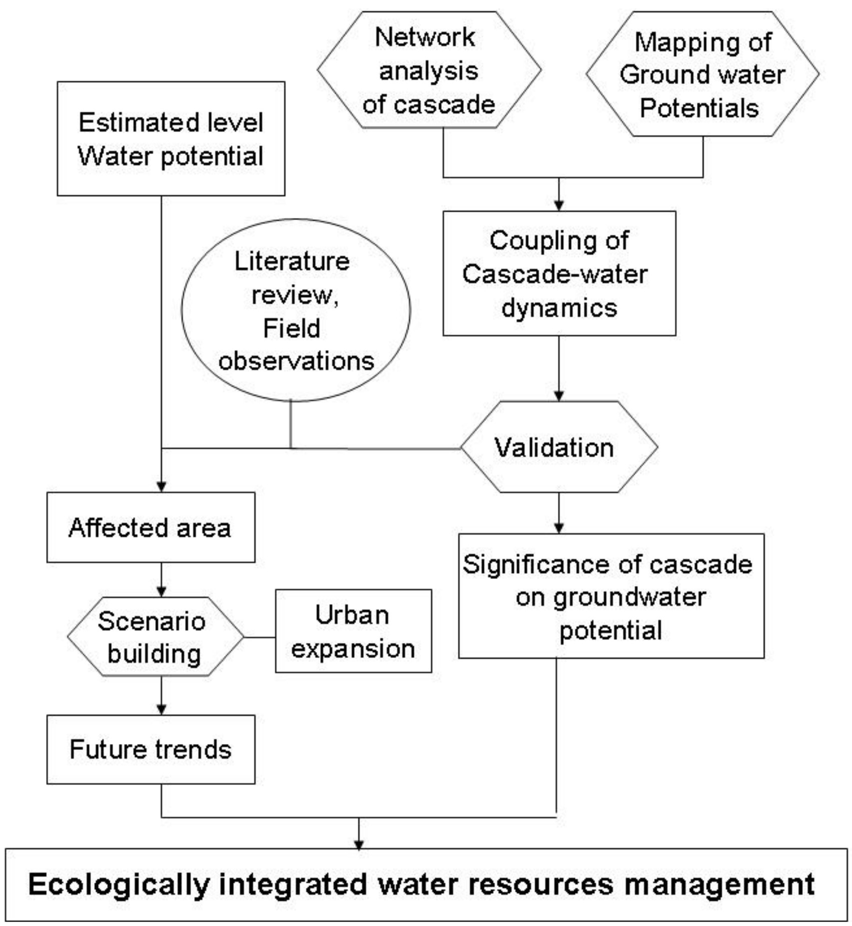


Figure 2: Summary of methodology followed for the investigation (developed by author)

In these regards, the terrain modeling was done in the Arc GIS 9.2 to identify the proper routes of cascades in the spatial domain, in which the Google Earth Pro service was utilized to gather elevation data. Furthermore, GIS based network modeling was performed onto the identified cascades lines in order to assess its functionality. Once the functional cascades were identified, the potentiality of cascades on the recharging of mechanisms were evaluated against the shallow groundwater potential which was mapped using the 190 point data on the depth of water level[‡] collected during field visit, questionnaire survey etc.

RESULTS AND DISCUSSIONS

3.1 Significance of cascades on the sustainable yield of aquifer

Using the spatial techniques available in the Arc GIS 9.2, the cascade lines and the shallow groundwater potential were compared in which the pattern of groundwater potential approximately seems to follow the pattern of cascade lines (Figure 3).

More clearly, it is observed that the area beneath the connected lines of cascades show higher groundwater potential while the area having disconnected lines of cascade having lesser potential – means, the STCS influences much on the shallow groundwater potential of this region and maintaining the sustainable production of water.

This further substantiated by the field/questionnaire data – among the data gathered from 190 wells, 17% of the wells are facing severe water shortages in the dry season in which 7% of wells have been further drilled due to insufficient water supply. Most of these water scarcity issues were reported in the area nearby disconnected lines of cascade as the functional efficacy of them on maintaining the water potentials have been reduced.

[‡] The depth of water table was measured as the distance between the ground surface to the top of the water table in the gbl (ground below level)

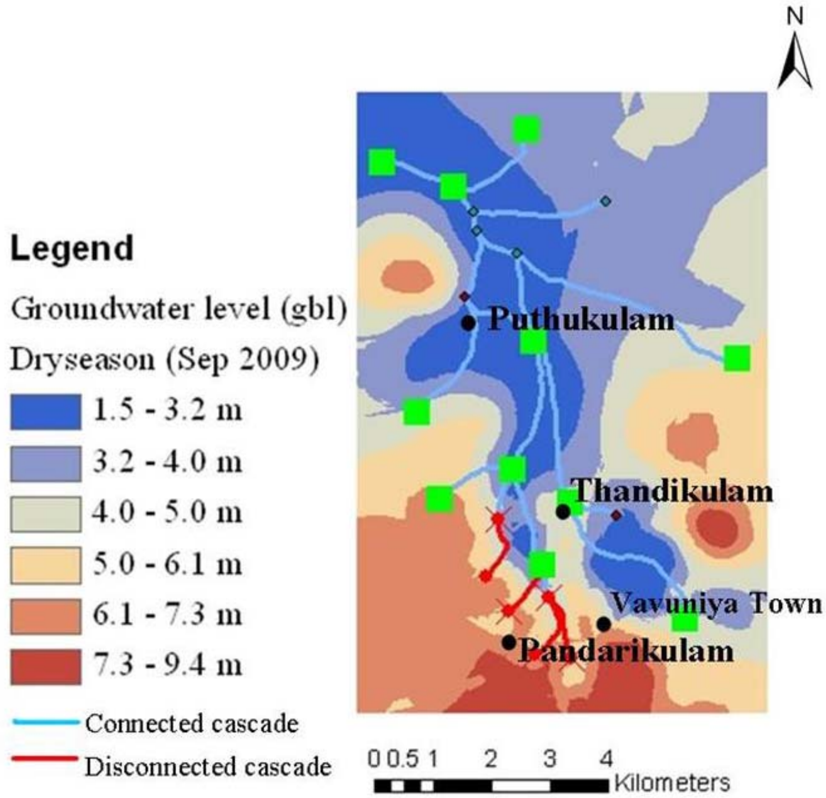
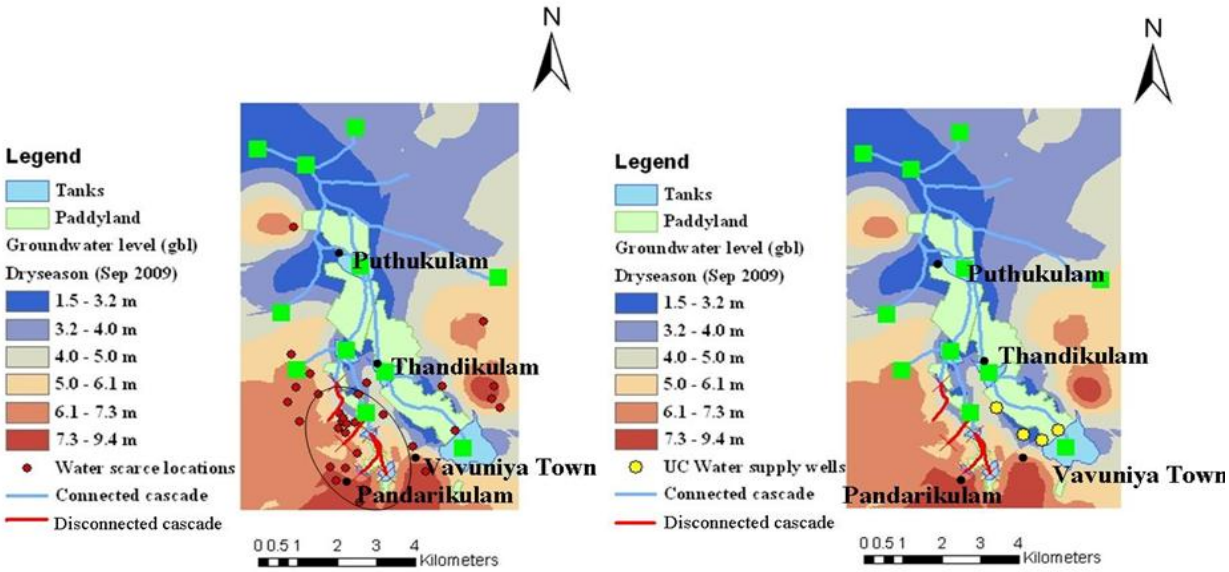


Figure 3: Connectivity/coupling of surface-subsurface hydrology in the selected transect of cascade – the cascades remain in its natural state are maintaining the sustainable production of water resources

The severe water shortages of this region makes the people to leave the agricultural lands arable which further aggravates the un-sustainable production of groundwater resources in this locality. This is supported by the field observations, i.e., the water shortage issues were often reported nearby the disconnected lines of cascades while the UC water supply wells are located closely by well functioning of cascades to ensure the uninterrupted supply of water (Figure 4).

In addition, it was observed that the competence of the cascades in sustaining the ground water potential in which the higher fluctuation of water levels reflects the sign of unhealthy cascades. As they unable to maintain the groundwater potential almost same in both dry and wet seasons, the sustainable production of water resources is failed at the area having disturbed lines of cascades.



(a) (b)

Figure 4: Field observations substantiate the hypothesis (a) Water shortage issues reported nearby disconnected cascade lines (b) UC water supply wells located close by connected cascades

3.2 Quantification of the area affected and its plausible scenarios

Based on the arguments developed, the illicit encroachments occurred onto the cascade lines have been reduced the functional efficacy has reduced the sustainable production of groundwater resources in some localities becomes a critical management issue. As the identification of such area may be useful for zoning plan, management etc., the following three aspects were considered to estimate the affected area.

i. ‘Observed water potential’ (obtained from questionnaire survey)
ii. ‘estimated level of water potential’, and,
iii. the ‘built up areas erected nearby the cascades’

All these maps were utilized in this regard to identify the area that has been affected by human induced changes using logical operations available from the Arc GIS 9.2 platform. That resulted to the map ‘Area of unsustainable production of groundwater due to illicit encroachments’ illustrated in Figure 5(a) and it is estimated as about 1.67 km^2.

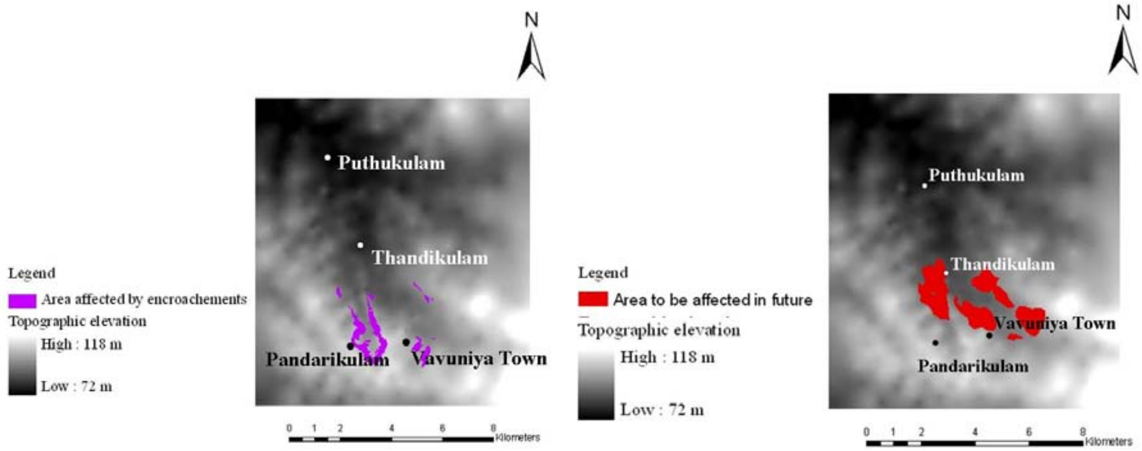


Figure 5:(a) Area of unsustainable production of groundwater (b) Area expected to be affected in future due illicit encroachments.

Considering the future trends of urban expansion, the area to be affected in future also must be identified to reduce the further degradation of cascades. In view of the urban expansion, the population density of each GN division was taken into consideration and buffer zones were created as concentric rings based on the weightage of population density of each GN division in which the area was divided into 3 Scale,

Scale 1 – population density >3000

Scale 2 – 1000 < population density < 3000

Scale 3 – population density < 1000

Based on the assumptions made that the built-up area occurs within the scale 1 is expected to be expand by 200 m buffer, built-up area occurs within the scale 2 is expected to be expand by 150 m buffer and the urban area within the scale 3 is expected to expand by 100 m buffer in near future. Accordingly the total estimated level of urban expansion was extracted. Assuming the final expansion of urban built-up area increases the extent of pavements that further reduces the functional efficiency of cascades leads to reduced recharge of groundwater, ultimately end up with unsustainable production of water resources.

The area expected to have reduced level of water potential was estimated using the map of observed level of groundwater potential and estimated level of urban expansion using spatial analyst tools/overlay/intersection available in Arc GIS 9.2. It was calculated and it is about 4.45km^2 illustrated in Figure 5(b).

In order to identify the moving trend of the unsustainable production of water, the spatial statistics was utilized to find the mean center of further drilled wells and water scare locations. Based on that, it was found that the nucleus of the water scare area is seems to be following the trend of urbanized area towards north.

CONCLUSIONS

As the potential of groundwater aquifer of the selected Vavuniya region is observed to be highly coupled with the pattern of cascade systems, those are found to be providing the sustainable production of water resources to its locality. Negative human induced changes that have occurred onto the cascade lines have reduced the groundwater potential significantly.

The higher annual fluctuation of groundwater table is the sign of unhealthy cascades as they lost their natural capacity to absorb water that was found close by the affected lines of cascades. Such affected area is estimated as 1.67km^2 which has been affected by urbanization and subsequent human activities. Considering the scenario building for urban expansion, the area of 4.88km^2 is expected to be reduced and may end up with the unsustainable production of groundwater.

The moving trend of the nucleus of lower potential area is expected to move along the cascade line towards northern region that follows the area undergoing urbanization. With the depletion of groundwater resources, the people are trying to deepening their wells to get sufficient water, this unsustainable consumption may affects the interactions between surface-groundwater that may disturbs the sustainability of water resources.

The limitations of this investigation were the lack of comprehensive field level data, lack of time series maps on groundwater potential, and, the lack of archived data on the underlying geology. Further, matters pertaining to civil security issues were also detrimental to the investigation as it prevented certain activities (i.e. GPS usage, lack of sufficient remotely sensed data). As such, considering these, the future research on these regards should focus on filed level tracer tests, geological mapping of focal area, GPS based survey studies and hydrological model building (for *flow* routing).

RECOMMENDATIONS

As the subsurface hydrology is mainly relies on the surface hydrology, the proper maintenance of cascade system is essential for the water resources management. As the management option, the urbanized activities taking place in the area proximity to wetland system should be avoided in future. Regular monitoring by the relevant authorities, enforcing laws and legislation may be useful to minimize these illicit encroachments further.

From a technical point of view, design and construction of proper drainage system, deepening of tanks to increase the water holding capacity can be carried out to store more water to maintain the sustainable production of water by means of increased recharge. Further, construction of small dams or bunds, underground dams, using recharge holes along the cascading system or the planting of trees or *vetiver* grass may increase the recharge of ground water for the sustainable production of groundwater resources.

Moreover, the unsustainable consumption and over extraction of groundwater resources of this region must be minimized. This may be achieved by water prizing system, promoting rainwater harvesting system in household level, introducing sprinkler/drip irrigation methods to farmers for reducing the usage of water. Furthermore, having a constructed wetland as wastewater treatment system is another way to enhance the recharge. Ultimately, in order to ensure the sustainable production of water resources and for the social harmony in future, the ecologically integrated management of groundwater resources is the best approach. i.e., the cascade systems must be maintained in its natural state without affecting its functionality.

REFERENCES

Madduma Bandara, C.M. (1985). Catchment ecosystem and village tank cascades in the dry zone of Sri Lanka : A time tested system of land and water resource management, Edited by Lundquist, J. et al., D. Reldel Publishing Company.

Madduma Bandara, C.M. 1985. Catchment ecosystems and village tank cascades in the dry zone of Sri Lanka: A time tested system of land and water resources management, In: Lundqvst, J; Lohm, U, and Falkenmark, M.(Eds.): Startegies for river basin Management pp.099-113.

Panabokke, C.R. (1996). The small tank cascade system of the Rajarata-their setting, distribution & the hydrography, IIMI, Colombo, 1-38.

Sophocleous, M. (2000). From safe yield to sustainable development of water resources - the Kansas experience. Journal of Hydrology 235 (2000) 27–43. Online: http://www.kgs.ku.edu/General/Personnel/rs/mas/2000/Sustainability.pdf

Sophocleous, M. A., Sawin, R.S., 1997. Safe yield and sustainable development of water resources in Kansas. Kansas Geological Survey, Public Information Circular, 9, 6p. Also available at http://www.kgs.ukans.edu/Publications/pic 9/pic 9_1.html/.

Somarathna, P. D. S. N., Dayawansa, N. D. K., De Silva, R. P., (2004). Evaluation of the performance of Tank cascade systems using multi-temporal satellite data, Water Professional Symposium, Water resources research in Sri Lanka. Online: http://docs.google.com/viewer?a=v&q=cache:7JPMNvso3RkJ:www.gissl.lk/WaterProf/2004/acrobatpapers/PDSN_Somarathne_15.pdf+cascade+systems+%2BRajarata&hl=en&gl=lk&pid=bl&srcid=ADGEEShYq0W9yZm_eKbQikMiOTznwax4FMcKFDbITyIARoi-ISsgnHsIqRy995iPKq4PNgGyhwrPYrOu1tEHX2TWpLMKBT-PFzImkLufuXNPxgl-JKWR_8M-8-f9tVqWJygp8xwKwWQ4&sig=AHIEtbQUzti3N7nfhiaWdxY1HPCDVGf95Q

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground water and surface water a single resource: U.S. Geological Survey Circular 1139, 77 p. Online: http://water.usgs.gov/ogw/pubs/WRI004008/gw2.htm#bm5 (22.03.2010)

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