Annual changes in the Fukushima residents’ views on the safety of water and air environments and their associations with the perception of radiation risks

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(Received 4 July 2017; revised 27 September 2017; editorial decision 15 December 2017)

ABSTRACT

Fukushima residents’ negative views on the safety of water and air environments have been a concern since the Fukushima Dai-ichi Nuclear power plant (FDNPP) accident. The objective of this study was to clarify the factors determining these negative views and their association with radiation risk perception using the opinion poll conducted by Fukushima Prefecture from 2010 to 2015. In a model, in which the objective variables were the views on the safety of water and air environments, and the explanatory variables were the regions constituting Fukushima and the age and sex of the residents, the odds ratio (OR) of the views on the safety of the water and air environments (reference region: the least affected region) was significantly low at 0.11 [95% confidence interval (CI): 0.04–0.28] to 0.18 (0.07–0.46) in the Hamadori region including the evacuation order area, from the accident in 2011 to 2015, with the exception of 2014. In another model, in which the region was excluded from the explanatory variables and radiation risk perception, the distance from the FDNPP and the air dose rate were added to the previous model as an explanatory variable, the views on the safety of the water and air environments were strongly associated with low radiation risk perception (low anxiety) in 2012–2015 [OR: 7.73 (5.25–11.4) to 10.3 (6.71–15.8)], distance from FDNPP, and age, but not with air dose rate. This result suggests that the radiation risk perception, distance from FDNPP, and age were factors determining people’s views on the safety of the water and air environment.

Keywords: annual changes; Fukushima disaster; radiation risk perception; safety views

INTRODUCTION

A large amount of radioactive material was released into the environment by the Tokyo Electric Power Company’s Fukushima Daiichi Nuclear power plant accident caused by the Tohoku earthquake and tsunami on 11 March 2011. The released amounts were estimated to be 100–500 PBq for ¹³¹I and 7–20 PBq for ¹³⁷Cs, and 23% of the ¹³⁷Cs released into the atmosphere was estimated to be deposited on the land surface of Japan [1]. The accident posed a risk of external and internal radiation exposure, and the radiation exposure in the affected areas has been estimated to be 20–30 mSv as the lifetime effective dose [2]. Although the dietary-derived internal exposure was extremely low in 2017 (0.001 mSv/year) [3], the accident has resulted in multiple risks for the residents, including psychological stress associated with risks due to evacuation [4] and anxiety about radiation [5]. Multiple risks caused many problems for various activities [6]. Many residents evacuated from the evacuation order...
area and other contaminated areas, and the total number of refugees peaked at about 165,000 people in May 2014 [7]. Various countermeasures have been taken since the accident to eliminate these adverse effects. Important countermeasures have included decontamination to reduce the external exposure risk, which was implemented mainly in living spaces such as houses, public facilities, and roads. For water environments such as rivers and lakes, riverside parks were also decontaminated [8]. In addition, the national and local government, research institutions, etc., have taken countermeasures against radioactive materials in the water environment to secure the residents’ safety and reduce their anxiety, including monitoring rivers and lakes, inspecting tap water, taking countermeasures against radioactive materials in agricultural ponds, and researching the environmental dynamics of radioactive materials. These countermeasures have eliminated various risks to the residents, leading to the lifting of evacuation orders and helping the residents to return to their homes.

Although these efforts have made progress, residents’ concerns about the safety of the water and air environments have still not been completely resolved. One reason why evacuees have not yet returned is their anxiety about the safety of the water [9]. Although the number of participants in waterside educational events was the largest in Japan prior to the accident, the number has not yet recovered to the former level [10]. The tendency to avoid drinking tap water has been reported to differ greatly by region, and the proportion of people avoiding drinking tap water was near 80% of those in cities where evacuation was ordered [11].

Among the various risks, fear and anxiety about radiation are particularly high [12], and a high perception of risk is known to lead to food avoidance [13]. Kahneman noted that ‘Rational or not, fear is painful and debilitating, and policy makers must endeavor to protect the public from fear, not only from real dangers’ [14]. While decontamination and FDNPP decommissioning work are progressing, it is reported that anxiety about a limited decrease in the air dose rate and the safety of the FDNPP is a factor in interfering with the return of residents [9]. It is necessary to clarify people’s real perception of radiation risks and how this affects their views on safety, as well as to clarify the actual exposure and risks of radiation. It is also necessary to investigate whether views on the safety of the water and air environments and/or radiation risk perception are associated with the contamination level with radiocesium in the residential environment and concern about long-term FDNPP decommissioning and entry of radioactive materials from FDNPP to the ocean via groundwater. Even though 6 years has passed since the accident, it is essential that the long-term trends in the residents’ anxiety about the water and air environments and their perception of radiation risks are established in order to make effective countermeasures to restore confidence in the safety of the water and air environments. However, temporal changes in views on the safety of the water environment and air environments after the accident, factors influencing the views on safety, and radiation risk perception have not been adequately studied to date.

In this study, we investigated the annual changes in residents’ views on the safety of the water and air environments and their the radiation risk perception by using the annual public opinion survey conducted by the Fukushima Prefectural Government. In order to clarify factors influencing the radiation risk perception, we evaluated the association between the radiation risk perception, age, sex, region of residence, distance from FDNPP, and air dose rate of the survey year, by using cross tabulation and binomial logistic regression analysis.

MATERIAL AND METHODS
Ethics approval
Ethics approval for this study was granted by the Fukushima Medical University Ethics Committee (Approval No. 2899).

Site description
Fukushima Prefecture is located within 200 km of Tokyo and covers an area of ~13.8 thousand square kilometers. The prefecture comprises three regions (Aizu, Nakadori and Hamadori), largely defined by topography and climatology (Fig. 1). The population is ~1.9 million as of January 2017 [15]. Approximately 70% of the total area is covered with forest, and there are abundant water resources, including many lakes and rivers, water springs and groundwater. This rich water environment has fostered biodiversity and various activities of the residents since the olden days [16].

Annual public opinion survey by the Fukushima Prefectural Government
A public opinion survey on prefectural policies is conducted every year by the Fukushima Prefectural Government to investigate the opinions and needs of the residents as a basis for policy countermeasures. The subjects were sampled from selected cities, towns and villages in the prefecture, including males and females aged 15 years or older by a stratified two-stage random-sampling method; the survey subjects vary every year. The questionnaires were reviewed each year and revised when necessary. The questionnaires were sent by mail to 1300 subjects each year, and the effective response rate was 54.8% to 63.4% (Supplementary Table 1) [17].

This study focused on the respondents’ age, sex, and living region as their personal attributes. Living region for evacuees refers to living region before the accident. Two questions were asked: ‘Do you feel that your living environment is safe from environmental pollution, including water and air pollution? (measuring the people’s views on safety of the water and air environments)’ and ‘Is your living space secure from radiation? (measuring their anxiety about radiation risks)’. The questions on safety views and on anxiety levels about radiation risks have been included since 2010 and 2012, respectively. Five choices were provided for answers: ‘yes,’ ‘somewhat yes,’ ‘neither yes nor no/not applicable,’ ‘somewhat no,’ and ‘no.’

Statistical analysis
First, we analyzed the differences in the views on safety of the water and air environments and in the anxiety levels about radiation risks between 2011 and 2015 for each region by using the Chi-squared test. For the views on safety of the water and air environments, we also analyzed the difference between 2010 and 2011. Bonferroni corrections were not applied in these tests. We analyzed the differences in these factors for each of the personal attributes by using the Chi-squared test and residual analysis. Next, binomial logistic regression analysis was
conducted the views on safety of the water and air environments as the objective variables. The explanatory variables were age, sex, and living region in Model 1, and anxiety about radiation risks was added to the variables of Model 1 for Model 2. In Model 3, distance from FDNPP and air dose rate in the survey year were added to the explanatory variables of Model 2 as indicators of anxiety about the long-term FDNPP decommissioning work and the contamination level of radioce- sium in the residential environment. The air dose rate reflected the radioceium concentration in the surrounding soil [18] and was suitable as the indicator. The residential area was excluded from the explanatory variables in Model 3 because the distance from FDNPP and the residential area showed a high variance inflation factor (VIF) (VIF > 10) and multicollinearity. We excluded anxiety about radiation risks from the explanatory variables of Model 3 (Supplementary Model 1) in order to identify factors other than radiation risk perception influencing views on safety of the water environment and air environments. Furthermore, in order to evaluate factors influencing radiation risk perception, we used a binomial logistic regression analysis with anxiety about radiation risks as the objective variable, and age, sex, distance from FDNPP and survey year as explanatory variables (Supplementary Model 2).

In the analysis, we classified the data as follows. First, we excluded responses from those under 20 years old, and responses that were incomplete or unreadable. Next, for the personal attributes, the age was classified into five groups (20s, 30s, 40s, 50s, and 60s and older) and the living region into four groups based on the affected level [Aizu, Nakadori, Hamadori excluding evacuation order areas (EOAs), and Hamadori including EOAs] (Fig. 1 and Supplementary Figure 1). The answers were classified into two groups: ‘yes’ and ‘somewhat yes’ were classified as ‘1,’ and ‘neither yes nor no/not applicable,’ ‘somewhat no,’ and ‘no’ were classified as ‘0.’ The references for the odds ratio (OR) were female for sex, 20s for age, and Aizu (the least affected region) for the living region. IBM SPSS Statistics 24 was used for the regression analysis. The distance from FDNPP was the distance (km) from FDNPP to municipal offices in the administrative districts where the respondents of the opinion survey lived. The means ± standard deviations (SD) of the distance for all the respondents were 62.6 ± 23.6 in 2012, 62.9 ± 22.5 in 2013, 61.8 ± 23.0 in 2014, and 61.5 ± 21.3 in 2015. The air dose rate (mSv/year) was value measured with real-time dosimeters at the municipal office at 0:00 on the start date of the opinion survey, and was obtained from the Nuclear Regulation Authority website (when unavailable, the value measured at a point near the municipal office was used) [19]. The air dose rate declined year by year, and the means ± SDs for all the municipal offices were 3.19 ± 4.92 in 2012, 1.93 ± 1.93 in 2013, 1.43 ± 0.64 in 2014, and 1.40 ± 1.80 in 2015. Low multicollinearity (variance inflation factor < 4.5) was confirmed in the analysis. In these analyses, the significance level is a P value of ≤0.05. Ethical approval for this study was granted by the Fukushima Medical University Ethics Committee (Approval number: 2899).

RESULTS

The percentage of people with high safety views on the water and air environments in 2015 for sex, age, and living region are shown in Supplementary Figure 3, and the annual changes in 2010–2015 for the regions are shown in Fig. 2. For the regions, the percentage of people with high safety views was 78% for Aizu, 58% for Nakadori, 59% for Hamadori excluding EOAs, and 34% for Hamadori including EOAs. The percentage of people with high safety views was significantly low in Hamadori including EOAs, and
significantly high in Aizu. Comparing the findings before and after the accident (2010 and 2011) indicates that the percentage of people with high safety views decreased significantly after the accident in all regions except Aizu: from 66% to 60% in Aizu, 65% to 23% in Nakadori, 59% to 14% in Hamadori excluding EOAs, and 69% to 20% in Hamadori including EOAs. When comparing findings for the year immediately after the accident (2011) with the data for 5 years later (2015), the percentage of people with high safety views increased significantly in 2015 in all regions except Hamadori including EOAs: from 60% to 78% in Aizu, 23% to 40% in Nakadori, 12% to 31% in Hamadori including EOAs, and 34% to 45% in Hamadori excluding EOAs. While the percentage of people with low anxiety in Aizu has recovered to the same level as or higher than that before the accident, it was still lower than the level before the accident in Hamadori including EOAs, even after 5 years. While the percentage of people with high safety views did not differ significantly in 2015 between males and females, those for age were significantly low in the 40s group and significantly high in the 60s and older group: 44% for males, 46% for females, 46% for 20s, 37% for 30s, 34% for 40s, 48% for 50s, and 49% for 60s and older.

The percentages of people with low anxiety (answers with ‘neither yes nor no/not applicable,’ ‘somewhat no,’ and ‘no’) about radiation risks in 2015 for sex, age, and region are shown in Supplementary Figure 4, and the annual changes in the regions in 2012–2015 are shown in Fig. 3. For the regions, the percentages of people with low anxiety in 2015 were significantly low in Nakadori and significantly high in Aizu: 73% in Aizu, 40% in Nakadori, 45% in Hamadori excluding EOAs, and 31% in Hamadori including EOAs. When comparing the data for 2 and 5 years after the accident (2012 and 2015), the percentages of people with low anxiety increased significantly in Aizu, Hamadori including EOAs, and Nakadori: from 60% to 73% in Aizu, 23% to 40% in Nakadori, 12% to 31% in Hamadori including EOAs, and 34% to 45% in Hamadori excluding EOAs. While the percentages of people with low anxiety did not differ significantly in 2015 for sex, those for age were significantly low in the 40s group and significantly high in the 60s and older group: 44% for males, 46% for females, 46% for 20s, 37% for 30s, 34% for 40s, 48% for 50s, and 49% for 60s and older.

Table 1 shows the results of binomial logistic regression analysis for Model 1. Between the regions, the ORs did not differ significantly before the accident (2010). However, the ORs were significantly lower than 1 after the accident (2011) in all areas and years, except in Hamadori including EOAs in 2014. This means that opinions of the safety of water and air environments were lower in Nakadori and Hamadori excluding EOAs, than in Aizu. When comparing the ORs in 2011 and 2015, although the ORs increased for Nakadori, and for Hamadori excluding EOAs, those for Hamadori including EOAs were almost constant. The ORs for sex were also almost constant. Those for age in 2015 were high in the ‘60s and older’ group [3.49, 95% confidence interval (CI): 1.74–7.02], indicating a relatively strong association between views on safety and age group.

Table 2 shows the results of binomial logistic regression analysis for Model 2. For 2015, the ORs were 5.11 (95% CI: 2.21–11.8) for the 60s and older group, 0.22 (95% CI: 0.08–0.61) for Hamadori including EOAs, and 10.2 (95% CI: 6.61–15.8) for low anxiety about radiation risks (i.e. low radiation risk perception). The ORs for low radiation risk perception were particularly high [8.12 (95% CI: 5.47–12.0) to 10.4 (95% CI: 6.78–15.8)] throughout the entire
Table 1. Binomial logistic regression analysis for Model 1 was conducted with the views on safety of the water and air environments as the objective variables

|        | 2010 Odds ratio (95% CI) | 2011 Odds ratio (95% CI) | 2012 Odds ratio (95% CI) | 2013 Odds ratio (95% CI) | 2014 Odds ratio (95% CI) | 2015 Odds ratio (95% CI) | 2010–2015 Odds ratio (95% CI) |
|--------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|------------------------------|
| Male   | 1.04 (0.76–1.44) ns      | 1.31 (0.91–1.89) ns      | 1.39 (1.00–1.94) *       | 1.18 (0.86–1.62) ns      | 1.23 (0.88–1.71) ns      | 1.27 (0.90–1.78) ns      | 1.22 (1.07–1.39) **          |
| Female (ref) | 1                     | 1                       | 1                        | 1                        | 1                        | 1                        | 1                            |
| 20–29 years (ref) | 1                     | 1                       | 1                        | 1                        | 1                        | 1                        | 1                            |
| 30–39 years  | 1.01 (0.52–1.95) ns      | 1.50 (0.60–3.72) ns      | 0.70 (0.31–1.57) ns      | 1.93 (0.84–4.44) ns      | 0.80 (0.37–1.70) ns      | 1.64 (0.73–3.67) ns      | 1.13 (0.83–1.55) ns          |
| 40–49 years  | 1.26 (0.66–2.38) ns      | 1.47 (0.60–3.59) ns      | 0.86 (0.39–1.94) ns      | 1.60 (0.71–3.61) ns      | 2.08 (0.99–4.39) ns      | 1.53 (0.70–3.34) ns      | 1.38 (1.01–1.88) *           |
| 50–59 years  | 1.69 (0.91–3.14) ns      | 1.98 (0.86–4.57) ns      | 1.04 (0.49–2.22) ns      | 2.38 (1.09–5.18) *       | 1.55 (0.76–3.16) ns      | 1.97 (0.92–4.24) ns      | 1.66 (1.23–2.23) ***         |
| 60 years and older | 2.45 (1.38–4.35) **      | 4.00 (1.83–8.75) ***     | 1.68 (0.83–3.39) ns      | 4.03 (1.96–8.29) ***     | 2.40 (1.25–4.60) **      | 3.49 (1.74–7.02) ***     | 2.74 (2.08–3.60) ***         |
| Aizu (ref) | 1                       | 1                       | 1                        | 1                        | 1                        | 1                        | 1                            |
| Nakadori | 0.98 (0.62–1.57) ns      | 0.22 (0.14–0.35) ***     | 0.27 (0.18–0.43) ***     | 0.40 (0.25–0.64) ***     | 0.53 (0.32–0.86) *       | 0.38 (0.22–0.67) ***     | 0.39 (0.32–0.48) ***         |
| Hamadori excluding EOAs | 0.76 (0.44–1.30) ns      | 0.10 (0.05–0.20) ***     | 0.34 (0.20–0.59) ***     | 0.25 (0.15–0.44) ***     | 0.39 (0.22–0.68) ***     | 0.39 (0.21–0.73) **       | 0.31 (0.25–0.40) ***         |
| Hamadori including EOAs | 1.12 (0.48–2.58) ns      | 0.14 (0.06–0.35) ***     | 0.11 (0.04–0.28) ***     | 0.18 (0.07–0.46) ***     | 0.47 (0.20–1.08) ns      | 0.13 (0.05–0.33) ***     | 0.24 (0.17–0.34) ***         |
| 2010    | 3.88 (3.08–4.89) ***     | 0.73 (0.57–0.92) **      | 1                        | 1                        | 1                        | 1                        | 1                            |
| 2011    | 1.47 (1.17–1.84) ***     | 2.60 (2.07–3.27) ***     | 3.02 (2.40–3.81) ***     | 0.73 (0.57–0.92) **      | 1                        | 1                        | 1                            |

The explanatory variables were age, sex, and living region (Model 1). CI = confidence interval, ref = reference, ns = not significant (P > 0.05), *P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001.
shows the results of binomial logistic regression analysis to those of Model 2. The OR for distance from FDNPP was high in 2013 and 2015. These results were similar except in 2014, showing an association between anxiety about radiation risk perception was high [7.73 (95% CI: 5.25–11.4) to 10.3 (95% CI: 6.71–15.8)] over the whole period (2012–2015), indicating a strong association between anxiety about radiation risk and low opinion of the safety of the water and air environments. The air dose rate did not show a significant association with views on safety of the water and air environments.

Table 2 shows the results of binomial logistic regression analysis (Supplementary Model 1). In 2015, the OR was 1.02 (95% CI: 1.01–1.03) for distance from FDNPP and 3.51 (95% CI: 1.75–7.05) for the 60s and older age group. The OR for distance from FDNPP was high [1.01 (95% CI: 1.00–1.02) to 1.02 (95% CI: 1.01–1.03)] over the whole period (2012–2015), showing strong association with views on the safety of the water and air environments. The OR for 60s and older was high in 2013, showing an association with anxiety about radiation risk and low opinion of the safety of the water and air environments. The air dose rate did not show a significant association with the safety view on the water and air environments.

Table 3 shows the results of binomial logistic regression analysis for Model 3. In 2015, the OR was 2.58 (95% CI: 1.00–6.69) for 30s, 5.01 (95% CI: 2.17–11.6) for 60s or older, and 9.96 (95% CI: 6.49–15.3) for low radiation risk perception, and 1.01 (95% CI: 1.00–1.02) for distance from FDNPP. The OR for low radiation risk perception was high [7.73 (95% CI: 5.25–11.4) to 10.3 (95% CI: 6.71–15.8)] over the whole period (2012–2015), and the OR of 60s and older was high in 2013 and 2015. These results were similar to those of Model 2. The OR for distance from FDNPP was >1 except in 2014, showing an association between anxiety about radiation risk and low opinion of the safety of the water and air environments. The air dose rate did not show a significant association with the safety view on the water and air environments. The OR for distance from FDNPP was >1 except in 2014, showing an association between anxiety about radiation risk and low opinion of the safety of the water and air environments. The air dose rate did not show a significant association with the safety view on the water and air environments.

Table 2. Binomial logistic regression analysis for Model 2 was conducted with the views on safety of the water and air environments as the objective variables

|          | 2012 Odds ratio (95% CI) | 2013 Odds ratio (95% CI) | 2014 Odds ratio (95% CI) | 2015 Odds ratio (95% CI) | 2012–2015 Odds ratio (95% CI) |
|----------|--------------------------|--------------------------|--------------------------|--------------------------|-------------------------------|
| Male     | 1.44 (0.99–2.10) ns      | 1.17 (0.82–1.67) ns      | 1.32 (0.90–1.92) ns      | 1.42 (0.96–2.09) ns      | 1.31 (1.09–1.58) **           |
| Female   | 1                        | 1                        | 1                        | 1                        | 1                             |
| 20–29 years | 1                        | 1                        | 1                        | 1                        | 1                             |
| 30–39 years | 0.82 (0.34–2.00) ns      | 2.01 (0.80–5.03) ns      | 0.81 (0.34–1.94) ns      | 2.63 (1.02–6.84) *        | 1.32 (0.84–2.07) ns           |
| 40–49 years | 1.14 (0.47–2.76) ns      | 1.74 (0.71–4.27) ns      | 2.20 (0.95–5.12) ns      | 2.28 (0.90–5.75) ns      | 1.71 (1.10–2.66) *           |
| 50–59 years | 1.07 (0.46–2.48) *       | 2.56 (1.08–6.07) *       | 1.27 (0.56–2.89) ns      | 2.35 (0.95–5.80) ns      | 1.65 (1.07–2.52) *           |
| 60 years and older | 1.80 (0.83–3.89) ns | 3.89 (1.75–8.62) *** | 2.02 (0.96–4.25) ns | 5.11 (2.21–11.8) *** | 2.81 (1.90–4.15) *** |
| Aizu (ref) | 1                        | 1                        | 1                        | 1                        | 1                             |
| Nakadori | 0.49 (0.29–0.81) **      | 0.95 (0.55–1.63) ns      | 1.17 (0.65–2.12) ns      | 0.69 (0.36–1.33) ns      | 0.77 (0.58–1.02) ns           |
| Hamadori excluding EOAs | 0.46 (0.25–0.86) * | 0.60 (0.32–1.13) ns | 0.85 (0.44–1.65) ns | 0.58 (0.28–1.22) ns | 0.59 (0.43–0.82) **          |
| Hamadori including EOAs | 0.24 (0.08–0.66) ** | 0.38 (0.13–1.15) ns | 1.00 (0.38–2.59) ns | 0.22 (0.08–0.61) ** | 0.39 (0.23–0.63) ***        |
| Low radiation risk perception (low anxiety) | 9.00 (6.08–13.3) *** | 8.12 (5.47–12.0) *** | 10.4 (6.78–15.8) *** | 10.2 (6.61–15.8) *** | 9.16 (7.49–11.2) *** |

The explanatory variables were age, sex, living region and low radiation risk perception (Model 2). CI = confidence interval, ref = reference, ns = not significant (P > 0.05), *P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001.
Table 3. Binomial logistic regression analysis for Model 3 was conducted with the views on safety of the water and air environments as the objective variables

|                      | 2012       | 2013       | 2014       | 2015       | 2012–2015  |
|----------------------|------------|------------|------------|------------|------------|
|                      | Odds ratio (95% CI) | Odds ratio (95% CI) | Odds ratio (95% CI) | Odds ratio (95% CI) | Odds ratio (95% CI) |
| Male                 | 1.43 (0.98–2.07) | ns          | 1.16 (0.81–1.66) | ns          | 1.30 (0.89–1.90) | ns          | 1.44 (0.98–2.13) | ns          | 1.31 (1.09–1.58) | **          |
| Female (ref)         | 1          | 1          | 1          | 1          | 1          |                | 1          | 1          |                |             |
| 20–29 years (ref)    | 1          | 1          | 1          | 1          | 1          |                | 1          | 1          |                |             |
| 30–39 years          | 0.82 (0.34–2.01) | ns          | 1.95 (0.78–4.89) | ns          | 0.81 (0.34–1.93) | ns          | 2.58 (1.00–6.69) | *          | 1.30 (0.83–2.05) | ns          |
| 40–49 years          | 1.15 (0.47–2.81) | ns          | 1.73 (0.70–4.26) | ns          | 2.22 (0.96–5.17) | ns          | 2.26 (0.90–5.69) | ns          | 1.71 (1.10–2.65) | *          |
| 50–59 years          | 1.06 (0.46–2.46) | ns          | 2.48 (1.04–5.90) | *          | 1.28 (0.56–2.90) | ns          | 2.32 (0.94–5.71) | ns          | 1.63 (1.06–2.50) | *          |
| 60 years and older   | 1.77 (0.81–3.85) | ns          | 3.78 (1.70–8.41) | ***        | 2.00 (0.96–4.20) | ns          | 5.01 (2.17–11.6) | ***        | 2.76 (1.87–4.09) | ***        |
| Low radiation risk   | **          | ***        | **          | ***        | 7.37 (5.25–11.4) | ***        | 10.3 (6.71–15.8) | ***        | 9.96 (6.49–15.3) | ***        |
| perception (low anxiety) | **          | ***        | **          | ***        | 7.73 (5.25–11.4) | ***        | 9.96 (6.49–15.3) | ***        | 9.02 (7.40–11.0) | ***        |
| Distance from        | 1.01 (1.00–1.02) | *          | 1.01 (1.00–1.02) | *          | 1.00 (1.00–1.01) | ns          | 1.01 (1.00–1.02) | *          | 1.01 (1.00–1.01) | ***        |
| FDNPP                | Air dose rate in | survey year | 0.99 (0.94–1.04) | ns          | 1.06 (0.96–1.16) | ns          | 1.13 (0.83–1.54) | ns          | 1.05 (0.93–1.19) | ns          |
| 2012 (ref)           | 1          |            |            |            |            |                |            |            |                |             |
| 2013                 | 1.42 (1.09–1.84) | **          |            |            |            |                |            |            |                |             |
| 2014                 | 2.50 (1.91–3.27) | ***        |            |            |            |                |            |            |                |             |
| 2015                 | 2.81 (2.15–3.69) | ***        |            |            |            |                |            |            |                |             |

The explanatory variables were age, sex, low radiation risk perception, distance from the FDNPP, air dose rate in survey year and year (Model 3). FDNPP = Fukushima Dai-ichi Nuclear power plant, CI = confidence interval, ref = reference, ns = not significant (P > 0.05), *P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001.

OR was 1.02 (95% CI: 1.01–1.03) for distance from FDNPP. The OR for distance from FDNPP remained high [1.01 (95% CI: 1.01–1.03) to 1.03 (95% CI: 1.02–1.04)] over the whole period (2012 to 2015), indicating a strong association between distance from FDNPP and low radiation risk perception. The OR for the air dose rate was high in 2013 and 2014, showing a relation to low radiation risk perception, but it did not show any significant association in the other years or over the whole period.

**DISCUSSION**

In this study, we investigated the relationships between views on the safety of water and air environments and some parameters (age, sex, living region, distance from FDNPP, air dose rate, and radiation risk perception), using annual public opinion surveys conducted by the Fukushima Prefectural Government. We also investigated the relationship between radiation risk perception and these parameters (age, sex, distance from FDNPP, air dose rate). The cross-tabulation results showed that opinions on safety of the water and air environments after the accident significantly differed between the regions, being especially high in Aizuwakamatsu, the least affected region, and low in Hamadori including EOAs. Because there were no significant differences between any of the regions before the accident, the low opinions of the safety of the water and air environments in Hamadori including EOAs was likely caused by the nuclear accident. Although the views on the safety of the water and air environments improved during the 5 years after the accident, they clearly did not recover to the level before the accident in Hamadori including EOAs. Moreover, the binomial logistic regression analysis revealed that high opinions of the safety of the water and air environments were strongly associated with low anxiety about radiation risks. Views on safety of the water and air environments differed significantly between the regions in Model 1, but not in Model 2, in which radiation risk perception was considered. Radiation exposure through food and drink is extremely limited in all the regions (0.001 mSv/year) [3], and exposure through the respiration of radioactive materials in the air is lower than that from food and drink [20]. However, our results suggest that people’s views on the safety of the water and air environments are still associated with radiation risk perception, and that the risk perception has been high in the region including EOAs. This is consistent with the previous study results, in which the evacuation experience affected the risk perception, regardless of whether it was voluntary or
compulsory evacuation [21]. Therefore, the evacuation order likely impacted the radiation risk perception and subsequently strongly affected views on the safety of the water and air environments.

Views on the safety of the water and air environments and radiation risk perception were strongly related to distance from FDNPP. Trauma and experiences related to the nuclear accident may also have been associated with the physical distance from FDNPP, possibly leading to the increase in radiation risk perception and the decrease in opinion regarding the safety of the water and air environments. Distance from FDNPP may be also a proxy for anxiety about the long-term FDNPP decommissioning work and about movement of radioactive materials from the FDNPP into the ocean via groundwater.

On the other hand, views on the safety of the water and air environments were not significantly associated with the air dose rate. In addition, radiation risk perception was not associated with the air dose rate over the whole period or for each year, except in specific years. These data indicate that subjective radiation risk perception and views on the safety of the water and air environments are weakly related to the air dose rate (objective information). Improved opinions on the safety of the water and air environments and decreased radiation risk perception (increased security feeling) as shown in Figs 2 and 3 cannot be explained by the decrease in the air dose rate. This result is consistent with the finding of a previous report [21] that dread risk perception was not associated with radiation dose in foods.

Views on the safety of water and air environments differed significantly between age groups, and was high in older people (60s and older) in the cross tabulation. In addition, the ORs of their views on environmental safety were found to be high in the binomial logistic regression analysis, even when adding radiation risk perception to the explanatory variables. These results suggest that factors other than radiation risk perception are associated with the views on safety. Previous studies showed that older people are interested in and sensitive to the river environment and in attending waterfront environment conservation activities [22, 23], and that experiencing a strong relationship with neighboring rivers leads to a positive awareness of the water environment [24]. This suggests that older people’s interest in the natural environment and their experiences in environmental conservation activities may be influencing their views on the safety of the environment.

More than 6 years has passed since the accident, and evacuation orders are being lifted. In this context, it is necessary to raise the residents’ awareness of the safety of the water environment and air environments in order to support the reconstruction of Fukushima. For example, if seeking to promote the return of younger people (with low opinions of the safety of the water environment) to a municipality where the evacuation order has been lifted, it may be effective to involve them in water environment activities with the older people. It is important that a negative viewpoint on interaction with the water and air environment is reflected in countermeasures, and that collaboration in local communities is encouraged, in addition to the measures being taken against radiation risks.

Limitations and future perspectives

There are some limitations in this study, one of which is that it was a cross-sectional study. While the annual prefectural public opinion survey provides a large volume of data, the subjects are not the same ones every year because of the selection by randomized two-stage stratification. For this reason, the continuity and stability of the results are weak in proving causation. The number of subjects is small in Hamadori including EOAs, and in the 20s group, although the response rates are relatively high. Accordingly, the factors that showed no significant differences in this study should be reconsidered in future work.

However, the results of this study are expected to contribute to the formation of safety views on the water and air environments in Fukushima, and to stimulating awareness in regional communities about environmental conservation activities, as well as guiding effective countermeasures against the risks from environmental pollution by radioactive materials.

SUPPLEMENTARY DATA

Supplementary data is available at Journal of Radiation Research online.

ACKNOWLEDGEMENTS

Some of the contents of this research were presented at the First International Symposium of the network-type Joint Usage/Research Center for Radiation Disaster Medical Science ‘Scientific Underpinning for Restoration from a Radiation Disaster’, and at the 51st Annual Conference of the Japan Society on Water Environment.

FUNDING

This work was partly supported by Fukushima Ken Genshiryoku Saigai Tou Fukko Kkin, and the Japan Society for the Promotion of Science (JSPS) KAKENHI [Grant No. JP16H05894].

CONFLICT OF INTEREST

The authors declare that no conflict of interest is associated with this manuscript.

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