A Quantitative Analysis of Surface water in the Uruboku Oya basin Demonstrating the Application Potential of IWRM Principles to Complex Irrigation Systems

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ABSTRACT

Utilizing IWRM principals to manage water resources is often limited to policy and institutional options which are qualitative in nature (Mehta et al., 2016). Though application friendly modelling examples which satisfactorily incorporate both water quantity and thresholds of quality are essential for watershed managers to ensure educated participatory management the lack of detailed case studies has been noted as a gap that needs to be filled. Muruthawela irrigation scheme of Uruboku Oya basin in Hambantota district of Sri Lanka having a medium scale reservoir of 47.8 MCM capacity, a source area of 4400 ha, and a command area of 1710 ha was taken as a case study. Irrigation, water supply & sanitation, hydro power, inland fishery and environment are the competing water use sectors associated with the system. This system which frequently experiences water conflict situations has limited data to evaluate sectoral water uses. A water balance model for this system was developed to assess multiple water uses by incorporating both water quantity and quality. A situation analysis was carried out with available measurements, guidelines and rational approximations using field observations. This study with an order of magnitude water balance study demonstrated the capability to evaluate the present water conflict scenario and then propose a solution to manage the water quantity and water quality of the system to satisfy all stakeholders. The study concluded that the alternative of IWRM can increase the cropping intensity of Muruthewela scheme by 35% (up to 100%) in maha with introduction of cowpea and allocation of 55.6 MCM for total Irrigation demand while allocating 0.9 MCM annually for water supply and sanitation sector. Pollution status in downstream of Muruthewela tank were evaluated at three locations, Node A –Udukiriwila, Node B-Wakamulla & Node C-Andupelena in order to identify the most vulnerable section for pollution due to agricultural & domestic return flows. The threshold value of dilution was taken as 8 as recommended by Central Environmental Authority (Central Environmental Authority, 1980). The study found that Node C-Andepelena is the most vulnerable section for pollution and the priority area which needs attention by all stakeholders. Pollution level at Node B-Wakamulla can be managed to a certain extent by releasing an environmental flow of 2.4 MCM (4.3% of Irrigation demand) annually

KEYWORDS: IWRM, Complex Irrigation Systems, Uruboku Oya

1. Introduction

Water is an essential commodity for both human and environmental sustainability and demonstrates a non-uniform distribution. Spatial and temporal irregularity of rain, varying watershed characteristics determining runoff and storage, the changes observed in the climate, and the uneven nature of sectoral water demands creates the need for sustainable water resources management.

Determining sectoral water policies to overcome water crisis situations requires consensus among various water users. Integrated Water Resources Management which is commonly known as IWRM has been recognized as the way to achieve this uphill task (Karthe et al., 2015). Application of the concepts has been questioned and evaluated many including Biswas (2004), Jacobs et al. (2016). It could be recognized that the missing building block for the fulfillment of IWRM is a rational water balance model which can operate in a data scarce situation while incorporating both water quantity and quality concerns. A simple easy to understand model based on first principles that enables order of magnitude evaluations would enable river basin managers to carryout sub basin level evaluations leading to easy consensus building

Hence a water balance modelling task was undertaken to evaluate the Muruthawela Irrigation system in the southern Sri Lanka where many water use sectors compete with each other. Since IWRM is to maximize of social and economic well being without affecting the essential ecosystem while utilizing water resources under equitable conditions, it is expected that this model would contribute towards educated IWRM through rational thresholds and allocations.

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2. Study area

Muruthawela reservoir and irrigation scheme in Urruboku Oya basin in Hambantota district of Sri Lanka constructed in 1970's has a storage capacity of 47.8 MCM, a source area of 4400 ha, and a command area of 1710 ha (Figure 2-1). Command area consists of 1710 ha of Muruthewela new lands in Tract I(T-1), Tract II(T-2) & Tract III(T-3) under the Left Bank Main Canal(LBMC); 324 ha of lands under Right Bank Main Canal(RBMC), 2430 ha of existing lands in Uruboku oya scheme. Lands in Tract I area cultivated in both yala and Maha seasons. Full extent of Tracts II & III are not cultivated in both seasons. In both seasons, due to riparian rights, Urubokka Oya Scheme receives priority when releasing irrigation water from the reservoir. In addition, the RBMC receives a discharge of 0.7 m^3/s for a period of 10 days for both July and August to fulfill the water shortage under cascade tank system in RBMC. The National Water Supply & Drainage Board (NWS&DB) extracts 2500 m3/day from the reservoir to fulfill the drinking & domestic requirements in the Weeraketiya and Walasmulla urban areas. Though areas away from the reservoir system receives pipe borne water, the Muruthewela new lands, T-1, T-2 and T-3 area within the system are yet to be served. There are approximately 2200 farmer families in Muruthewela, T-1, T-2, and T-3 whose main livelihood is from irrigated agriculture. These families are facing many hardships due to inadequate irrigation water. There are consistent conflicts between the farmers of the Muruthawela Scheme and Urubokka Oya Scheme over irrigation water releases while there is another conflict between Muruthawela farmers and the NWSDB because of the water extractions for the domestic pipe networks.

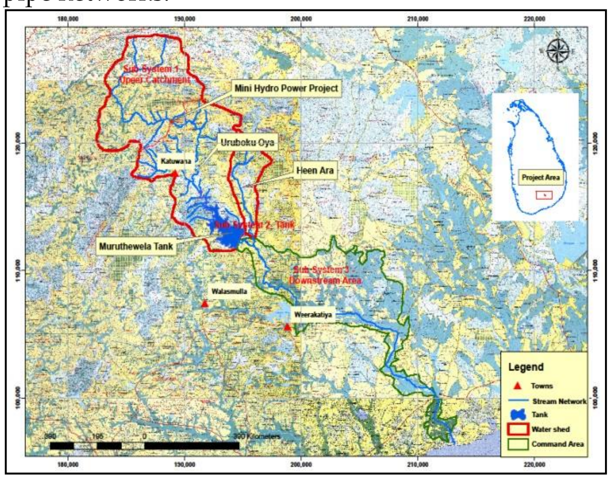

Figure 2 1 Location Map of the project area

3. Methodology

3.1. Situation Analysis

The watershed of the reservoir and the command area were mapped (Figure 2-1). A schematic diagram of the system and the sub watersheds indicating the flow of water within the system is in the Figure 3-1.

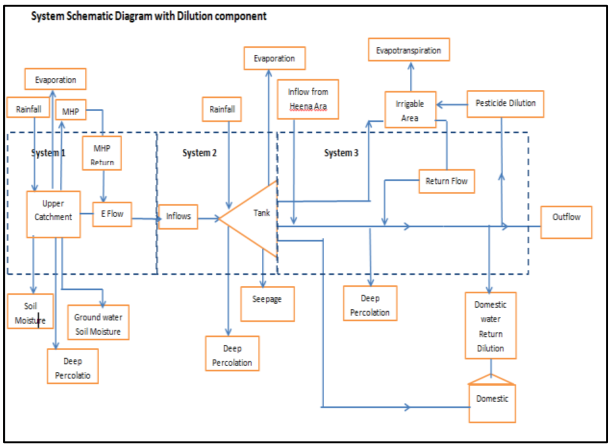

Figure 0-1 Schematic diagram of the system

The entire system was considered as three sub systems namely, Sub System 1: Upper Catchment; Sub System 2: Reservoir; Sub System 3: Downstream system. A stakeholder questionnaire survey within the system which was conducted to identify the priority problems in the project area revealed that the burning issue was inadequate water availability for cultivations. Accordingly, the study targeted to investigate the alternatives to increase the cropping intensity while satisfactorily providing water for other water users. Reservoir operation data were available with the Department of Irrigation. The study area was in the IL2 agro-ecological region. Evaporation data were obtained from the closest station which was at Ridiyagama. A monthly water balance model for a water year encompassing all three systems was developed using the planning guideline of the irrigation department (Department of Irrigation,1984). The rainfall, water demands and practices of an average year were incorporated to the water balance study to calibrate the model and to evaluate the present situation. Afterwards, the guideline recommended, 75% probable rainfall was used as the input to evaluate the water requirements at critical points within the watershed. In order to overcome the data scarce situation, order of magnitude computations were carried out using the guideline recommendations to fill the gaps in observations.

Steps incorporated in the water balance computations for each system and the associated equations are described below.

3.2. System 1- Upper Catchment

System 1 consisted of a model that receives rainfall and generates direct runoff based on a runoff coefficient, enhances soil moisture and then facilitates evaporation depending on the availability of soil moisture. The equations used to evaluate monthly water balance was,

$[Q_{RF} - (Q_{SRO} + Q_{Deep} + Q_{ET})] = Q_{GWSM(t)} - Q_{GWSM(t-1)}$
$= 0$ ------------------------------- (1)

Where, Q_{RF} = Rainfall Volume Q_{SRO} = Surface Runoff; Q_{Deep}= Deep percolation; Q_{ET} =Evapotranspiration; Q_{SM}=Soil Moisture; Q_{GWSM}=Ground Water Soil Moisture

Coefficients used when developing the water balance model for system 1, are shown in Table 3-1.

Table 3 1 Coefficients and Factors used

Name of Coefficient / Factor	Value
Soil moisture coefficient	0.607
Initial GW soil moisture content	3.0 MCM
Surface Runoff Coefficient	0.383
Deep percolation coefficient	0.01
Pan evaporation coefficient	0.51

Runoff coefficient for the watershed was initially computed using the land cover and other physical parameters (Chow 1988). A spreadsheet model was developed to compute monthly runoff over the selected year. The pattern of watershed streamflow observed during field visits, annual water balance, watershed runoff coefficient were observed and fine-tuned to obtain the most plausible direct runoff in the stream.

Muruthewela reservoir data was obtained from Irrigation Department. 75% probability rainfall data corresponding to IL2 agro ecological region and evaporation data of Ridiyagama were used in the study (Department of Irrigation, 1984). Watershed water balance components are in Figure 3-2.

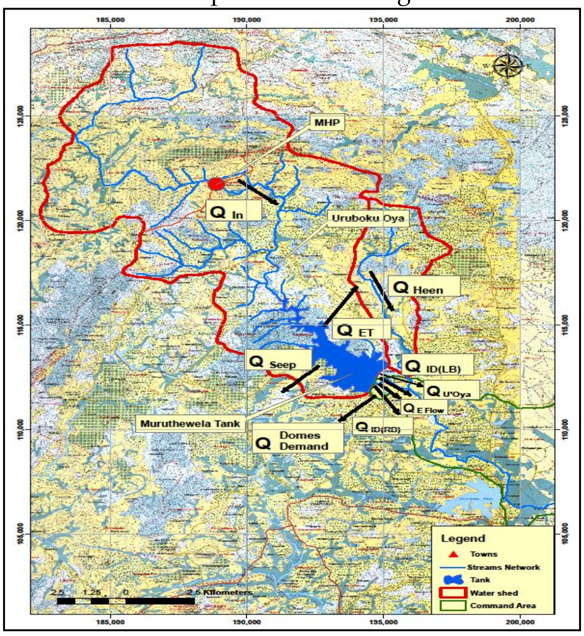

Figure 3 2 Water Balance components in the system

The notations in Figure 3-2 are described below.

Q_{In} = Inflow to the tank
Q_{Heen} = Inflow from Heen Ara
$Q_{ID(LB)}$ = Irrigation Demand for M'wela LB
$Q_{ID(RB)}$ = Irrigation Demand for M'wela RB
$Q_{U'Oya}$ = Water issues for Uruboku oya
$Q_{E\ Flow}$ = Water issues for Environmental flow
$Q_{Domes\ Demand}$ = Domestic Demand
Q_{ET} = Evaporation loss
Q_{Seep} = Seepage loss

After the MHP, the environmental flow is assumed as 90 % probability of exceedance from the flow duration curve and it was assumed that the MHP loss is 5%.

3.3. System 2 – Reservoir water balance

Reservoir water balance was computed using the equation (2),

$Q_{In} + Q_{Initial} - Q_{Evapo} - Q_{seep} - Q_{ID} - Q_{domes}$ = Change in storage ---------------------------(2)

Where,

Q_{In} = Inflows to the tank
$Q_{Initial}$ = Initial tank storage
Q_{Evapo} =Evaporation ; Q_{seep} = Seepage loss
Q_{ID} = Irrigation Demand
Q_{domes} = Domestic Demand

3.4. System 3- Downstream Area

Water balance of the downstream area requires the consideration of irrigation water to Muruthawela RB, LB, Old lands under Uruboku Oya. In each area water requirement was taken on the purpose of water use. The water balance equation for the system 3 is shown in the equation (3).

$Q_{LB} + Q_{RB} + Q_{U'oya} + Q_{Heen} - Q_{Deep} - Q_{ET} -$
$N1 * Q_{pest(return)} - N2 * Q_{Domes(return)} = 0$ ------(3)

Where,

Q_{LB} = Issues for Muruthewela LB
Q_{RB} = Issues for Muruthewela RB
$Q_{U'oya}$ = Issues for Uruboku oya
Q_{Heen} =Inflow from Heen Ara
Q_{Deep} = Deep percolation
Q_{ET} = Evapotranspiration
N1 = Dilution factor for pesticides return flow
N2 = Dilution factor for domestic return flow
$Q_{pest(return)}$ = Return flow contaminated with pesticides and weedicides
$Q_{Domes(return)}$ =contaminated domestic return flow

Return flow from the irrigable area taken as 30% as per Irrigation Department practice is contaminated with pesticides and weedicides. Crop factors, Crop water requirements, Staggers etc., were determined using ID guidelines and discussions with field officers. Environmental flow is the water quantity that should prevail in the downstream of the reservoir to water quality and environmental sustainability.

The downstream area is cultivated with Cowpea and Paddy. There are several types of water issues, namely, Q_{LB}, Q_{RB}, $Q_{U'oya}$ as in the equation. Water demand from the reservoir was initially computed using the known water uses and then developing a spreadsheet model reflecting the temporal variation of water demands by each downstream water release. There is a direct water demand from the reservoir for the NWSDB distribution.

The past data facilitated the determination of temporal variation of water releases during a typical year. The parameter suitability, order of magnitude of inputs and outputs were fine-tuned by considering the spillage and reservoir water level fluctuations. Reservoir water balance results for the year 2014/2015 are shown in the Figure 3-3.

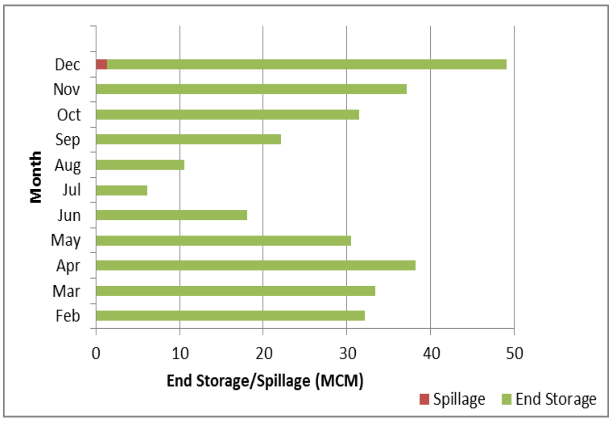

Figure 3 3 Water Balance results with actual Rainfall for Present situation

The individual assessments were combined to establish the water quantity balance in the project area. This enabled the assessment of present situation with an order of magnitude perspective. Parameter values, evaluation of inputs and outputs were holistically evaluated to determine the behavior of surface water under a data scarce situation for watershed evaluation in a distributed manner. Subsequent to the establishment of the present set up, the 75% probable rainfall was taken as the input to determine whether the system performance is satisfactory as per planning guidelines. Corresponding system outputs are shown in Figure 3-4.

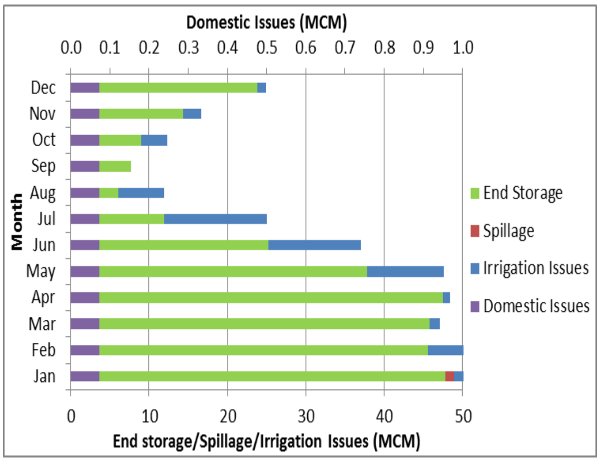

Figure 3 4 Water balance outputs for 75% Probable Rainfall

3.5. Water Quantity and Quality

In case of water quality incorporation, 03 sub components and 03 nodes (Node A-Udukiriwila, Node B -Wakamulla & Node C-Andupelena) in the downstream area were used (Figure 3-5).

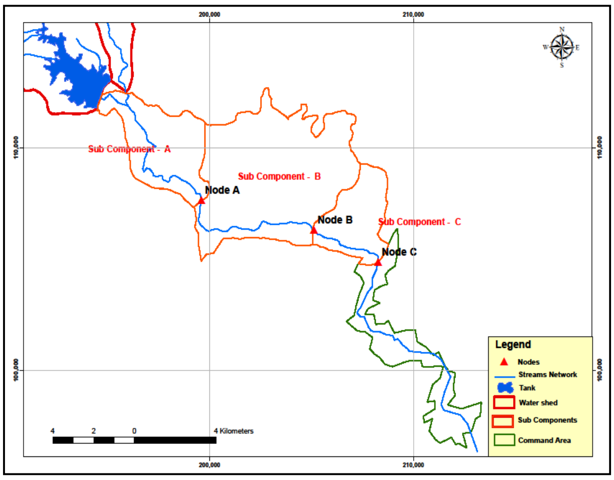

Table 3 5 Sub Components and Nodes

At each node, water balance computations evaluated unpolluted water and polluted water. Initially the total fresh/unpristene water quantity was estimated, then the polluted inflows from domestic and agriculture were identified by assigning pollution levels. Then the balance of the water at each node (Figure 3-6) was computed to evaluate the state of water at each identified node. Unpolluted water was the water which was polluted to a level below the threshold dilution permitted by the authorities and for this the CEA guide (Central Environmental Autority, 1980) was used. Following Irrigation Department practice, return flow from the irrigable area contaminated with pesticides and weedicides was taken as 30%. The return flow from domestic water was taken as 15% and taken as polluted to a level exceeding the threshold value of 8. As an example, the water quantity and quality at node A & B are shown in Figure 3-7 & 3-8.

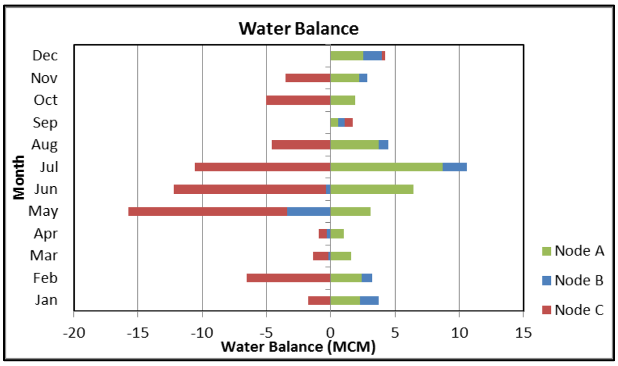

Figure 3 6 Water Balance at Nodes

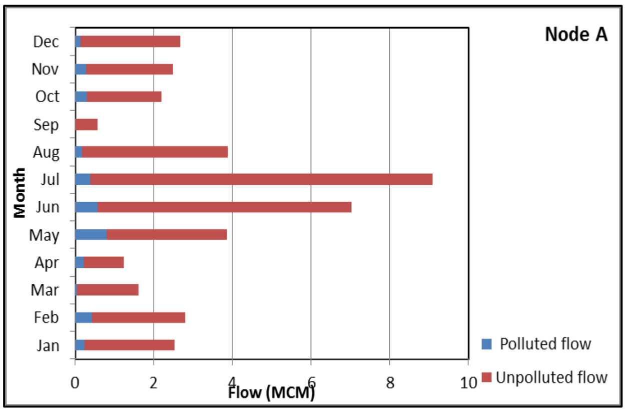

Table 3 7 Polluted & Unpolluted flows at Node A

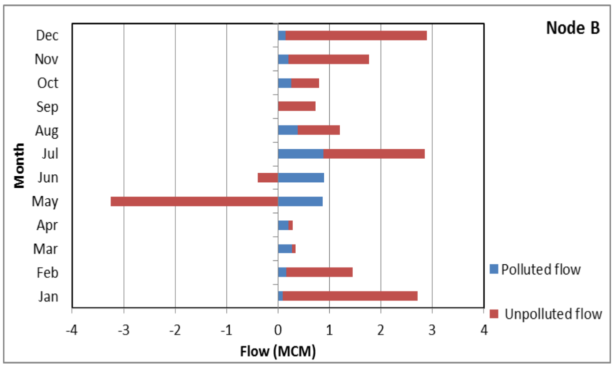

Table 3 8 Polluted & Unpolluted flows at Node B

3.6. Water Management Options

The situation analysis with the planning guidelines confirmed that there is a water quantity problem if the present demand level of water users is maintained. The main reason is that at the present level there is a water quantity deficit with a polluted status in the system. If water demands for irrigation can be managed at a low level with low water requiring crops, then farmers may be able to increase cropping intensity while balancing sectoral water requirements. The water allocation was carried out while looking at the water quality concerns at critical nodes. The cropping pattern and the final water allocation details are shown in the Figure 4-1 & 4-2.

4. Results

4.1. Multi sector water Allocation

Annual water balance which was carried out using 75% probability rainfall values recognized the following multi sector water demands as shown in the Table 4-1.

Table 4 1 Multi Sector water Demands

Month	Water Demands in MCM				
	Irrigation	Water Supply & Sanitation	Environment	Hydro Power	Spillage
Jan	1.2	0.1	0.0	2.6	0.15
Feb	5.0	0.1	0.0	0.9	
Mar	1.3	0.1	1.1	0.6	
Apr	2.3	0.1	1.3	0.9	
May	9.9	0.1	0.0	0.2	
Jun	10.7	0.1	0.0	0.0	
Jul	11.2	0.1	0.0	0.1	
Aug	5.1	0.1	0.0	0.1	
Sep	0.0	0.1	0.0	0.5	
Oct	3.3	0.1	0.0	1.3	
Nov	2.3	0.1	0.0	2.1	
Dec	1.1	0.1	0.0	2.8	
Total	55.6	0.9	2.4	11.9	0.15

Final water allocation for each sector is shown in Figure 4-1. It is proposed to release an environmental flow of 1.1 MCM & 1.3 MCM in March & April respectively (2.4 MCM annually) from the tank in order to minimize the level of pollution at Node B. The tank spills only in January and lowest storage is 6.15 MCM in August

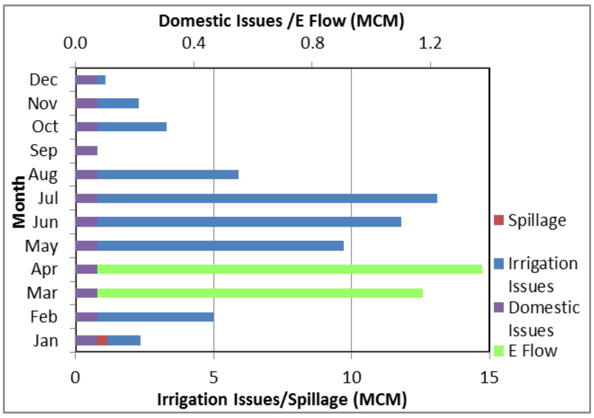

Figure 0-2 Final water allocation

4.2. Proposed Cropping Pattern

The cropping intensity will be increased in Maha by 35% (up to 100%) and that of Yala will remain same at 59% with introduction of low water consumption crop like cowpea in Muruthewela Tr.I, Tr.II & Tr. III areas while allocating water for other sectors. Proposed cropping pattern in Muruthewela area is shown in Figure 4-2.

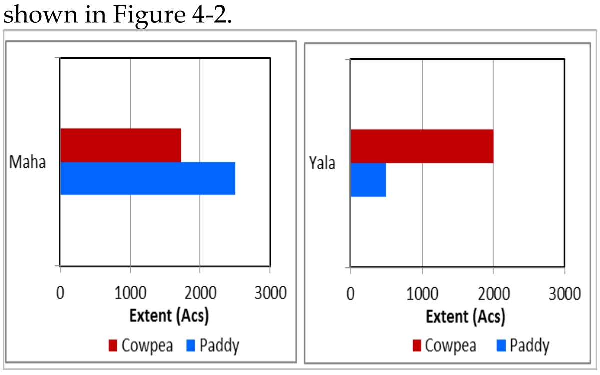

Figure 4 2 Proposed cropping pattern

4.3. Pollution status in downstream area

Pollution level of Uruboku oya flow at Node A (Udukiriwila) is satisfactory which is below the threshold value of 8 recommended by Central Environmental Authority (Figure 3-7). But, at Node

B (Wakamulla), pollution levels in March, April, May & June are higher than the threshold value. An environmental flow of 1.1 MCM & 1.3 MCM are released in March and April (2.4 MCM per year) to minimize the pollution level at Node B. But in the months of May & June, still the status of water pollution is higher than the allowable threshold value of 8 (Figure 3-8).

Node C (Andupelena) is the most vulnerable section in the river for pollution. Pollution status at Node C is shown in Figure 4-3

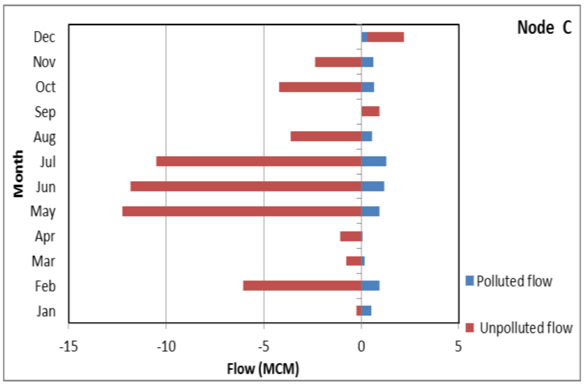

Figure 4 3 Pollution status at Node C

4.4. Catchment Parameters

i). During the annual water balance, some catchment parameters were adjusted. Initial soil moisture content was adjusted to 3.0 MCM and soil moisture coefficient was 0.607. Other adjusted parameters were, runoff coefficient as 0.383, deep percolation coefficient as 0.01 and pan evaporation coefficient as 0.51.

ii). A seepage loss of 5% was unadjusted and accepted parameter values.

iii). Irrigation return flow of 30% from irrigation demand & domestic return flow of 15% were unadjusted which are still questionable parameters that require further studies.

5. Discussion

5.1. The System Water Balance

In order to carry out a system water balance for a data scarce scheme like Muruthewela, an order of magnitude evaluations were done. With the absence of streamflow data in Uruboku Oya upstream of Muruthewela tank, it was necessary to find the runoff coefficient to calculate the inflow. Initial value for runoff coefficient was assumed and it was verified using Iso- yield curves (Department of Irrigation, 1984) and at the field by field observations.

The model was developed based on various assumptions as we don't know exactly how the catchment area behaves when rainfall comes and how each component contributes to the catchment. The main assumption made in this study is that the evaporation takes place only from the top most soil moisture content where as in reality, a fraction of the surface runoff and ground water soil moisture also contribute to the total evaporation in the area. But, when ground water soil moisture is concerned, it is very unlikely to evaporate from that component or it can be neglected. When surface runoff is considered, there is a possibility to evaporate from this component. But, surface runoff may not be there throughout the year. So, it is reasonable to assume that the evaporation takes place from the top most part of soil moisture. The model was developed using the initial values of soil moisture coefficient, deep percolation coefficient, pan coefficient etc. these parameters needs to be verified.

75% probable rainfall, reference crop evapotranspiration and monthly evaporation of Ridiyagama were used as the main inputs in the annual water balance study (Department of Irrigation, 1984). But, due to the consequences of climate change, change in land use and runoff coefficients, further refinement of these values are necessary

Water balance model verification was done using the monthly average rainfall of year 2014/2015 with the existing condition.

5.2. Water Quality

To get the exact figures of pollution, it is necessary to do water quality measurements. But, this is an order of magnitude evaluation of water quality and quantity in a watershed. This will help water planners in watershed planning in terms of crop management, pollution control etc. in a data scarce situation. Normally in seasonal planning, only water quantity is concerned at present. But, this study discusses the pollution aspect too especially identify the most troubled areas, introduces environmental flows in order to maintain the water quality below the threshold limit etc. Still there is no such literature attempting a planning level water quantity and water quality estimation so far. This is a very simple method. Once the most vulnerable area for pollution is identified, detailed and continuous data collection program can be done to improve this order of magnitude study. This is an advantage of this study.

5.3. Critical parameters and sub watersheds

In system 1 water balance, runoff coefficient is the most critical parameter which depends on the various catchment characteristics such as land use type, soil type etc. The inflows to the tank depends on the runoff coefficient.

In system 2, pan evaporation coefficient is the critical parameter.

In system 3, level of pollution in the agricultural and domestic return flows is the most important factor in the water balance. In this study, it is assumed that the level of pollution in these return flows is greater than the threshold value of 8 by considering it as polluted water.

After carrying out water balance study for three sub components (three Nodes) separately in the downstream area, the most critical Nodes could be identified. By evaluating polluted water from return flows and unpolluted water in the river and by allocating a quantity of water that needs to dilute the contaminated return flow to the threshold value of 8, the state of pollution at each Node was identified. At Node B, water balance in March, April, May & June months are negative values which indicates that there is no water available in the river to dilute the polluted water as recommended. By releasing an environmental flow of 1.1 MCM & 1.3 MCM in March and April months respectively from the tank, this pollution status can be minimized and then the pollution will exist only in May and June. At Node C, except in September and December, pollution will exist in all other months. Hence, sub component C (Node C- Andupelena) is the most vulnerable section for pollution. After this study, priority order of sub components / Nodes that need attention by stakeholders can be identified.

6. Conclusions

1) Cropping intensity of Muruthewela scheme can be increased by 35% (up to 100%) in Maha with introduction of other field crop (cowpea) and in Yala, it will remain same as 59%. Cropping intensity of Uruboku oya can be maintained at 200% which is the existing condition. Annual water allocation for irrigation sector is 55.59 MCM
2) Existing annual water allocation of 0.9 MCM can be maintained for water supply & sanitation sector.
3) River water use and healthy ecosystem downstream of mini hydro power weir can be ensured by releasing a monthly environmental flow of 0.05 MCM from the weir
4) Environmental sustainability of the reservoir area and inland fishing activity can be enhanced by keeping the reservoir capacity more than the capacity at minimum operating level.
5) The following catchment parameters were adjusted
   - Initial soil moisture content – 3.0 MCM
   - Soil moisture coefficient - 0.607
   - Runoff coefficient - 0.383
   - Deep percolation coefficient - 0.01
   - Pan evaporation coefficient - 0.51
6) Irrigation return flow of 30% from the irrigation demand & domestic return flow of 15% were unadjusted which are still questionable parameters that require further studies
7) Sub component A, Node A (Udukiriwila) section downstream of the reservoir was identified as the safest section with respect to pollution due to agricultural and domestic return flows. Pollution level at Node B (Wakamulla) can be minimized by releasing an environmental flow of 2.4 MCM annually (0.11 MCM & 0.13 MCM for March & April respectively) so that a healthy riverine ecosystem downstream of the reservoir upto Node B is ensured. Node C (Andupelena) was identified as the most vulnerable section for pollution. To overcome this problem, a water manager has either to release sufficient environmental flow while forgoing the cultivation or to organize awareness programs for farmers and take action to minimize the usage of pesticides and weedicides. If the threshold value of 8 for dilution (Central Environmental Authority, 1980) is revised to a further low value in future, one of the above two options has to be followed.

7. References

Biswas, Asit K. "Integrated water resources management: a reassessment: a water forum contribution." *Water international* 29.2 (2004): 248-256.

Chow, V.T., Maidment, D.R., & Mays, L.W. (1988). Applied Hydrology. McGraw- Hill, New York.

Department of Irrigation, Sri Lanka (1984 , May). *Design of Irrigation Headworks for small catchments* (2nd Edition, revised)

Jacobs, Katharine, et al. "Linking knowledge with action in the pursuit of sustainable water-resources management." *Proceedings of the National Academy of Sciences* 113.17 (2016): 4591-4596.

Mehta L., Movik S., Bolding A., Derman B. & Manzungu E. (2016). Introduction to special issue – Flows and Practices : The politics of Integrated Water Resources Management (IWRM) in Southern Africa. *Water Alternatives* 9(3), pp. 389-411

Karthe et al. (2015), Science-Based IWRM Implementation in a Data-Scarce Central Asian Region: Experiences from a Research and Development Project in the Kharaa River Basin, Mongolia. *Water* 2015(7), pp.3486-3514