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# Perceived environmental and health risks of nuclear energy in Taiwan after Fukushima nuclear disaster

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## Abstract

After the nuclear disaster in Fukushima in Japan in 2011, a nation-wide survey using a standardized self-administered questionnaire was conducted in Taiwan, with a sample size of 2,742 individuals including the residents who live within and beyond 30 km from a nuclear power plant (NPP) to evaluate the participants' perceived nuclear risk in comparison with their perceived risks from selected environmental hazards and human behaviors. The three leading concerns of nuclear energy were "nuclear accidents (82.2%)", "radioactive nuclear waste disposal (76.9%)"and "potential health effect (73.3%)". 77.6 % of the respondents perceived a higher relative risk of cancer incidence for those who live within 30 km from a NPP than those who live outside 30 km from a NPP. All the participants had a higher risk perception of death related to "nuclear power operation and nuclear waste" than cigarette smoking, motorcycling, food poisoning, plasticizer poisoning, and traveling in air. Moreover, the residents of Gongliao where the planned fourth NPP is located had a significantly higher perceived risk ratio (PRR) of cancer incidence (adjusted odd ratio, aOR: 1.84, p value: 0.017) and perceived risk of death (aOR 4.03, p value <0.001) related to nuclear energy. The other factors such as female gender (aOR/p value, 1.25/0.026 and 1.34/0.001 respectively), lower education levels (aOR/p value: 1.31/0.032 ; 2.03/<0.001 ), and the participants' concerns about nuclear accidents (aOR/p value: 1.33/0.022; 1.51/<0.001) and potential health effects (aOR/ p value: 2.95/ <0.001; 2.56/<0.001) were found to be commonly associated with the PRRs of "cancer incidence" and "perceived risk of death" related to nuclear energy, respectively. In addition, the respondents' concerns about nuclear waste disposal and possible eco-environmental damage made significant contributions (aOR/ p value: 1.39/ 0.001; 1.40/<0.001) to predict their perceived risk of death related to nuclear power. These factors are considered as important indicators and they can be used for suggesting future policy amendments and public referendum on the decision of the operation of the planned NPP.

**Keywords:** Nuclear power plant, nuclear accident, public concerns, perceived health risk

# 1. Introduction

1.1 Existing studies on nuclear-related risk perception

With the increasing threats of energy shortage and the impact of global climate change, many countries are facing more challenges of identifying alternative sources of energy to ensure a more sustainable environment. The arguments about using nuclear power as a green and clean solution to global climate change were ardently disputed, accompanied with the issues of radioactive wastes management (Barke and Jenkins-Smith 1993; Slovic et al. 1991).

Before the Fukushima accident, an opinion poll conducted by the International Atomic Energy Agency indicated that public acceptance of building a new NPP had an increasing trend in the United States and Europe in recent ten years(OECD 2010). The report indicated that many Europeans agreed that nuclear energy increased their energy supply, ensured lower and more stable energy prices and helped to limit global warming. They suggested that one of the greatest risks associated with nuclear energy was the safety of disposal of radioactive waste. The risks of nuclear energy were considered to outweigh its advantages by 53% of the European respondents overall, whilst only 33% thought that the advantages outweigh the risks that it posed.

After the Fukushima accident, an international comparative study involving a sample of nearly 19,000 people in 24 countries in June in 2011 indicated that the support for nuclear power had dropped significantly, with 62% worldwide opposed to further development of nuclear power (Carrington 2011). Also, increasing concerns about potential nuclear accidents has reduced the support for nuclear energy in many other countries including America, Japan, Switzerland, UK and Taiwan since the Fukushima nuclear accident occurred in 2011 (Hixson 2012; Ho et al. 2013; Ieong et al. 2014; Keller et al. 2012; News 2012).

A risk rating measurement developed by Slovic et al. (Slovic 1987) had been widely used in risk perception analysis to identify different characteristics of risk perception among 30 items related to various types of technologies and human activities, based on the research participants'

judgments on their perceived magnitude of risks. The difference between the risks perceived by the public and the scientifically estimated risk is regarded as the biggest problem in public acceptance of nuclear energy. Risk assessment of everyday activities involved subjective judgment that depends on the perception of risk by individuals. Recently, a study based on the risk rating scales indicated that nuclear power was regarded as a high-risk item by the Japanese respondents in the past 25 years, whereas the perception by the public fluctuated with events such as the Chernobyl and Fukushima accidents (Kanda et al. 2012).

Public responses to environmental risks such as nuclear-related risks can be explained by a complex cognitive process. It is now widely recognized that effective communication is a crucial element during and after a nuclear accident (Covello 2011; Robertson and Pengilley 2012). Risk perceptions of nuclear power are mainly influenced by trust on the authorities and operators, as well as demographic characteristics such as age, gender, ethnicity, race, attitude and knowledge of nuclear power , and perceived effects on the quality of everyday life of residents near a NPP (Greenberg 2009; Hung and Wang 2011). Several studies revealed that people who were opposed to nuclear power plants (or had high risk perception toward nuclear power) often associated nuclear power plans (NPPs) with potential nuclear accidents, waste disposal, excess radioactivity and nuclear safety, negative health consequences, negative environmental effects and socio-economic impacts (Aldrich 2012; Jenkins-Smith et al. 2011; Keller et al. 2012; Parkhill 2010). However, the information about how the above-mentioned concerns influenced lay people's risk perception toward nuclear power has not been well addressed. The interaction of the local setting exposed to the nuclear power plants with existing personal knowledge and experience of nuclear energy had a significant impact on risk perceptions of local residents towards nuclear power (HC 2009). Studies have shown that public perception and acceptance of nuclear power play very important roles in determining the promotion and development of nuclear technology (Greenberg 2009; Jenkins-Smith et al. 2011).

1.2 Potential high risk of nuclear safety in Taiwan

Taiwan established its first nuclear power plant in the 1970s. There are 3 NPPs involving six reactors currently operating, while the fourth NPP is being planned and under construction. The nuclear energy currently contributes slightly less than 20% of the overall power supply in Taiwan. Geographically, the first and the second nuclear power plants are located in 22 km and 28 km, respectively, from the capital Taipei City where there is a population of more than six million. The journal *Nature* highlighted the above-mentioned two nuclear plants in Taiwan as the world's second and third most dangerous power plants (Butler 2011). The nuclear safety issues were raised quickly in Taiwan after Fukushima nuclear accident in 2011, as both the NPP 1 and 2 are located in its northeast coastal line where is prone to the effects of tsunamis and earthquakes, and which may affect more than 6 millions of population within a radius of 30-40 km (Chao 2011).

Public opposition to the new 4$^{th}$ NPP increased from around 58% in March 2011 to 74% in March 2013, reported by the public polls (Wang 2013; Ying-cheng 2011). It indicated that the public poses concerns about nuclear power in Taiwan two years after Fukushima nuclear disaster. With an increasing anti-nuclear movement in progress, an expectance on the termination of operation of the planned 4$^{th}$ NPP has been ongoing to be discussed after Fukushima nuclear accident (Ho et al. 2013). It showed that trust was the key determinant of the acceptance of a new nuclear power plant and a very small proportion (17%) of respondents in Taiwan trusted the Government's nuclear safety management after Fukushima accident.

1.3 Hypothesis and purpose of the study

As the renewed concerns in Taiwan, the study hypothesizes that the Fukushima nuclear disaster might have trigger public concern about potential environmental and health effects associated with nuclear energy so as to increase their risk perception toward nuclear power plants in Taiwan (Figure 1).

A series of nuclear risk perception research have been conducted in several developed countries since 1990s, but population-based risk perception studies are limited in the Asia-Pacific region. Therefore, the purpose of the study is to provide population-based evidence to further investigate the main public concerned items associated with nuclear energy and to evaluate the perceived risks of cancer and death potentially related to nuclear energy in comparison with those of other technologies or human activities; and understanding the effect of the public's concerned nuclear safety, geographic linkage with nuclear power plants, and demographic characteristics which might be underlying public perception of nuclear-related health risks. The results obtained from this study are expected to illustrate useful information for decision making on the planned new NPP and nuclear safety management.

## 2. Methods

### 2.1 Study areas and participants

A cross-sectional study of the risk perception on nuclear power in Taiwan was conducted from August of 2011 to February of 2012 after the Fukushima nuclear accident in Japan. Surveys were conducted in three townships within 5 km of the 1st Nuclear Power Plant (NPP1) and the 2nd Nuclear Power Plant (NPP2) in the northern Taiwan, the Shimen (SM), Wanli (WL), and Jinshan (Brandejsky et al.) townships, as well as three townships within 15 km of the Third Nuclear Power Plant (NPP3) in southern Taiwan, the Hengchun (HC), Manzhou (MZ), and Checheng (Pugh-Clarke et al.), and the township of Gongliao (GL) within 2 km of the planned 4$^{th}$ NPP on the northeastern coast of Taiwan. Residents and students in "other areas" of more than 30 km away from the NPPs were also included in the survey conducted in the communities and schools distributed around Taiwan (Figure 2).

In order to compare the responses of different communities, we decided to study all the townships hosting the three existing NPPs and the GL township which hosts the planned fourth NPP. Out of 346 communities which were beyond 30 km away from the above area in Taiwan, 17 communities and townships were randomly sampled for the study as 'other regions'. With the townships decided, the questionnaires were administered and collected according to the proportion of the total populations of specific townships. To make collection of effective samples from these townships feasible, interviewers would conduct the surveys during regular daytime hours and mostly on weekdays in each community simultaneously. Interviewers' work stations were set up in several public business locations such as convenience stores, bus stations, main business streets, shopping centers, local administration centers, schools, hospitals and health service centers when local residents who walked into these stations were invited to respond to the questionnaires. Some of the questionnaires were responded to by college students distributed in a dozen townships in the regular classes. More than 3100 persons were invited to take the survey during the study period,

with a response rate of 91%. Around half of the respondents were from the local townships hosting the NPPs and the GL township, while the 'other regions' accounted for half of respondents, including local residents, office workers and college students.

**2.2 Study instrument and measurements**

The study was approved by the Ethics Committee of Taipei Medical University (IRB NO: TMU-JIRB-201109002). The collection of questionnaires were undertaken by the participants according to standard guidelines, including face-to-face interview, by research assistants who had received eight hours of specialized training. The questionnaire comprised social demographic characteristics (age, gender, education level, marriage and number of children under 12), geographic linkage with a NPP by region (the existing NPPs, the planned NPP and beyond 30 km with a NPP), the concerned items of nuclear safety, and perceived risks of cancer incidence and death related to nuclear energy as well as perceived risk of nuclear power in comparison with five selected risk items. The options of the concerned items of nuclear safety included 'nuclear accidents', 'radioactive nuclear waste disposal', 'potential health effects', 'earthquakes and natural disasters', 'eco-environmental damage', 'social-economical risk' and 'impact of community development.

Thirty volunteers joined the pretest. Several experts including community representatives and opinion leaders who were familiar with the issue were invited to validate the questionnaire's contents and Cronbach's alpha was used to determine the internal consistency of a problem set on nuclear risk perception ($\alpha$=0.818, 95%CI=0.45-0.49, $p<0.001$). Interviewees were provided with an explanatory consent form and almost all respondents answered the questionnaires independently, while a few seniors and handicapped residents were assisted in answering.

**2.2.1 Outcome/Dependent variables**

The perceived risk of cancer incidence and risks of death related to nuclear power operation and nuclear waste were used as one of the key indicators of perceived health risk. The respondents

were asked “How many people do you think have cancer for each 1,000 residents living within 30 km of a nuclear power plant?” followed with the question “How many people do you think have cancer for each 1,000 residents beyond 30 km of a nuclear power plant?” as two related questions that the respondents would respond in a logic pattern that the ratio between both answers could then be obtained. The respondent’s perceived relative risk (PRR) of cancers incidence related to nuclear power operation and nuclear waste was calculated by dividing the risk level perceived by the same respondent regarding both risks. A PRR value greater than 1 represented a higher perceived cancer risk living near a nuclear power plant. Questionnaire survey was undertaken by well-trained interviewers following standard guidelines. The interviewers explained the purpose of the research to the respondents and emphasized that “there is no correct or standard answers about the questions. But please answer them according to your own experience and perception.”

(Formula)

Perceived relative risk (PRR) = (The perceived cancer cases per 1000 persons living **within** 30 km with a NPP)/ (The perceived cancer cases per 1000 persons living **beyond** 30 km with a NPP)

A logistic regression analysis was employed to verify the research hypothesis and to evaluate the relationships between opinions on the perceived relative risks of cancer incidences and other determinant variables such as gender, age, education, geographic linkage with NPPs, and the items of public concerns of nuclear safety (Model 1). The respondents were further divided into two groups, according to the ratios of the PRRs of cancer incidence. The ratio higher than 1 was coded as “1” and the ratio equal or lower than 1 was coded as “0”.

Six specific risk items of common major concerned public programs or issues, including “nuclear power operation and nuclear waste”, “cigarette smoking”, “motorcycling”, “food poisoning”, “plasticizer poisoning” and “travel by air” were compared in the same scale by the respondents for perceived risks of death. There were lots of items of technology and daily

activities with close relationship with daily living activities of the public. The six items were chosen for the following reasons: (1) Most of them listed in classic risk perception studies as risk comparison items to represent every-day-life risk (expect ‘plasticizer poisoning’). (2) With the different severity, most of them render immediate and long-term health risks. Some were voluntary-undertaken risk, and some were none voluntary-undertaken such as ‘nuclear power operation and nuclear waste’; (3) ‘Plasticizer poisoning’ included due to several plasticizer (a commonly used food preservative) poisoning incidents occurring and a broad media coverage in Taiwan for a few months before and during the study period (Lu 2011).

The perceived risk was assessed using a risk ranking technique, which was similar to those developed by Slovic et al (Slovic et al. 1981). The respondents were asked to rank the above risks as “1 to 6” (1: the highest risk). On data process, the highest risk item was scored as “6”; the second highest risk scored as ”5”; the third highest risk scored as ”4” and so on. The mean scores of perceived risk of death from these six concerned items were compared among respondents in different regions. A separate logistic regression was employed to verify the hypothesis and to associate the relationship between opinions on the perceived risk of death and other determinant variables such as gender, age, education, geographic linkage with NPPs and the public concerned items of nuclear safety (Model 2). The respondents were further divided into two groups, according to the ranking of the perceived risk of death related to “nuclear power operation and nuclear waste”. Those ranking “the highest or the second highest risk” were categorized in the group “high risk perception” and coded as “1”. Others were categorized as “the third, fourth, fifth and sixth highest” and were grouped as “low risk perception (LRP)” and coded as “0”.

### 2.2.2 Predictor/ Independent variables

Demographic variables of these respondents such as age, gender, education, marriage status, living with children under age of 12 or not were included in the analysis. The concerned risk

items included of ‘nuclear accidents’, ‘radioactive nuclear waste disposal’, ‘potential health effects’, ‘earthquakes and natural disasters’, ‘eco-environmental damage’, ‘social turmoil and public demonstrations’ and ‘impact of community development’. They were transformed into categorical variables to assess the association with the outcome variable of interest, such as the perceived risk of cancer incidence and perceived risk of death related to nuclear power operation and nuclear waste.

### 2.3 Data Analysis

The data were analyzed using the IBM Statistical Package for the Social Sciences version (SPSS) 19.0. Based on geographic proximity to an NPP, the data were analyzed using descriptive statistics to compare the differences in demographic distributions and the participants’ concerned issues, as well as their perceived cancer incidence and risk perception of death related to NPPs and nuclear waste. Chi-square tests were used to examine the relationships between the outcome variable(s) and the independent variables. Two logistic regression models were performed independently to examine the effects of the demographic variables combining with other independent variables on the two dependent variables: perceived risk of cancer incidence and risk perception of death related to nuclear facilities. Odd ratios (OR) and 95% confidence intervals (95%CI) were also calculated in the regression modeling.

## 3. Results

### 3.1 Demographic Characteristics

A total of 2,819 individuals responded to the survey, with a response rate over 90%. There were 2,742 valid questionnaires included in the final analysis, excluding 77 questionnaires with incomplete and missing values. There is no significant difference found in the distribution of the level of perceived risk of cancer incidence and perceived risk of death related to nuclear energy between those in "JS, SM, WL" and "HC, MZ, and CC" (Chi square test, all p values>0.05). Also there were similar distribution of gender (female: 59% vs 61%, p>0.05, Chi square test) and ages (mean$\pm$SD: 35$\pm$17, 37$\pm$12, p>0.05, t test) among the respondents of the two regions. Therefore we merged them to the same group defined as those close to the existing NPPs (page 12, line 5-10).

Table 1 showed the demographic distributions of all the respondents by regions. These included 988 residents (36.0%) in six townships within 30 km of the existing nuclear power plants, including SM, WL and JS in the Northern Taiwan, HC, MZ and CC in the Southern Taiwan, and 270 residents (9.8%) in GL of the planned 4th NPP, while 1,484 respondents (54.1%) were from other townships beyond 30 km from the NPP. 61% of the respondents were younger than 35 years old, with the mean age 34.0 ($\pm$15.6) years old. There were 1,427 females (52.0%) and 1,315 males (48.0%). Of all the respondents, 70.5% had a college or university degree; 43.1% were or once married; 70.8% lived with one or more than 1 child under the age of 12.

### 3.2 Nuclear-related risk perception

The region-stratified distributions of the perceived relative risks (PRR) of cancer incidences related to nuclear power plants was shown (Figure 3). A highest proportion of GL residents expressed higher PRR of cancer incidence for people who live close to an NPP, followed as those in other areas beyond 30 km with a NPP and those in the JS, SM, WL, HC, MZ, CC township near existing NPPs.

To quantify risk perception, the participants were asked to rank six specific items of common technologies or human activities in consideration of the risks of death from these technologies or activities, including the risk toward nuclear operation and nuclear waste. A consistently higher perceived risk levels of death from nuclear operation and nuclear waste were shown by all study groups, as compared with other major risks (Figure 4). The level of perceived risk of death (4.4±1.8) related to nuclear operation and nuclear waste was significantly higher than the other 5 items (p values <0.001 in paired sample t-tests), while the average levels of perceived risk from cigarette smoking, motorcycling, food poisoning, plasticizer poisoning and air traveling were 4.1±1.4, 3.7±1.8, 3.6±1.4, 3.0±1.5 and 2.3±1.5 respectively. Moreover, the GL residents perceived much higher risk (5.6±1.1, p<0.001 in chi-square test) of nuclear power and waste than the risk levels perceived by the respondents of other areas (4.4±1.7) and the JS, SM, WL, HC, MZ, CC township (4.3±1.9).

In terms of the concerns and potential impacts from nuclear power plants, the top three concerned aspects of nuclear safety were “nuclear accidents (82.2%)”, “radioactive nuclear waste disposal (76.9%)” and “potential health effects (73.3%)”, shown in Table2, followed with catastrophic consequences resulting from “earthquakes and natural disasters (58.5%)” and “eco-environmental damage (57.0%)”. In contrast, less were concerned about the potential social-economic effects related to nuclear facilities such as “social turmoil and public demonstrations (33.2%)” and “impact of community development (30.0%)”.

The region-stratified distributions of the perceived relative risks (PRR) of cancer incidences and death related to nuclear power operation and nuclear waste was shown (Table 2). 2,128 respondents (77.6%) perceived a higher cancer incidence risk for people who live near an NPP. A much higher proportion (91.0%) of GL residents expressed high PRR of cancer incidence for people who live close to an NPP. More than half of the total respondents (57.9%) perceived that “the risk of death related to nuclear power operation and nuclear waste” was the highest or second

highest than other technologies and human activities. Residents living within and beyond 30 km to a nuclear power plant were shown with similar perception toward risk of death (54.9% and 54.4% respectively). However, 88.1% of GL residents perceived the much higher risk of death due to nuclear power operation and nuclear waste than those in other regions.

### 3.3 Factors associated with perceived relative risk of cancer and deaths derived from nuclear power operation and nuclear waste

The potential related factors with PRR of cancer incidence and death from nuclear power plants were shown in Table 3. Age, gender, education and marital status were significantly associated with PRR of cancer incidence and perceived risk of death (p values= 0.029/0.047, 0.052/<0.001, 0.041/<0.001 and 0.044/0.010 respectively; Chi-square tests). A significantly higher proportion of GL residents had high PRRs of cancer and death compared with the other two groups living within or beyond 30 km from a NPP (both p values < 0.001, Chi-square tests).

The results (Table 3) indicated that The PRRs of cancer was strongly associated with their concerns and worries about “nuclear accidents”, “radioactive nuclear waste disposal”, “potential health effects”, “eco-environmental damage” and “impact of community development” (p values <0.001; Table 3), but not on damage from “earthquakes and natural disasters” and “social turmoil and public demonstrations” (p values > 0.05). All those concerned items were significantly associated with respondents’ perceived risk of death (p value for “earthquakes and natural disasters”= 0.024, all the other p values <0.001)

In order to examine the overall effect of the significant concerned items (as shown on Table 3) along with demographic variables on respondents’ PRR and perceived risk of death toward nuclear facilities, logistic regression modeling was employed to identify the significant predictors among the concerned issues or potential impacts related to nuclear power operation and nuclear waste. As many demographic variables and geographic locations were significantly associated with

participants' PRR of cancer and risk perception of death toward nuclear facilities, these variables were considered as potential confounding factors and controlled in the modeling. Table 4 showed that respondents' concerns and worries about nuclear accidents and potential health effects (aOR= 1.33, p=0.022; aOR= 2.95, p<0.001 respectively) were significant factors in predicting the respondents' PRR related to nuclear facilities after controlling for the significant demographic variables and regions. It is clear that the respondents who was concerned about potential health impact related to NPP and nuclear waste were 2.9 times more likely to had high PRR of cancer. It also indicated that the major concerns and worries including nuclear accidents, radioactive nuclear waste disposal, potential health effects and eco-environmental damage were significant factors in predicting the respondents' risk perception of death toward NPP and nuclear waste (aOR=1.51, p value <0.001; aOR=1.39, p value=0.001; aOR=2.56, p value <0.001; aOR=1.40, p value <0.001 respectively).

## 4. Discussion

The results of this study identified a relatively high risk perception toward nuclear power plants and nuclear waste, compared with the other five modern technologies or human activities among the study populations in different geographic locations. The results were similar to the findings of other international comparative risk researches (Hinman et al. 1993; Kanda et al. 2012) which suggested that people's beliefs about the unknown risk and potentially catastrophic outcomes drove their increasing risk perception and opposition toward nuclear power (Slovic 2000; Visschers 2007). As indicated by Kanda and her colleagues (Kanda et al. 2012), public risk perception of nuclear power was constantly high in their longitudinal surveys. On the other hands, the public's fears about nuclear power and radioactive contamination of food were even more after the Fukushima accident.

Apart from the psychometric scales used to compare perceived risk of nuclear power with the risks of selected technologies or human activities, this study also developed two new measures to quantify the participants' perception of the risk of cancer incidence and the risk of death related to nuclear energy. The study found that the GL residents, who did not live close to a nuclear power plant, their risk perceptions of cancer and death were extremely high compared with those of the residents living near an existing NPP or beyond 30 km of an NPP. Moreover, the levels of PRR and the risk perception of death among the residents who lived near a power plant were lower than or similar to other participants living in other areas (general population). The results suggested that the public tended to worry or concern about something uncertain or they don't know. However, when they learn more or get together with it, they stop worrying. These findings showed similarities to Kuchinskaya's study (Kuchinskaya 2011) that residents living in affected areas were not necessarily more risk conscious or concerned more about the risk of living in those areas. As the local residents living in the nearby areas continuingly received information about the nuclear power plants, their risk perception was not higher than that of general public. Moreover, a study

conducted in 2000 showed that the risk perception toward nuclear power plants and nuclear waste among local people residing near the 1st and the 2nd NPPs was significantly higher than that of nuclear experts and university students (Lee, 2000). Although local people living in the nearby areas tended to worry about potential risks related to nuclear power plants which they had only little knowledge of, it was likely that their knowledge about the facilities would grow over a long period of time. In addition, as they had been continuingly receiving information from social media, the power company, political parties and government experts about the actual risk of nuclear power plants for over 30 years, their level of nuclear-related risk perception appeared to decline to a level close to or even lower than that of general public.

The results also noted that participants who were female, and with lower education level tended to perceive higher cancer risks for living near an NPP. The findings were in line with the results of various risk studies (Keller et al. 2012; Visschers 2012) that young females tended to be more health conscious. It is noticeable that education was strongly associated with participants' perceived risk of death as well as the participants' PRR. In this regard, people with lower education level projected a higher risk of cancer and death toward the NPPs.

Many studies showed that people who were opposed to nuclear power plants (or had high risk perception toward nuclear power) often associated NPPs with potential nuclear accidents, waste disposal, radioactivity and nuclear safety, negative health consequences for health, negative environmental effects and socio-economic impacts (Aldrich 2012; Jenkins-Smith et al. 2011; Keller et al. 2012; Parkhill 2010). However, the information about how the above-mentioned concerns influenced lay people's risk perception toward nuclear power was not clear. In order to fill this gap, we developed a unique indicator PRR and demonstrated that those perceived a high risk of death also appeared to be with higher PRR toward cancer. We further analyzed the overall nuclear-related concerned items associated with their PRR of cancer and death, controlling the demographic variables. It was demonstrated that nuclear accidents and potential health effects were

positively associated with their PRR of cancers. As public concerns over nuclear safety and uncertain health effects attributed to radiation exposure in Taiwan inevitably intensified since the Fukushima accident (Kanda et al. 2012; Yamamura 2012), the participants in this study seemed to relate their risk of cancer incidence to recent disaster in Japan and addressed great worries about uncertain health effects. The result also evidenced that the participants who expressed higher concerns about nuclear accidents, nuclear waste disposal, potential health effects, and environmental impacts tended to perceive higher risk of death from nuclear power. This was similar to the results in Keller's studies on the acceptance of using new-generation nuclear power plants to replace old ones (Keller et al. 2012).

The emerging debates regarding the risks and benefits of nuclear power largely centered on the differences in risk perception between experts and lay people. Pro-nuclear scientists suggested that lay people often over-estimated nuclear risks. They also asserted that the benefits (such as lowering $CO_2$ emissions, more affordable and safer energy) of using nuclear power should be acknowledged (de Groot et al. 2013; Doyle 2011; Wigg 2007). In contrast, the general public were concerned about imminent nuclear disasters and uncertain health effects (Bator 2012; Jenkins-Smith 2011). Political decisions on nuclear power are usually based on scientific reports and probabilistic risk assessments conducted by experts while paying less attention to public risk perceptions. The science-driven decisions (or "top-down" approach) would lead to a loss of trust in government and scientists and increased conflicts (Jenkins-Smith 2011; Jerónimo 2011). Therefore, risk communication needs to acknowledge the differences in risk perceptions of various stakeholders/social contexts and value the point of view of lay people(Bator 2012). A good risk communication approach also needs to incorporate stakeholder inputs and involve local people in the decision making processes of issues that concern them in order to reduce their perceived risk of NPPs (Goodfellow 2011; Skarlatidou et al. 2012).

### 5. Limitations of this study

There remain several limitations in this study. Firstly, the populations of the townships hosting these three NPPs are relatively old, as the young generations tend to move to the cities. This may have limited the generalization of the study results. Secondly, the Fukushima accident was not just a single event but rather a number of events with varying impacts after the initial event, but we conducted the survey from August 2011, that is five months after the initial incident. The results would not be able to reflect the impacts of serial events precisely. It is possible that the respondents' perceived risk toward NPP may change over time. A longitudinal follow-up study design would be able to overcome the issues emerging in a cross-sectional study.

## 6. Conclusions

The findings of this study have indicated that all the public' perceived related risks toward nuclear operations in Taiwan were relatively high compared with the other five common technologies or human activities. The concerned issues associated with their perceived risk of cancer and perceived death risks related to nuclear power included nuclear accidents, potential health effects, radioactive nuclear waste disposal, and environmental damage. These concerns are deemed to shape public risk perception toward nuclear power plants and nuclear waste in Taiwan. The results can be useful references to develop effective risk communication strategies to better address public concerns on the development and management of nuclear power as well as the decision on the planned NPP. Moreover, further studies of the effects of media on nuclear-related risk perception are expected. Longitudinal studies would be desirable to further understand the the changes in perception alone with major events in the future.

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**Table 1. Description of demographic characteristics of the respondents (n=2742)**

| Variables | Total No. (%) | Geographic linkage with NPPs by region | | |
|---|---|---|---|---|
| | | Existing NPPs | A planned new NPP | Beyond 30 km with a NPP |
| | | JS,SM,WL, HC,MZ,CC | GL | Other areas |
| Total sample | 2742 (100) | 988 (36.0) | 270 (9.8) | 1484 (54.1) |
| Age (years old) | | | | |
| ≤ 35 | 1676 (61.1) | 539 (54.6) | 51 (18.9) | 1086 (73.2) |
| > 35 | 1066 (38.9) | 449 (45.4) | 219 (81.1) | 398 (26.8) |
| Gender | | | | |
| Female | 1427 (52.0) | 582 (58.9) | 90 (33.3) | 755 (50.9) |
| Male | 1315 (48.0) | 406 (41.1) | 180 (66.7) | 729 (49.1) |
| Education Level | | | | |
| Senior high school or lower | 808 (29.5) | 403 (40.8) | 208 (77.0) | 197 (13.3) |
| College, or University and postgraduate | 1934 (70.5) | 585 (59.2) | 62 (23.0) | 1287 (86.7) |
| Married | | | | |
| Yes | 1183 (43.1) | 506 (51.2) | 225 (83.3) | 452 (30.5) |
| Never | 1559 (56.9) | 482 (48.8) | 45 (16.7) | 1032 (69.5) |
| Living with children under the age of 12 | | | | |
| Yes | 802 (29.2) | 354 (35.8) | 87 (32.2) | 361 (24.3) |
| No | 1940 (70.8) | 634 (64.2) | 183 (67.8) | 1123 (75.7) |

NPP, nuclear power plant; JS, Jinshan; SM, Shimen; WL, Wanli; HC, Hengchun; MZ, Manzhou; CC, Checheng; GL, Gongliao

**Table 2. Respondents' risk perceptions toward nuclear power (n=2742)**

| Variables | Total No. (%) | Geographic linkage with NPPs by regions | | |
|---|---|---|---|---|
| | | Existing NPPs | A planned new NPP | Beyond 30 km with a NPP |
| | | JS,SM,WL, HC,MZ,CC | GL | Other areas |
| Concerned items of nuclear safety | | | | |
| Nuclear accidents | 2255 (82.2) | 788 (79.8) | 260 (96.3) | 1207 (81.3) |
| Radioactive nuclear waste disposal | 2108 (76.9) | 720 (72.9) | 247 (91.5) | 1141 (76.9) |
| Potential health effects | 2010 (73.3) | 656 (66.4) | 236 (87.4) | 1118 (75.3) |
| Earthquakes and natural disasters | 1605 (58.5) | 517 (52.3) | 204 (75.6) | 884 (59.6) |
| Eco-environmental damage | 1562 (57.0) | 570 (57.7) | 200 (74.1) | 792 (53.4) |
| Social turmoil and public demonstrations | 911 (33.2) | 259 (26.2) | 140 (51.9) | 512 (34.5) |
| Impact of community development | 821 (30.0) | 237 (24.0) | 189 (70.0) | 1087 (26.7) |
| Higher perceived relative risk (PRR) [a] of cancer incidence | | | | |
| >1 | 2128 (77.6) | 686 (69.4) | 246 (91.0) | 1193 (80.4) |
| ≤1 | 614 (22.4) | 302 (30.6) | 24 (9.0) | 291 (19.6) |
| Perceived risk of death [b] related to" nuclear power operation and nuclear waste" | | | | |
| High risk perception (HRP) | 1587 (57.9) | 542 (54.9) | 238 (88.1) | 807 (54.4) |
| Low risk perception (LRP) | 1155 (42.1) | 446 (45.1) | 32 (11.9) | 677 (45.6) |

a: Perceived relative risks (PRR) of cancer incidence=people having cancer for each 1,000 residents living within 30 km of a NPP / people having cancer for each 1,000 residents beyond 30 km of a NPP.

b: The respondents were further divided into two groups, according to the ranking of the perceived risk of death related to "nuclear power operation and nuclear waste". Those ranking "the highest or the second highest risk" were classified to the group of "high risk perception (HRP) ". Others ranking "the third, fourth, fifth and sixth highest" were classified to the group of "low risk perception (LRP)".

**Table 3. Associations between selected factors and perceived relative risk (PRR) of cancer incidence and perceived risk of death related to nuclear power operation and nuclear waste**

| Variables | Perceived relative risk (PRR) [a] of cancer incidence | | | Perceived risk of death [b] | | |
|---|---|---|---|---|---|---|
| | >1 | ≤1 | p value ($\chi^2$ test) | High risk perception (HRP) | Low risk perception (LRP) | p value ($\chi^2$ test) |
| Total sample | 2128 | 614 | | 1587 | 1155 | |
| **Demographic factors** | | | | | | |
| Age (years old) | | | | | | |
| ≤ 35 | 1326 (62.3) | 353 (57.5) | 0.029* | 952 (60.1) | 738 (63.9) | 0.047* |
| > 35 | 802 (37.7) | 261 (42.5) | | 635 (39.9) | 417 (36.1) | |
| Gender | | | | | | |
| Female | 996 (46.8) | 308 (50.2) | 0.052 | 708 (44.6) | 605 (52.4) | <0.001*** |
| Male | 1132 (53.2) | 306 (49.8) | | 879 (55.4) | 550 (47.6) | |
| Education Level | | | | | | |
| Senior high school or lower | 1511 (71.0) | 413 (67.2) | 0.041* | 1030 (64.9) | 931 (80.6) | <0.001*** |
| College, or University and postgraduate | 617 (29.0) | 201 (32.8) | | 557 (35.1) | 224 (19.4) | |
| Married | | | | | | |
| Yes | 1251 (58.8) | 319 (52.0) | 0.044* | 889 (56.2) | 696 (60.3) | 0.040* |
| Never | 877 (41.2) | 295 (48.0) | | 698 (43.8) | 459 (39.7) | |
| Living with children under the age of 12 | | | | | | |
| Yes | 617 (29.0) | 195 (31.7) | 0.351 | 462 (29.1) | 342 (29.6) | 0.853 |
| No | 1511 (71.0) | 419 (68.3) | | 1125 (70.9) | 813 (70.4) | |
| **Geographic linkage with NPPs** | | | | | | |
| Region | | | | | | |
| JS,SM,WL,HC,MZ,CC | 660 (31.0) | 317 (51.6) | <0.001* | 538 (33.9) | 448 (38.8) | <0.001* |
| GL | 234 (11.1) | 39 (6.4) | | 224 (14.1) | 25 (2.2) | |
| Other areas | 1234 (57.9) | 268 (42.0) | | 825 (51.9) | 682 (59.0) | |
| **Concerned items of nuclear safety** | | | | | | |
| Nuclear accidents | 1805 (84.8) | 464 (75.5) | <0.001*** | 1385 (87.3) | 871 (75.4) | <0.001*** |
| Radioactive nuclear waste disposal | 1698 (79.8) | 424 (69.0) | <0.001*** | 1311 (82.6) | 800 (69.3) | <0.001*** |
| Potential health effects | 1702 (80.0) | 340 (55.3) | <0.001*** | 1338 (84.3) | 681(59.0) | <0.001*** |
| Earthquakes and natural disasters | 1234 (58.0) | 333 (54.2) | 0.068 | 943 (59.4) | 638 (55.2) | 0.024* |
| Eco-environmental damage | 1311 (61.6) | 307 (50.1) | <0.001*** | 1055 (66.5) | 556 (48.1) | <0.001*** |
| Social turmoil and public demonstrations | 724 (34.0) | 190 (30.9) | 0.131 | 578 (36.4) | 345 (29.9) | <0.001*** |
| Impact of community development | 679 (31.9) | 152 (24.7) | <0.001*** | 576 (36.3) | 243 (21.0) | <0.001*** |

a: Perceived relative risks (PRR) of cancer incidence=people having cancer for each 1,000 residents living within 30 km of a NPP / people having cancer for each 1,000 residents beyond 30 km of a NPP.

b: The respondents were further divided into two groups, according to the ranking of the perceived risk of death related to "nuclear power operation and nuclear waste". Those ranking "the highest or the second highest risk" were classified to the group of "high risk perception (HRP) ". Others ranking "the third, fourth, fifth and sixth highest" were classified to the group of "low risk perception (LRP)".

*: p <005, **: p<0.01, ***: p<0.001

**Table 4. Multiple logistic regression models used to predict perceived relative risk of cancer incidence and the perceived risk of death related to nuclear power operation and nuclear waste (n=2742)**

| | Model 1: Perceived relative risk (PRR) [a] of cancer incidence | | Model 2: Perceived risk of death [b] related to" nuclear power operation and nuclear waste" | |
|---|---|---|---|---|
| | Adjusted OR (95% CI) | P value | Adjusted OR (95% CI) | P value |
| **Demographic factors** | | | | |
| Age (years old) | | | | |
| ≤ 35 | 1.01 (0.77-1.33) | 0.923 | 1.16 (0.92-1.47) | 0.203 |
| > 35 | 1 | | 1 | |
| Gender | | | | |
| Female | 1.25 (1.03-1.53) | 0.026* | 1.34 (1.14-1.58) | 0.001** |
| Male | 1 | | 1 | |
| Education Level | | | | |
| Senior high school or lower | 1.31 (1.02-1.67) | 0.032* | 2.03 (1.65-2.50) | <0.001*** |
| College, or University and postgraduate | 1 | | 1 | |
| Married | | | | |
| Yes | 1.00 (0.76-1.31) | 0.994 | 1.03 (0.82-1.29) | 0.817 |
| Never | 1 | | 1 | |
| **Geographic linkage with NPPs** | | | | |
| Region | | | | |
| JS,SM,WL,HC,MZ,CC | 0.55 (0.45-0.68) | <0.001*** | 0.97 (0.81-1.17) | 0.780 |
| GL | 1.84 (1.12-3.04) | 0.017* | 4.03 (2.64-6.15) | <0.001*** |
| Other areas | 1 | | 1 | |
| **Concerned items of nuclear safety** | | | | |
| Nuclear accidents | 1.33 (1.04-1.69) | 0.022* | 1.51 (1.21-1.88) | <0.001*** |
| Radioactive nuclear waste disposal | 1.25 (0.99-1.57) | 0.060 | 1.39 (1.13-1.70) | 0.001*** |
| Potential health effects | 2.95 (2.36-3.69) | <0.001*** | 2.56 (2.09-3.12) | <0.001*** |
| Earthquakes and natural disasters | --- | --- | 1.02 (0.86-1.21) | 0.849 |
| Eco-environmental damage | 1.02 (0.82-1.27) | 0.842 | 1.40 (1.16-1.68) | <0.001*** |
| Social turmoil and public demonstrations | --- | --- | 0.86 (0.71-1.05) | 0.143 |
| Impact of community development | 0.83 (0.64-1.06) | 0.134 | 1.08 (0.86-1.34) | 0.513 |
| **Model fit (Sig.)** | $R^2$=12.5% (p<0.001) | --- | $R^2$=18.6% (p<0.001) | --- |

a: Perceived relative risks (PRR) of cancer incidence=people having cancer for each 1,000 residents living within 30 km of a NPP / people having cancer for each 1,000 residents beyond 30 km of a NPP.

b: The respondents were further divided into two groups, according to the ranking of the perceived risk of death related to “nuclear power operation and nuclear waste”. Those ranking “the highest or the second highest risk” were classified to the group of “high risk perception (HRP) ”. Others ranking “the third, fourth, fifth and sixth highest” were classified to the group of “low risk perception (LRP)”.

*: p <005, **: p<0.01, ***: p<0.001

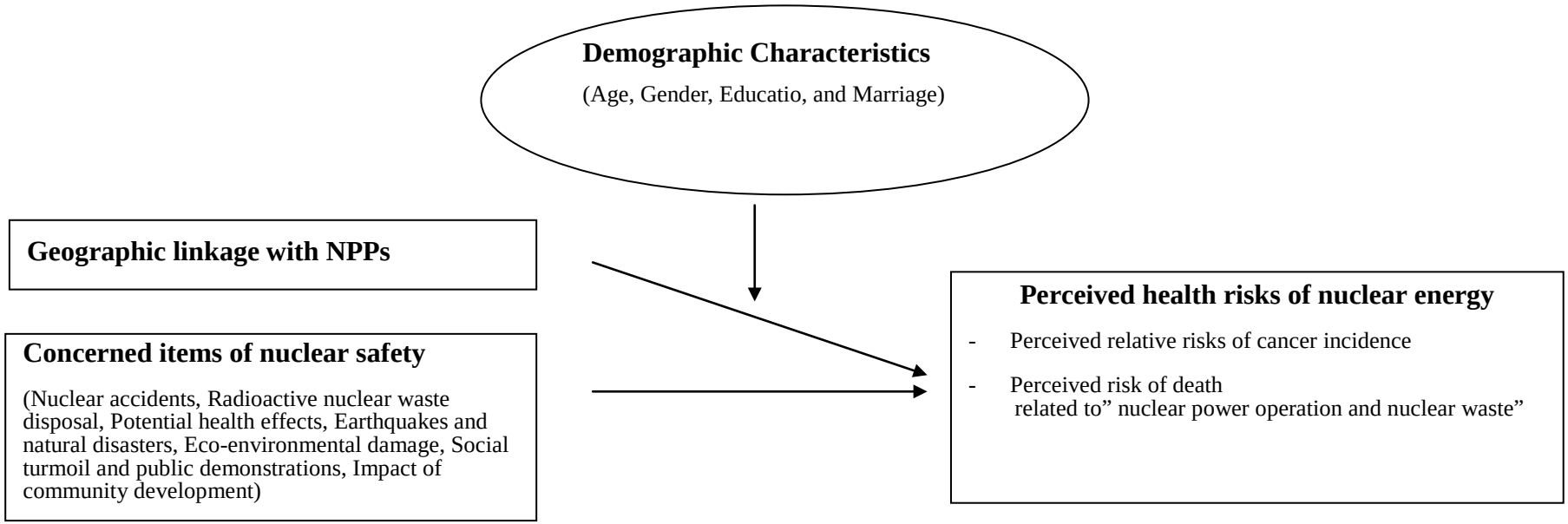


**Figure 1. Research hypothesis and analysis framework.**

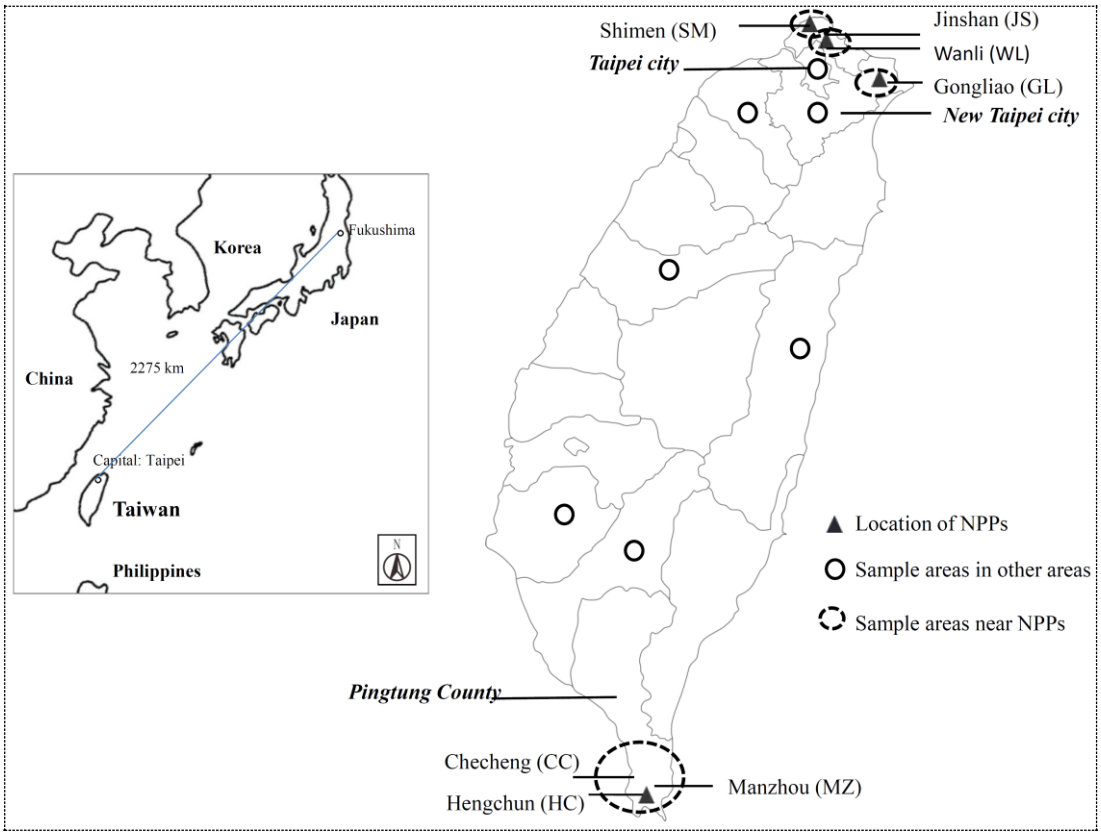


Figure 2. Geographic distribution of the sample areas near the nuclear power plants in Taiwan.

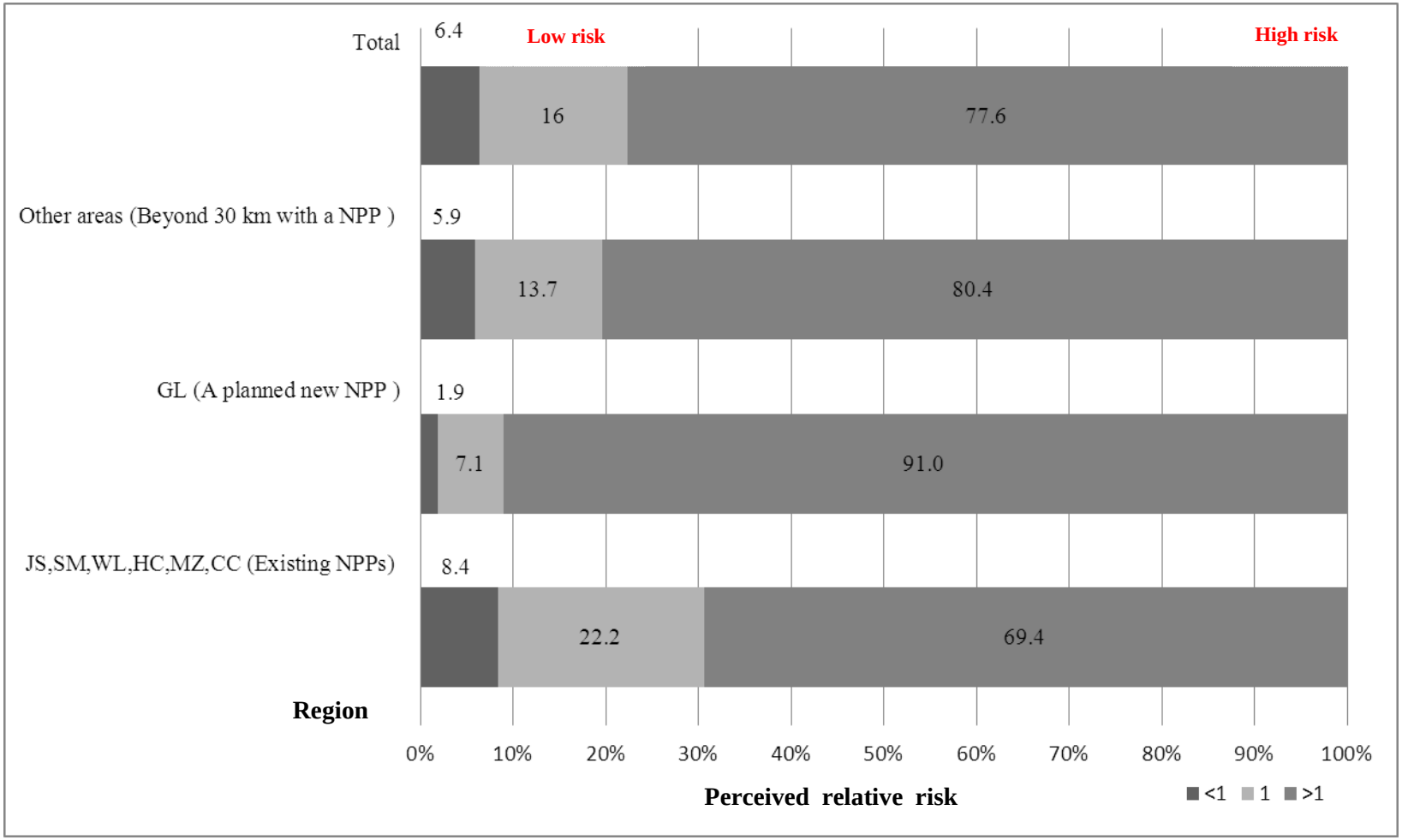


**Figure 3. Comparison of the levels of perceived relative risks of cancer incidence by region**

NPP, nuclear power plant; JS, Jinshan; SM, Shimen; WL, Wanli; HC, Hengchun; MZ, Manzhou; CC, Checheng; GL, Gongliao

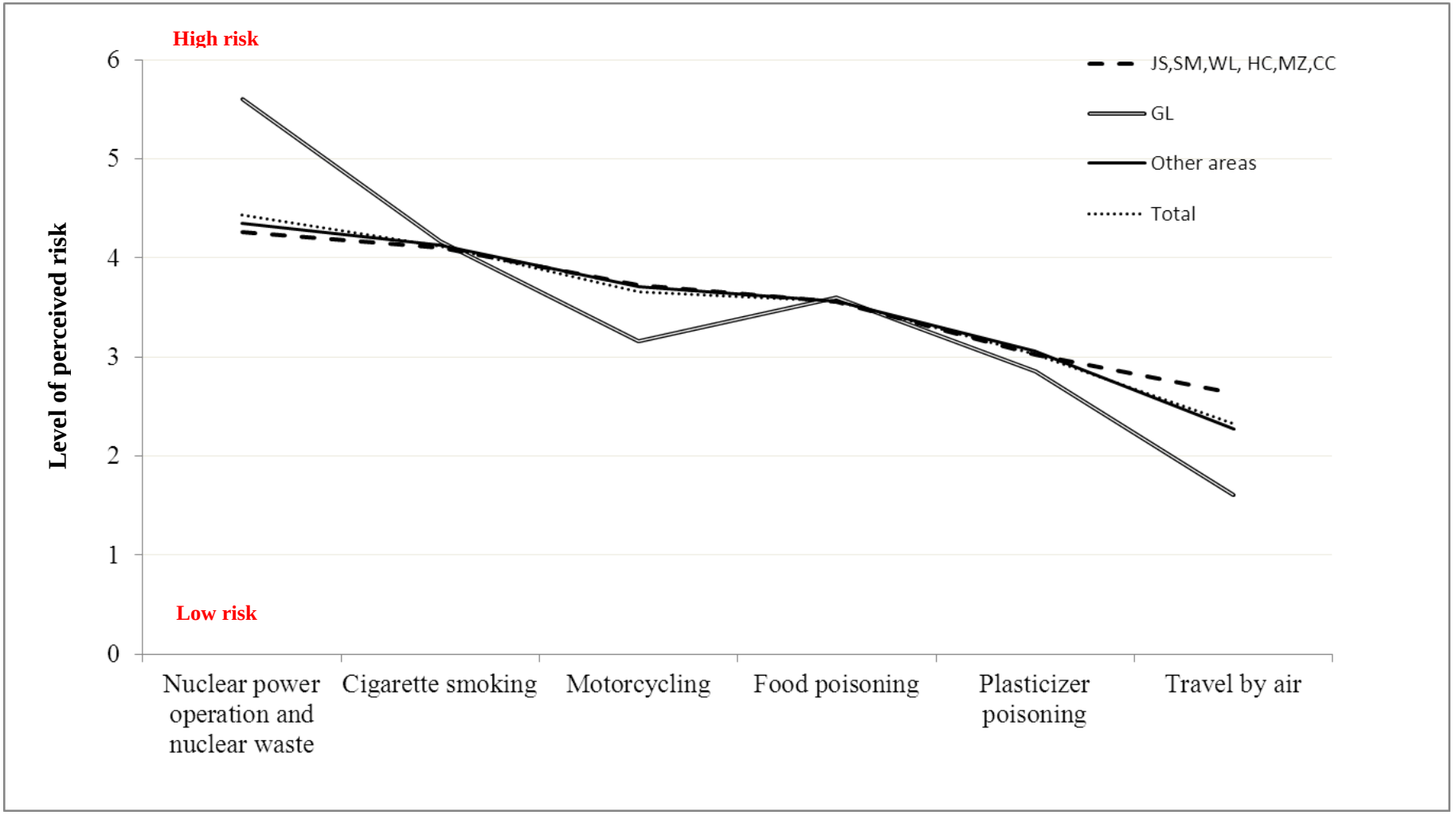


**Figure 4. Comparison of the levels of perceived risks of death between nuclear plants/nuclear waste and 5 common human activities/behaviors by region**

NPP, nuclear power plant; JS, Jinshan; SM, Shimen; WL, Wanli; HC, Hengchun; MZ, Manzhou; CC, Checheng; GL, Gongliao