Multi-Scale GIS Modelling: Radionuclide Transport from the Semipalatinsk Polygon

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Abstract

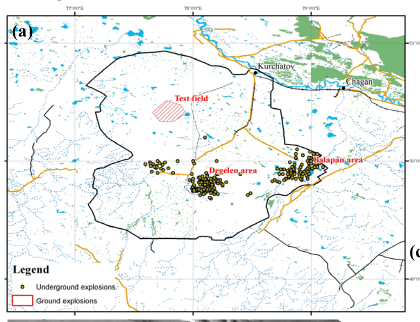
In this study, the software complex MigRad (Migration of Radionuclide) was developed, tested and applied for the territory of the Semipalatinsk test site (STS; Republic of Kazakhstan). It is oriented on integration of large volumes of different information (mapping, ground-based, satellite-based survey, and multi-environment and -scale modelling). The MigRad was designed as a tool for comprehensive analysis of complex territorial processes influenced by former nuclear explosions on the STS territory. It provides possibilities in detailed analyses for (i) extensive cartographic material, remote sensing, and field measurements data collected in different level databases; (ii) radionuclide migration with flows; (iii) thermal anomalies caused by explosions and observed on STS and adjacent territories, and (iv) long-range transport of radionuclides with analysis of dynamics.

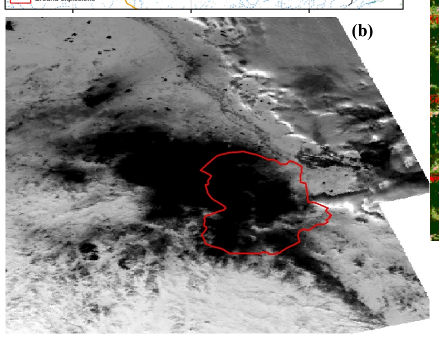
Introduction

The STS, created in 1947, was used to carry out tests of nuclear weapons. The consequences of such impact turned out to be very serious and will probably reveal themselves over a long period of time. The last test was conducted in Oct 1989, but the level of radiation on STS is still much higher than background values. Due to precipitation, water and wind soil erosion radionuclides are transported and redistributed over the STS territory as well as beyond its boundaries. Therefore, people living in the nearby areas and rather far from its boundaries, consuming vegetable and animal products (which might be contaminated with radionuclides), can obtain an external irradiation and, thus, are always under continuous risk of radioactive pollution.

Semipalatinsk Test Site

TST is situated at the intersection of three administrative regions: Pavlodar, Karaganda, and North-Kazakhstan oblasts, and it is extended from 49°N, 77°E to 51°N, 79.5°E (total area of 18000 km^2). The local climate is sharply continental with high daily and annual variations of air temperature. Due to existing natural characteristics the main mechanisms of radionuclide migration are connected with water (due to rains) and wind soil erosion. According to *Tleubergenov (1997)*, from 1949 to 1962 — 118 aboveground nuclear tests were conducted there, 30 of them — surface nuclear tests. Since 1961 — 348 underground nuclear tests were carried out on the STS territory. The nuclear devices were placed and test conducted in horizontal tunnels (215) and in vertical wells (133). Locations of exploded nuclear tests are shown in Fig. 1a.





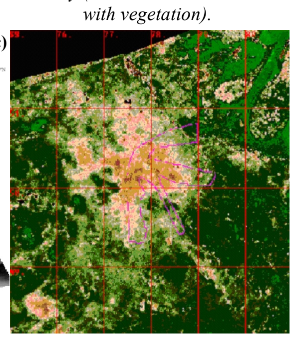


Figure 1. *(a) The locations of nuclear explosions in the Semipalatinsk test site; (b) Satellite-based image NOAA/ AVHRR on 17 Feb 1997 of the STS territory; (c) Satellite-based image NOAA/ AVHRR on 2 May 1997 of the STS territory (shown areas not covered with vegetation).*

Thermal Anomaly

The anomaly high temperature of the underlying surface is one of the factors imposing strong influence on wind erosion formation. It was discovered using remote sensing data (*Sultangazin et al., 1998; Zakarin et al., 1998*). Satellite-based images of the STS territory obtained since 1997 showed clearly outlined heat epicentres where temperature by 7-10° exceeds the average background temperature of the surrounding area. This effect is especially clearly identified at the end of summer – beginning of spring (when snow on STS is melting earlier than surrounding areas) (Fig. 1b). This effect completely suppresses vegetation growth in dry years (Fig. 1c). At first, anomaly high temperatures were registered from ground-based measurements of the surface temperature before and after explosions. Further studies (*Zakarin and Balakay, 2003*) showed that in the recoil zone of explosion the temperature had increased by 10–12°, and such overheating remained after explosion during all period of observations. The areas of anomalous zones vary from year to year (based on remote sensing data), but one thing all they have in common — TST area is always presented. The high temperature and absence of vegetation give rise to more intensive deflation processes in soil and as a result the increased wind transfer of radioactive substances from its surface.

GIS Project MigRad

From our point of view the most important processes in terms of their impact on population include transfer of radionuclides by surface waters to the closely-located areas and long-range atmospheric transport of radioactive species from the STS territory to other regions of the Republic of Kazakhstan as well as neighbouring countries. The modern way to evaluate abovementioned processes is based on application of the geo-information system (GIS). In our study (*Balakay, 2008*), development of the GIS oriented project called MigRad (with integration of territorially distributed data from different databases and results of multi-environment and multi-scale modelling and remote sensing methods) was performed including:

- informational modelling for STS area using GIS technologies and remote sensing data;
- modelling of radionuclide migration with surface waters and precipitation/ rain flows causing local redistribution of radioactivity in underlying surface (using RUNOFF; *Haith et al., 1984*);
- cartographic modelling of wind epicentres carrying radioactive aerosols and considering localization of nuclear tests areas, distribution of surface activity of radioactive substances, and repeatability of high temperature areas;
- modelling and analysis of long-range atmospheric transport, dispersion, and deposition of ^{137}Cs from 3 selected locations —Balapan, Delegen, and Experimental Field — within the STS area (using DERMA; *Baklanov et al., 2006; Mahura et al., 2005*).

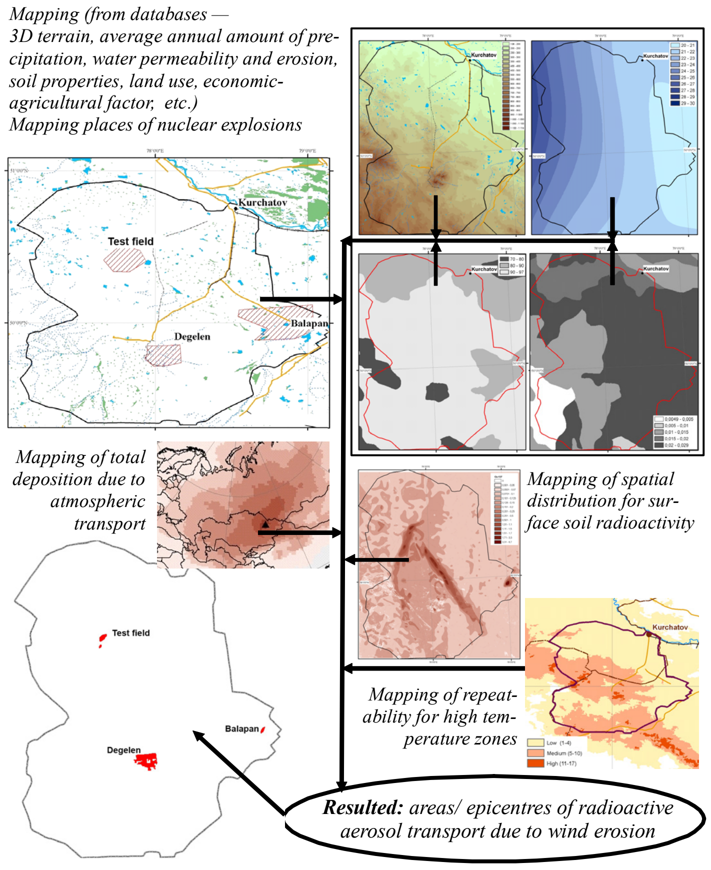


Figure 2. *Scheme of mapping the epicentres of radioactive aerosol transport due to wind erosion within the STS area.*

The schematics for detection places of maximal probable localization of sources for wind carrying out of aerosols is shown in Fig. 2. The method is based on assumption that under other equal conditions (vegetation cover, types of soil cover, etc.) the main defining factors are: a) places where testing/ explosions of nuclear devices were conducted; b) distribution of surface activity of radionuclides is calculated for the moment of modelling; and c) repeatability of high temperature zones increasing erosion ability of underlying surface.

Acknowledgments

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Horizontal redistribution of radionuclides over the territory occurs under the action of a great number of factors. The most important of them is washing-off of the upper soil layers by surface waters, which causes migration of accumulated in them radioactive substances. Such processes are accompanied by formation of new zones of radionuclide accumulation in the areas of relief lowering, which dramatically change spatial structure of dose status of population.

The transboundary atmospheric transport of radioactive substances from the STS territory is the most complicated function of the MigRad system. It includes, the long-term runs of the Danish Emergency Response Model for Atmosphere (DERMA), post-processing of radionuclide concentration and deposition fields, their integration into GIS environment (Fig 3) for further evaluation of impact on the largest populated cities of Kazakhstan.

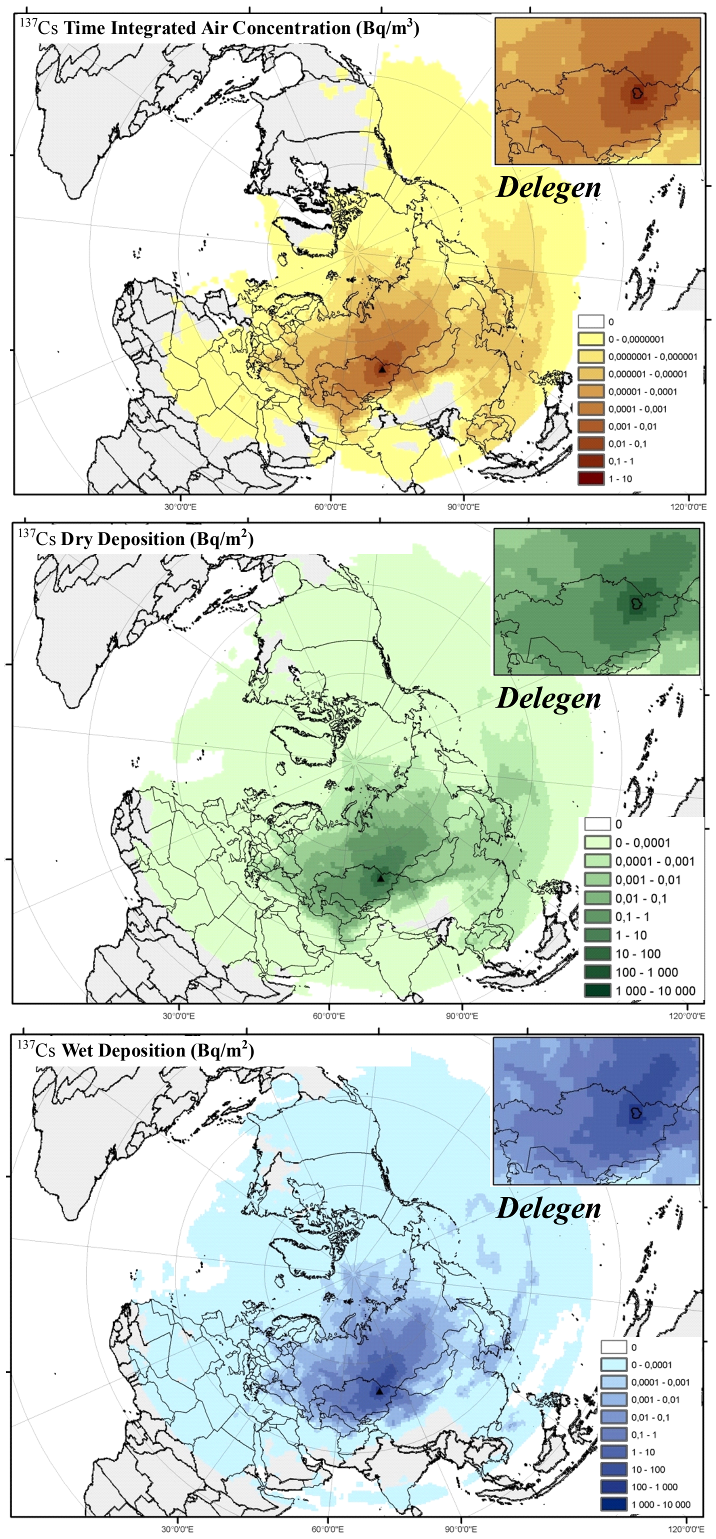

Figure 3. *Caesium-137 average annual integrated concentration (Bq/m^3), dry deposition (Bq/m^2), and wet deposition (Bq/m^2) of radioactive pollution spreading from the epicenter located in the vicinity of the Delegen testing ground.*

For simplicity, in long-term simulations of radionuclide atmospheric transport, dispersion and deposition patterns we assumed: 1) a continuous "unit discrete hypothetical release" of radioactivity with discrete emitting of puffs; 2) only 1 radionuclide of key importance, ^{137}Cs; 3) simulations on a daily basis considering 10 days of atmospheric transport; 4) simulations covered period from 1 Jan to 31 Dec (years of 1983, 1985, 2000); 5) calculated parameters included air and time integrated air concentrations, dry, wet, and total depositions.

At post-processing the simulated values were re-scaled depending on erosion ability of soil cover and surface activity of ^{137}Cs in the epicentres of carrying-out of radioactive aerosols (assuming fraction of ^{137}Cs mobile forms was equal to 10% in spring-summer; and in autumn-winter – 0, since sources of wind transport are either covered with snow or their soil is frozen).