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SUSTAINABILITY OF WATER AND SANITATION SYSTEMS

The early recognition of environmental impacts

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IN DEVELOPING COUNTRIES problems concerning water quality have agravated during the last decade. While in industrialized countries the traditional and modern types of water pollution (e.g. domestic, industrial, nutrients) occured in over a 100- year period, in developing countries however they have occured within one generation [WHO, 1989].

Short time technical measures have important immediate effects, but for achieving sustainability it is critical to develop tools for long term planning which allow a better understanding of how different strategies affect outcomes and how strategies are sensitive to different levels and types of financing [Bower, 1989].

In industrialized countries the method of Material Flux Analysis (MFA), has been shown to be a suitable instrument for early recognition of environmental problems and evaluation of environmental measures [Baccini and Brunner, 1991]. It has been shown that it is possible to combine data from market research on one hand with data from urban waste management on the other hand to observe the metabolic dynamics of a region [Baccini et al. 1993]. However, this method has not been applied yet in Developing Countries due to the low data availability and the poor data quality.

The aim of this paper is to show how the method of MFA was applied to a region in a Developing Country with regard to water resource management.

Methods

Characterization of the research region

Tunja is the capital of the county of Boyaca. It is located in the eastern chain of the Andes at an altitude of 2800 m above sea level and has an area of 117 km2. Tunja has 114'000 inhabitants, with 95% living in the urban area. The population growth from 1985 to 1993 was 2.7% / year [DANE, 1994]. The project was carried out together with the local University, UNIBOYACA.

System analysis for water

The system for the waterbalance (74km^2) is defined by the catchment area in the south, east and west and by the political border on the northern part of the municipality. The following processes were chosen to define the water balance in the region:

Water-supply

Supplies *Households, Industry* and *Institutions* of the municipality with water. The water is imported from an external reservoir and extracted from the *Lower Aquifer*. The losses in the supply are about 40%, whereas the illegal consumption is assumed to be 15% [EAAT, 1993]

Soil/upper aquifer:

Includes 1m of *Soil* (pedosphere) where e.g evapotranspiration, interception, CO$_2$ fixation take place and 9m corresponding to the *Upper Aquifer*. The area is divided into sealed, agricultural and unproductive soil.

Household/industry

In this process the water is consumed. The consumption of *Households* is 84%, of *Institutions and Commerce* 13% of the total consumption. In this region *Industry* (3% of total consumption) does not play an important role.

Groundwater, lower aquifer

The *Lower Aquifer* is divided into two main aquifers, which have together a magnitude of 70 to 200m. In the valley they are located at about 200 to 400 m below the surface.

Surface water

The internal surface water is the Rio Chulo

In Fig. 1 the system analysis for the water balance is shown.

Parameter or element choice

The parameters were chosen taking into account three aspects. First, they had to be measurable with the infrastructure available at the UNIBOYACA in Tunja, so that monitoring could be carried on. Second, they had to reflect the human activities taking place in the region. Third, they had to be representative for pollution and nutrients. As only 3% of the water is consumed by *Industry,* it was assumed that the sewage quality was dominated by *Household* sewage. In studies of urban regions in industrialized countries it was shown that the phosphorous (P) content in sewage is originated by feces and washing water, and thus the P-flux can be correlated to the amount of food and detergents consumed [Baccini et al., 1993]. Carbon (C) is a good indicator for organic pollution and can also be correlated with the human activities "to nourish" and "to clean".

Data sources

The data sources can be divided into measured data and calculated or estimated data. The measured data are marked in Fig. 1 with (*****). On one hand they were taken from regional or national statistics. On the other hand during two months (1 month dry and 1 month wet

Fig. 1: System analysis of the region.
The systemborder is the catchment area,*: measured data

season) measurements of the water flux were carried out at the surface water before entering and before leaving the system and at the external surface water.

The dilution capacity of the surface water for sewage (carrying capacity) can be determined in two ways. First it is given as the rate of sewage to exported surface water. Second it is the rate of the concentration of the indicator element in the sewage and the concentration of the indicator element in the surface water leaving the region. P as dissolved orthophosphate (40% of the total P, [Boller, 1994]) and C as Chemical Oxygen Demand (conversion factor COD to TOC of 3:1 [Boller, 1994]) were measured at the marked points including spot checks of sewage and water used for irrigation.

A plausibility control of the element fluxes (water flux * concentration) was made calculating the fluxes from the input side into *Household*. With a survey the amount of food and detergents consumed were measured. The element fluxes were calculated as good amount *concentration. Both element fluxes were compared.

Results

Fig. 2 shows the water balance for the study area for the year 1993. The error margin of the fluxes is about 20%.

The largest fluxes in the system are precipitation (*Atmosphere* to *Soil/Upper Aquifer)* and evapotranspiration (*Soil/Upper Aquifer* to *Atmosphere*) consisting of the evaporation from the precipitation and the evapotranspiration from irrigation of plants. The total evapotranspiration is more than 90% of the precipitation. Thus the netto input from *Atmosphere* is 2 mio m3 / year.

The second important input flux is the import of drinking water from an external reservoir to *Water-Supply*. It makes 85% of the total flux into *Water-Supply*. The other 15% of the water are extracted from *Lower Aquifer*. The total amount of water entering *Water-Supply* is about 70% of the water amount leaving the region in form of surface water. Only a small proportion of 15% of the *Surface Water* leaving the region is originating from surface water entering the region (*External Surface Water)*.

The infiltration rate into *Lower Aquifer* is about 2 mio m^3 / year and lies in the same order of magnitude as the extraction rate. A doubeling of the amount of water extracted could already lead to an overexploitation of the groundwater. Due to the geological conditions of the region no significant sewage infiltration due to leaking sewage sytems into *Lower Aquifer* is expected [Alarcon, Suarez, 1991].

In the urban area about 6 mio m^3 / year are consumed, which correponds to 160 l / cap.year. The supply losses are 4 mio m^3 / year. 87% of the consumed water is transported to *Surface Water* without any treatment and makes about 30% of the total output flux. That means that the carrying capacity of the region is about 3. The measured P and COD concentrations in sewage were 15 ± 4 mgP / l and 420 ± 60 mg COD / l. The concentrations found in the surface water were 6.5 ± 0.5 mgP / l and 230 ± 30 mgCOD / l, thus leading to a dilution factor of 2 to 3 [Calixto R., Valcarcel V., 1994], [Rios O., Tovar D., 1994]. The high variation of more than 20% for the sewage data are due to the high daily fluctuations in concentration and the low amount of samples taken. Nevertheless the dilution factors calculated out of both data series are in good agreement. The concentrations of P and C in the surface water before leaving the urban area are 100 and 40 fold respectively higher than the concentration in the surface water before entering the region.

In Table 1 the element fluxes calculated from the measured data in the environment and the element fluxes calculated from the measured data are shown. The results are in good agreement. This finding verifies that even with poor data availability and quality it is possible to establish an element flux, knowing the main sources of origin of this element and crosschecking it with spot measurements [see also Baccini et. al, 1993].

Table 1: Comparison calculated P and C fluxes from measurements in surface water and measured inputs .

Discussion

The MFA is used to analyse two possible scenarios in water resource management. The first scenario is an installation of a complete sewer system according to swiss standards, the second an on site sewage treatment for example the installation of septic tancs. Using Figure 2 the changes in the system will be shown.

Scenario 1: Installation of a complete sewer system

The installation of a complete sewer system would lead to less losses of sewage and to an increase of the flux sewage to surface water. Therefore, the water flux of the surface

Fig.2: Water balance of the region in mio m^3/year (for fluxes) and mio m^3 (for stocks)

water will increase with growing population and water consumption per capita, thus doubling onto the year 2020 assuming a population growth rate of 2.7% and no augmentation in water consumption per capita. This means that the dilution capacity of the region will be reduced to 1.5. The installation of a sewage treatment plant would reduce the P and C-flux to the surface water at about 80%-95% [Boller, 1994]. The concentrations of P and C in the surface water would be reduced compared to the situation today but will still be about 20 times higher (P) and 3 times higher (C) than the concentrations in the surface water before entering the region.

Scenario 2: On site treatment of sewage and disposal (septic tanks)

In this scenario the direct sewage flux to surface water will be zero. The water will infiltrate into *Soil/Upper Aquifer* from where it later evapotranspirates to *Atmosphere*, is exported by the *Upper Aquifer*, infiltrates to *Lower Aquifer* or exfiltrates to *Surface Water*. The amount of evapotranspiration is dependant specially on the vegetation around the soaking pits. It is assumed, that it is about 25% of the infiltrating water. The amount of water exported by the *Upper Aquifer* or infiltrating to the *Lower Aquifer* is estimated to be 25%. This, however has to be verified. Thus, the amount of exfiltrating water will be about 50% of the sewage water. The quality of the water in the *Upper Aquifer* will decrease and not be suitable for drinking water. The quality of surface water will be determined by the quality of the exfiltrating water which depends on the water quality infiltrating from the septic tank and the capacity of the soil to adsorb (P) or degrade (C) pollutants. If it is assumed that 30-40% of the pollutants are degraded in the septic tank, 90% of the rest is adsorbed in the soil, and a part is exported by the *Upper Aquifer*, the proportion of pollutants exfiltrating to *Surface Water* will be about 5% of the original load. Thus, the concentrations of P and C in the surface water leaving the region will be 10 times higher (P) and about double (C) than the concentrations in the surface water before entering the region, being in the same order of magnitude as the concentrations found in scenario 1.

Conclusions

Even with low data availability and poor data quality the MFA can be applied as an instrument for early recognition of environmental problems. Thus future environmental consequences of planned activities can be early recognized, giving the possibility of avoiding resource depletion and evaluate environmental measures for improvement of water quality.

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