Drainage Management in an Urban Watershed under Climate Change Scenario using IWRM Concepts

J.P.G. Jayaratne and N.T.S. Wijesekera

ABSTRACT

Surface water and ground water pollution becomes a critical factor in urban areas because having high density of population and infrastructure. Drainage management is very critical and final results is poor water quality status in natural streams when fails to manage the system. This paper aims to demonstrate the capability of developing a water balance model facilitating a quantified watershed management with incorporation of IWRM principles to give solutions for an urban watershed. Then watershed is to be divided in to sub watersheds as necessary in a spatially distributed manner by inspecting the stream network. After that water balance model can be developed considering rainfall, surface runoff, water consumption, return waste discharges of industries and domestic, pan evaporation values and dilution factors etc. Then possible solution can be proposed to achieve a satisfactory water environment for each sub watershed. Subsequently, the situation of growing domestic and industrial units by year 2025 can be evaluated after incorporating a solution for the present situation. In case of climate change, the three scenarios considered a decrease in rainfall of 7%, an increase of 8% in evaporation, a decrease of lowest rainfall and an increase in peak flow. The final output demonstrated the solutions suggested for the worst case scenario.

KEYWORDS: Drainage Management, Urban Watershed, Climate Change, Scenario, IWRM

1. Introduction

In urban watersheds, high density of resident population, associated infrastructure such as roads, supermarkets, shops, and industrial compounds cause water pollution due to huge quantities of solid and liquid wastes. This pollution is often high in areas where there is noticeable domination of brown land area over green areas. Hence surface water and groundwater pollution has become a critical factor in case of urban drainage management. Isolated, independent nature of operations, lesser shouldering of social responsibilities, un availability for collective actions, higher political interference etc., are the nature of most operations in these regions and the repercussions are well reflected by the poor water quality status of natural streams which mostly appear artificial lined drains with dirty coloured water almost with no life. Integrated Water Resources Management (IWRM) is the most widely accepted concept for water resources management. IWRM provides the framework to manage water compromising with various sectoral uses. Though there are many water resources and hydrologic research carried out in Sri Lanka, there are no case study examples to demonstrate the potential of using IWRM for drainage management in urban watersheds.

Drainage management in urban area while adhering to IWRM principles especially with the incorporation of participatory approach becomes very complex without acceptable quantifications considering diverse water uses, associated sectors, environmental thresholds and water balance. In this backdrop, a case study application was undertaken to study the possibility of using IWRM principles to manage the Attidiya watershed in the Western Province of Sri Lanka.

Watershed at Attidiya (4.5 sq. km) with a population of about 47,300 is in the middle of the oldest industrial zone of Colombo district, Sri Lanka (Figure 1). This basin with a central drainage stream which barely carries water appears as heavily polluted. The head office of National Water Supply Drainage Board (NWSDB) Sri Lanka is located at very close proximity to this main stream (Show all these locations in the map and label properly). Hence this area was selected for a case study with the intention of promoting an IWRM demonstration exercise that may be taken up by the NWSDB. Accordingly, a water resources assessment using catchment water balance to quantitatively study the drainage water from domestic units and industries units and then to evaluate the situation of Attidiya watershed under the expected climate change scenario.

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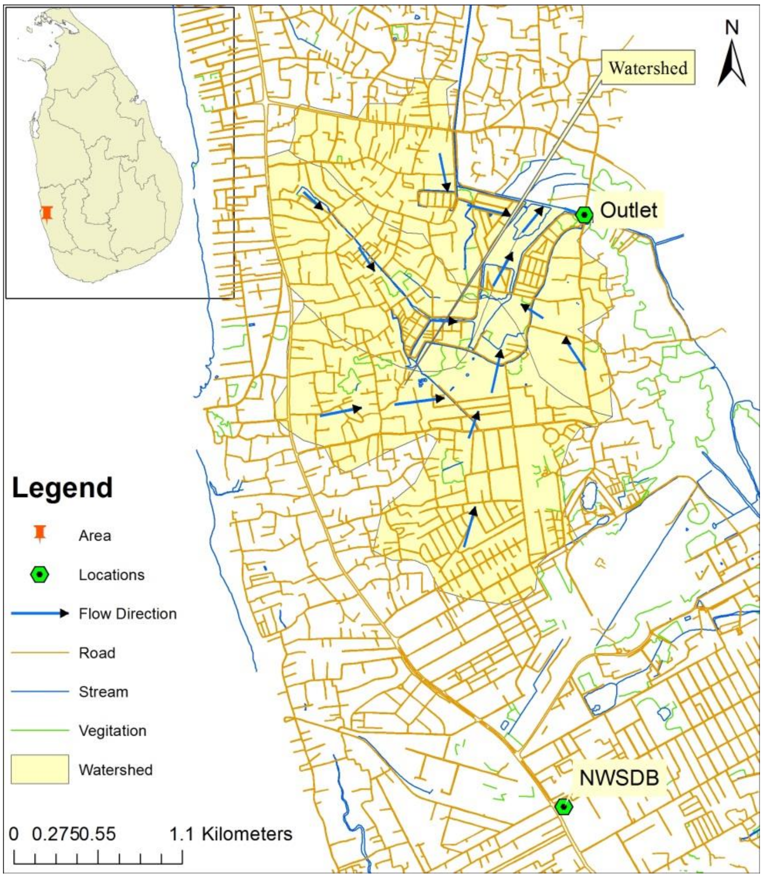

Fig. 1 Map of selected watershed of Attidiya

2. Design

2.1. Situation Analysis and Scenario

After inspecting the stream network, Attiditya watershed was divided into four sub watersheds in order to monitor the area in a spatially distributed manner. Drainage direction maps, location of industries, distribution of housing etc., were also identified. Absence of paddy lands, the demarcation of rain fed green areas, identification of areas with domestic and industrial water supplied externally by NWSDB were major land use considerations. Water balance model for each sub catchment was developed by considering a domestic consumption of 120 liter/person/day and a return waste water discharge of 80% according to the design manuals of NWSDB. Pan evaporation values from the Irrigation Department Guidelines and rainfall corresponding to the Ratmalana principal meteorological station were used. In case of industry and domestic wastewater, the model considered a factor of 0.5 for a surface runoff discharge after the flowing through the soaking pits. Pollution threshold values were incorporated by using the Central Environmental Agency recommendation of 8 times dilution. The water balance model in a step by step manner computed and considered the available room to discharge pollutants to water while ensuring that the water status is within the CEA thresholds. Water outflow from each sub catchment was evaluated to finally capture the cumulative effect at the outlet of main watershed. The water balance model developed using a spreadsheet initially used the actual rainfall to evaluate model performance by matching the computed flow values with those observed and captured during field visits. After the calibration of models parameters while observing the soil moisture levels, runoff coefficients and the pattern of stream flow, the spreadsheet was used to study the watershed with 75% probable rainfall which is the recommendation in the design guidelines (Irrigation Guide 1984 – Design of Irrigation Head works for Small Catchments). The situation analysis was identified the order of magnitude of water status in each sub catchment. Possible solutions with quantifications to convince the water users in the watershed were proposed. Subsequently, the situation of growing domestic units and industrial units by the year 2025 was evaluated.

2.2. Incorporation of Climate change

Water balance model also enabled the evaluating the watershed in case of climate change. Three scenarios were considered and they were 1) Annual rainfall decrease by 7%, 2) Evaporation increase of 8%, and 3) an increase in the high rainfall and a decrease in the low rainfall. Final outputs demonstrate the solutions suggested for the worst case scenario when there is a collective effective from all the scenario.

3. Data and Analysis

3.1. Area and population density in sub watersheds

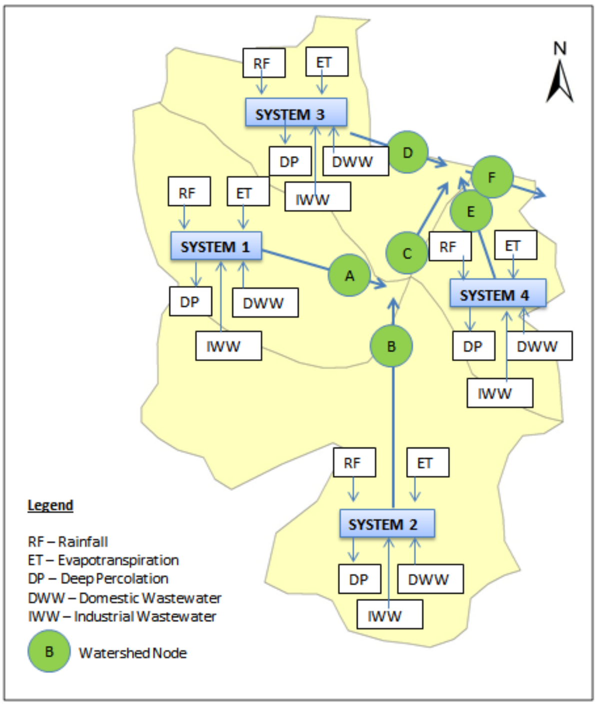

Fig. 2 Map of sub watersheds and system diagram

Population, industry and social data were obtained from divisional secretariat offices of Ratmalana and Dehiwala and were tabulated according to sub watersheds (Table 1).

Table 1. Area, Population density, no of industries and no of houses in sub watersheds

Sub Watershed	Area Sq.km	Population Density Persons/Sq. km	Number of Large Industries	No of Housing Units
Sub 1	1.15	12,689	0	2,722
Sub 2	1.88	9,892	7	4,632
Sub 3	0.64	14,247	1	1,685
Sub 4	0.87	5,790	1	659
Total	4.54	10,425	9	9,698

3.2. Rainfall and pan evaporation

Ratmalana rainfall data from 1931-1990 were averaged for the annual water balance. Monthly Pan Evaporation values were taken from the Irrigation Department Guidelines.

Table 2. Rainfall and Pan Evaporation

Month	Rainfall mm	Pan Evaporation mm
Jan	93	93
Feb	69	94
Mar	134	106
Apr	268	101
May	301	95
Jun	171	89
Jul	119	94
Aug	107	105
Sep	199	98
Oct	93	79
Nov	414	78
Dec	160	89
Total	2,128	

Analysis was based on the water balance of the watershed first considering the rain that generated unpolluted runoff depending on the land use, soil moisture and other physical parameters subjected to the influence of evaporation. Then the next step of the water balance was to consider the return flow from domestic units and industries together with the direct runoff from rain. At each sub catchment node, the water quantity balance was checked with the use of equations 1 and 2.

$$Rainfall - Evaporation - Runoff - Deep\ percolation = Change\ of\ Storage \ldots\ldots \quad (1)$$

$$Streamflow = Runoff + Wastewater(Domestic\ Units\ +\ Industries) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Water balance with the incorporation of water quality was computed considering that the freshwater from the rain could be polluted up to the threshold value stipulated by the Central Environmental Authority (General Standards Criteria for the Discharge of Industrial Effluents into Inland Surface Waters). In this exercise the equation 3 was utilized.

$$Dilution\ factor\ \eta = \frac{Q\ Runoff}{Q\ wastewater} \ldots\ldots\ldots\ldots\ \ldots \quad (3)$$

3.3. Institutions involvement in the area

Many institutions involve for varies kind of activities in the area. Therefore participatory approach is to be applied according to the Integrated Water Resources Management.

Table 3. Institutions involvement in the area

Institution	Activities Involvement
Divisional Secretariat – Ratmalana & Dehiwala	Administration & Coordination activities in the area
Urban Council (Dehiwala./Mt. Lavinia)	Solid Waste Management, Small Developments, Health Management
CEA	Environment Management
NWSDB	Water Supply & Sewerage Management
SLRDC	Flood Control & Drainage Management
Irrigation Department	Irrigation Water Management
UDA	Urban Development Activities
NHDA	Housing Development Activities
RDA, PRDA, UC	Road Construction & Maintenance
Metrological Department	Metrological Activities
CEB	Power Supply
Telecom	Communication
Education Department	Scholl Children Education
Government Hospitals	Health Maintenance

4. Results

4.1. Present Status

Present status at key sub watershed node and at the main watershed outlet is shown by results in Table 3. All watersheds reflected a highly polluted status while the sub catchment 2 demonstrated the most polluted state. The sub watershed 4 proved to be in the best state with a water quality level below the pollution thresholds stipulated by the CEA.

Table 3. Present Status of the Watershed

Sub Watershed	Watershed Node	Rain Volume m3	Fresh water Run off m3	Total WW Runoff m3	Fresh Water requirement to dilute WW m3	Available Fresh water within CEA threshold m3
1	A	2,386,756	1,455,921	255,214	2,041,711	-585,789
2	B	3,921,100	2,391,871	413,011	3,476,365	-1,084,494
2+3	C	6,307,856	3,847,792	635,922	5,195,051	-1,347,259
3	D	1,320,201	805,322	180,403	1,487,028	-681,705
4	E	1,804,621	1,100,819	102,656	850,444	250,374
1+2+3+4	F	9,432,677	5,753,933	905,293	7,395,648	-1,641,715

To show the monthly variation at the outlet of the watershed is shown in the table 4.

Table 4. Monthly variation in the watershed at outlet point

Month	Rain Volume m3	Fresh water Runoff m3	Total WW Runoff m3	Fresh Water requirement to dilute WW m3	Available Fresh water at out let within CEA Threshold m3
Jan	412,236	251,464	76,888	628,123	-376,659
Feb	305,853	186,570	69,447	567,337	-380,767
Mar	593,975	362,325	76,888	628,123	-265,799
Apr	1,187,950	724,649	74,408	607,861	116,788
May	1,334,227	813,879	76,888	628,123	185,755
Jun	757,983	462,370	74,408	607,861	-145,492
Jul	527,485	321,766	76,888	628,123	-306,357
Aug	474,293	289,319	76,888	628,123	-338,804
Sep	882,097	538,079	74,408	607,861	-69,782
Oct	412,236	251,464	76,888	628,123	-376,659
Nov	1,835,117	1,119,421	74,408	607,861	511,560
Dec	709,224	432,627	76,888	628,123	-195,497
	9,432,677	5,753,933	905,293	7,395,648	-1,641,715

According to the table 4 it can be seen that in the last column the values are plus only in 3 months such as April, May & November. That means those three months the out let water quality is satisfactory according to the CEA threshold value. In the other words all the other 9 months in the year water quality at the out let of the watershed is unsatisfactory that is polluted according to the CEA threshold value. In figure 3, it shows in graphically the values in the table 4.

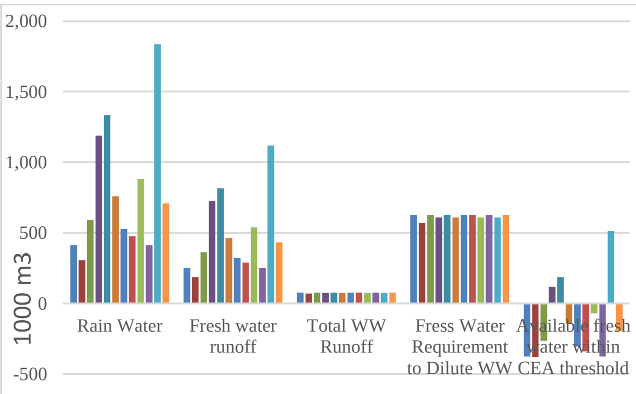

Fig. 3 Monthly variation in graphically

Therefore to increase the available fresh water at the out let of watershed the total wastewater quantities should be reduced because runoff fresh water cannot be increased that is rainfall cannot be increased. Therefore wastewater of domestic and industries should be treated to reduce wastewater runoff quantities and quality.

To reduce the domestic wastewater it should either be treated at individual house premises or collected to a central point and treated. Actually industrial wastewater can be treated at the site and can be discharged to streams to reduce dilution water requirement. However it can be seen that if treating of 68% domestic wastewater and 60% of industrial wastewater the resultant runoff will be sustained at the out let of the watershed.

4.2. Pollution variation in three options incorporation of climate change

According to the model results for the 3 scenarios incorporation of climate change as mentioned in the section 2.2 for the 2025 the worst case was developed in the option 1(decrease rainfall by 7%). That means most pollution level become by decreasing rainfall of the watershed. Therefore solutions are to be given for the option 1.

Table 5. Pollution variation in three options at the outlet point of watershed

Option	Rain Water	Fresh Water Runoff	Total WW Runoff	Fresh Water Requirement to Dilute WW	Available Fresh water within CEA Threshold
1	9,432,677	5,753,933	1,040,482	8,492,488	-2,738,555
2	9,432,677	5,753,933	1,032,817	8,415,838	-2,661,905
3	9,767,435	6,076,321	905,293	7,395,648	-1,319,326

4.3. Solutions

According to the results of the model it can be observed that generally 71.5% wastewater quantity should be reduced or treated to become best stat at the out let of the watershed if consider whole watershed. However according to the population density, no of industries availability and pollution levels of sub watersheds wastewater reduce or treatment percentage will be varied sub watershed wise as following table 6. Sub watershed 3 is most critical and sub watershed 4 is not critical.

Table 6. Wastewater reduce or treatment % requirement in sub watersheds in the year 2025

Sub watershed	% of WW treatment requirement	
	Domestic	Industries
1	76%	70%
2	76%	70%
3	80%	80%
4	55%	55%

5. Discussion

5.1. System water balance

When doing system water balance, the accuracy depends on the required data availability to the relevant area, verification of the data and assumptions made. This study was done under data scare situation and used available literature and assumptions.

However, for accuracy of this type of analysis accurate data should be needed such as Rainfall, Runoff Coefficient, Deep Percolation Coefficient, Soil Moisture Coefficient, Pan Evaporation Value, Evapotranspiration factor, Initial Ground Water Surface Moisture Content, Inflow and Out flow quantities from the system etc. to do the system water balance. Up dated geographical Maps to calculate the Watershed areas and land use patterns also needed to calculate the runoff factors etc. In addition to that to run the model, population, no of housing units, no of industries, Water Consumptions of domestic industries and others, Wastewater factors for Domestic Industries and others, Wastewater Runoff Factors, Wastewater Deep Percolation Factors, Wastewater Quality, Standard Criteria for Discharge of effluents in to inland surface etc. will be needed. All the date and Parameters available are to be verified whether those values can be matched to this area and situations. For example, runoff factors should be verified because this watershed lies in urbanized area and land use patter is directly affected to it. Field visits also are to be done to identify and verify the data available.

The model was developed based on various assumptions and few of them are; wastewater produce 80% of water consumption in houses, wastewater produce 40% of water consumption in industries, 50% runoff from domestic wastewater and other 50% deep percolation, 8 times fresh water requires to treat domestic water, 10 times fresh water requires to treat industrial water etc.

5.2. Water Quality

Actually to handle this type of analysis water qualities at the end point of sub watersheds, out let points of industries etc. should be measured to calculate actual fresh water requirements to treat polluted water. In addition to that this study average pollution conditions were used, but actual condition is different because pollution level variation occur in different places. Therefore, doing actual designs water planners should obtain the water quality measurements periodically in varies locations to represent whole area to decide exact level of pollutions.

5.3. Literature Attempting

Water planners should attempt to find historical data relevant to the area such as water quantity, water quality, water flows, environmental flows, flood levels etc. If not it should be started data collection programme.

5.4. Critical Parameters

In this analysis three scenarios were used to evaluating case of climate change as decreasing rainfall, increasing evaporation and stream event of increasing highest rainfall and decreasing lowest rainfall. When selecting these critical parameters, it should be refer literature, past records and papers to identify correct parameters.

5.5. Critical Watershed

In this area the land use pattern is different in each sub watershed. According to the Table 1 it can be seen that in sub watershed1population density is medium, in sub watershed 2 availability of industry is high but population density is medium, in watershed 3 population density is very high and in watershed 4 very low population densities. According to the analysis it shows that in watershed 3 wastewater pollution level is high and required wastewater treatment percentage is very high to come state situation. In addition to that sub watershed 1 & 2 domestic wastewater pollution is high.

Therefore, stake holders should give more attention to sub watershed 3 because situation becomes critical in future if it is not given attention to that. However, sewer central collection system will be needed in future for sub watershed 1, 2 & 3 because population density is increasing day by day. In addition to that IWRM principals in participatory approach will be needed to overcome the critical situation.

6. Conclusion

Model demonstrates pollution level of surface water and ground water in an urban watershed when fails to manage. It quantifies the critical situations. Then possible solutions can be proposed to achieve a satisfactory water environment for each sub watershed. Prediction of climate change impact gives in advance how to create mitigate options and what can be adaptions applied to the watershed. Awareness of stakeholders, land users according to the IWRM principals as required time is essential because after become the worst situation it is very difficult to overcome and come back to ecofriendly situation.

7. Acknowledgement

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