Modelling the fate and transport of organic micropollutants and phosphates in the Simiyu River and Speke gulf (Lake Victoria), Tanzania

Justus Rwetbula

Abstract

Lake Victoria is the largest freshwater lake in Africa, and one of the major sub-basins within the Nile basin sharing its resources with Tanzania, Kenya and Uganda. The water quality of Lake Victoria has been declining due to point and non-point pollution sources from domestic, industrial and agricultural activities. Pollution from agricultural activities is mainly fertilizers and pesticides. The main processes affecting the fate of pollutants in runoff are water discharge, erosion and sediment transport, and chemical, biological and biochemical interactions within the soil-plant-water system. To avoid environmental problems, the riparian countries established the Lake Victoria Environmental Management Project (LVEMP), a World Bank funded project, which became operational in 1997, aiming at the rehabilitation of the degraded lake ecosystem. Many efforts have been made investigating contaminants contributing to the deterioration of the lake water quality. None of these has quantified the impact of agriculture as the application of agrochemicals leading to contaminant loads of phosphorous and pesticides generated from river catchments that discharge in Lake Victoria. In Tanzania there are many Tanzanian rivers polluting Lake Victoria. The Simiyu catchment, located in the southeast of Lake Victoria, is considered to be one of the main contributors to the deterioration of Lake Victoria, because it is relatively large (10,800 km^2), with many agricultural activities, using agrochemicals and generating high yields of sediments. The catchment is generally flat, dominated by wasteland, bushland, grassland and cultivated landuse types, and sandy loam soil type. Chemicals are mainly transported by surface runoff in dissolved or particulate form. Hence, proper water quality management cannot be initiated without a clear understanding of the hydrological processes in the Simiyu river basin. Therefore, models capable of predicting flow and water quality are needed to study the hydrologic behaviour of the catchment and to predict effects of land use and waste management for decision making. Currently simulation models linked with GIS prove to be more useful in predicting runoff, and sediment and nutrient/chemical transport from agricultural watersheds. However, these require extensive and detailed input data that cannot be easily measured or obtained due to limited resources. The main objective of this Ph.D. thesis is to develop and apply a physically-based, distributed watershed model for prediction of river discharge/runoff and contaminant (phosphorous and pesticides) transport in the Simiyu catchment, Tanzania.

To carry out this study, it was necessary to obtain baseline data to what extent the Simiyu river contaminants are entering Lake Victoria. Field measurement campaigns, inclusive ground truthing for satellite images were carried out between 2001 and 2004 in the Simiyu catchment and Speke gulf (Lake Victoria). Respectively twelve and eight monitoring stations were established in the Simiyu river and Speke gulf. Activities involved, measurements of discharge in the Simiyu river and of currents in the Speke gulf, water and sediment sampling in the Simiyu river and Speke gulf, and analysis of water quality parameters as phosphorous, pesticides, organic carbon, suspended and bottom sediments, etc. In addition, meteorological data (i.e. precipitation, evapotranspiration, etc.) was collected, and DEM, landuse and soil maps were

developed from satellite images, field investigation and information from literature. These data together with the field work were used for model calibration. The average discharge in the Simiyu river is about 30 m^3/s during the rainy season. Five sampling campaigns were carried out in the Simiyu river and Speke gulf. In the water samples observed total phosphorous concentrations were on average about 1000 mg/m^3 in the Simiyu river, and about 770 mg/m^3 in the Speke gulf. Three organochlorine pesticides, DDT, HCH and Endosulfan, were frequently detected in the water samples. In the Simiyu river total concentrations were in order of 10000 $\mu g/m^3$ for DDT, HCH, and Endosulfan, and in the Speke gulf 1000 $\mu g/m^3$ for DDT, and 10000 $\mu g/m^3$ for HCH and Endosulfan. Organophosphate pesticide, pyrethroids, etc. were either less frequently or not detected probably because there are less used and also degrade faster than organochlorines. Generally, higher concentrations appeared during high river flows, suggesting contaminant loads are released from agricultural fields during rain events.

A grid-based distributed hydrologic model WetSpa, developed at the Department of hydrology and hydraulic Engineering of VUB is applied to fulfil the proposed objectives. The hydrologic processes considered in the model include precipitation, interception, depression, surface runoff, infiltration, evapotranspiration, percolation, interflow, and groundwater flow. The model combines topography, landuse and soil maps in raster format, and meteorological data, and predicts discharge and contaminant hydrographs and spatial distribution of hydrologic characteristics in the catchment. Contaminant loading is estimated as a function of the runoff and contaminant release rates for different landuse types. A diffusive approximation method is used to trace runoff and contaminant transport to the basin outlet.

The model is evaluated based on three year data (2001-2004) of daily river discharge and measured contaminant (phosphorous and pesticides) concentrations and loads at the catchment outlet of Simiyu river. Satisfactory results are obtained. The estimated annual flow and total phosphorous load are about $500x10^6$ m^3 and $709x10^3$ kg. The estimated annual total pesticide load is 3600 kg, mainly dominated by HCH (1800 kg), Endosulfan (1500 kg) and DDT (300 kg) pesticide chemicals originating from agricultural fields. The contaminants mainly occur during the rainy season and are subsequently deposited to Lake Victoria. Applied phosphorous release rates are 2.3 g/m^3 for cultivated land, 1.3 g/m^3 for wasteland, grassland, and bushland, and pesticides from agricultural fields over 5 mg/m^3. Although encouraging results are obtained, there is a need of establishing more sustainable climatological stations, and continuous river discharge and contaminant concentration observations, so that more accurate predictions can be obtained.