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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Modelling of Water Resources: Water Balance, Water Use and Water Security

Prasanna Ratnaweera, Gamini Kulatunga, H Sriyananda, Sri Lanka

This paper presents three interacting models that facilitate the establishment of water management policies targeting sustainable and equitable use of water. For a given sub-basin, the water balance model attempts to establish the balance of water flows across the system boundary. Considering the whole system, the inflows have to balance the outflows. However, the water use model, set inside the system, allows for water within the system to be used many times over, thus increasing water availability. The water security model defines a multi-dimensional metric for water security depending on the water use model. The model structure allows for compatibility across boundaries, enabling construction of a composite mode for a basin, and hence a model for the country considering trans-basin exchanges.

Introduction

MODELLING different aspects of water and its use is a complex task that involves scientific as well as socio-political factors. Sound models that reflect these complexities and are capable of modelling the situation at the local level (extendable to country-level) are essential for the decision making process, especially when one is interested in sustainable use of water as against the 'use and management of water resources'.

In the absence of dependable models, 'water reforms' carried out during the last quarter century in most parts of the world were based on the premise that commercialisation would improve overall water security. They assumed that the future demand has to be met from re-allocation of already harnessed water resources, and neglected issues relating to the 'Fundamental right to water' of weak and marginalized communities.

It has been shown in numerous studies [e.g. Kulatunga [2006] that policies based on this premise, when implemented, have led to unmitigated disasters. Such policies have favoured transferring water from the impoverished domestic sector, subsistence agriculture and water that is vital to maintain the eco-system, to export-oriented industrial agriculture and industrial sectors.

Three basic models are proposed for the study of water security of a community at the sub-basin level. Net water input to a sub-basin is mostly dependant on natural phenomena, even though it too is subject to human intervention. Water use for domestic needs, water to maintain the eco-system, water for agricultural needs, commercial and industrial needs are of varying importance. This enables us to prioritize water use within constraints of water availability, which is stipulated in the water balance model. When water is allocated for a particular use, its quantity, quality and accessibility determine the state of water security (or water insecurity). The term water security has gained acceptance both at national and community level. Though there is unanimity among stakeholders to maximize the overall water security, there is wide disagreement on how it should be achieved.

A water security model should capture the state of water security at local level. It also can be used as a simulation tool to evaluate interventions proposed considering adverse impacts on all water needs. Such a model also allows for community participation in decision making and to seek consensus in implementing use and conservation strategies. A water security model should have built-in safeguards to protect fundamental rights to access basic needs such as water and food. It also should maintain fairness in meeting all stakeholders needs.

The water balance model

The proposed water balance model considers water available at sub-basin level. This is expressed as: Rainfall + surface inflow + sub-surface inflow – surface outflow – sub-surface outflow – evaporation = surface storage + sub-surface storage (refer Figure 1). Water accumulated as 'surface water' consists of surface storage in reservoirs, canals, streams, soil moisture and sub-surface water available for reuse. Water that percolates and enters sub-surface storage is termed `sub-surface' water.

Water balance requires both qualitative and quantitative input parameters. Quantifying precipitation, evaporation, relative humidity and average temperatures can be carried out at local level. The model recognises the difficulties in quantifying water that enters and exits the sub-basin as surface and sub-surface water, hence requires estimation

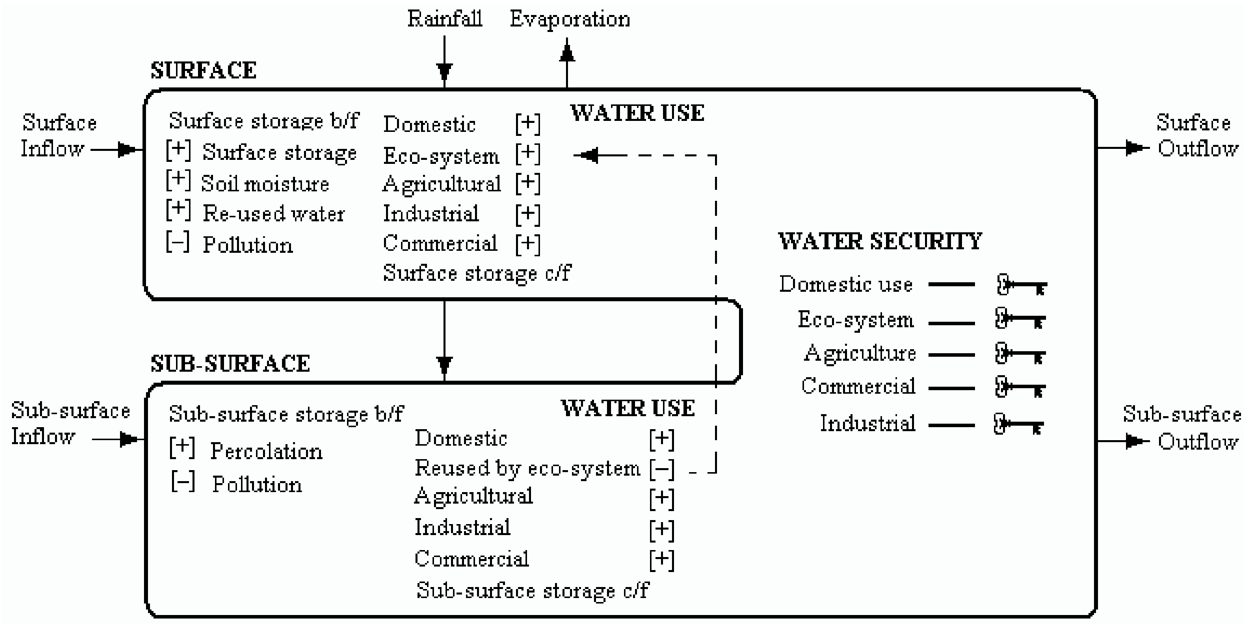

Figure 1. Water balance, water use and water security

of such quantities. The estimates need to be supported with both qualitative and quantitative information. For instance, understanding sub-surface geology with measurement of groundwater levels in open dug wells may help understand sub-surface behaviour.

The water balance model assists us to model temporal distribution of water. Long term climatic data and local knowledge is useful to prepare for extreme events such as floods and extended dry weather periods. It could also model changes that are brought about through rehabilitation of sub-catchments and land use planning.

The water use model

A water use model is a tool that helps users to prioritize and optimize water use. Such a model deviates significantly from models that promote market mechanisms to effect changes in water use.

Water uses can be broadly categorised as water for domestic needs, to maintain the eco-system, water for agriculture and food sovereignty, commerce and industry. In highly water stressed regions, these become competing needs. Water quality, access to water, real cost, opportunity cost, market price etc. are factors that affect water use. These factors decide the state of water security at household and community level.

Sri Lanka had practised water reuse in ancient times, as a means to enhance water security. At present, potable quality water is used even when water with a lesser quality or reused water suffices the requirement. Water reuse through structured interventions, e.g. in agriculture, enhance water security significantly. This also can be practiced in the domestic environment for various uses. Figure 2 illustrates this concept with respect to domestic water usage. This shows instances where multiple, alternate and parallel sources are mobilised to meet each of the sub-categories of domestic water requirements. Even the requirements for the highest quality water, i.e. water for drinking and cooking, can be met by more than one source – pipe-borne water is not always the only option for meeting this requirement.

However, this imposes certain constraints on water use and disposal. Excessive use of fertilizer and agro-chemicals in agriculture will have to be discouraged as is the disposal of un-treated industrial waste into ground water resources and waterways.

The other defining feature of this model is that a major proportion of used water is re-cycled through the natural water storage and filtration system. This can of course be enhanced by man-made waste treatment and storage devices. The quantities shown in the figure are subject to certain natural continuity constraints:

- Ground water and pipe borne water suffice water requirement for drinking and cooking; i.e. $g1 \leq Q1 \leq P1+G1$.
- Ground water, pipe borne water, harvested rainwater and water from water ways meets bathing and washing requirements; i.e. $g2+s2+w2 \leq Q2 \leq P2+G2+H2+W2$.
- Water from groundwater and water ways used for low quality cleaning; i.e. $g3+s3+w3 \leq Q3 \leq G3+W3$.
- Water from groundwater, waterways, rainwater and surface runoff used for home gardening; i.e. $g4+s4+w4+e4 \leq Q4 \leq G4+W4+R4+S4$.

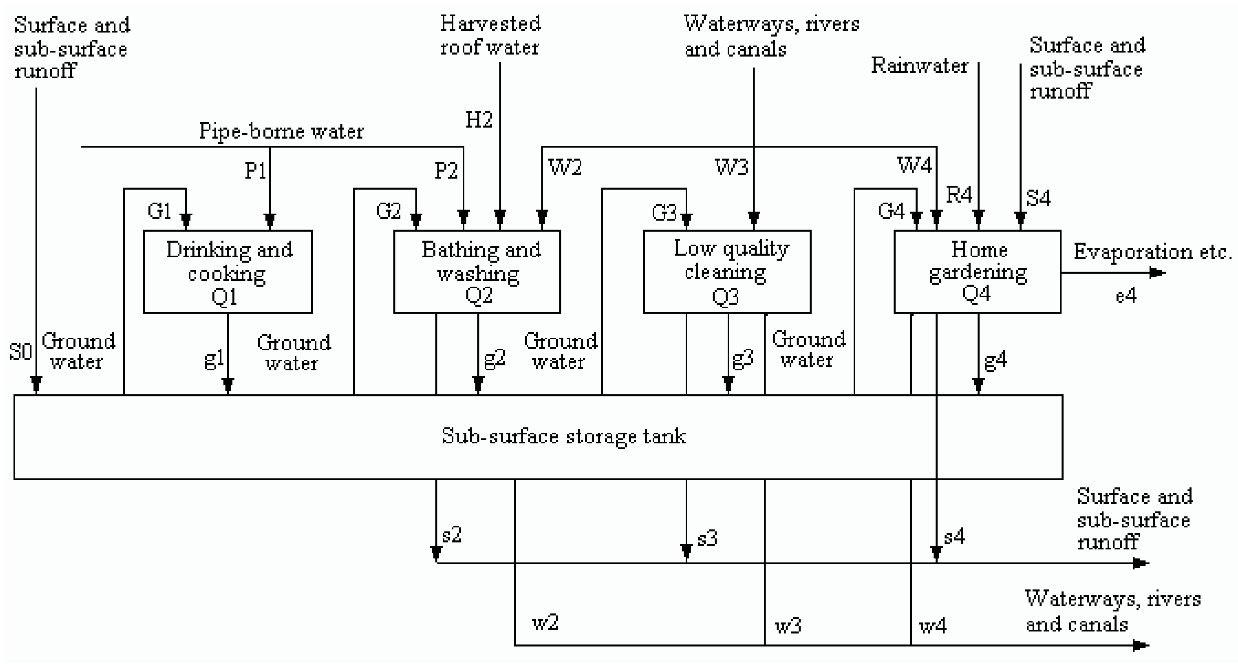

Figure 2. Domestic water re-use model showing variations in water quality

The constraints such as (P1 + P2) ≤ available pipe-borne water supply, are imposed as compatibility constraints in the water balance model. This model allows for a fair degree of flexibility in meeting domestic water requirements without having to compromise on water quality and being subject to high tariffs.

The water security model

Water security can be simply defined as the ratio of water availability to water use. When sufficient quantities are not available a state of water insecurity prevails. As we know, reality is not as simple as defined; many domestic users have to travel long distances to get their drinking water supplies; some are compelled to be satisfied with low quality water for drinking needs; households in certain regions having to pay a high price for potable water; the discharge of industrial and agricultural effluents to surface and groundwater has affected domestic water use; lateritic mining of hillocks has affected groundwater recharge; consumers having to pay high tariffs for pipe borne water.

A marginal reduction in water availability among marginalized communities may see a drastic reduction in their water and food security. It is also seen that such changes, natural or man-made can impact agriculture and the ecosystem of the region.

Commercialization of water distribution in various countries was implemented in the disguise of `water sector reforms’. This facilitated the transfer of water to profitable uses, making water unaffordable to certain marginalized communities. Such attempts that jeopardize livelihood of communities require safeguards to improve water security, based on water resource development, conservation and re-use measures.

Sri Lanka being one of the few `water rich’ countries of the world, can achieve a high water security with respect to domestic [sd], ecological [se], agriculture for food [saf], commercial [sc] and industrial [si] water uses.

Domestic water security [s_d]

Ratnaweera [2001] described a method to assess household water security (HWS) based on a qualitative approach. This method describes parameters using linguistic ratings and weights assigned for water uses (i.e. drinking, cooking, water sanitary needs, bathing, washing and home gardening). The model computes daily HWS over a one year study period. The HWS obtained at household level need to be aggregated to represent ‘persistently low’ index while it should also made to represent the community.

Aggregating over time for a single household

Here, it is proposed to use a 7-day ‘moving minima’ to represent a ‘persistently low’ water security. This is computed based on the minimum security of the 7 days considered. This is justified on the basis that a persistent water shortage is a defining parameter, irrespective of its abundance at other times.

Aggregating over a community

When aggregating over a community, the principle invoked is that the community as a whole will be affected if a ‘significant number' of households has a low HWS. Apart from moral and ethical considerations, evidence from epidemiological studies on the spread of diseases will have a bearing on determining what is meant by a 'significant sector'. As a first approximation, it is proposed to consider 5% of the households within a community as being a significant sector of that community.

Thus, the average household water security index (HWSI) of the lowest 5% group will constitute the index for the whole community. As households with the lowest HWSI are usually the most vulnerable, any transfer of water from domestic use to any other use will effect the domestic water security index of the community as a whole.

Other water security indices

As with domestic water use, other uses too have multiple activities or sub-uses. For example, water required to maintain the eco-system is required for sustaining forest cover. This facilitates ground water recharge, maintains soil moisture, prevents soil erosion, and also provides watering holes for wild life and birds.

Water needs discussed here may involve many sources with varying priorities assigned based on the type of need. Such a situation can be ideally represented using a qualitative approach, a fuzzy logic based model with linguistic ratings and weights representing model parameters.

The indices sd, se, and saf assess securities to secure livelihood and existence, hence it is vital that each of these needs to be satisfied. The indices sc and si representing commerce, export oriented agriculture and industries can be aggregated as economic water security of the community.

Participatory approach

The proposed model can be considered a decision making tool towards implementing sustainable practices, with respect to water use. Hence it is required to obtain community participation in decision making at all stages.

The proposed model also requires stakeholder inputs in defining model variables, qualitative ratings and weights, and their interpretations since their perceptions and opinions are equally important as those of the traditional planners and decision makers.

Community perception on parameters such as water quality, convenience etc. may defer significantly with those outside the community. Perceptions on the said parameters may differ across communities.

The model proposed is capable of accommodating such differences, and if conscientiously applied with true community participation, should yield water use (and reuse) patterns leading to general acceptance. In situations where there is an acute water scarcity (this is not the case even in the so-called arid zone in Sri Lanka), the community will be able to arrive at satisfactory compromises.

Conclusions

A structured water model consisting of a water balance model, a water use model and a fuzzy logic based model for evaluation, a multi-dimensional water security index is proposed. This can be used to determine water use patterns acceptable to the community through a vigorous participatory process, avoiding the pitfalls of both bureaucratic control and of commercialisation.

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Contact addresses

Prasanna Ratnaweera,
Senior Lecturer, Department of Civil Engineering,
The Open University, Nawala, Nugegoda, Sri Lanka.

Gamini Kulatunga,
Senior Lecturer, Department of Agricultural and Plantation, Engineering, The Open University, Nawala, Nugegoda, Sri Lanka.

H Sriyananda, Professor of Electrical Engineering, Department of Electrical and Computer Engineering,
The Open University, Nawala, Nugegoda, Sri Lanka.