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Implementation of Hydrological Dispersion Module of JRODOS for the assessment of ^{137}Cs transport and fate in rivers, reservoirs and ponds of the Fukushima Prefecture

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Abstract – The Hydrological Dispersion Module of JRODOS was implemented for the predictions of the long term dynamics of radiocesium in the rivers and ponds of the Fukushima Prefecture and for the forecasting of radiocesium dynamics in the reservoirs under the influences of the extreme flush floods generated by the typhoons. The possibilities of HDM for the assessment of the efficiency of the potential remediation measures for the diminishing water contamination were tested for several water systems.

Keywords: radionuclide / dispersion in surface waters / model / Fukushima accident / JRODOS

1 Introduction

As one of the tasks of the EC PREPARE project of the Hydrological Dispersion Module (HDM) of the decision support system – JRODOS (Zheleznyak *et al.*, 2010, 2016; Gallego *et al.*, 2016; Maderich *et al.*, 2016) was planned to be implemented and tested for the simulation of the radionuclide transport in the water bodies of the region of Japan contaminated by the atmospheric fallout from the Fukushima-Daiichi Nuclear Power Plant (FDNPP).

2 Contaminated water systems at Fukushima-Daiichi NPP

The Institute of Environmental Radioactivity (IER) at Fukushima University was established in July 2013. One of the key directions of IER researches is monitoring and laboratory investigation of radionuclide dynamics in biotic and abiotic components of the rivers, reservoirs, lakes and the near-shore ocean. IER has started to participate in the PREPARE project at the end of 2014.

The contaminated territory of Fukushima Prefecture is characterized by an expansive hydrographic network, dominated by the largest river of the area – Abukuma, Mano, Niida (Nitta), Mizunashi, and Ukedo (Figure 1). All these rivers transport radiocesium to the Pacific Ocean. The river catchments contaminated after the FDNPP accident became a long-term source of secondary contamination of water

bodies. The contaminated sediments are involved into the sedimentation processes in the reservoirs that reduces the fluxes of radiocesium from the heavily contaminated exclusion zone to the populated areas (Figure 1). The modeling of the fate of ^{137}Cs in these river-reservoir systems are needed for the risk assessment of the short-term extreme events (floods, dam breaks) as also for the long term forecasting. Other important water bodies in this region are the numerous small ponds which are widely used for the irrigation purpose at the coastal zone.

The monitoring and laboratory studies provided by IER (Konoplev *et al.*, 2016) have demonstrated that the radiocesium transport in the water systems of the Fukushima prefecture in comparison with the well studied water systems of the Chernobyl region is characterized by the higher role of the sediments in the transportation of the contamination by water flow. It is a consequence of the mountain kind of the Fukushima rivers, the types of the soils and the intensive soil erosion under the impacts of the heavy typhoon rainstorms. The implementation of JRODOS HDM was provided on the basis of the results of these experimental studies.

3 Modelling of flood generated radiocesium transport

The comparative modeling of the ^{137}Cs dynamics in the water and in the upper bottom layer of the reservoirs was provided by two models of RODOS HDM to assess the impacts the previous

Figure 1. Density (Bq/m^2) of ^{137}Cs fallout at the FDNPP (data from <http://ramap.jmc.or.jp>) and the locations of IER monitoring sites (red dots) (left). The main rivers of the area and the river reservoirs (pink arrows) on the GoogleMaps map (right).

extreme hydro-meteorological conditions—typhoon generated high flood on the radionuclide transport in these water bodies and for the forecasting of the consequences of the potential future extreme floods. New version of the two dimensional model COASTOX of JRODOS HDM (Zheleznyak *et al.*, 2016) was customized for the reservoirs at Mano Dam-Mano River, at Yokokawa Dam-Ota River, and at Takanokura Dam-Mizunashi River. Three-dimensional model THREETOX of JRODOS HDM (Maderich *et al.*, 2016) was implemented for Yokokawa and Takanokura reservoirs. These reservoirs located in the mountain part of the river watersheds are rather deep (maximum depth up to 30–50 m). There are used as water storage for the agricultural, municipal and industrial needs of the downstream populated plane regions.

The simulations of the typhoon generated flood of November 2011 in all reservoirs by both models demonstrates propagation of the most contaminated bottom sediments from the shallow “near river mouth” areas of the reservoirs to the deeper areas in the central part of the reservoirs and near dams during the high speed currents period of the flush floods. Such process (Figure 2) will be repeated during each flood providing the relocation of the most contaminated sediments to the deepest parts of the reservoir (Figure 2). All these deep reservoirs have vertical temperature stratification and the difference in the magnitude and direction of flow velocities at the deepest parts of the reservoir (Figure 2). Therefore the bottom sediments in the shallow coastal areas of the reservoir

can be contaminated quicker by the inflowing contaminated water during the floods than deepest areas in which near bottom velocities are very small. This process can be simulated only by 3D model.

4 Modeling of long term radiocesium transport

MOIRA-RIVER model integrated in JRODOS HDM (Gallego *et al.*, 2016) has been customized for the Niida River watershed. The watershed was divided into 20 strips. For the left and right sides of each strip regarding the river channel (40 boxes) the characteristics of the watersheds surface, fallout density and the water flow were averaged as input data. The simulated by MOIRA_RIVER results present (Figure 3) the long-term dynamics of ^{137}Cs in river water, suspended sediments and the fishes. The model can be used after the further calibration for the assessments of the efficiency of the remediation activities on the watershed by the diminishing of the deposition density in some of the watershed “boxes”.

MOIRA-LAKE JRODOS model was customized for the small irrigation ponds at the Okuma town at the FDNPP. The model will be used for the forecasting of water, sediment and fish contamination in the ponds and for the assessment of the impacts of potential removal of the contaminated sediments in the ponds on the water purification.

Figure 2. Hydrothermodynamics of Takanokura Reservoir simulated by 3D model THREEETOX: (a) velocity at near dam area at water surface, (b) velocity near bottom, (c) the vertical profile of the water temperature along the reservoir). Dynamics and ^{137}Cs density in the bottom calculated by 2D COASTOX model for the 4th day (d) and 6th day (e) of the high flood of November 2011.

Figure 3. JRODOS MOIRA_RIVER interface demonstrating the computed temporal dynamics of ^{137}Cs on suspended sediments in 20 Niida river strips in period 01.2011–01.2016.

5 Conclusions

The Hydrological Dispersion Module of JRODOS extended within EC PREPARE Project is implemented for the water systems of the Fukushima Prefecture. The initial model testing confirms that that HDM JRODOS can be used as a tool for further predictions of the long term dynamics of ^{137}Cs in the rivers, reservoirs and ponds of the Fukushima Prefecture and for the forecasting of ^{137}Cs short term dynamics

under the influences of the extreme flush floods generated by the typhoons. It is shown that HDM can be used as a tool for the assessment of the efficiency of the remediation measures that are planning in the Fukushima Prefecture to diminish the contamination of the water bodies.

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