Assessment of heavy metals transport in Harrach River watershed, Algeria, by using distributed hydrological model with object–oriented design

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1. INTRODUCTION

In recent years there has been a marked increase in the development and application of numerical models to predict rivers water quality characteristics. One of the main reasons for this increase is that numerical models offer a powerful tool for investigating the complex interactions between estuary morphology, sediment fluxes and water quality [1]. The evolution of these prediction tools now creates much more opportunities for operational and economic optimization than were available a generation ago. Computer systems and software are less expensive, more accessible, and easier to use than ever before. At the same time, increased accessibility creates more opportunity for misapplication under field conditions. More effectively, water quality prediction models must be used in ways appropriate to the task at hand; they require the expertise of knowledgeable technical specialists and reliable input data. Water quality prediction can be expensive and potentially inconclusive if not approached in a systematic manner [2].

In recent years, the quality of water in the world has experienced a deterioration because of uncontrolled industrial discharges, heavy metals pollution occurs in much industrial wastewater such as that produced by metal plating facilities, mining operations, battery manufacturing processes, the production of paints and pigments, and the ceramic and glass industries. The transport processes of heavy metals are an important existing problems in the riverine waters. The prediction of these processes may carried out by using numerically model.

The distributed hydrological model can reproduce different flows simultaneously, surface water flow, river flow, infiltration layer flow and groundwater flow. The most significant feature of the Distributed Hydrological Model is that it can model the all flow regimes based on physics, which suggests that this model may be a useful tool to predict concentrations of pollutants in rivers accurately.

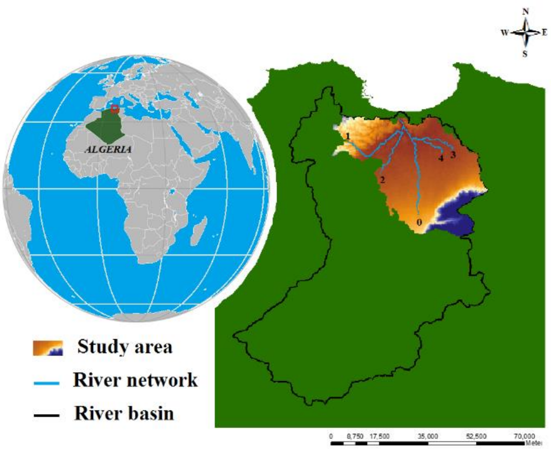
In this study, distributed hydraulic model with object-oriented design has been extended and improved to predict lead (Pb) and mercury (Hg) concentrations transport and fate in Harrach valley in Algeria. Where, we make use of numerical model GeoCIRC (Geophysical flow Circulation model) developed by Nakayama et al. (2015)[3].

Hydraulic momentum transport were reproduced by distributed hydrological model with object-oriented design. Transport of dissolved heavy metal, such as mercury and lead, were modeled as one of instances of transportable object. Total heavy metal including accumulated component were also estimated by partition model in the assumption of equilibrium state. Moreover, to assess the effect of point source load reduction from factories as a countermeasure to contamination another simulation was conducted where it being assumed that each heavy metal concentration in waste water from factory were reduced less than the values were determined from general regulation in waste water qualities.

2. METHODS

2.1 Study area description

Harrach River, located in semi-arid area in Algeria, has provided important water resources in Alger, capital city of Algeria. The watershed of this valley covers an area of 1236.28 km^2 with an extent of 51 km from north to south and 31 km from east to west. This valley has been severely polluted by many industries with heavy metals .High Heavy metals concentration has been observed in Harrach valley, which suggests that this river basin is suited to our investigation purposes [4] (Fig.1).



Figs. 1 Study area location.

2.2 Field observations and data preparation

The modeling was carried out for a particular observed Pb and Hg concentration data of wastewater discharged from factories at different points along Harrach valley (Table.1). This data has got from the analysis results carried by the cooperation team JICA/ONEDD (JICA: Japanese International Cooperation Agency/ ONEDD: Observatoire National de l’Environnement et de Developpement Durable) [4].

2.3 Hydrological model

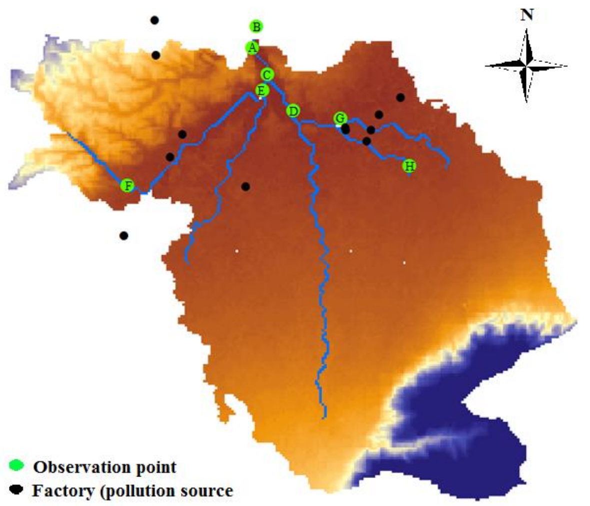
The numerical model GeoCIRC (Geophysical flow Circulation model) developed by Nakayama et al. (2015)[3]. In this study, this model has been extended and improved to predict the Pb and Hg concentrations transport and fate in Harrach valley in Algeria. The detailed description of the model is available in Nakayama K. et al. (2000) [5].

Table 1 Mercury and lead concentration in wastewater rejected in Harrach valley from factories [4].

Factories	Discharge m³/day	Hg mg/L	Pb mg/L
SOACHLORE	390	51860	/
Tannery SEMMACHE	30	11	2.2
AGENOR	3000	17	/
EMB	320	21	2.4
Raffinerie d'Alger	7	18	0.51
BAG	100	/	0.6
ENPEC	150	/	244
GARNITEX	1.5	/	1.7
EDENAL	/	/	3.4
EPE CATEL SPA	12	/	0.94
Hydrotraitement	/	/	22

Table 2 Mercury and lead concentration in observation point in study area [4].

	Hg		Pb	
	water (μg/l)	sediment (μg/l)	water (mg/l)	sediment (mg/l)
A	26.2	598	0.37	0.512
B	2.9	6.8	0.73	0.4
C	6.19	613	1	0.224
D	6.71	6	0.53	0.34
E	2.9	378.4	0.89	0.598
F	4.76	1124.8	0.8	0.346
G	2.49	298	/	/
H	314	3624	0.6	/



Figs. 2 Observation point and pollution point location in study area.

2.4 Heavy Metal Transport Model

The model for heavy metal transport has been using an advection-dispersion equation. The transport of total heavy can be derived by the summing of dissolved and absorbed particulate heavy metal equations as following [6), 7)]:

$$\frac{\partial C_T A}{\partial t} + \frac{\partial C_T Q}{\partial x} - \frac{\partial}{\partial x}\left[AD_{tx}\frac{\partial C_T}{\partial x}\right] = A(A_a + A_{SPa}) \quad (1)$$

Where C = concentration of heavy metals dissolved in water column, Q = discharge, A = wetted cross-sectional area, A_a = source or sink of dissolved heavy metal, SP = concentration of heavy metals in sediment, A_{SPa} = source or sink of absorbed particulate heavy metal, D_{tx} = diffusion coefficient.

More details about the sources and sink terms is available in Kashefipour S. M. and Roshanfekr, A, (2012) and Roshanfekr, A., et al. (2008) [8), 9)].

The distribution of metal between dissolved and particulate phase can be described by partition coefficient K_d:

$$K_d = \frac{SP}{C} \quad (2)$$

where SP = concentration of heavy metals in sediment and C = concentration of heavy metals dissolved in water column.

2.5 Model setup

Surface elevation data were required for the model preparation. River network is calculated from DEM data which were downloaded from USGS website. Hydrologic information, such as watershed boundaries and river networks, were extracted from a DEM. The steps for watershed delineation and ArcGIS operation are referred to ArcGIS Desktop Help website.

In calculation, we placed a virtual inflow point in river 1 as a boundary condition instead of river discharge from the upperstream catchment by considering the catchment area. That is, 100,000 m3/day which was determined from the magnitude of the same order as the average river discharge (at downstream end) multiplied by the area ratio of upperstream catchment to the whole of the catchment were given as a virtual inflow at the river connection point of river 1, at the most-meandering point. The discharge data at point source loads from the area near the river 0 and 3 were assumed as 10,000 and 100 m^3/day at river 0 and 3 in order to represent river discharge at the downstream end of river 0.

Partition coefficients of Pb and Hg concentrations due to interaction between stream water and sediment were assumed by the equation (2) as K_{dPb}=325 (L/kg) and K_{dHg}=10,000 (L/kg), respectively. This scenario included partitioning of these two metals with no parameters dependence and the simulation concentrations were verified by observed data conducted in the study area (Table.2).

Another simulation was conducted to assess the effect of point source load reduction from factories as a countermeasure to contamination. In the case, heavy metal concentrations in waste water from factory were reduced less than 0.5 mg/L in Pb and 0.01 mg/L in Hg, respectively (these values were determined from general regulation in waste water qualities in Algeria [4)]).

3. RESULTS AND DISCUSSION

Fig. 3 shows the concentration transport of Pb and Hg in each river.

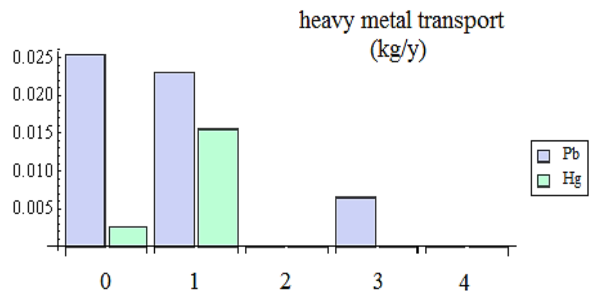


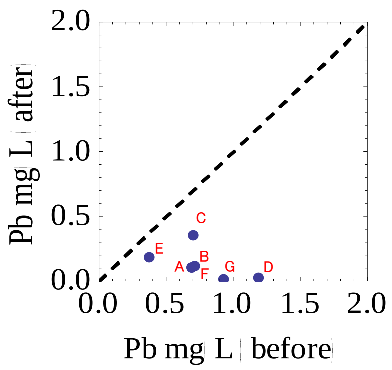
Fig. 3 Pb and Hg concentration transport.

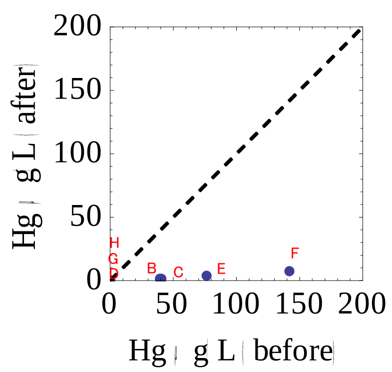
According to the verification, the simulation results were well represented especially in rivers 0, 1 and 3 for Pb, in contrast, the simulation results in rivers 1 and 0 were well represented for Hg.

Since The industrialized area in the catchment of rivers 1 and 3 where are many factories are located with high Pb concentration, point source loads from these areas were assumed to contaminate significantly in Pb in river 1 and 3 and the downstream of river 0 compared with others rivers. About the Hg, the factory “SOACHLORE” has a quite large point source load which it may have an impact in simulation result in river 1.

Heavy metal transport in Harrach River basin could be numerically simulated by using distributed hydrological model. Hydrological model with object-oriented design was verified as a powerful tool for Pb and Hg contamination to improve applicability efficiently because of its flexibility of handling many transportable materials. That is, the column object which constitutes calculation domain were incorporated in the object-oriented design model in order to govern vertical transport of physical quantities, and the connection object which controls horizontal transport of physical quantities between column objects [3]. Therefore, various transportable quantities including target chemical substances discharged in watershed can be arbitrarily instantiated in these objects more efficiently than conventional model.

The **Figs. 4** show the comparison in Pb and Hg in stream water before/after countermeasure of source load reduction. For Pb concentration in point G and D could be effectively improved. In contrast, Pb derived from contaminated area with large volume of stream water still remained in the other points. As similarly, the reduction of Hg source could be improved in the downstream reach of Harrach River basin.





Figs. 4 Comparison in Pb and Hg in stream water before/after countermeasure of source load reduction. Observed point were shown in **Table.2.**

4. CONCLUSIONS

In order to assess the heavy metals concentration transport and the effect of the countermeasure of point source loads reduction in Harrach River, a distributed hydrological model with objects oriented design was applied to estimate Pb and Hg concentration and river discharge in this river.

Hydrological model with object-oriented design was verified as a powerful tool for heavy metals contamination to improve applicability efficiently because of its flexibility of handling many transportable materials. The applicability of the model can be improved by combining of various heavy metal even with less dataset.

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