The Application of Visual Analytics Methods to Analyze the Dynamics of Stillbirth in Radiation Contaminated Areas of the Bryansk Region after the Chernobyl Disaster (1986-2016)

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The relevance of the research *is due to the complexity of the stage of exploratory data analysis and hypotheses for further verification by methods of statistical and/or data mining.*

Objective: *to apply methods of visual analysis and cognitive visualization for exploratory analysis and advance preliminary hypotheses in the process of analyzing the dynamics of stillbirth of boys and girls in all areas of the Bryansk region with different density of radioactive contamination by long-lived radionuclides Cesium-137 (^{137}Cs) and Strontium-90 (^{90}Sr), on the basis of official statistics for the long-term period (1986-2016).*

Research methods: *visual analytics and cognitive visualization, mathematical statistics: Shapiro-Wilk test, Student t-test, homoscedasticity test, linear regression.*

Research results: *the research results confirm the feasibility of using methods of visual analytics and cognitive visualization for exploratory analysis and advancement of preliminary hypotheses. The use of cognitive visualization in the process of exploratory data analysis allows the researcher to better understand the main trends and patterns in the analyzed data. This makes it possible to reduce the time required to form hypotheses by two to three times and to improve the quality of the hypotheses put forward.*

Keywords *visual analytics, cognitive visualization, stillbirth rate, statistical data analysis, teratogenic impact, Chernobyl disaster, Bryansk region, radioactive contamination, ^{137}Cs, ^{90}Sr.*

1. Background

One of the most important indicators to assess the standard of living of the population and predict its growth is the frequency of stillbirths. According to the world health organization (WHO) [13], about 2.6 million stillbirths are reported worldwide each year, with 98% of these stillbirths occurring in low-and middle-income countries. This problem also exists in high-income countries – one in 320 children is stillborn.

The main risk factors for stillbirths are low attendance at antenatal care facilities [1], socio-economic problems [7] complications during childbirth, the mother's age over 35 years, acute and chronic infections of the mother during pregnancy, high blood pressure, diabetes, etc. [5, 6, 12].

Additional exposure to ionizing radiation can disrupt normal embryonic development and lead to both fetal death and congenital malformations – physical abnormalities, metabolic disorders and genetic defects [2, 8].

31 years after the Chernobyl disaster in the radiation-contaminated territories of Ukraine, Belarus and Russia, radioactivity, determined mainly by long-lived ^{137}Cs and ^{90}Sr, will still be relevant and remain radiologically significant for several more decades [10, 14].

316 thousand people are currently living in the radioactively contaminated areas in 749 settlements of the Bryansk region [4]. At the same time, soil contamination density of ^{137}Cs and ^{90}Sr in the most contamination South-Western territories (SWT) in 2015 exceeds the established limits tenfolds (up to 2116 kBq/m^2 for ^{137}Cs and up to 60 kBq/m^2 for ^{90}Sr) [3].

Within the framework of the international scientific and educational cooperation of the Ministry of education and science and DAAD under the program "Mikhail Lomonosov" (state task 19.9992.2017/5.2), a comparative analysis of the frequency of stillbirths of boys and girls in the Bryansk region, characterized by different contamination density as a result of the Chernobyl disaster long-lived radionuclides ^{137}Cs and ^{90}Sr [11]. The presented work is a continuation of the study [11], the purpose of which is the use of visual analysis methods to comparative assessment the dynamics of the stillbirths rate of boys and girls in the contaminated areas of the Bryansk region after the Chernobyl disaster for a long period (1986-2016).

2. Objects and methods of research

One of the forms of visual analytics is to solve the problems of data analysis by visualization methods, which were used during the exploratory analysis to study the nature and properties of the available data, and to detect hidden patterns in them. Visual analytics methods can be used to visualize the results of calculations, as well as for exploratory analysis – the study of data and identify hidden patterns in them. In this paper, we used the methods of cognitive visualization at the initial stage of analysis of the available data. The use of cognitive visualization techniques allows the researcher to better understand the nature of the available data and put forward hypotheses that will be further tested by statistical analysis.

Statistical data on the absolute values of stillbirths of boys and girls in the Bryansk region were obtained on the basis of official materials of Bryanskstat for the thirty-one-year period (1986-2016) [9].

In the future, the rate of stillbirths was calculated – the number of stillbirths per 1000 births for 1986-2016. The stillbirth rate was defined as the total number of stillbirths to the total number of births in each city and district of the Bryansk region.

The analysis of stillbirth rates for the period 1986-2016 was carried out in the following groups of districts of the Bryansk region: 1) South-Western territories (SWT) belonging to the most radioactive contaminated due to the Chernobyl disaster in the Russian Federation (2 cities and 7 districts); 2) the region without SWT (control group) (2 cities and 20 districts); 3) the whole region (4 cities and 27 districts).

Statistical analysis of the obtained data was performed using the means of Stata SE 14.2 package. For a reasonable choice of methods for testing statistical hypotheses, we tested the normality of the distribution of stillbirth rates. Since the sample size is small (n=31), the Shapiro-Wilk criterion widely used in such situations was used. He showed that the sample for all 31 districts of the Bryansk region is far from the normal distribution. Therefore, it was considered nine of the most radiation-contaminated South-Western areas (Gordeevsky, Novozybkovsky, Zlynkovsky, Krasnogorsky, Klintsovsky, Klimovsky and Starodubsky districts, city Klintsy and Novozybkov), and for them the Shapiro-Wilk test has already given a satisfactory answer about the normality of the distribution at a significance level of 0.04. Therefore, in the study of these nine areas, parametric criteria can be applied, which we have done. The Student's t-test was used to check the statistical significance of deviations. The time series was also checked for homoscedasticity. It is found that in most cases the homoscedasticity is satisfactory and allows the use of General methods of statistics.

The density of radioactive contamination of ^{137}Cs and ^{90}Sr was estimated according to official data of scientific and production Association "Typhoon" [3].

The initial data after preprocessing were presented in the form of the following mathematical model:

$$M = \langle Y, D, P, B, S, R \rangle,$$

where:

Y – year;

D – district or city of Bryansk region;

P – number of population;

B – number of newborns per year $B = \langle B_B , B_G \rangle$ where B_B – the number of newborns for boys, B_G – the number of newborns for girls;

S – number of stillbirths per year $S = \langle S_B , S_G, S_{RB} , S_{RG} \rangle$, where S_B – number of stillbirths of boys, S_G – number of stillbirths of girls, S_{RB} – rate of stillbirths of boys, S_{RG} – rate of stillbirths of girls;

R – the level of radioactive contamination $R = \langle R_{Cmin} , R_{Smin}, R_{Cavg} , R_{Savg}, R_{Cmax} , R_{Smax} \rangle$ where R_{Cmin} – the minimum level of radioactive contamination with ^{137}Cs; R_{Smin} – the minimum level of radioactive contamination of ^{90}Sr; R_{Cavg} – average level of radiation contamination of ^{137}Cs; R_{Savg} – the average level of radioactive contamination of ^{90}Sr; R_{Cmax} – the maximum level of radiation contamination of ^{137}Cs; R_{Smax} – the maximum level of radioactive contamination of ^{90}Sr.

3. Results and discussion

Processing of the data and visualization of the processing results were carried out using the tools of the Tableau Desktop package. Since statistical and data mining is a rather laborious procedure, it is advisable to perform cognitive visualization of the initial and pre-processed data for the purpose of exploratory analysis and generation of hypotheses, which can be further confirmed or disproved [15, 16].

Hypothesis No. 1. We let's put the stillbirth rate of boys and girls on the axes, and put on the plane the points reflecting the values of the stillbirth rate for each district of Bryansk region for each year from 1986 to 2016. Radiation-contaminated areas (Gordeevsky, Novozybkovsky, Zlynkovsky, Krasnogorsky, Klintsovsky, Klimovsky and Starodubsky districts, city Klintsy and Novozybkov) highlight in red, the remaining areas are allocated to blue (Fig. 1). Analyzing the resulting figure 1, we put forward hypothesis No. 1: there are no significant differences in the stillbirth rates of boys and girls in the radioactively contaminated and non-contaminated areas of the Bryansk region. The performed statistical analysis confirmed this hypothesis (Table 1).

During the 31 years after the Chernobyl disaster (1986-2016), the total stillbirth rate in the radiation-contaminated SWT is 6% and 8% less than the values of these indicators calculated for the whole Bryansk region (average values) and for the control group of residents of the Bryansk region, not including the SWT, respectively. The stillbirth rate of girls in the SWT is lower than that estimated for the whole region and for the control group by 9 and 12%, respectively, and of boys by 4 and 5%, respectively. The differences are not statistically significant ($p > 0.05$) – table. 1.

Hypothesis No. 2. We calculate the average stillbirth rate for five years separately for boys and girls. The horizontal axis shows data for five years, the vertical axis shows the stillbirth rate (Fig. 2). The top graph shows the stillbirth rate for girls, while the bottom graph shows the rate for boys. Red color shows the rate of stillbirth in radioactive contaminated areas, blue – in other areas of the Bryansk region. Visually, the general trend of the graphs is directed downwards, despite the existing fluctuations, which suggests the presence of a trend for an overall decrease in the stillbirth rate, both boys and girls in whole areas of the Bryansk region.

Table 1. The stillbirths rate of boys and girls (per 1000 births, M±m) in the Bryansk region and the average density of radioactive contamination with Cesium-137 and Strontium-90 in 1986-2016 [11]

Areas	The stillbirths rate (1986-2016 гг.), M ± m			The average contamination density, kBq/m² (1986–2016)	
	Boys	Girls	Total	Cesium-137	Strontium-90
Whole region ($n_м$=7570; n_g=7132)	8.32 ± 0.42	7.55 ± 0.39	7.94 ± 0.32	5.4–566.7	0.5–20.3
Bryansk region (without SWT) (nb=5938; ng=5593)	8.45 ± 0.45	7.81 ± 0.44	8.13 ± 0.41	5.4–47.3	0.5–7.4
SWT (nb=1632; ng=1539)	8.03 ± 0.52	6.88 ± 0.52	7.46 ± 0.42	55.8–566.7	1.7–20.3

Note: $p > 0.05$; n_b – the average sample size for the number of births of boys, n_g – the average sample size for the number of births of girls.

Our further regression analysis showed that the dynamics of the stillbirth rate has a decreasing character for the long-term period (1986-2016) for all the considered territorial groups (the dependence of the stillbirth rate on the year):

1. Radioactively contaminated areas (Bryansk region without SWT): *trend $y = -0.165\,x + 338.14$, standard deviation SD = 0.86, correlation coefficient $r = -0.62$, $p = 0,055$, 95% confidence interval (-0.283; 0.004);*

2. Radioactive contaminated areas (SWT): *trend $y = -0.165\,x + 338.14$, standard deviation SD = 0.73, correlation coefficient $r = -0.74$, $p = 0,014$, 95% confidence interval (-0.286; -0.044).*

Checking the significance of the linear trend showed that it is significant for radioactively contaminated areas (p = 0.014) and less significant for non-contaminated areas (p = 0.055).

Hypothesis No. 3. We calculate the average level of radiation contamination over five years and build a visualization: on the horizontal axis, we postpone the average level of radiation contamination ^{137}Cs, on the vertical – ^{90}Sr (Fig. 3). Visually, the general trend of the graphs is monotonically directed down to the left to zero (Fig. 3), which indicates a gradual decrease in radiation contamination in all areas according to the law of radioactive decay.

Let's consider another visualization: let's put the stillbirth rate of boys and girls on the axes and put on the plane the points reflecting the values of the stillbirth rate of boys and girls for each district of the Bryansk region over a five-year periods (1986-1990, 1991-1995, 1996-2000, 2001-2005, 2006-2010, 2011-2016). As a result, there is a completely chaotic dynamics of stillbirth rates (Fig. 4).

The subsequent regression analysis showed that there were no significant dependencies between the density of radioactive contamination with ^{137}Cs ($p>0.303$), ^{90}Sr ($p>0.315$) and the stillbirth rates for the whole Bryansk region during the 31-year period after the Chernobyl disaster (1986-2016) – Table 2.

In addition, there were no significant dependencies between the density of radioactive contamination with ^{137}Cs ($p>0.668$), ^{90}Sr ($p>0.841$) and the stillbirth rates not only for the Bryansk region as a whole, but also in radiation-contaminated SWT (Table 3).

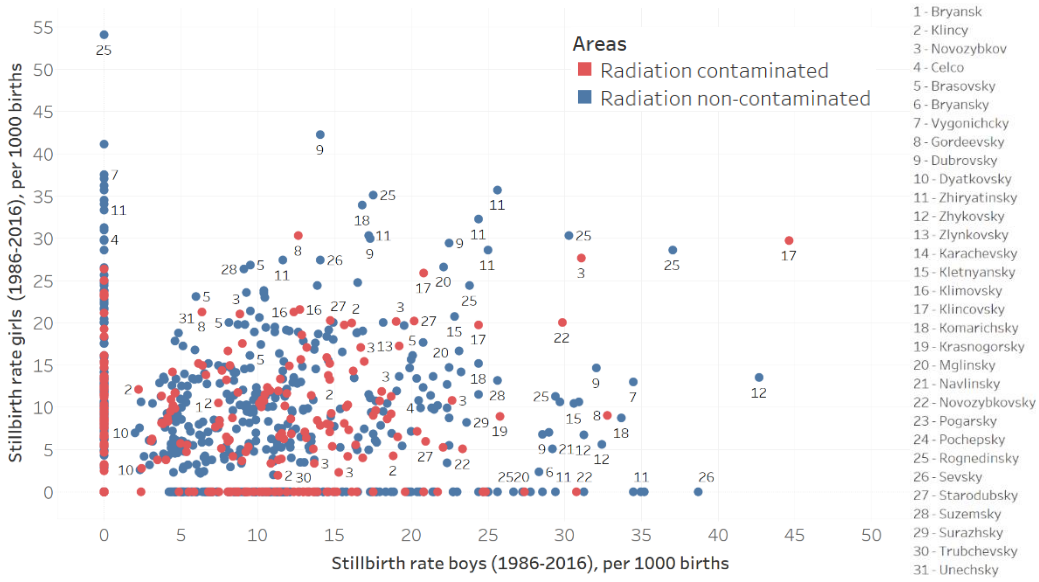

Fig. 1. The stillbirths rate of boys and girls in the radioactively contaminated and non-contaminated areas of the Bryansk region for each year from 1986 to 2016 (red – radioactive contaminated areas, blue – the rest of the Bryansk region)

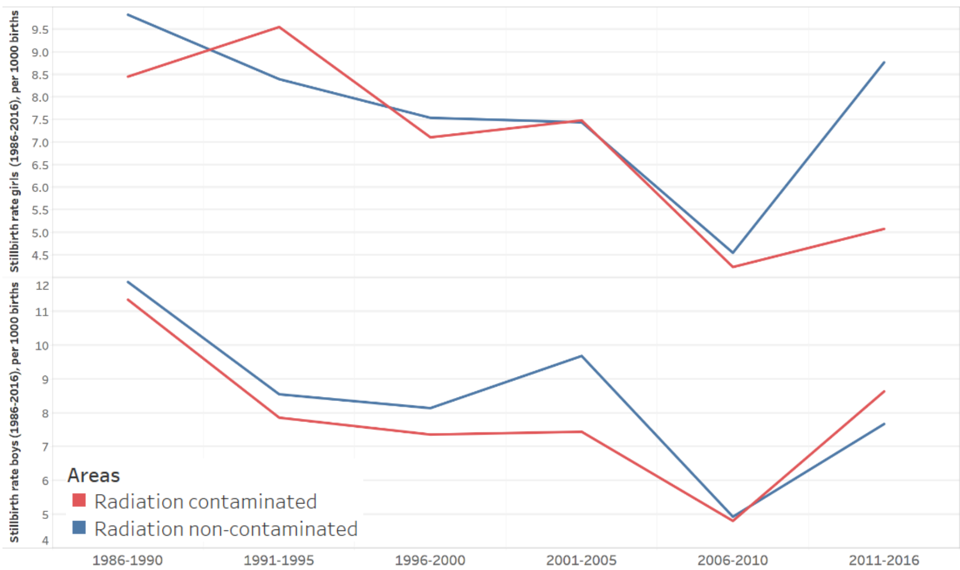

Fig. 2. The stillbirths rate (averaged over five years) of boys and girls in the radioactively contaminated and non-contaminated areas of the Bryansk region (red shows radioactive contaminated areas, blue – the rest of the Bryansk region)

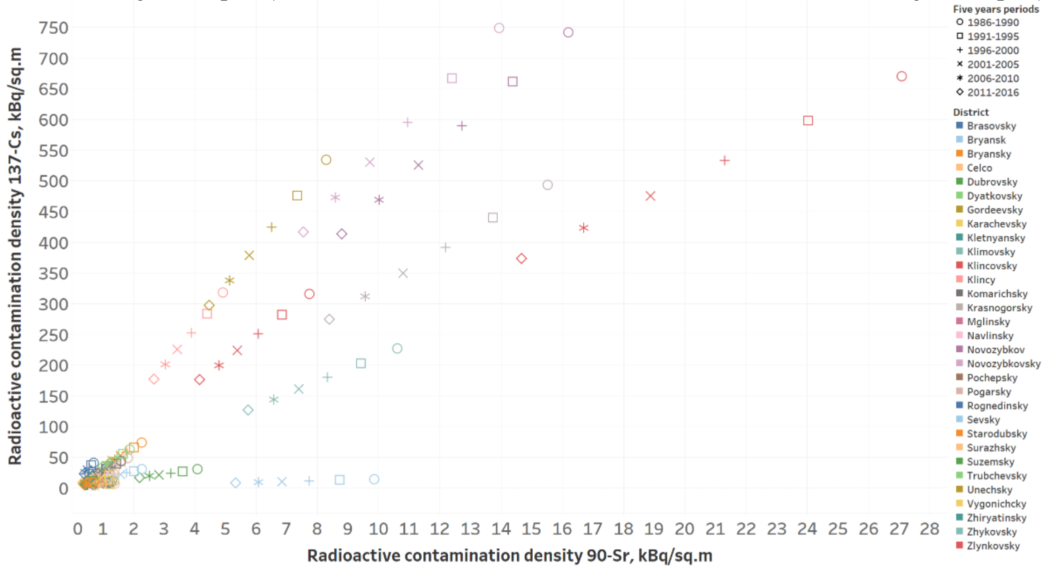

Fig. 3. The average density of radioactive contamination ^{137}Cs and ^{90}Sr in all districts of the Bryansk region over five-year periods (1986-1990, 1991-1995, 1996-2000, 2001-2005, 2006-2010, 2011-2016)

Table 2. Linear regression between ^{137}Cs and ^{90}Sr radioactive contamination density and total stillbirth rates of boys and girls in all districts of the Bryansk region (1986-2016) [11]

Source	*SS*	*df*	*MS*	Number of obs = 961		
Model	161.1	1	161.1	F (1, 959) = 1.06		
				Prob > F = 0.303		
Residual	145243.7	959	151.5	R-squared = 0.0011		
				Adj R-squared = 0.0001		
Total	145404.8	960	151.5	Root MSE = 12.31		
Sb_rate_bg	*Coef.*	*Std. Err.*	*t*	***P*>|*t*|**	*95% Conf. Interval*	
^{137}Cs_average	-.0023	.0022	-1.03	***0.303***	-.0066	.0021
Cons	16.09	.4703	34.2	0.000	15.17	17.01
Source	*SS*	*df*	*MS*	Number of obs = 961		
ыModel	153.4	1	153.4	F (1, 959) = 1.01		
				Prob > F = 0.315		
Residual	145251.5	959	151.5	R-squared = 0.0011		
				Adj R-squared = 0.0000		
Total	145404.8	960	151.5	Root MSE = 12.31		
Sb_rate_bg	*Coef.*	*Std. Err.*	*t*	***P*>|*t*|**	*95% Conf. Interval*	
^{90}Sr _average	-.0839	.0834	-1.01	***0.315***	-.2476	.0797
Cons	16.13	.4927	32.72	0.000	15.17	17.02

Hypothesis No. 4. We calculate the total rate of stillbirths in the five year periods for boys and girls for the five most contaminated districts of the Bryansk region (city Novozybkov, Novozybkovsky, Zlynkovsky, Gordeevsky, and Krasnogorsky districts). On the horizontal axis, we put the density of radioactive contamination, on the vertical axis, the stillbirth rate. Fig. 5 shows the dependence of the stillbirth rate on the density of radioactive contamination ^{137}Cs, Fig. 6 – ^{90}Sr. Visually, in most of the graphs there is a clear upward trend, despite the existing fluctuations, which suggests the dependence of the stillbirth rate, both boys and girls in the five most radiation-contaminated areas of the Bryansk region on the contamination density of both ^{137}Cs and ^{90}Sr.

Table 3. Linear regression between ^{137}Cs and ^{90}Sr radioactive contamination density and total stillbirth rates of boys and girls in radiation contaminated SWT (1986-2016) [11]

Source	*SS*	*df*	*MS*	Number of obs = 279		
Model	25.53	1	25.53	F (1, 277) = 0.18		
				Prob > F = 0.668		
Residual	38322.3	277	138.3	R-squared = 0.0007		
				Adj R-squared = -0.003		
Total	38347.8	278	137.9	Root MSE = 11.76		
Sb_rate_bg	*Coef.*	*Std. Err.*	*t*	***P*>|*t*|**	*95% Conf. Interval*	
^{137}Cs_average	.0016	.0037	0.43	**0.668**	-.0058	.0090
Cons	14.29	1.48		0.000	11.39	17.20
Source	*SS*	*df*	*MS*	Number of obs = 279		
Model	5.61	1	5.61	F (1, 277) = 0.04		
				Prob > F = 0.841		
Residual	38342.2	277	138.4	R-squared = 0.0001		
				Adj R-squared = -0.0035		
Total	38347.8	278	137.9	Root MSE = 11.76		
Sb_rate_bg	*Coef.*	*Std. Err.*	*t*	***P*>|*t*|**	*95% Conf. Interval*	
^{90}Sr _average	.0250	.1242	0.20	**0.841**	-.2195	.2695
Cons	14.63	1.31	11.20	0.000	12.06	17.20

As a result of the regression analysis, interesting patterns were found in the five most contamination SWT with a radioactive contamination density of ^{137}Cs from 373 to 567 kBq/m^2 and ^{90}Sr from 6 to 20 kBq/m^2. In contrast to the results obtained for the whole Bryansk region and the SWT, in the most radioactively contaminated areas (city Novozybkov, Novozybkovsky, Zlynkovsky, Gordeevsky, and Krasnogorsky districts) linear regression reveals a statistically significant relationship of stillbirth rates with the contamination density with ^{137}Cs ($p > 0.0001$) and to a lesser extent with ^{90}Sr ($p>0.088$) – table. 4.

Table 4. Linear regression between ^{137}Cs and ^{90}Sr radioactive contamination density and total stillbirth rates of boys and girls in the five most contamination SWT (1986-2016) [11]

Source	*SS*	*df*	*MS*	Number of obs = 155		
Model	2218.3	1	2218.3	F (1, 153) = 17.00		
				Prob > F = 0.0001		
Residual	19965.3	153	130.5	R-squared = 0.100		
				Adj R-squared = 0.094		
Total	22183.6	154	144.5	Root MSE = 11.42		
Sb_rate_bg	*Coef.*	*Std. Err.*	*t*	***P*>|*t*|**	*95% Conf. Interval*	
^{137}Cs_average	.0295	.0072	4.12	**0.0001**	.0154	.0437
Cons	-.7343	3.58	-0.21	0.838	-7.80	6.33
Source	*SS*	*df*	*MS*	Number of obs = 155		
Model	420.1	1	420.1	F (1, 153) = 2.95		
				Prob > F = 0.088		
Residual	21763.5	153	142.2	R-squared = 0.019		
				Adj R-squared = 0.012		
Total	22183.6	154	144.0	Root MSE = 11.93		
Sb_rate_bg	*Coef.*	*Std. Err.*	*t*	***P*>|*t*|**	*95% Conf. Interval*	
^{90}Sr _average	.308	.1793	1.72	**0.088**	-.0461	.6624
Cons	9.79	2.38	4.12	0.000	5.09	14.48

4. Conclusion

The use of cognitive visualization in the process of exploratory data analysis allows the researcher to better understand the main trends and patterns in the analyzed data, which in turn allows two to three times to reduce the time required for the formation of hypotheses and improve the quality of hypotheses (the ratio of confirmed hypotheses to previously put forward). The hypotheses put forward should be further tested by statistical and/or data mining methods. The use of cognitive can significantly reduce the time to search for statistically valid hypotheses and ultimately the labor costs of statistical and/or data mining by testing fewer hypotheses.

It should also be noted that it is necessary to conduct a more comprehensive study of the dynamics of the stillbirth rate in the future, taking into account not only the effects of technogenic radioactive contamination, but also socio-economic problems, mothers over 35 years old, acute and chronic diseases and infections of the mother during pregnancy, etc.

The use of visual analysis methods for exploratory analysis of data on the dynamics of stillbirths in the radioactive contaminated areas of the Bryansk region after the Chernobyl disaster for a long period (1986-2016) allowed us to formulate a number of hypotheses. The obtained hypotheses were tested and further research was conducted [11], which allowed us to make the following conclusions:

1. During 31 years after the Chernobyl accident (1986-2016) there were no significant differences in the stillbirth rate of both boys and girls in the radioactively contaminated and non-contaminated areas of the Bryansk region.

2. A significant decrease in the stillbirth rate in all the considered territorial groups has been revealed over the time since the Chernobyl accident (the period from 1986 to 2016).

3. There are no significant dependencies between the density of radioactive contamination with ^{137}Cs, ^{90}Sr and the stillbirth rates for the whole Bryansk region during the 31-year period after the Chernobyl disaster (1986-2016). In addition, there were no significant dependencies between the density of radioactive contamination with ^{137}Cs and ^{90}Sr and stillbirth rates not only for the whole Bryansk region, but also separately in radiation-contaminated SWT.

4. In contrast to the results obtained for the whole Bryansk region and the SWT, in the most radioactively contaminated areas, linear regression reveals a statistically significant relationship of stillbirth rates with the contamination density with ^{137}Cs and to a lesser extent with ^{90}Sr.

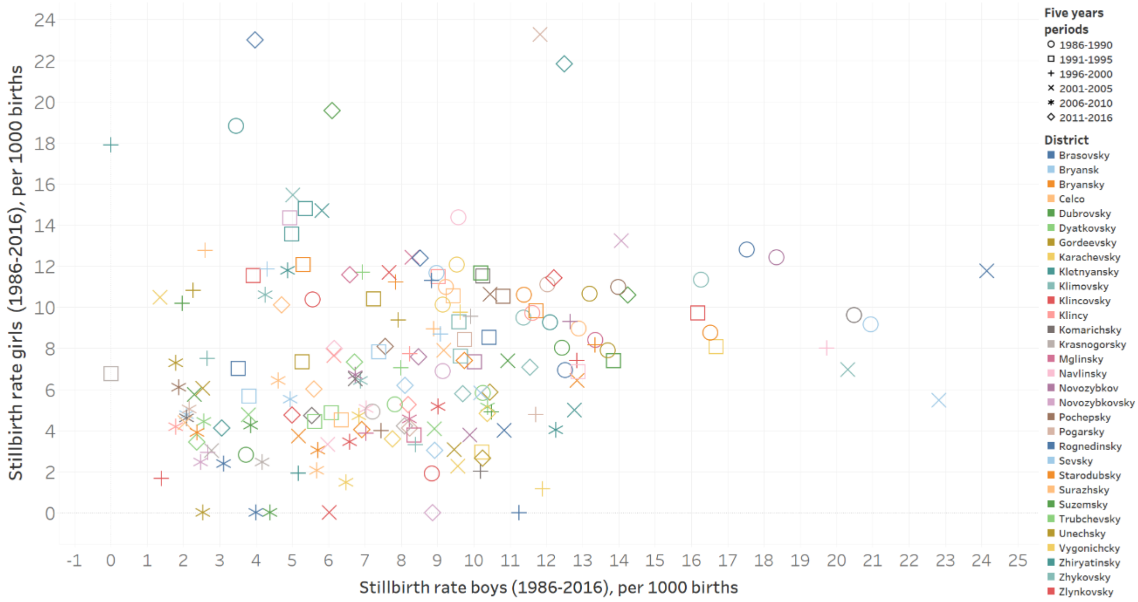

Fig. 4. Stillbirth rate of boys and girls in all districts of the Bryansk region over five-year periods

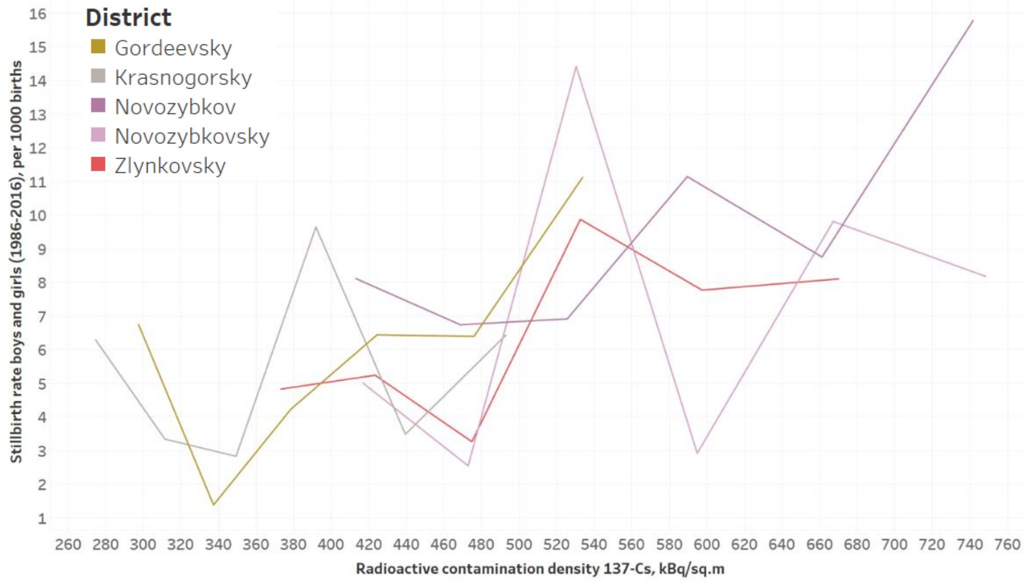

Fig. 5. Dependence of the total stillbirth rate of boys and girls in the five most contamination districts of the Bryansk region on the density of radioactive contamination ^{137}Cs over five-year periods

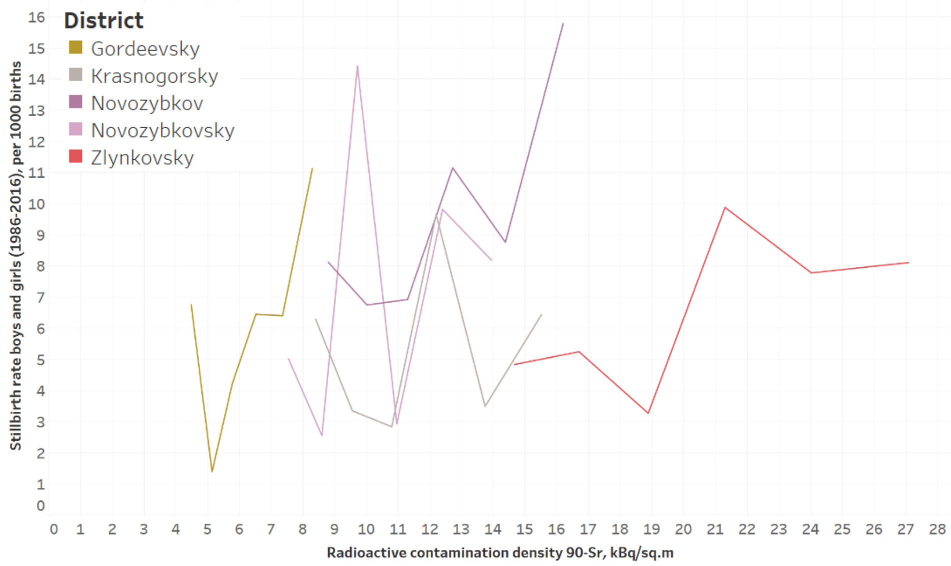

Fig. 6. Dependence of the total stillbirth rate of boys and girls in the five most contamination districts of the Bryansk region on the density of radioactive contamination ^{90}Sr over five-year periods

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