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Simulation of pollutant dispersion of a free surface flow in coastal water

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ABSTRACT

This paper numerically investigates the effect of point source pollution discharged from intentional release flowing into waters. The consequences of such contamination on ecosystems are very serious. Accordingly, effective tools are highly demanded in this respect, which enable us to come across an accurate progress of pollutant and anticipate different measures to be applied in order to limit the degradation of the environmental surrounding. In this context, we present a predictive hydrodynamic model using ANSYS Fluent software in order to explore the dispersion phenomenon of pollutant injected at a free surface. The idea was developing a numerical study aimed at tracking the dispersion of pollutant rejected by an industrial waste in a portion of sewer system and then in seawater, taking into account the influence of climatic parameters on the spread of pollutant. Numerical results agree well with the experimental data, and showed that pollutant dispersion is mainly influenced by the presence of vortices and turbulence. Hence, it was observed that the pollution spread in coastal water is strongly correlated with climatic conditions in this region.

1. Introduction

Ocean engineers have always been interested in coastal structures and their impacts on environment.

The direct reject of wastewater is one of the major factors of coastal and marine environment degradation, because it is discharged directly into sea with a high concentration of pollutants. Thus, if this discharge is not controlled, the effluent may return to the coastal regions without being sufficiently diluted; so it can contaminate areas for farming, fishing grounds or beaches.

The fresh and oceanic waters have become the receivers of different pollutants (chemical, organic, radioactive or microbiological) of various origins (urban, industrial or agricultural).

In this context, several studies that simulate pollutants in rivers and coastal areas are still based on two-dimensional (2D) models (Ani et al., 2009; Blaise et al., 2010; Chen et al., 2009; Cristea, 2013; De Brye, 2007; De Brye et al., 2011). An example is a study of De Brye (2007), he used the SLIM model to establish the boundary condition of the Scheldt model in the coastal region of Belgian. He used a two-dimensional model with the finite element method to describe the evolution of water depth as well as the velocity averaged along the vertical. Such studies using the finite difference method were the object of many hydrodynamics models (De Brauwere et al., 2011, 2014; Gourgue et al., 2013; Lee and Seo, 2007; Sassi et al., 2011; Vaz et al., 2007).

Vaz et al. (2007) developed a hydrodynamic study problem for the Ria de Aveiro coastal region using "MOHID" software. It was observed that tides are distorted, as they progress from the beginning to the end of the channel. It was also noted that the general characteristics of the wave are those of a damped progressive wave which presents a decrease of the tidal amplitude, and then an increase of the phase lag due to the effect of bottom friction. De Brauwere et al. (2011) developed a new model (SLIM-EC) to assess the importance of tides, river discharge, point sources and upstream concentrations. It was observed that the impact of the waste water treatment plants (WWTPs) inside the model domain is minor. It was suggested that investment in WWTPs may not be the most efficient management action, to improve the water quality in terms of fecal contamination.

Although the 2D models can satisfy the analysis of environmental pollutants, they have several limits such as the lack of ability

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Nomenclature

L	channel length, (m)
H	channel height, (m)
l	channel width, (m)
h	height of water in the channel, (m)
E_{sill}	sill thickness, (m)
H_{sill}	sill height, (m)
L_{sewer}	length of the sewer outfall, (m)
H_{sewer}	height of the sewer outfall, (m)
x_i, y_i, z_i	cartesian coordinates, (m)
t	time, (s)
U, V, W	velocity component along x, y and z directions, (m/s)
$CaSO_4$	calcium sulfate (industrial pollutant)
S_0	solubility of pollutant in water, (kg/l)
g	gravitational acceleration, (m/s^2)
p	pressure, (Pa)
A	area of the sewer outfall, (m^2)
P	perimeter of the sewer outfall, (m)
C	concentration of the pollutant, (kg/l)
D	molecular diffusivity, (m^2/s)
D_H	hydraulic diameter, (m)
Re_H	Reynolds number
I	turbulence intensity, (%)
k	kinetic energy of turbulence, (m^2/s^2)
S_i	surface tension
ν_i	volume of phase i
P_k	producing turbulence

Greek symbols

ρ	density, (kg/m^3)
μ	dynamic viscosity, (kg/m s)
υ	kinematic viscosity, (m^2/s)
υ_t	turbulent viscosity, (m^2/s)
ε	dissipation rate of turbulent kinetic energy, (m^2/s^3)
τ_{ij}	viscous stress tensor, (kg/m s^2)
α_i	volume fraction of phase i

to analyze the vertical variations of pollutants concentrations that can affect the accuracy of the results. Thus, a three-dimensional (3D) model of pollutants dispersion coupled with hydrodynamic modeling could overcome these drawbacks. The 3D models for pollutants dispersion in free surface flows (rivers, streams, seawater, etc.) have been recently investigated to provide information about water quality and possible ways to improve it (Alvarez-V´azquez et al., 2001, 2006; Bottacin-Busolin et al., 2011; Buil, 1999; Jin et al., 2010; Khaldi et al., 2014, 2015; Schaffner et al., 2009).

For example, Buil (1999) used 3D modeling using CFX software to predict the transport and the fate of a pollutant in the natural environment. The code was validated experimentally using the water height measurements in a rectangular channel. However, the pollutant concentrations obtained by simulation in different flow sections have not been compared with experimental data. Khaldi et al. (2014) used Fluent 6.3 to study the impact of pulsation on the dissolved pollutant dispersion in a free surface flow. It was observed that the distribution of the injected waste material was affected by the pulsation, and that an important swirling action was produced compared to the constant rate injection case. Alvarez-V´azquez et al. (2006) collected and extrapolated data about water pollution at selected points along the river to examine the characteristics of pollutant distribution. A mathematical formulation and an efficient algorithm were given to solve this problem. They studied water height, velocity and concentration distribution along the river at different times. The results have shown that a sampling point of wastewater discharge is not enough, they should subdivide it into two new zones to achieve more accurate results in that river section. Schaffner et al. (2009) developed an MFA model to identify an overview of the nutrient flows from different pollution sources to the Thachin River Basin. They described the state of the system very accurately and they allowed data variability to be detected as a

Fig. 1. Map of Tunisia indicting the location of the sewage disposal in Monastir city.