Original paper

Cardiovascular mortality in northwestern Russia in relation with geomagnetic disturbances

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Resumen

El objetivo del estudio fue identificar en el noroeste de Rusia los impactos de las perturbaciones geomagnéticas, los factores socioeconómicos y antropogénicos en la mortalidad causada por enfermedades cardiovasculares (CVE, por sus siglas en ingles). Se analizaron 9,057 muertes por CVE en la ciudad de Kirovsk (península de Kola, 67.6 N, 33.7 E), relacionadas con las estaciones del año de 1948 a 2010. Se aprecian tres picos significativos en el número total de muertes en varones por CVE: en mayo, septiembre e invierno. El pico máximo de mayo predominó para los varones, excepto en la población de mayor edad (≥ 70 años). Parece que se relaciona con cuestiones emocionales y físicas derivadas del aumento de hormonas en primavera. En cuanto a las mujeres, se mostraron dos máximos significativos de muertes por CVE en otoño e invierno, y un pico en primavera insignificante. La distribución estacional de las tormentas geomagneticas moderadas (50 <Ap<100 nT) tenía un patrón bimodal con picos de primavera y otoño. Este patrón bimodal derivado de la variación estacional también se encuentra presente en los grupos mayores de edad (≥ 70 años), tanto en hombres como en mujeres. El análisis con el Método Multi-Taper (MTM, por sus siglas en inglés) reveló períodos de ~9-10 años, ~ 4.7 años y ~2.3 años, con un nivel de certeza de ≥90%. Estos períodos parecen coincidir con los principales ciclos de variaciones del índice aa de la actividad geomagnética. En la región de este estudio no se detectó una relación significativa entre la contaminación atmosférica y la mortalidad por enfermedades cardiovasculares.

Palabras clave: actividad geomagnetica, muertes por enfermedades cardiovasculares.

Abstract

The aim of the study was to identify the impact of natural (geomagnetic disturbances), socioeconomic and man-made factors on mortality from cardiovascular diseases (CVD) in Northwestern Russia. Data from 9057 CVD deaths in Kirovsk town (Kola Peninsula, 67.6 N, 33.7 E) were analyzed with respect to seasons of the year from 1948 to 2010. Total male CVD deaths showed three significant peaks in May, September and winter. The May maximum was dominant for all males, except for the oldest age (≥70 years) group and seemed to be caused by emotional and physical effects of increased hormones in spring. Total female CVD deaths showed two significant maxima in autumn and winter and one insignificant spring peak. Seasonal distribution of the moderate (50<Ap<100 nT) magnetic had a bimodal pattern with spring and autumn peaks. This bimodal pattern of seasonal variation is also present in the female and male oldest age (≥70 years) groups. Multi-Taper-Method (MTM) spectral analysis revealed periods of ~9-10 years, ~4.7 years and ~2.3 years at confidence level of ≥90%. These periods seem to coincide with the main cycles of variations of the aa-index of geomagnetic activity. There is no significant association of air pollution and CVD mortality at the region.

Key words: geomagnetic activity, cardiovascular deaths.

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Introduction

According to the World Health Organization, every year about 17 million people globally die of Cardiovascular diseases (CVD), particularly from heart attacks and strokes. CVD remain to be the leading cause of mortality, accounting for nearly 50% of all deaths in the European Region (WHO, 2013). Development of the demographic crisis in the past decade in Russia made it necessary to study the dynamics of CVD mortality.

When studying the impact of environmental parameters changes on the dynamics of CVD-related deaths a question arises about the relative role of socioeconomic and natural factors. In Russia mortality has increased steeply in the first part of the 1990s, after the collapse of the Soviet Union (Shkolnikov *et al*., 1998; Norstrom, 2011). Possible explanations of this recent phenomenon have been discussed in the literature including social stress, medical care collapse, environmental pollution or alcohol consumption (Shkolnikov *et al*., 1998; Norstrom, 2011). All these interpretations were socioeconomic in nature. On the other hand, a number of studies were devoted to a possible relationship between some heliogeomagnetic factors and CVDs (Villorezi *et al*., 1994a,b; Stoupel *et al*., 1995; Shumilov *et al*., 1998, 2003; Halberg *et al*., 2000; Cherry, 2002; Cornelissen *et al*., 2002; Palmer *et al*., 2006; Kleimenova *et al*., 2007; Breus *et al*., 2008; Mendoza and Diaz-Sandoval, 2000; Mendoza and de la Peña, 2010; Diaz-Sandoval *et al*., 2011; Samsonov *et al*., 2014). For example, a significant increase has been established in the heart attacks and strokes (13% and 7.5% respectively) during large magnetic storms (Breus *et al*., 2008). Unfortunately, most of these studies were performed at low and middle latitudes, where the effect of heliogeophysical factors is insignificant. Conversely, at high latitudes, where electromagnetic disturbances caused by solar activity are strongest and, therefore, can be regarded as one essential environmental factor, almost no such studies were carried out. There are only few works concerning the effect of cosmophysical factors on human health in the magnetically active auroral zone (Shumilov *et al*., 2003, 2014) and in the relatively geomagnetically quiet polar cap zone (Shumilov *et al*., 1998) and subauroral latitudes (Samsonov *et al*., 2014).

In this work, we aimed to establish the effect of geomagnetic disturbances and other environmental factors on CVD mortality in the town of Kirovsk (Kola Peninsula, Northwestern Russia), which is known to be in the zone of maximum occurrence of auroras and their related geomagnetic disturbances.

Data and methodology

Statistical data of the period 1948-2010 (756 months) for Kirovsk town (67.6 N, 33.7 E) have been used in the analysis. Date, gender and age were recorded for each case. Information for this study was obtained from the official death certificates that were collected in the registry office.

Kirovsk is a town on the Kola Peninsula, 175 km south of Murmansk, with a population of approximately 30 thousands. It is located right at the auroral zone of geomagnetic activity, where the intensity and occurrence level of geomagnetic disturbances and pulsations grow in a wide frequency band. On the other hand, Murmansk Oblast is one of the industrialized and densely populated regions of Russia, where copper-nickel, iron, apatite-nepheline and rare-earth ores are widely developed and processed.

The rates of CVD mortality were calculated (number of cases per 100 thousand people) both for women and men. The seasonal distribution data validity was verified with the help of Student criterion, using MATLAB applied software package. Periodicity studies in yearly number of CVD deaths were determined using the Multi-Taper Method (MTM) of the power spectrum analysis (Thomson, 1982), detrending the time series to obtain stationarity carried out by subtracting the trend (5th order polynomial fit). MTM spectral analysis was performed with the help of the SSA-MTM software toolkit (Ghil *et al*., 2002). Significance was tested at the 90% and 95% confidence level against a red-noise background (Ghil *et al*., 2002).

The Ap and *aa* indexes are measures of the general level of geomagnetic storm activity over the planet. In this study, daily Ap indices from 1 January 1948 to 31 December 2010 were obtained from the World Data Centre for Geomagnetism, Kyoto, Japan (http://wdc.kugi.kyoto-u.ac.jp). The yearly *aa* indexes were from the British Geological Survey (www.geomag.bgs.ac.uk).

Results

During the period (1948-2010) 9057 CVD deaths were investigated, 4082 of them were men. It is known that CVDs occur almost equally in men and women, which is confirmed by the statistical data for Kirovsk. The largest number of CVD deaths occurred in 2002 (953.9 persons per 100 thousand people) and the smallest one occurred in 1960 (113.7).

Figure 1 presents variations of the rates of mortality from cardio-vascular diseases (I_h) in Kirovsk during the period 1948-2010. A sharp increase is seen in the CVD mortality level since 1991 (more than twice compared to the period of 1948-1990), which, most likely, was connected with socio-economic stresses of that period. As we can see from Figure 1a, in the first maximum of the curve (1996) the value of the rate (I_h=623) of CVD mortality exceeds almost three times the average value for the period of 1948-1990 (I_h=230). The detrended data are shown in Figure 1B.

MTM spectral analysis was applied to the annual detrended time series of I_h. MTM analysis revealed periods of ~9-10 years, ~4.7 years and ~2.3 years at confidence level of ≥90% (see Figure 2A). These peaks seem to coincide with the main spectral peaks of the aa-index of geomagnetic activity (see Figure 2B).

Seasonal patterns of CVD mortality for the period of 1948-2010 are illustrated in Figure 3. The comparative analysis revealed significant differences in seasonal distributions of CVD mortality in relation to sex and age groups. As we can see from Figure 3A, total male CVD deaths show two significant peaks in May and September. Another winter peak is also present, but is not significant. The May maximum is dominant for all males, but not for the oldest age (≥70 years) group (Figure 3B). In the oldest age group winter and September peaks are significantly higher, than the annual average (see Figure 3B). Total female CVD deaths show two significant maxima in winter and autumn and one insignificant spring peak (see Figure 3C). Seasonal distribution of the moderate magnetic storms for the period studied is also presented in Figure 3D. The bimodal pattern of spring and autumn peaks is evident at this distribution (see Figure 3D). This bimodal pattern of seasonal variation is also presented in the female and male oldest age (≥70 years) groups (see Figures 3B, C). It should be noted that winter peaks are presented in all seasonal variations of CVD death events.

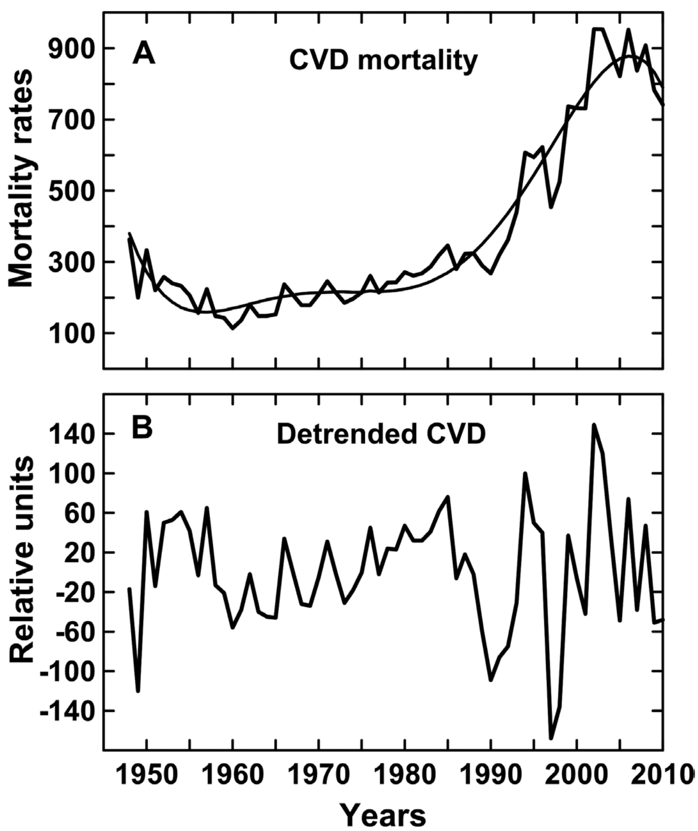

Figure 1. Variations of CVD mortality rates (the number of deaths per 100 000 persons) at Kirovsk during 1948-2010. (A) Original time-series (thick line) and a 5th order polynomial fit (dashed line). (B) Detrended CVD data obtained by subtracting the polynomial fit.

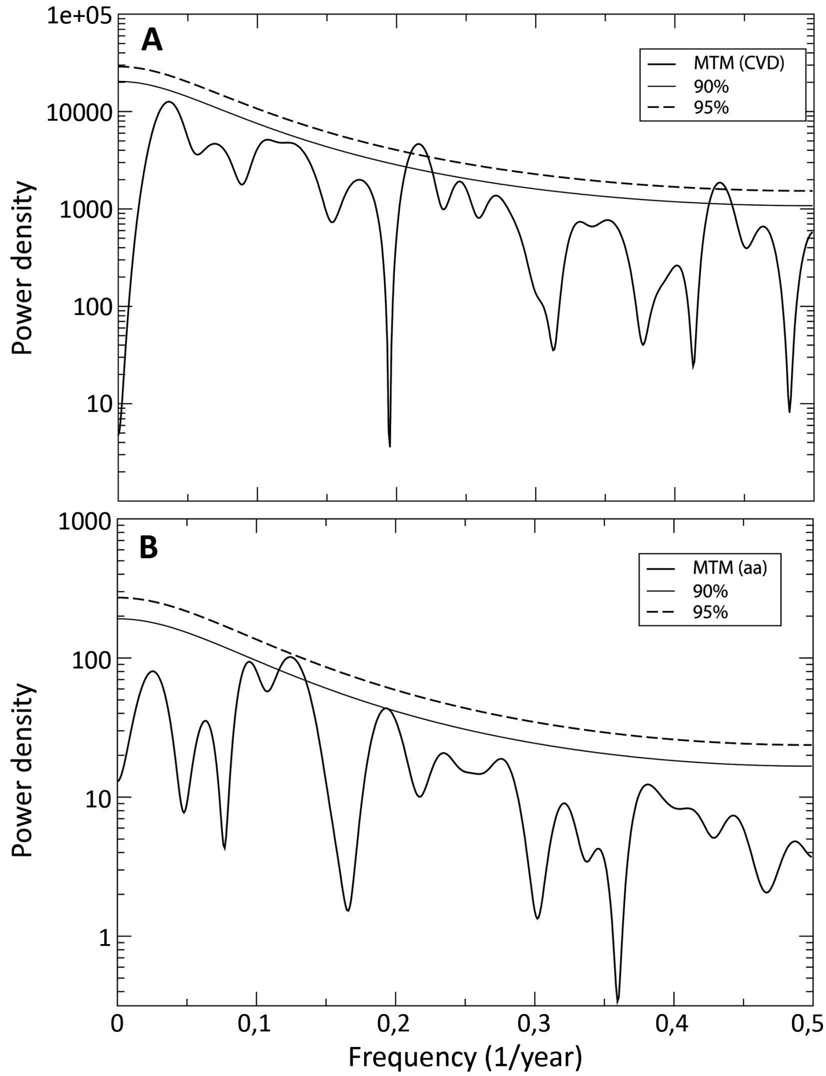

Figure 2. MTM spectrum analysis of CVD mortality rates at Kirovsk (A) and geomagnetic aa-indexes (B) over 1948-2010. The thin and dashed lines denote the 90% and 95% levels of significance respectively.

In this paper, the effect of air pollution on CVD mortality was assessed. Murmansk Oblast is one of the industrialized and densely populated regions of Russia. The world's largest producer of phosphate-based fertilizers Apatit company is located in Kirovsk. Another largest Russian nickel-copper plant "Severonikel" is located in the town of Monchegorsk (67.9N, 32.9E) at a distance of 80 km from the town of Kirovsk. Figure 4 shows the variation of CVD mortality I_h in Kirovsk and emissions of copper Cu, nickel Ni, sulfur dioxide SO_2 and solid substance Sd from "Severonikel" plant for the period from 1995 to 2009 (Karnachev *et al*., 2014). It is clearly seen that any connection between CVD deaths and air pollution does not exist.

Discussion

As it was noted earlier, a sharp increase has been observed in CVD death rate since 1991 (more than twice compared to the period of 1948-1990), which, most likely, was connected with socio-economic stresses during that time in Russia (see Figure 1A). It should be as well noted that in some studies this growth of mortality in Russia is explained by the end of the anti-alcohol campaign and increased alcohol consumption in the 1990s (Shkolnikov *et al*., 1998; Norstrom, 2011). Sure, as one can see from Figure 1b, some reduction in CVD mortality in the period of 1985 – 1991 seemed to be nearly connected to the period of the anti-alcohol campaign, but it was not

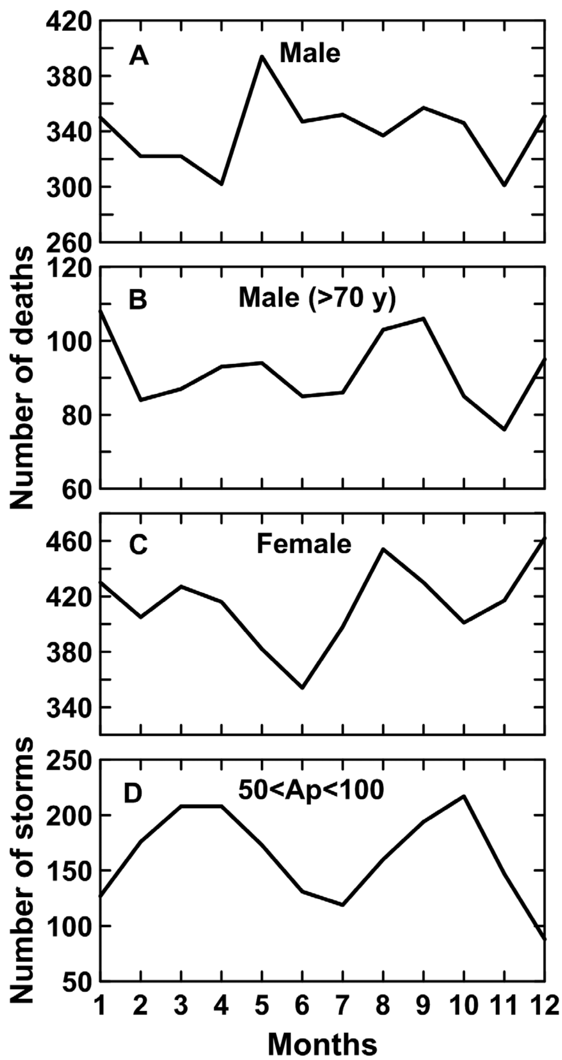

Figure 3. Seasonal distribution of the number of CVD deaths at Kirovsk for total male (A), for male old age (> 70 years) group (B) and for total female (C); seasonal distribution of the moderate (50<Ap<100 nT) magnetic storms (D).

significant compared with other variations. The subsequent sharp increase in CVD deaths was significantly higher than the previous level of it. This result does not contradict with the conclusion that socioeconomic dispossession might have been considered as a possible risk factor for CVD deaths (Pujades-Rodrígues *et al*., 2014).

Kola Peninsula is located within the auroral zone of geomagnetic activity. Due to the specific configuration of the geomagnetic field lines high latitudes are quite different from middle and low latitudes in the intensity and the spatial and temporal characteristics of the cosmophysical factors. As a rule those factors are more pronounced at here. The influence of cosmophysical factors on human health is reflected in Figure 2. Here the results of MTM-spectrum analysis of CVD death rate are given. Analysis of the distribution of CVD deaths in Kirovsk revealed periodicity of ~9-10 years attributed to solar cycle. The periods of ~4.7 years and ~2.3 years observed are also correlated with similar periodic variations in and geomagnetic aa-indexes (see Figure 2B). These periods seem to be the third and the fifth harmonics of the 11-year solar cycle, respectively.

Total female CVD deaths demonstrate two significant peaks in winter and autumn and one non significant spring peak (see Figure 3C). A similar pattern in CVD deaths is evident in the male oldest age (≥70 years) group (see Figure 3B). The bimodal pattern of seasonal variation with two equinoctial maxima is also presented in the seasonal distribution of the moderate magnetic storms (see Figure 3D). It is as well known that the bimodal pattern of seasonal variation with equinoctial maxima in March-April and September-October is typical for the distribution of the magnetic storms in the weak-to-moderate categories of storm intensity (Gonzalez *et al*., 2002). This seems to be connected to the seasonal change in the geometry of the Earth's magnetic field relative to the direction of the interplanetary magnetic field (Russel and McPherron, 1973). At the same time, it seemed to be difficult to associate the presence of the winter peak in total CVD deaths with geomagnetic activity. Note, that the seasonal pattern of CVD mortality with a winter peak is observed at some countries in both the Southern and Northern hemispheres, being higher at middle latitudes (Douglas *et al*., 1995; Douglas and Rawles, 1999; Healy 2003; Kleimenova *et al*., 2007; Diaz-Sandoval *et al*., 2011; Marti-Soler *et al*., 2014). Thus, the effect of winter peak in CVD mortality has a global nature. At some studies it had been concluded that temperature alone cannot explain the winter peak in CVD deaths (Douglas and Rawles, 1999; Healy, 2003; Diaz-Sandoval *et al*., 2011). As it concerns the May maximum in total male CVD deaths a similar result was obtained for all male admissions with coronary heart diseases (CHD) in Scotland (Douglas *et al*., 1995). These authors showed that the dominant May increase in CHD is a predominantly male phenomenon and replaced in the older male age group (> 75 years) by a bimodal pattern (Douglas *et al*., 1995). These conclusions are consistent with our results (see Figure 3A, B). Therefore, to our mind, the cause of the age related May peak in male CVD deaths seems to have no relation to geomagnetic activity. Douglas *et al*. (1995) suggested that the male, age related May maximum in CHD was caused by emotional and physical effects of increased hormones in spring in men having cardiovascular disorder. Note that Mikkola *et al*. (2013) showed that there were sex-related differences in CVD mortality.

Thus the contribution of geomagnetic activity to the distribution of CVD deaths seems to be real, but not significant, socioeconomic factors being predominant. This confirms our previous studies, where it was shown that only in 15% of cases, geomagnetic activity had an adverse effect on the intrauterine development of the fetus at high latitudes (Shumilov *et al*., 2003). The influence of geomagnetic disturbances is predominant on female and older male (>70 years) CVD deaths.

Electromagnetic emissions (EME) are considered as the most probable cosmophysical factors that influence the human organism. Some studies suggest as a critical factor that affects the human cardiovascular system are geomagnetic micropulsations Pc1 and Pi1 having a frequency (0.2 – 5 Hz) comparable with the frequency of heart rate beatings (Kleimenova *et al*., 2007; Samsonov *et al*., 2014). Geomagnetic pulsations Pc1 are connected with geomagnetic storms and demonstrate a winter maximum in their occurrence (Kleimenova *et al*., 2007). In turn, micropulsations Pi1 are observed at high latitudes during geomagnetic substorms and seem to have a bimodal pattern with two equinoctial maxima in their seasonal distribution (Samsonov *et al*., 2014). So, the appearance of additional equinoctial maxima in the CVD death occurrence at high latitudes may be explained by the influence of micropulsations Pi1 on the heart rhythm (see Figure 3). Nearly similar seasonal pattern with multiple peaks was found in the ambulance calls for myocardial infarction in Yakutsk (subauroral latitudes) (Samsonov *et al*., 2014). Synchronization of rhythms of the heart with geomagnetic field variations can occur taking into account that the human organism is an open non-linear system being in the state of non-stable dynamic balance (Kleimenova *et al*., 2007; Breus *et al*., 2008; Samsonov *et al*., 2014).

Another important property of EME, found experimentally, is its capability of affecting the secretion of melatonin – one of the main hormones (the hormone of pineal gland or epiphysis) (Weydahl *et al*., 2001). Melatonin is one of the most important regulators of the immune system and biological rhythms in animals and men acting as a free radicals absorber and an antioxidant in organism (Cherry, 2002). It was shown that at high latitudes the geomagnetic disturbances, with a well manifested daily course, perform the part of an exterior synchronizer of biological processes in human organism by affecting the melatonin production (Weydahl *et al*., 2001).

Note that our results showed no significant association between air pollution and CVD mortality (see Figure 4). This does not contradict to other studies where the main pollutants affecting the cardiovascular diseases and mortality are fine particles and SO_2 (Dockery, 2001; Lin *et al*., 2004). Most of these results were obtained exclusively for highly urbanized regions (Dockery, 2001; Lin *et al*., 2004).

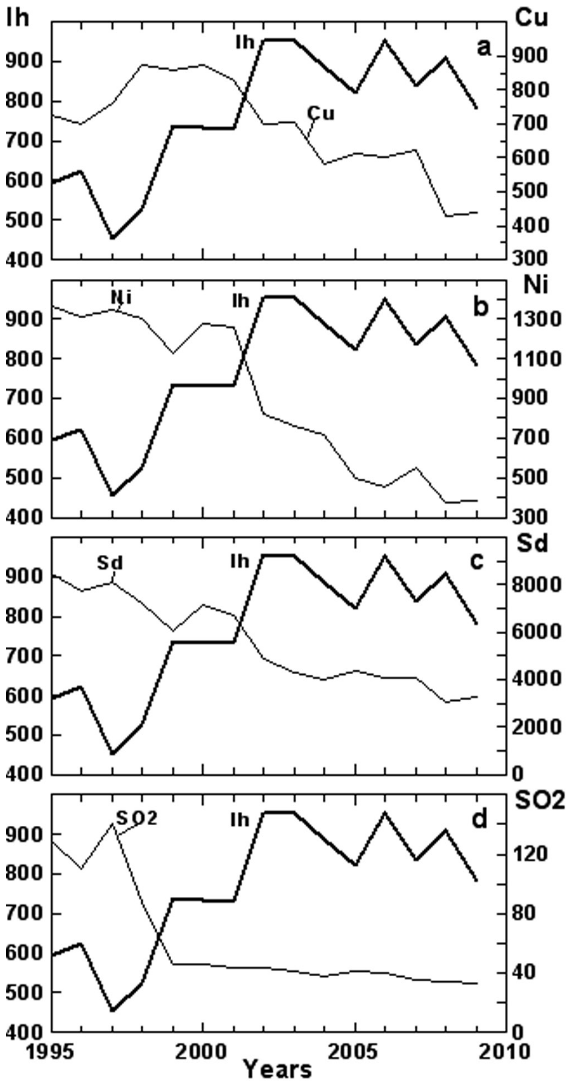

Figure 4. Variations of CVD mortality rates *Ih* at Kirovsk (curve 1) and emissions of atmospheric pollutants by "Severonikel" plant (curve 2): Cu (tons/year) (a), Ni (tons/year) (b), fine particles Sd (tons/year) and SO_2 (thousands tons/year).

Conclusions

1. A sharp increase has been observed in CVD death occurrence in Kirovsk since 1991 (more than twice compared to the period of 1948-1990), which, more likely, was connected to socio-economic stresses during that period in Russia. Some reduction of CVD mortality rate in the period of 1985 – 1991 seemed to be caused by some effects of the anti-alcohol campaign, however it was not significant compared with other variations.

2. Our analysis revealed significant differences in seasonal distributions of CVD mortality depending on sex and age groups and their response to external geomagnetic disturbances. The influence of geomagnetic disturbances is predominant in female and older male (>70 years) CVD deaths. The cause of the age related May peak in male CVD deaths seems to have no relation to geomagnetic activity being explained by emotional and physical effects of increased hormones of men during spring time.

3. MTM-spectral analysis of the distribution of CVD death events in Kirovsk revealed periodicity of ~9-10 years attributed to the solar cycle. The periods of ~4.7 years and ~2.3 years are rather well correlating with similar periodic variations in geomagnetic aa-indexes.

4. The contribution of geomagnetic activity to the variations of CVD death rate seems to be real, but not significant, socioeconomic factors are predominant.

5. Our results demonstrated no significant association between air pollution and CVD mortality in the region.

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