APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS TO EVALUATION A CONCENTRATION OF CHLORINE RELEASED INTO AN ATMOSPHERE IN THE CASE OF ROAD ACCIDENT

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Abstract: *Modelling propagation of hazardous substances released in road accidents is important issue from the point of view of safety in road transport. The paper presents use of the Geographic Information Systems to analyse the impact of the emissions of hazardous compounds in the built-up area. In the paper dispersion of pollutants released in a road accident, involving a chlorine tanker truck, followed by chlorine spillage has been analysed. It is assumed that the accident took place in a mountainous area on a bypass within a built-up area. Concentrations of pollutant have been calculated in the own program. The calculation of field of wind speed was taking into account the terrain elevation and type of land cover. The package Idrisi Taiga has been applied in the pre-processing stage. It was used to generate a site map with buildings and aerodynamic roughness map. Meteorological conditions were also taken into account: wind speed and direction, temperature, atmospheric pressure and atmospheric stability class. The computer program consist two basic modules: diagnostic model of air velocity field and Lagrangian model of particles, being the original implementation of the Lagrange model of particles. In both models, some elements of mathematical modelling were applied. The models have been successfully validated and verified. The results of the calculations of concentrations of chlorine have been analysed in the Geographic Information System. The following analyses have been made, among others: designation of hazardous zones AEGL 1-3, determination spatial size of built-up areas within the zone, analysis of changes in pollution concentrations over time. The proposed analyses allows to determine areas exposed to deadly and highly dangerous concentration of chlorine.*

Keywords: COMPUTER MODELLING, ROAD SAFETY, ROAD TRANSPORT, POLLUTION DISPERSION, HAZARD MATERIALS, GIS ANALYSIS

1. Introduction

Modelling the propagation of hazardous substances released as a result of a road accident is an important element in the assessment of hazards resulting from the use of transport means to transport chemical substances. Determining the probable effects of a tanker collision that results in leakage into the air is possible due to the use of computer programs such as ALOCHA or HPAC, but they do not take into account many elements, such as the complexity of the topography of the terrain. These elements can be taken into account thanks to the use of proprietary computer models and programs.

Computer simulations for the case analyzed in this paper regarding a sudden road accident with the participation of a chlorine tanker were carried out in proprietary programs based on the diagnostic model of the air velocity field and the Lagrange model of particles. In both models, elements of mathematical modelling were applied. These models were validated and verified (Brzozowska, 2013; Brzozowska, 2014a).

An analysis of the spread of pollutants as a result of a road accident involving a tank carrying chlorine is presented, accompanied by a leak of substance into the air. The occurrence was simulated in the city of Bielsko-Biala (Poland), on the bypass road in the built-up area.

At the stage of pre- and post-processing, the GIS Idrisi Andes Spatial Information System was used.

2. Modelling the effects of releases of hazardous substances in transport

2.1. Serious accidents in road transport

According to data provided on the European Commission's Eurostat websites, in the years 2012-2016, in the European Union, road transport carried from 74 billion t km to 84 billion t km of hazardous goods. Also in Poland, the transport of hazardous goods from year to year is growing (according to the same commission) and in 2012 it amounted to 6 801, in 2015 already 9 174 million t km, and in 2016 8 444 million t km, which was ca. 3% of the total amount of goods transported by road (Transport, 2016).

The safety of road transport is regulated, among others, by the provisions of the European Agreement for the International Road Transport of Dangerous Goods (ADR). It is a widely used standard, subject to constant amendments in the forum of the United Nations Economic Commission for Europe. In Poland, there is also the Act of 19 August 2011 on the transport of dangerous goods (Journal of Laws 2011 No. 227 item 1367), which defines the rules for the transport of dangerous goods.

According to the analyzes carried out by the Supreme Audit Office (NIK, 2012), irregularities were detected in about 5% of the vehicles inspected, most of them related to incorrect security in the event of a fire.

The subject of the problem of transport of dangerous substances is taken by many authors. At work (Oggero et al., 2006), an analysis of 1,932 cases has been made, which occurred during road and rail transport of hazardous substances from the beginning of the 20th century to July 2004 in Great Britain. The obtained results indicate an increase in the frequency of major accidents (incidents) over the time. Over half of the accidents happened on roads (63%). The most common accidents were related to the releases - 78%, then with fires - 28%, explosions - 14% and gas clouds - 6%. The causes of accidents were analyzed, the type of substances and the consequences for the population (number of people killed, injured or evacuated).

In the United States (Erkut et al., 2007) the most cases concerned flammable materials - over 42%, caustic materials - 37.5%, poisonous - more than 5%, oxidants - 3% and mixed - almost 4%. Other accidents - more than 8% related to other hazardous substances. About 40% of accidents involving hazardous materials were caused by human error and also as a result of road accidents, and almost 20% were related to the failure of containers.

Welles et al. (2004), based on research carried out in New York, states that: 21% of accidents related to hazardous substances occur in relation to transport, 39% due to faulty equipment and 33% due to human error.

The assessment of the effects of this type of events is a considerable task and requires the use of appropriate tools.

2.2. Modelling the effects of major accidents in road transport

The impact of accidental releases of toxic chemicals can be minimized by providing accurate information and organizing the work of the team to prevent the effects of major accidents. This is possible thanks to the use of programs and computer systems that allow to estimate the effects in real time. They are a key tool to support decision-makers in the planning of pre-trial and rescue proceedings in case of an accident (Alhajraf et al., 2005, Quaranta et al., 2002, Zhao et al., 2012). An example of such a system may be ARAC (Atmospheric Release and Advisory Capability) developed by Lawrence Livermore National Laboratory (LLNL) (Ermak et al., 2002). In these systems, one of the necessary modules is the dispersion module. Spatial information systems are also used, among others to estimate the number of people in the range of danger (Chakraborty and Armstrong, 1995, Fisher et al., 2006).

A variety of computer programs are used to model the effects of releases of hazardous substances. In the programs used in Poland by the State Fire Service to assess the toxic zones of vapours hazardous to health and life arising during chemical spills, the direction and speed of the wind, the class of atmosphere stability and air temperature are usually taken into account. The most frequently used programs include: ALOHA (Areal Locations of Hazardous Atmospheres), a program for estimating hazardous areas in the event of emergency release of hazardous substances (NOAA, 2013); ALOFT-FT (A Large Outdoor Fire Plume Trajectory Model - Flat Terrain - Mcgrattan (2003)); FDS (Fire Dynamics Simulator - McGrattan et al. (2007)); CFAST (Consolidated Model of Fire Growth and Smoke Transport - Peacock et al. (2013)). The ALOHA program is mainly used because of its ease of use. The results are presented in the form of graphic zones whose boundaries can be defined individually. In the program, indirect construction can also be taken into account by selecting one of three possible types of aerodynamic roughness of the ground.

In this work, we used our own computer program based on independently operating models: air velocity field and dispersion of pollutants. The first of them belongs to the group of diagnostic models, the second is the original implementation of the Lagrange model of particles. The flow chart is shown in Fig.1.

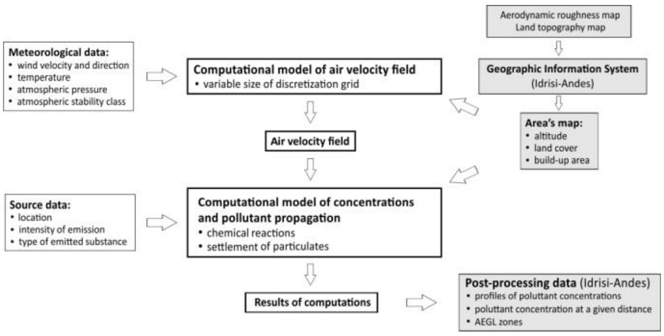


Fig.2. *Stages of proceedings in the custom program*

The description of mathematical models is presented in Brzozowska L., (2013) and Brzozowska L., (2014a), and their implementation and application to the simulation of the effects of dangerous substances, among others, in: Brzozowska L., (2014b) and Brzozowska L. (2016).

3. Analysis of the effects of the sudden release of chlorine resulting from a road incident

This chapter presents the use of the Spatial Information System to analyze the effects of the sudden release of a dangerous substance resulting from a road accident involving a tanker carrying chlorine (Brzozowska L., 2016). Analysis and visualization of results was carried out in the Idrisi Andes program.

3.1. Chlorine as a hazardous substance

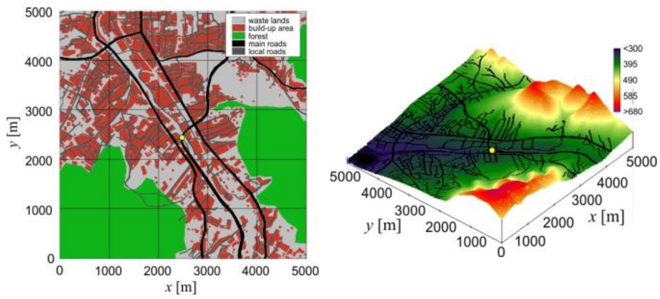
On the one hand, chlorine, used for the production of industrial and consumer products, helps improve the quality of everyday life (Clugg, 2012, Dandrieux et al., 2006), on the other is also very toxic and considered one of the most dangerous materials from the hazardous materials group. Classified as Toxic Inhalation Hazard (TIH) and Poison Inhalation Hazard (PIH). Gaseous chlorine becomes particularly dangerous when released into the air. The risk of exposure depends on how close the source of release is to a given person. Chlorine is easily dispersed in atmospheric air and can therefore be a threat to a large population. Ultimately, the consequences of the release depend on the intensity of the emission, the location of the source, the shape and type of surrounding terrain and meteorological conditions. Any unintentional release that is not associated with an accident is called 'Non-Accident Releases' (NARs) (Clugg, 2012).

One of the major disasters associated with the transport of chlorine was the train accident on January 6, 2005, in Graniteville, South Carolina, which resulted in the car bursting and the release of 54 tons of chlorine (Railroad Accident Report, 2005). Over 5,000 people were evacuated in a sparsely populated area; over 500 people required treatment; nine people died. Both this accident and others caused that urban planners and emergency, transport and chemical industries had to deal with the issue of the sudden release of chlorine. In addition, the transport of dangerous substances may become the target of terrorist attacks in the urban area (Bauer, 2013, Buckley et al., 2012).

The simulations of spreading in several prognostic models carried out by Hanna et al. (2008) suggest that lethal concentration from large chlorine releases (50+ tons) will be maintained in a toxic cloud more than 10 km long in the wind.

3.2. The analyzed case

In the calculations, it was assumed that the accident occurred on the Bielsko-Biala bypass, on the S69 road (Fig. 2). There is a sharp turn here. As Fabiano et al. (2005) points out, the areas where traffic accidents most frequently occur are curves as well as tunnels, uphill slopes and high downhill slopes.



a) b)

Fig.2. *Modelled area with buildings - a) and terrain - b) the place of the collision and the route of the bypass road were marked*

As a result of the collision of a tanker carrying 20 tons of chlorine, chlorine leaked into the air in the amount of 10 tons. It was assumed that the leak had a Gaussian curve, and most of the substance was extracted within the first hour of simulation (70%), the duration of the simulation was set to two hours. The maximum leakage is 4500 g/s.

The emission took place at a height of 1.5 m above the ground surface - roadway, in a place with coordinates $x^{(1)}$= 2500 m and $x^{(2)}$= 2250 m (this place is marked in figure 2), in built-up area. The wind direction at the time of chlorine leakage is the eastern direction, the wind velocity taken as input to the diagnostic model (when calculating the initial air velocity field) is u= 2 m/s. Atmospheric condition, air temperature 20°C. Two wind directions were considered: Case 1: east - E ($u^{(1)}$=-2 m/s, $u^{(2)}$=0 m/s) and Case 2: south-east - SE ($u^{(1)}$ = -1.5 m/s, $u^{(2)}$=1.5 m/s).

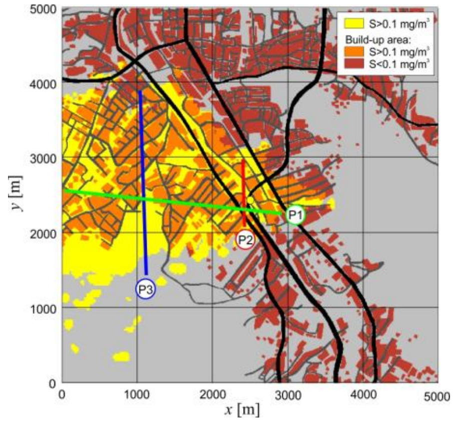
3.3. Assessment of the effects of chlorine emission as a result of an sudden road accident

A series of analyzes of the simulation results obtained in the custom computer program were carried out. The analyzes were performed in the spatial information system Idrisi Andes.

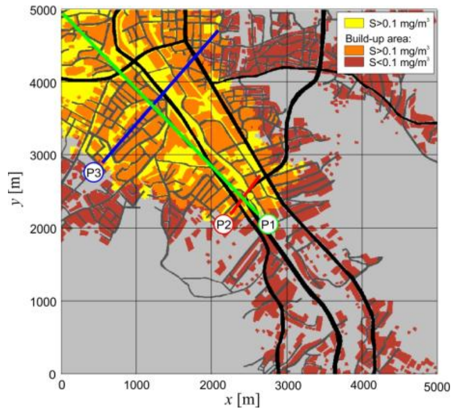
Chlorine threshold values compliant with the 30-minute chlorine exposure standards - AEGL, as well as the value of 0.1 mg/m^3, as the maximum permissible 30-minute concentration specified in Polish law, were adopted for the analysis. The limit values for AEGL are: AEGL-3 – 81 mg/m^3, AEGL-2 – 8.1 mg/m^3, AEGL-1 – 1.5 mg/m^3.

Figure 3 shows the simulation area where the concentrations reached values above 0.1 mg/m^3. Profiles selected for further analysis were also marked. In contrast, Figure 4 presents the results of modelling with marked built-up areas under the influence of AEGL-1 ... 3 concentrations.

Both wind directions were considered.

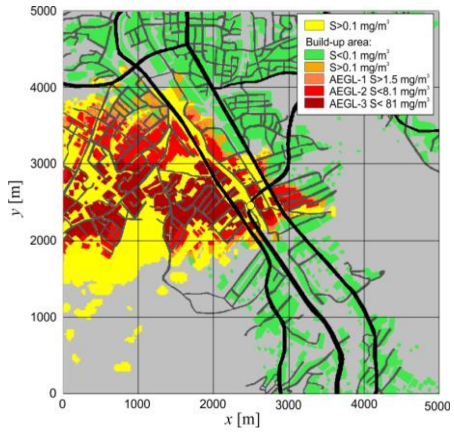


a)

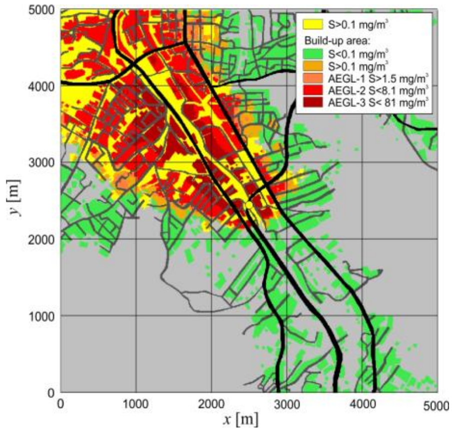


b)

Fig.3. *The modelled area under the influence of the pollution cloud and the analyzed profiles for two wind directions: a) case 1, b) case 2.*



a)



b)

Fig.4. *The modelled area under the influence of pollutant concentrations with different values, for two wind directions: a) case 1, b) case 2.*

Table 1 shows the percentage of the risk of sudden release of chlorine as a result of a traffic accident.

Table 1. *The area under the influence of pollutant concentrations above the threshold values for both wind directions*

AEGL zones	Build-up area [%]	
	Case 1	Case 2
AEGL-1	2.8	3.2
AEGL-2	11.9	23.2
AEGL-3	15	10.1

The following figures (Fig. 5) present simulation results for selected profiles. The profile of building and pollution concentrations is presented.

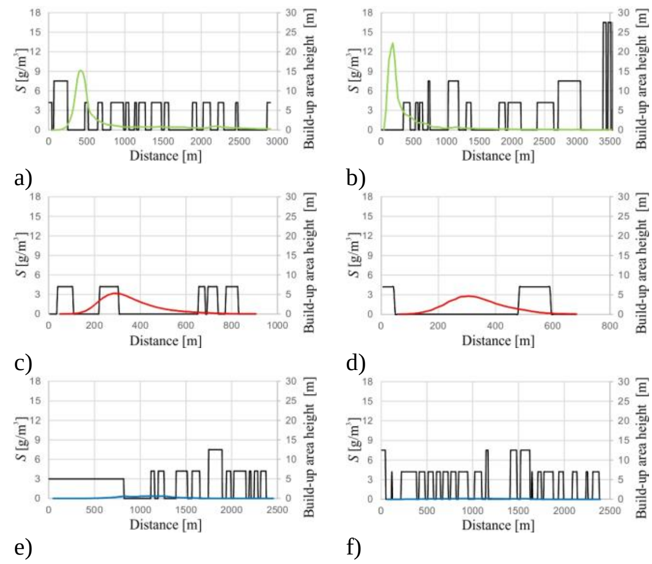


Fig.5. *Elevation and pollution profiles: a) P1, case 1, b) P1, case 2, c) P2, case 1, d) P2, case 2, e) P3, case 1, f) P3, case 2.*

Figure 6 shows the values of average concentrations in the building area depending on the distance from the emission source.

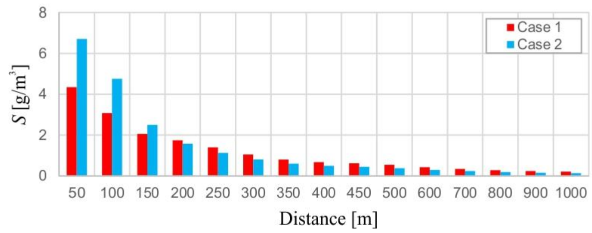


Fig.6. *Pollution concentrations at a distance from the source for both analyzed cases.*

4. Summary

Import of simulation results into the spatial information system enables to perform a series of spatial analyzes of calculated distribution of pollution concentration in it. The GIS software has built-in modules that are used during the development of charts and maps presenting information relevant to the surface of the earth. The maps developed as part of the work illustrate areas exposed by the occurrence of above-normative concentration levels (endangered areas). They can be used for taking action during the crisis (unsealing of the tank in which the toxic substance is transported).

After the computer simulation, it was found that the chlorine pollution cloud, in which the concentration of pollution exceeds 0.1 mg/m^3,, covers 24.3% and 24.9% of the entire area. Built-up areas under the influence of this concentration constitute 33.8% and 42% of the building area, respectively for case 1 and case 2.

Detailed analysis of the concentration of contamination in the streak axis (profile 1) and across the streak (profiles: 2 and 3) shown in Figure 5 indicates that the highest values of the pollutant are emitted in the immediate vicinity of the emission source. The maximum value of pollutant concentration for profile P1 in both cases exceeds 9 g/m^3. Also, large concentration values are observed in the graphs for P2 profiles (S> 3 g/m^3). Only at a considerable distance from the source (P3 profiles) the concentration of contamination is clearly smaller. The maximum concentration then does not exceed 360 mg/m^3. But it is more than 4 times the threshold value of AEGL-3.

In both analyzed cases, about 3% of the development area is within the pollution concentration range in the AEGL-1 zone. Built-up areas with a concentration threatening the health of living organisms (AEGL-3) constitute 15% (case 1) and 10.1% (case 2) of the whole area of buildings. Rescue operations (zone AEGL-2) can be taken at 11.9% and 23.2% of the area.

The analysis of average values of concentration of pollution in the area of buildings at a given distance from the source of emission testifies to the occurrence of high chlorine concentrations over 1 km (207 mg/m^3 - case 1; 134 mg/m^3 - case 2) from the place of unsealing the tank. Therefore, from the point of view of health care for residents, using the discussed software one should develop a map of the threatened areas, draw up maps of evacuation plans and indicate places of road blockade.

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