2009). Assuming a multiplicative risk model and an average level of the natural background radiation of approximately 1 mSv/a yields a doubling dose of approximately 4 mSv/a for childhood leukemia. Since childhood leukemia was doubled within 5 km of all German NPP (Kaatsch et al. 2008), this would mean, in reverse, that some kind of dose equivalent of 4 mSv/a was acting within 5 km of NPP. As Scherb and Voigt (2007) have shown, the sex odds ratio per mSv/a is in the order of magnitude of 1.015 per mSv/a. Thus, 4 mSv/a would yield a sex odds ratio of 1.06, and this in turn would distort the normal sex odds of 1.05 in central Europe to a sex odds in the vicinity of NF to 1.11. This means that a normal proportion male (p_{m0}) of H_0: $p_{m0} = 0.51$ would increase to H_1: $p_{m1} = 0.53$. As we have approximately 110 000 births within 5 km distance from NF in our study region, the power of the two-sample Binomial test for testing H_1 against H_0 would be close to 100% for this rather large effect. On the other hand, if the effect within 5 km of NF was in the range of an equivalent increase of 1 mSv/a, i.e. in the range of a doubling of the natural background radiation, then the power were 75%. Therefore, if the additional dose caused by NF within 5 km was in the range of 1 mSv/a, then the power of our data was nearly sufficient. The power were totally insufficient within 5 km distance if the effect was in the order of magnitude of some fraction of 1 mSv/a, say 0.2 mSv/a (power ≈ 8%), similar to the overall Chernobyl exposure in the average in all of Europe (Drozdovitch et al. 2007). On the other hand, as we have nearly 5 million live births within the 35 km circles of the NF, the power for such a 0.2 mSv/a equivalent within 35 km distance were 79%.

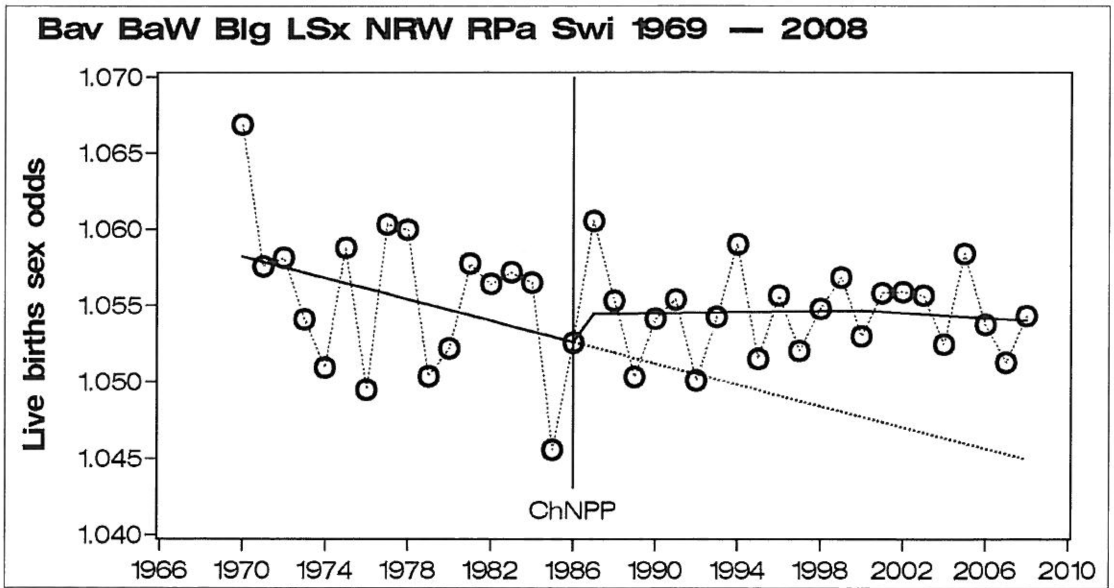

Figure 3: Trend of the live births sex odds (male/female) in Belgium (Blg), Switzerland (Swi), Baden-Württemberg (BaW), Bavaria (Bav), Lower Saxony (LSx), and North Rhine-Westphalia (NRW), and Rhineland-Palatinate (RPa) combined.

3. Results

As one of a number of elementary plausibility checks, we retrieved the annual sex odds trend from the compiled municipality-specific data set for the whole study region (n = 316 360). As the study region is situated in the central part of Europe, with less extreme low or less extreme high levels of Chernobyl fallout, one may expect a trend similar to the overall (average) European trend in Figure 1. The consistent and affirmative result is shown in Figure 3. However, whereas all the effects in Figure 1 (jump and broken stick effects) are highly significant (Scherb 2010), the corresponding effects in Figure 3 are not significant. One of the reasons for these non-significant effects ($p>0.1$) is the relatively small number of observations available here. In Europe (Figure 1), we have roughly 10 times more births than in our study region. From the non-significance of the temporal effects in Figure 3, we may conclude that for preliminary and orientating analyses of distance from NF sex odds trends there will be most likely no relevant temporal confounding. Consequently, in the following distance trend analyses, the only temporal components included will be the operational time periods of NF. Taking into account the secular downward trends of the sex odds and the Chernobyl effect is probably not relevant at this stage.

During the operation time periods of the ascertained total 28 NF in Germany and Switzerland, lagging for gestation period, and within 5 km distance from these sites, there is a non-significantly increased sex odds with a sex odds ratio vs. the remainder of the study region and non-operational time periods of SOR_{5km} = 1.0056, p = 0.3615. However, within the distances of 15 km, 30 km, and 50 km, with higher statistical power due to larger populations, we may observe more precisely estimated elevated sex odds ratios of SOR_{15km} = 1.0040, p = 0.0463, SOR_{30km} = 1.0035, p = 0.0026, and SOR_{50km} = 1.0017, p = 0.0567. Because there seems to be an optimum balance between effect strength and statistical power (population size) somewhere between 30 km and 40 km, we emphasize the distance 35 km in Table 2 and Figure 4. In Table 2 we list the 35 km SOR and p-values for single NF. Conversely, in the sense of a NF-specific sensitivity analysis, we also list p-values of the overall comparisons with the specific NF excluded ("hold one NF out"). No NF has a dominating influence on the overall effect. This is similar to the KiKK study.

Figure 4 to Figure 7 show the sex odds within 1-km-distance rings vs. the distance from the nearest NF in Switzerland and in the German states combined. The 35 km jump model and the Rayleigh model are significant: p = 0.0006 and p = 0.0023 (F-test). The simple reciprocal distance trend model reaches only one-sided borderline significance (p = 0.1240, F-test), but may be mis-specified in case the presumable dose response association was nonlinear or exposure was non-monotonic in the near vicinity of the NF. The reciprocal distance model restricted to the data above 10 km distance fits the data somewhat better (p = 0.0016, F-test).

4. Discussion

An important task of environmental health research is the investigation of a possible causal relationship between exposure and the frequency of a biological trait. Changes in the sex odds of officially recorded population-based statistics, e.g., live births, stillbirths, or cancer incidence, may be sentinel indicators for detrimental health effects of more or less concealed changes in the environment. Since sex odds shifts have been observed after the Chernobyl accident, and an increased childhood cancer incidence was seen in the vicinity of NPP, the question arises whether the human sex odds at birth is also distorted in the vicinity of NF. Because childhood leukemia was approximately doubled within 5 km distance from German reactors (Kaatsch et al. 2008), we looked at the secondary sex odds in the vicinity and within operation time periods of NF in Belgium, Switzerland, and the following parts of Germany: Baden-Württemberg, Bavaria, Lower Saxony, North Rhine-Westphalia, and Rhineland-Palatinate (geo-spatial temporal approach). As Belgium reveals a relatively low overall sex odds, has only 3 NF, and has a restricted observation period beginning in 1989 only, Belgium was excluded for the purpose of the present paper. In the German and Swiss data, there is a non-significant increase of the sex odds below 5km from NF. However, within greater distances of 15 km, 30 km, or 50 km we observe significant or borderline significant increases of the sex odds. Because an impartial Rayleigh function is also significant, this could mean that exposure to emitted radio nuclides is non-monotonically distributed and/or that dose response relations are non-linear, yielding an (apparent) maximum risk at about 15 km distance. Consequently, this pilot investigation yields some evidence of a relatively far-reaching genetic effect in the vicinity of 28 NF in Germany and in Switzerland. Further studies in this important area of environmental health research are recommended.

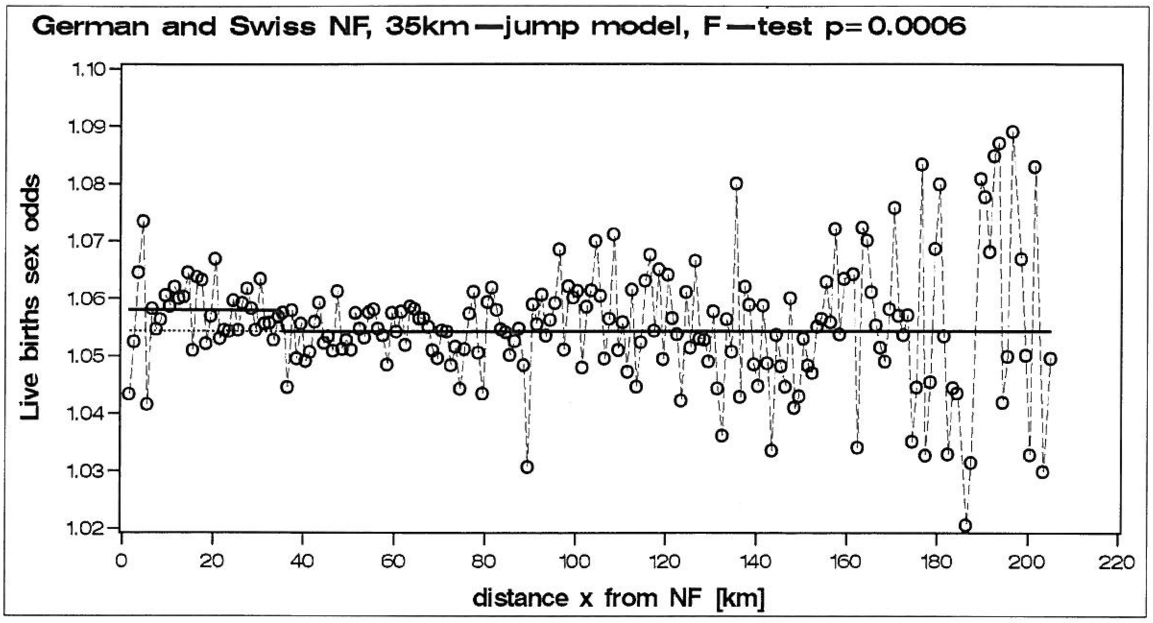

Figure 4: Distance trend model: ln(sex odds) = a + b*d_{35km}(x); a = 0.0530, 95%-CI = [0.0520, 0.0540]; b = 0.0035, 95%-CI = [0.0014, 0.0055]; SOR_{jump} = 1.0035.

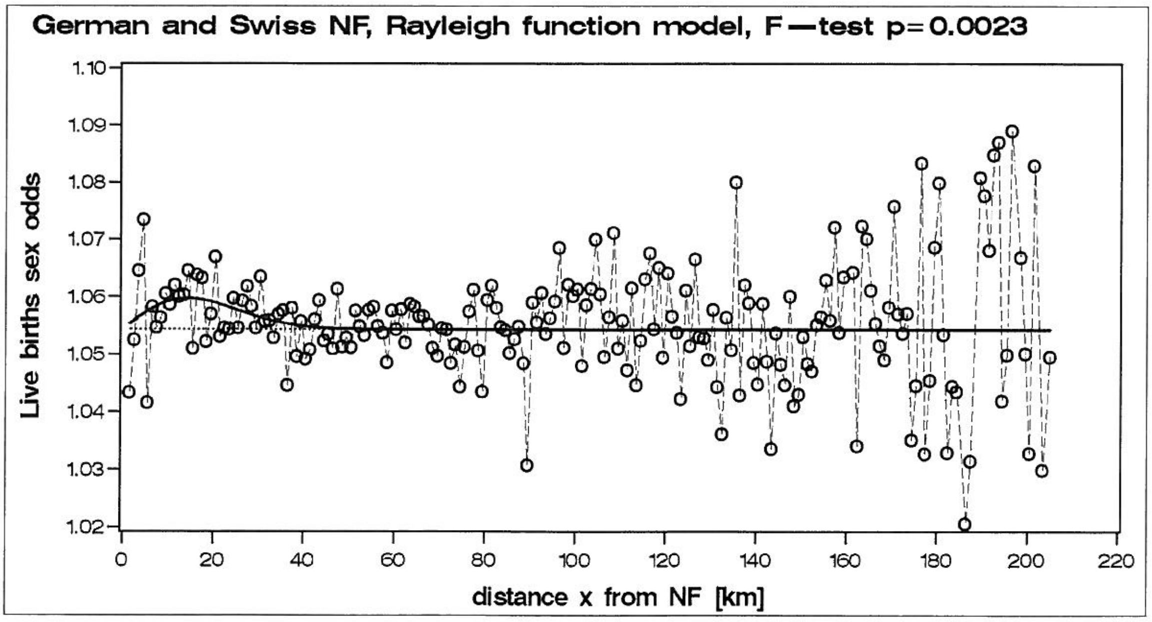

Figure 5: Distance trend model: ln(sex odds) = a+b*x*exp(-c*x^2); a = 0.0529, 95%-CI = [0.0519, 0.0540]; b = 0.00058, 95%-CI = [0.00010, 0.00106]; c = 0.00240, 95%-CI = [0.00058, 0.00422]; peak at 14.4 km, SORpeak = 1.0051.