# Endogenous Derivation of the Optimal Policy Measures To Improve the Water Quality in the Barada Basin, Syria

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## Abstract

Barada Basin, where the capital of Syria, Damascus, is located, and hence where most of the human activities are concentrated, suffers from serious environmental problems. According to the list of priorities that has been set by Ministry of Environment and WB in 1997 an immediate action plan should be carried out to address the water pollution issues in Barada Basin. Huge amounts of wastewater (domestic, industrial, and agricultural) are discharged every day to the land, Barada and Awaj Rivers without sufficient treatment.

In order to address the problem a feasible integrated solution should be set to recover the deterioration of environment that has already happened and prevent any further contamination. Taking in consideration the effects on the economic growth, attempts should be made to find an optimal policy reflecting a trade off between the economic growth and conservation of the environment in general and water resources in particular.

In this paper, the water pollution problem in Barada Basin has been analyzed. Simulations of a mathematical model have been run in order to find an optimal feasible policy improving the environmental status in Barada Basin. This model includes an ecological model that describes the behavior of the pollutants and an economic model that describes the market instruments. A set of policies have been proposed based on the the simulations.

## Introduction:

The Syrian Arab Republic lies on the eastern coast of the Mediterranean Sea between Turkey and Lebanon, Iraq, Jordan, and occupied territories. It is a largely arid country with a land area of about 185,000 km$^2$ of which around one third is arable land or forest and the remainder is desert and rocky mountainous areas. In 2000 the population of Syria reached 17 million, representing a growth rate of about 3.3%. 51% of the population lives in urban centers, mainly in Damascus and Aleppo. In recent years, there has been steady economic growth across almost all sectors, averaging around 4% per year since 1990. Agriculture, forestry and fisheries dominate at almost 20% of the economy, followed by industry and mining (16% GDP), with finance, trade and transportation all making significant contributions [20].

Trying hard to keep step with development, Syria has had non-ignorable economic growth in most of the sectors especially agriculture and light industry. However, that causes dramatic effect on the environment in general and natural resources particularly. Haphazard urbanization, overexploitation of land and water resources, deforestation, and lack of waste treatment have led to the change in climate cycle causing remarkable decrease in rainfall. This consequence collaborates with water contamination to make the situation worse and exacerbate the problem of water resource depletion. Barada Basin is one of the tragic examples of such a problem.

Barada Basin, where the capital of Syria, Damascus, is located, and hence where most of the human activities are concentrated, suffers from serious environmental problems due to the huge migration from rural areas, illegal settlements, industrialization, urbanization, and overexploitation of environmental media. According to the list of priorities that has been set by Ministry of Environment and WB in 1997 an immediate action plan should be carried out to address the water pollution issues in Barada Basin. Huge amounts of wastewater (domestic, industrial, and agricultural) are discharged every day to the land, Barada and Awaj Rivers without sufficient treatment converting the only-two water bodies in the region to waste dump.

The procedures that are undertaken to address the problem are very limited due to the absence of environmental law, limitation of the legislation, and lack of environmental awareness. Most of the manufactories discharge their contaminants to the sewerage system or simply to the land and rivers without treatment, free of charge. In addition the distribution of micro and small scales industries makes the situation difficult to control.

The inadequate agricultural practices have also contributed to exacerbating the water pollution due to overuse of fertilizers, pesticides, water resources and inappropriate irrigation methods.

In order to address the problem a feasible integrated solution should be set to recover the deterioration of environment that has already happened and prevent any further contamination. Taking in consideration the effects on the economic growth, attempts should be made to find an optimal policy reflecting trade off between the economic growth and conservation of the environment in general and water resources in particular.

This study is focused on improving the water quality of Barada and Awaj Rivers by introducing a set of policy measures. These policy measures will be analyzed and determined by running simulations of a mathematical model based on data available.

**Background of the Barada Basin**

The Barada Basin is located in the southwest area of Syria and stretches from the western mountainous of Damascus including Sheikh and Kalamon Mountain in the north to the Qunatera and Jolan Height in the south and from Lebanon in the west to the Syrian Desert in the east. The basin occupies an area of 8,630 $km^2$ divided into two distinct landscapes

- A mountainous area in the northwestern mountain range which occupies an area of 3500 $km^2$, consisting of the East Lebanese and Palmyra Mountains, with an altitude of 2,814 m at the Al-Sheikh Mountain Peak.
- A plain area consisting of Ghouta and the surrounding plains with an area of approximately 5,100$km^2$ ranging from about 595 m to 1,400m above sea level.

The basin includes Damascus Prefecture, 70% of Rural Damascus Prefecture, 11% of Daraa Prefecture, and 19% of Sweida Prefecture.

The weather varies due the difference in the topographic height. It varies from desert in the plain area to mild wet in the area with height more than 2000m. The annual rainfall distributes irregularly around the basin. The biggest amount that is around 1500-1800mm falls in the western area of the basin on height more than 2000m in Haramon and Sheer Mountain, while the least falls in the plain area (Ateibeh and Hijane Lakes) and is approximately 90mm. The annual evaporation in the mountain area is between 300- 350mm while in the plain area between 90-100mm. However in the Ghouta evaporation is approximately 380mm. Prevailing winds are northwesterly in the northwestern part of the basin and south westerly in the southeast.

The total population of the basin is 3.6 million, accounting for approximately 21% of the total population of Syria. The population of Damascus City was around 1,49 million in 2000. The annual growth rate in population varies between 1.68% in Damascus City and 4.48% in other zones of the Basin.

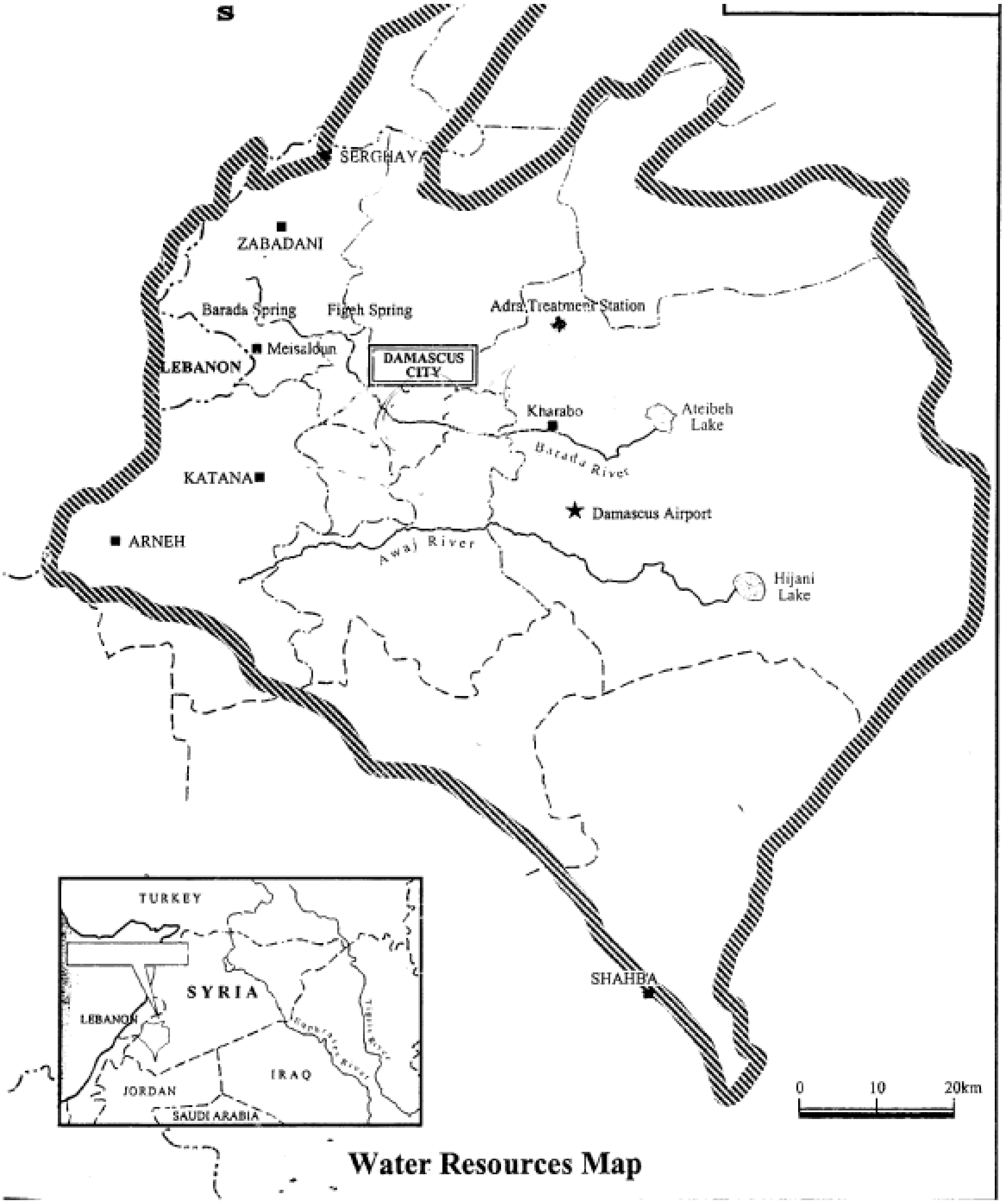


Figure 1: The map of Barada Basin Ministry of Environment, Syria, 1999

The main economic activities in the basin are industry, services, and agriculture. The employment levels in the basin are slightly higher than the national average, and higher again in Damascus city (29.5% and 31% respectively). The total number of employed people in the basin is 174,116, excluding those employed within the government and military sectors. Employment is dominated by the service sector, which accounts for 68% of basin employees. This is similar to the national figure of 65%. Other employment sectors are industry 27.5%(national 26%), and agricultural 4.5% (national 9%)[20].

Barada Basin consists of Barada River basin (2,348km$^2$), Awaj River Basin (1,456km$^2$), and other small valleys Basin (4,386km$^2$). These rivers have their catchment area in mountains located on the northwest of the study area and flow into the Damascus plain located on central and southeast of the study area. They have closed basins without any outlet to the sea. In the basin there are more than 50 springs supplying stable water for domestic and irrigation use in the surrounding areas. Among these springs, Barada and Fijeh are used as the main water resources for Damascus City

Barada and Awaj Rivers are continuously flowing in the Basin. The main water resource is Barada; whose flowage basin area is approximately 1380km$^2$ and 3.1m$^3$/s is an annual average flowage. Barada River starts from Barada spring (22% of the total river flow) on the Sheer Mountain continuing through Damascus where it is divided to seven lanes to reach to Ateibeh Lake. Though the flow of Barada is supported by many springs. The main one is Figeh spring with 7.71m$^3$/s annual average flow (55%). This spring is the most important water source in the basin, providing 4.6m$^3$/s annually for drinking water. Going out of the mountain area, Barada River reaches 14 m$^3$/s as an annual average flowage but almost all this water is used for irrigation. Consequently Barada reaches its estuary only in the high rain season [4] [8].

Awaj River forms after the two tributaries Sibrani and Jinani united in the Haramon Mountain's foot. The flowage basin is around 1120km$^2$. The annual average flow in normal circumstances is 4,7m$^3$/s but has in recent years become approximately 2.2m$^3$/s so it reaches its estuary (Hijane Lake) only in the high rain season. The high flow season for the two rivers is from January till June and the low flow season from July till November. The water flowage system of the rivers is affected by many factors such as irrigation and wastewater [4].

**The current environmental situation in the Basin**

Except Damascus City and a few suburban areas all the settlements of the basin discharge their wastewater to land or the two rivers causing a high level of contamination. Almost all the wastewater generated from industrial activities is discharged without treatment, except some big new factories, mainly to Barada River. The estimated amount of BOD for the industrial wastewater that flows to Barada River is approximately 12.5 ton/day. Although industrial contamination of groundwater is not firmly established, this is quiet probable since the aquifers are replenished by river water [20].

Historically, the Barada River was a very vital water resource. Around it was a huge, beautiful wood full of different kinds of trees called `Ghouta`. This wood was a source of food for the people who lived around and constituted a rich ecosystem. This river was not only source of water for the people but was also a source of inspiration and considered a culture heritage. However, in the recent years the Barada River has become completely dead due to

1. High amounts of contamination over the self-purification capacity.
2. The climate change and the remarkable decrease of rainfall in the area.
3. Piping the water of the main supporter spring (Feige Spring) to use as drinking water.

**Methodology**

To be able to achieve our research purpose, the adopted method should express all key factors and parameters reflecting the environmental situation and affecting human activities. The reason is that to find an optimum policy not only on paper but also for implementation in practice. For this reason, we developed a mathematical model for analyzing the optimal policy. This model should be dynamic, representing the changes in the environment and in socioeconomic activities within a defined period of time [5][6]. The method can be separated in four steps:

1. Divide the basin into catchment areas according to the administrative classification in order to be able to collect basic data.
2. Set the dynamic model that includes the two complementary sub-models. The ecological model, which describes spatial and chronic change of the pollutants discharged to the river, and the socioeconomic model, which describes the social and economic activities in the catchment areas beside the relationship between the activities and the amount of contaminants.

3. Propose an optimal set of policies set based on the optimization criterion. Optimal means a trade off between the highest economic growth and the least harm for the environment in general and for the water resources in particular.

The mix policy measures is analyzed in this paper are

- Introducing set of abatement techniques for domestic wastewater.
- Introducing set of treatment type for manufacturing industry.
- Introducing Subsidy system for remediation technologies.
- Optimal utilization of the existing tax system in the basin.
- Subsidy system between the zones is introduced based on cooperation among those zones.

**The model variables and definitions**

Since assembling data is not available for all area of The Barada Basin, the study area will includes the only the drainage basin of each The Barada River and The Awaj River. It includes two provinces, Damascus and Rural Damascus. The province of Rural Damascus affiliates six districts. Two of these districts lie on both basins as shown in table 1.

Table 1: The flow of water in the sub-district affiliated to both rivers:

| **Province** | **District** | **Sub-District** | **Water flow** |
|---|---|---|---|
| Damascus City | | | Barada River |
| Damascus Rural | Damascus Rural Center | Babilla | Barada River |
| | | Jaramana | Barada River |
| | | Erbeen | Barada River |
| | | Al-Kissweh | Awaj River |
| | | Kafar Batna | Barada River |
| | | Mleiha | Barada River |
| | Al-Tal | Al-Tal Center | Barada River |
| | | Rankus | Barada River |
| | | Sednaya | Barada River |
| | Darya | Darya Center | Awaj River |
| | | Suhnaya | Awaj River |
| | Douma | Douma Center | Barada River |
| | | Harran Al-Awamid | Barada River |
| | | Harasta | Barada River |

| | | | |
|---|---|---|---|
| | | Al-Dmir | Awaj River |
| | | Al-Nashabieh | Barada River |
| | | Al-Ghozlaniy | Awaj River |
| | Zabadani | Zabadani Center | Barada River |
| | | Dimas | Barada River |
| | | Serghaya | Barada River |
| | | Ain Al-Fijeh | Barada River |
| | | Madaya | Barada River |
| | Katana | Katana Center | Awaj River |
| | | Al-Haramoun | Awaj River |
| | | Saasa | Awaj River |

The study area is divided to nine zones according to districts flow to each river. The tenth zone is the irrigation project area where the treated wastewater from Adra treatment plant is used for irrigation, as shown in table 2.

Table 2: Classification of zones

| **Zone Index I** | **Zone** | **Population** | **Average growth rate%** |
|---|---|---|---|
| 1 | Zabadani | 106,423 | 1.66 |
| 2 | Damascus | 1,539,164 | 4.47 |
| 3 | Al-Tal | 122,257 | 4.47 |
| 4 | Damas-Rural | 505,268 | 4.47 |
| 5 | Irrigation project | 238,352 | 4.47 |
| 6 | Douma-North | 305,194 | 4.47 |
| 7 | Katana | 196,217 | 4.47 |
| 8 | Darya | 235,280 | 4.47 |
| 9 | Al-Kissweh | 106,297 | 4.47 |
| 10 | Douma-South | 64,329 | 4.47 |

In The Barada Drainage Basin zone 1,2,3,4,5, and 6 are located. However, 1,2,5,6 only are located along the river. In The Awaj Drainage Basin zone 7,8,9,10 are located but zone 8 is not located along the river. Zone 4,9 are affiliated to same district and the same for zone 6,10.

The socioeconomic activities are classified according to the source of contamination mainly to industries, household, and land use as shown in table 3.

Table 3:The classification of socioeconomic activities

| **Index** | **Socioeconomic activities** |
|---|---|
| 1 | Industries |
| 2 | Household wastewater |
| 3 | Land use |

To estimate the pollution load from each industrial activity, these activities is classified as shown in Table 4.

Table 4: The classification for industries

| **Index j** | **Industry** |
|---|---|
| 1 | Manufacturing |
| 2 | Agriculture |
| 3 | Live stock |
| 4 | Other (services, trade, etc.) |

The manufacturing industry is classified as shown in table 5 in order to set variation of remediation techniques:

Table 5: The classification of manufacturing

| **Index m** | **Manufacturing industries** |
|---|---|
| 1 | Food |
| 2 | Metal and electric devices |
| 3 | Wood |
| 4 | Chemical |
| 5 | Textile |

To calculate the pollution generated from land use the classification shown in Table 6 was adopted.

Table 6: The classification of the land use.

| **Index k** | **Land use** |
|---|---|
| 1 | Crops |
| 2 | Forest |
| 3 | City area |
| 4 | Other |

The selected pollutants are as follows

Table 7: The classification in the pollutants

| **Index p** | **Pollutant** |
|---|---|
| 1 | TN |
| 2 | TP |
| 3 | BOD |
| 4 | Chromium |
| 5 | Cadmium |
| 6 | Lead |
| 7 | Iron |

The abatement facilities for domestic wastewater treatment are introduced [7], [11] as shown in Table 8.

Table 8: Classification of abatement types for domestic wastewater

| **Index q** | **Abatement Type** |
|---|---|
| 1 | Septic tanks |
| 2 | Oxidation ponds |
| 3 | Trickling filters |
| 4 | SABF |
| 5 | Activated sludge |

The manufacturing industry is the main source of pollution in industrial wastewater. The abatement type required is shown in table 9.

Table 9: Classification of industrial wastewater treatment

| **Index g** | **Type** |
|---|---|
| 1 | Pretreatment |
| 2 | Chemical treatment |
| 3 | Biological treatment |
| 4 | Advanced treatment |

**The model specification**

In order to understand the ecological model figure 1 shows water flow direction in Barada and Awaj Basins

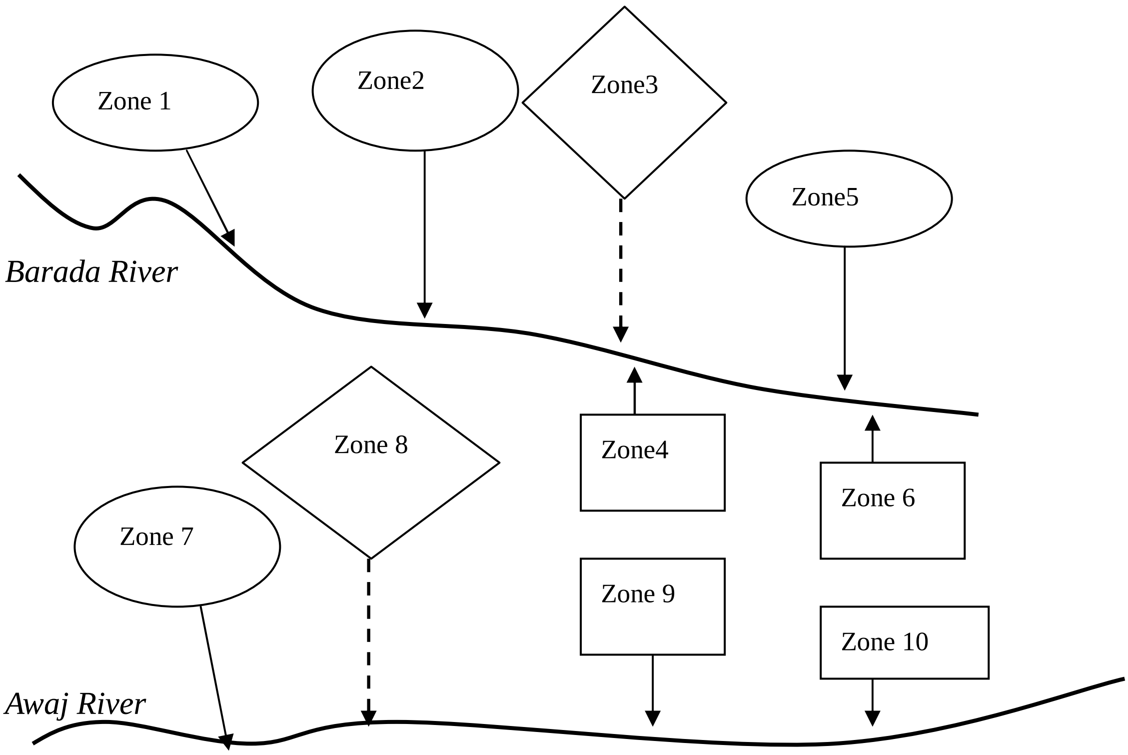


Figure 1: The direction of water flow from zones to rivers

The total pollution flows to each The Barada and Awaj Rivers is calculated by the pollution generates from each zone according to figure 1.

$$
\begin{aligned}
TB_p^B(t) &= TB_{1p}(t) + TB_{2p}(t) + TB_{3p}(t) + TB_{4p}(t) + TB_{5p}(t) + TB_{6p}(t) \\
TB_p^A(t) &= TB_{7p}(t) + TB_{8p}(t) + TB_{9p}(t) + TB_{10p}(t)
\end{aligned}
\quad \text{.....(1)}
$$

$TB_p^B(t)$: The total amount of pollutant p flowing to Barada River at time t.

$TB_p^A(t)$: The total amount of pollutant p flowing to Awaj River at time t.

The total amount of pollutants generate from each zone is related to

1. Household (includes industry j=4): To reduce pollution, abatement facilities that shown in Table 8 are introduced. Then the amounts of each pollutant are calculated regarding the number of population with and without treatment.
2. Non-point source of pollution:
   - Agriculture: the amounts of each contaminant are calculated regarding Land use area.

- Livestock: the amounts of pollutants are calculated according to number of animals.
- Other land use: as shown in table 6.

3. Manufacturing: To reduce the contamination, abatement types in table 9 are introduced. Then the amounts of pollution are calculated regarding the production with and without treatment.

The following equation clarify what is explained above:

$$TB_{ip}(t) = \sum_{m} e_{mp}\left( Y_{i1m}(t) - \sum_{g} \delta_{gp} \overline{\pi_{mg}} KW_{img}(t) \right)$$
$$\sum_{q} e_{qp} P_{iq}(t) + \sum_{k} e_{kp} L_{ik}(t) + eA_{i} \quad \text{..............................(2)}$$

$TB_{ip}(t)$ : Total amount of pollutant p generated in zone i at time t.

$Y_{i1m}(t)$ : Total production of manufacturing industry m in zone i at time t.

$KW_{ig}(t)$ : Capital stock for treatment type g for manufacturing m in zone i at time t.

$\delta_{gp}$ : Percentage of pollutant p reduced by treatment type g

$\overline{\pi_{mg}}$ :The amount of production from manufacturing m whose wastewater is treated by treatment type g.

$P_{iq}(t)$ : Population of zone i using abatement technique q at time t.

$L_{ij}(t)$ : Area of land used for land use k in zone i at time t.

$e_{mp}, e_{qp}, e_{kp}, e$ : Emission coefficients to rivers of pollutant p for industry m, abatement q, land use k, and livestock respectively.

However, in zone 2 where Damascus City located the domestic wastewater is treated in Adra treatment plant so the total pollution generated from this zone is due to industrial activities and land use:

$$TB_{2p}(t) = \sum_m e_{mp}\left(Y_{2m}(t) - \sum_g \delta_{gp}\overline{\pi_{mg}}KW_{2mg}(t)\right) + \sum_k e_{kp}L_{2k}(t) + eA_2 \quad \text{……………………….(3)}$$

Besides, in zone 5 the treated wastewater of adra plant is used for irrigation so the total pollution generated is, in addition to the contamination generated from socioeconomic activities in that zone, the amount of pollutants carried by treated water, especially heavy metals, as shown in the following equation:

$$TB_{5p}(t) = \sum_m e_{mp}\left(Y_{5m}(t) - \sum_g \delta_{gp}\overline{\pi_{mg}}KW_{5mg}(t)\right) + \sum_q e_{qp}P_{5q}(t) + \sum_k e_{kp}L_{5k}(t) + \lambda_p TB_{2p}(t) + eA_5 \quad \text{……..(4)}$$

$\lambda_p$ : Percentage of untreated amount of pollutant p carried by water after treatment in The Adra Plant.

Land use change

The land use changes due to investment in each industry and demand for residential areas. Changing the land use means changing the amount of contamination generated. The following equation shows the calculation of the changes in area of land:

$$L_{ij}(t+1) = L_{ij}(t) + \Delta L_{ij}(t) \quad \text{……………………………………………….(5)}$$

$\Delta L_{ij}(t)$ : Change in land use k in zone i at time t.

$$\Delta L_i^c(t) = \theta_i^{\,p}\eta_i P_i(t) + \theta_j^i I_{ij}(t) \quad \text{……………………………………………..(6)}$$

$\theta_i^p$ : The per capita demand of residential area in zone i.

$\theta_j^i$ : The demand of investment lot for industry j.

$I_{ij}(t)$ : Investment for industry j in zone i at time t.

*Water balance and water quality*

In order to revive the water of the rivers, the wastewater will be back to the river after treatment.

➢ Barada River:

The following equation calculate the water balance at border of zones carried by Barada River as a basis for calculation the concentration of pollutants at those borders:

$$F_1^B(t) = Q^B + R_1 + W_1(t) - E_1 - DW - Ir_1 \text{.......................................(7)}$$

$$F_2^B(t) = F_1^B(t) + R_2 + W_2(t) + W_3(t) - E_2 - TW - Ir_2 \text{...........................(8)}$$

$$F_5^B(t) = F_2^B(t) + R_5 + W_5(t) + -E_2 + TW - Ir_5 \text{................................(9)}$$

$F_1^B(t), F_2^B(t), F_5^B(t)$ : Flow of The Barada River at the border between zones 1&2, 2&5, and 5&6 respectively.

$Q^B$ : Amount of spring water flows to Barada River.

$R_1, R_2, R_5$ : Annual average rainfall in zones 1,2,5 respectively.

$Ir_1, Ir_2, Ir_5$ : Annual water used for irrigation in zones 1,2,5 respectively.

$E_1, E_2, E_5$ : Annual average evaporation in zones 1,2,5 respectively.

$DW$ : Amount of drinking water pumped from the Figeh Spring to Damascus City.

$TW$ : Amount of treated water in the Adra treatment plant.

$W_1(t), W_2(t), W_3(t), W_5(t)$ : Amount of wastewater flow to Barada River after treatment in zones 1,2,3,5 respectively.

The following equations calculate the water quality for each pollutant discharged to Barada River at the border between zones. The concentration of the pollutants at these points affect the evaluation of the water quality:

$$Wq_{1p}^B(t) = (1-\zeta_1)TB_{1p}(t) / F_1^B(t) \text{..............................................(10)}$$

$$Wq_{2p}^B(t) = (1-\zeta_2)\left\{ \begin{array}{l} (1-\zeta_1)TB_{1p}(t) + TB_{2p}(t) \\ + (1-\zeta_3)TB_{3p}(t) \end{array} \right\} / F_2^B(t) \text{......................(11)}$$

$$Wq_{5p}^B(t) = (1-\zeta_5)\left\{ \begin{array}{l} (1-\zeta_2)\left[ \begin{array}{l} (1-\zeta_1)TB_{1p}(t) + \\ TB_{2p}(t) + (1-\zeta_3)TB_{3p}(t) \end{array} \right] \\ + TB_{5p}(t) \end{array} \right\} / F_5^B(t) \text{..........(12)}$$

$Wq^B_{1p}(t), Wq^B_{2p}(t), Wq^B_{5p}(t)$ Quality of water at the border between zones 1&2, 2&5, and 5&6 respectively.

$\zeta_1, \zeta_2, \zeta_3, \zeta_5$: Natural purification coefficients for the zones 1,2,3,5 respectively.

- Awaj River:

$$F_7^A(t) = (1 - Ir_7)(Q^A + R_7 + W_7(t) - E_7) \quad \text{.............................................(13)}$$

$$F_9^B(t) = (1 - Ir_9)(F_7^A(t) + R_9 + W_9(t) + W_8(t) - E_9) \quad \text{..................................(14)}$$

$F_7^A(t), F_9^A(t)$: Flow of The Awaj River at the border between zones 7&9 and 9&10 respectively.

$Q^A$: Amount of spring water flows to Awaj River.

$R_7, R_9$: Annual average rainfall in zones 7,9 respectively.

$Ir_7, Ir_9$: Annual water used for irrigation in zones 7,9 respectively.

$E_7, E_9$: Annual average evaporation in zones 7,9 respectively.

$W_7(t), W_8(t), W_9(t)$: Amount of wastewater flow to Barada River in zones 7,8,9 respectively.

$$Wq^A_{7p}(t) = (1 - \zeta_7) TB_{7p}(t) / F_7^A(t) \quad \text{..................................................(15)}$$

$$Wq^A_{9p}(t) = (1 - \zeta_9) \begin{Bmatrix} (1 - \zeta_7) TB_{7p}(t) + TB_{9p}(t) \\ + (1 - \zeta_8) TB_{8p}(t) \end{Bmatrix} / F_9^A(t) \quad \text{........................(16)}$$

$Wq^A_{7p}(t), Wq^A_{9p}(t)$ Quality of water at the border between zones 7&9, and 9&10 respectively.

$\zeta_7, \zeta_8, \zeta_9$: Natural purification coefficients for the zones 7,8,9 respectively.

The amount of wastewater

$$W_i(t) = \omega^p P_i(t) + \sum_j \omega_j Y_{ij}(t) \quad \text{..................................................(17)}$$

Population

$$P_i(t) = \sum_q P_{iq}(t) \quad \text{……………………………………………………….(18)}$$

$P_i(t)$: Population in zone i at time t.

The population using a certain abatement type is related to capital stock. The following equation calculates the number of people whose wastewater can be treated by existing capital stock for a certain abatement type.

$$P_{iq}(t) = \pi_q KH_{iq}(t) \quad \text{……………………………………………………...(19)}$$

$\pi_q$ : Population whose wastewater can be treated by one unit of capital stock using abatement q.

$KH_{iq}(t)$: Capital stock for abatement type q in zone i at time t.

The population increase by the time as following

$$P_i(t+1) = (1+\eta_i)P_i(t) \quad \text{…………………………………………………..(20)}$$

*The economic model*

The economical model is based on the following assumptions:

1. An increase in the number of workers in an industry requires an investment in that industry
2. The commuting between the zones is negligibly small.
3. Assumption implies that working population living in zone i must equal to the number of workers employed in zone i
4. The number of workers in any zone is a fixed part of the population in that zone.
5. The production depend on the number of workers

Relation between population and number of workers in each zone:

$$\sum_j N_{ij}(t) = \tau_i P_i(t) \quad \text{……………………………………………………..(21)}$$

$\tau_i$ : Percentage of working population in zone i.

The change in work force by industry and zone should not exceed certain limits:

$$\Psi^l N_{ij}(t) \leq N_{ij}(t+1) \leq \Psi^u N_{ij}(t) \text{ ………………………………………(22)}$$

Due to lack of economic data the production is assumed to be related to the demand for workers. An increase of production requests an increase of labor:

$$N_{ij}(t) \geq \beta_j Y_{ij}(t) \text{ ……………………………………………….….(23)}$$

$\beta_j$ Labor force required per production unit in industry j.

Also the demand of the capital:

$$K_{ij}(t) \geq \alpha_j Y_{ij}(t) \text{ ……………………………………………………..(24)}$$

$\alpha_j$ : The capital required per production unit in industry j

$K_{ij}(t)$: Capital stock of industry j in zone i at time t.

Capital is accumulated by investment in each industry, in each zone at each time period:

$$K_{ij}(t+1) = (1-\sigma_j)K_{ij}(t) + I_{ij}(t) \text{ ………………………(25)}$$

$\sigma_j$ : The depreciation rate.

$I_{ij}(t)$: Investment in zone i, industry j at time t.

Also, the capital accumulates due to investment in abatement technology. Such investments are supported by the local government with subsidies from central government to certain percentage.

$$KH_{iq}(t+1) = (1-\sigma_q)KH_{iq}(t) + \left(\frac{1}{1-\vartheta_q}\right)SH_{iq}(t) \text{ …………………………..(26)}$$

$\sigma_q$ : The depreciation rate for abatement technology q.

$\vartheta_q$ : The rate of subsidy from central government for abatement technology q.

$SH_{iq}(t)$: The subsidy from local government to abatement technology q in zone i at time t.

The same is applied for industrial wastewater treatment. However, the government subsidies to certain percentage for remediation investment regardless the type of abatement.

$$KW_{im}(t) = \sum_{g} KW_{img}(t) \quad \text{.........(27)}$$

$$KW_{im}(t+1) = (1-\sigma_m)KW_{im}(t) + \left(\frac{1}{\vartheta_m}\right)SW_{im}(t) \quad \text{.........(28)}$$

$\sigma_m$ : The depreciation rate for abatement capital in manufacturing industry m.

$\vartheta_m$ : The rate of subsidy from central government for manufacturing industry m.

$SW_{im}(t)$: The subsidy from central government manufacturing industry m in zone i at time t.

*Cooperation among zones*

In order to have sufficient investment in wastewater treatment, a subsidy system between the zones will be introduced based on cooperation among the zones.

This subsidy is a redistribution among the zones:

$$\sum_{i} NNE_i(t) = 0$$

*Tax system*

New tax system is not introduced. Optimal use of existing tax is considered.

*Budget balance*

The expenditure is less than or equal the revenue from taxes.

$$\sum_q SH_{iq}(t) + \sum_m SW_{im}(t) \leq P_i(t)XH + XI\sum_j Y_{ij}(t) + NNE_i(t) \quad \text{.........(29)}$$

$XH$ : Tax rate per capita in zone i.

$XI$ : Tax rate per production.

*Flow of the market*

The gross regional product (GRP) for any zone is the sum of total production (all industries) multiplied by the value added of production in each industry:

$$GRP_i(t) = \sum_j \mu_{ij} Y_{ij}(t) \quad \text{...................................................(30)}$$

$GRP_i(t)$: Gross regional product of zone i at time t.

$\mu_{ij}$ The value added in industry j and zone i.

On the other hand, the gross regional product equal to consumption plus investments and net transfers (subsidies to or borrowing from) to other zones:

$$GRP_i(t) = C_i(t) + \sum_j I_{ij}(t) + \sum_q \left(\frac{1}{1-\vartheta_q}\right) SH_{iq}(t) + \sum_m \frac{1}{\vartheta_m} SW_{im}(t) + NNE_i(t) + NE_i(t) \quad \text{.......................(31)}$$

The net transfer should not exceed a percentage of GRP:

$$-0.2GRP_i(t) \leq NE_i(t) \leq 0.2GRP_i(t) \quad \text{........................................(32)}$$

The consumption is the population of every zone times the consumption per capita:

$$C_i(t) = \varepsilon_i P_i(t) \quad \text{..........................................................(33)}$$

$\varepsilon_i$ : Consumption per capita.

$C_i(t)$ : The consumption in zone i at time t.

*The objective function*

$$MAX = \sum_t \left( \frac{1}{1+\rho} \right)^t \sum_i GRP_i(t)$$

s.t. (1), (10), (11), (12), (15), (16), (17)

**Simulation**

The simulation is being carried out for 10 time periods of one year starting in the year 2000 using a linear programming called Lingo. Unfortunately, the Results have not obtained yet. Hopefully, it will be ready by the time of the conference. As a results of simulation, these points may required

- Running more simulation cases to examine the changes of pollutant concentration on the market flow.
- Modifying of policy measures to meet the standards and objectives.
- Add more abatement techniques.
- Trying to includes policy set related to non-point sources of pollution if possible.

**Conclusion and further development**

This paper is a first stage in developing a new policy regarding the water pollution remediation and water resource management in The Barada Basin, Syria. The research will be extended to analyze the water scarcity in the basin and reviving The Barada River. In the conference a detailed results and conclusion will be provided.

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