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Objective air quality index versus subjective perception: which has a greater impact on life satisfaction?

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Abstract

Although the $PM_{2.5}$ concept was put forward in 1997, it came into Chinese people's sight in 2011, and became a household name in 2013 in China. Previous studies did not involve this indicator, so we need to re-examine and compare the effects of objective air quality data and subjective perception on Life satisfaction (LS). The data were collected from Xi'an, a megacity of Northwest China. Particles smaller than 2.5 μm in diameter ($PM_{2.5}$), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and Air quality index (AQI) acquired from air quality stations were used to calculate pollutant concentrations near the vicinity of subjects' home by Geographical information system (GIS) software. In this paper, the ordinal logistic regression models are used to explain ratings of LS in terms of the objective air pollution data, social and economic variables. The results indicate that the objective air pollution data has significant and negative effects on LS of the surveyed respondents. However, when the subjective perception of air pollution is considered in the regression models, it shows that the subjective perception of air pollution has a significant negative impact on LS, while the effects of $PM_{2.5}$, NO_2, SO_2, and AQI on the LS become insignificant. Furthermore, the research significances and policy suggestions are discussed in this paper.

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Graphic abstract

Keywords Life satisfaction · Subjective well-being · Air quality · Perception of air pollution

1 Introduction

Nowadays, Life satisfaction (LS) research is an increasing interesting subject both in the public and within the disciplines (Mackerron & Mourato, 2009) due to air pollution caused by urbanization and industrialization (Ambade, 2012; Ambade & Shubhankar, 2020). Many studies present the influencing factors of LS including income, health (Helliwell, 2003), climate (Maddison & Rehdanz, 2011), and environmental quality (Barrington-Leigh & Behzadnejad, 2017; Nelson, 2004; Rehdanz & Maddison, 2008; Welsch, 2006). The agriculture crop production may decrease due to climate change (Meshram et al., 2018, 2020), which can affect human well-being. Undoubtedly, environmental quality is one of the people's main concerns. Due to the emission and accumulation of particles smaller than 10 µm in diameter (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and heavy metals, the ambient air quality is affected adversely (Ambade et al., 2018). As for the relations between the air quality and LS, many researchers think it is a new subject in the process of economic development (Welsch, 2005) and sustainable development (Boğaçhan and Huisingh, 2015). The environment quality is related to human health, mood, and life (Schmiedeberg & Schroer, 2014), which has emerged as a popular topic of essential concern for the public, policy-makers, and academic researchers.

Firstly, air pollution in China is more serious than the developed countries, since the rapid economic growth and huge population base of 1.4 billion in China have led to increased emissions of air pollutants from mining, industrial emission, motorization, urbanization, and energy consumption, to name a few (Kan et al., 2012; Li et al., 2014). Among the twenty most polluted cities around the world, however, there are sixteen in China (Shu & Zhu, 2009). Today people even say that haze is not news, and no haze is news in China. Meanwhile, a lot of environmentally friendly policies are distributed successively in China because the Chinese government takes environmental issues very seriously (Shi, 2015). Furthermore, air quality has been applied to evaluate local officials' political achievement in China. Under this background, however, we still don't know the link between air pollution and self-reported LS in China, especially after the term particles smaller than 2.5 µm in diameter ($PM_{2.5}$) came into Chinese people's sight. Secondly, there are not still too adequate researches about LS in Western China where the haze is more serious than that in Eastern China and other developed countries. Moreover, these studies are mainly carried out in the developed countries (Welsch, 2007). Thirdly, there are differences in air quality standards between developed countries and China. For example, the air quality standards in USA are more rigorous than those in China (Fig. 1). Therefore, the relevant results about developed countries are difficult to be applied to China. Finally, $PM_{2.5}$ came into Chinese people's sight in 2011, and it became a household name in 2013 in China. So previous studies did not involve this indicator. It is necessary to examine the effects of $PM_{2.5}$ on LS. In addition, residents' awareness of environmental protection has risen to unprecedented heights, since the haze became the common social issue in China. Under this situation, we need to reassess the influence of subjective perception on the self-reported LS.

It is to be noted that there has been an increasing body of relevant studies in recent years, the majority of which support that there is a negative relationship between local

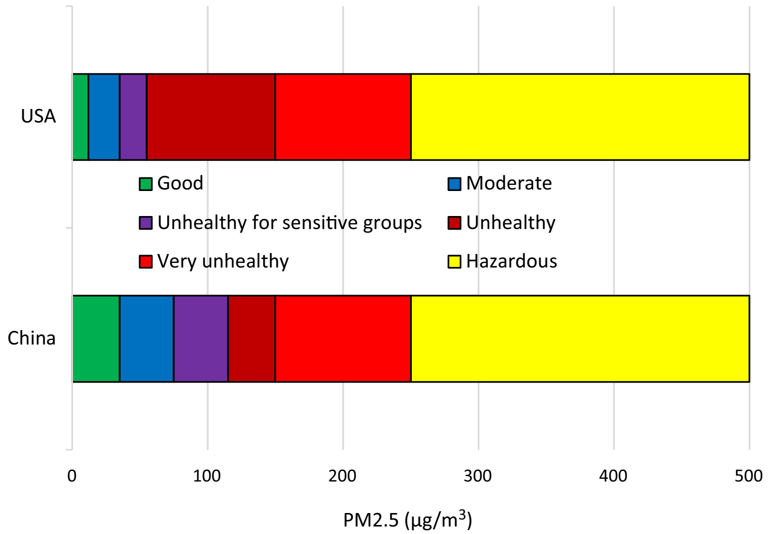

Fig. 1 Comparison of air pollution level of USA and China

environmental pollution and LS (Ferrer-I-Carbonell & Gowdy, 2007; Li et al., 2014). Luechinger (2009) reveals that there is a significant negative effect of SO_2 concentrations on LS. Smyth et al. (2008) also highlight that SO_2 concentration has a significant and negative influence on subjective LS on the basis of pollution data of urban areas from 30 cities in China. It is also reported that NO_2 concentrations have a detrimental impact on LS (Ferreira et al., 2013; Mackerron & Mourato, 2009). Due to the highly toxic health effects of particulate matter (Kumar et al., 2020a, 2020b), the number of researches related to fine particle matter is increasing. However, the majority of studies on LS focused on the effect of PM_{10} on LS. For instance, PM_{10} concentrations affect the public's satisfaction with air quality (Ambrey et al., 2014; Orru et al., 2016; Silva et al., 2012). There are few studies exploring the impact of $PM_{2.5}$ on LS. Moreover, the effects of other indices such as the Air quality index (AQI) are also rarely identified in the previous studies on LS. Government agencies apply AQI to report the daily air quality and communicate to the public how clean the air currently is or what health effects may be.

In the context of analyzing air pollution effects on LS, AQI and $PM_{2.5}$ are appropriate to measure. First, it is easily perceived by the local residents, and second, the health impacts are well-known. Third, with the popularity of smart phones, people can query air quality through application (app) at any moment. Meanwhile, AQI and $PM_{2.5}$ have become the main contents of the weather forecast since 2012. Consequently, the majority of people have access to more air pollution information than before. In order to compare with previous studies, SO_2 and NO_2 concentrations are also analyzed in this study.

The relationship between perception of environmental quality such as air pollution and self-reported LS also was studied in some studies (Praag & Baarsma, 2005), since people may assess environmental pollution according to their own values and life experiences related to such problems (Hagerty, 2000; Liao et al., 2015). Some scholars highlighted that the subjective perception of air pollution was significantly and negatively associated with the LS in Europe, Asian, and South American countries based on the individual-level or country-level data (Ferreira & Moro, 2010; Luechinger, 2009, 2010; Menz, 2011).

In the light of the reviews above, people's LS is affected by both actual environmental conditions and the perception of air quality. However, the subjective and the objective air quality were usually treated as independent variables in the previous studies, so the relationship between them and their effects on LS are need to be explored, which highlight the importance of assessing the relationship between the two variables and their joint effects on LS.

The study area, Xi'an, not only is the largest city in Northwest China with over 10 million permanent residents, but also is one of the most seriously environmental polluted cities in current China (Gao, 2015). For instance, the annual average concentration of $PM_{2.5}$ in Xi'an has been up to 158.1 μg/m^3 in 2014, which is almost 5 times of the annual average standard of WHO (World Health Organization). Factually, the air pollution problems in Xi'an become more serious because of basin terrain, urban growth, increased motorization, and coal burning. To date, Xi'an ranks as one of the capital cities with the worst air quality in China. Therefore, this paper takes Xi'an city for example to analyze and compare the effects of actual air pollution indicators (AQI, $PM_{2.5}$ concentrations, SO_2 concentrations, and NO_2 concentrations) and perception of air pollution on the self-reported LS.

2 Methods

2.1 Air quality data

Air quality data was provided by Xi'an Environmental Protection Bureau. The data set comprises average daily concentrations of $PM_{2.5}$, AQI, NO_2, and SO_2 of 13 regulatory monitoring stations distributing 11 urban districts in Xi'an city. The survey was conducted in July 2014, so the monthly average concentrations were calculated up to July 2014. In addition, the identified indices were applied to the regression analysis.

But these indexes between 13 monitoring stations in the study area are still unknown. The solution is to apply a GIS-based interpolation method, namely Inverse distance weighting (IDW) to provide air quality ($PM_{2.5}$, AQI, NO_2, SO_2) information between 13 monitoring stations (see Ferreira et al., (2013) for additional details on the method). The average pollutant concentrations based on the 500 m × 500 m grid squares are defined as the pollution levels near the respondents' home. Whereas, other factors such as building heights are also identified to affect the perception of air pollution and LS. These problems are expected to be solved in the future.

2.2 Survey

LS used in this study has the same meaning with happiness, well-being, and quality of life. Many scholars hold that these terms are able to interchangeable (Mackerron & Mourato, 2009; Rehdanz & Maddison, 2005). The questionnaire was designed to contain five parts, twenty-one variables as follows:

1) Life satisfaction (LS) is the ordinal dependent variable and ranges from 1 = extremely dissatisfied to 5 = extremely satisfied.
2) Perception of air pollution (AIR) is the independent variable in this study and is used in many models (Liao et al., 2015; Rehdanz & Maddison, 2008). A five-point Likert scale is used to measure the AIR (1 = not at all, 5 = very serious).

3) Social relations variables (trust, neighbor, relatives, group, etc.) are independent variables and play a significant role in social support related to human well-being (Appleton & Song, 2008).
4) Psychology variables including discrimination and loneliness are also influencing factors on LS (Borg et al., 2006).
5) Socio-demographic factors have been proved a key factor affecting LS in previous studies (Ferreira et al., 2013; Shu & Zhu, 2009; Sing, 2009), which including age, gender, education, household income and marital status, therefore, are also investigated in this study (shown in Tables 1 and 2).

Before the formal survey, 2 graduate students and 1 undergraduate student were trained in survey methods. A four-stage stratified sampling technique was conducted. In the first stage, Xi'an was divided into nine districts. In the second stage, 18 primary sampling units were chosen randomly from the lists in the Xi'an Statistics Yearbook 2014. In the third stage, 25 respondents over 18 years old were selected randomly from the resident registration lists of each primary unit. And a total of 450 respondents were selected randomly. Finally, the respondents were investigated by face-to-face interviews independently in July 2014. No gifts or other rewards as a token of appreciation were granted to the respondent after he or she completed the survey. There were 396 valid questionnaires with an effectiveness rate of 88%. Table 1 shows the basic information of the samples.

2.3 Data analysis

We aim to explore the relationships among objective air pollution, perception of air pollution and LS based on the LS-perception-objective air quality model (shown in Fig. 2). Firstly, frequency analysis is employed to evaluate LS. Then the ordinal logistic regression model is conducted to estimate the magnitude and significance of connections between LS and other various variables due to LS is an ordinal variable. Eight ordinal logistic regression models of LS were estimated. Each model includes socio-economic variables, demographic variables, psychology variables, and social relationships variables, attitude, and perception of air pollution. Model 1, 3, 5, and 7 add objective measures of air pollution parameters (AQI, SO_2, NO_2, $PM_{2.5}$), while model 2, 4, 6, and 8 add both perception of air quality and objective measures of air pollution parameters. As an exogenous variable, the perceived air pollution (AIR) is also added to the model in other studies (Liao et al., 2015). The data were analyzed by the software SPSS with the version 20.0. And the models' significance level is less than 0.1 ($P < 0.1$).

3 Results

3.1 Air quality

Although different countries have very similar air quality indices, their air quality standards are different from each other. For the sake of contrast to other countries, Table 3 shows the air quality indices and standards of China. According to these indices, the histogram of AQI, SO_2, $PM_{2.5}$, and NO_2 concentrations are shown in Fig. 3.

Table 1 Summary of variables

Variable	Definition	Mean	Std. dev
Life satisfaction	All things concerned, how satisfied are you with your life? 1 = Extremely dissatisfied; 5 = extremely satisfied	3.31	0.86
Air	What is the respondent's perception of air pollution?(1 = not at all serious to 5 = extremely serious)	2.44	0.89
Trust	Dose the respondent think others can be trusted?(1 = not at all; 5 = very strongly)	3.26	0.83
Trustgov	Dose the respondent think the government can be trusted? (1 = not at all; 5 = very strongly)	2.68	0.97
Neighbor	Does the respondent speak to neighbor at least once a week?(1 = yes, 0 = no)	0.42	0.49
Relatives	Does the respondent often connect with relatives? (1 = yes, 0 = otherwise)	0.15	0.35
Groups	Does the respondent participate in groups, clubs or organizations (1 = yes, 0 = no)	1.73	0.44
Help	Would the respondent like to help others? (1 = yes, 0 = no)	0.52	0.50
Outdoor	Does the respondent spend more than 1 h outdoor on an average weekday? (1 = yes, 0 = no)	0.63	0.48
Gender	1 = male, 2 = female	1.46	0.50
Age	1 = < 30 years; 2 = 30–40 years; 3 = 41–50 years; 4 = 51–60 years; 5 = > 60 years	2.91	1.15
Education	1 = Elementary school; 2 = Junior high `school; 3 = Senior high school; 4 = Secondary Technical School; 5 = > college	3.90	1.15
Income	How much is the respondent's annual household's income? (1 = 10,000–30,000 Yuan, 2 = 30,000–60,000 Yuan, 3 = 60,000–100,000 Yuan, 4 = 100,000–200,000 Yuan, 5 = > 200,000Yuan)	3.12	3.46
Home	Does the respondent own his accommodation? (1 = yes, 0 = no)	0.57	0.50
TV	Doses the respondent watch TV more than 1 h each day? (1 = yes, 0 = no)	0.61	0.49
Married	Is the respondent married? (1 = yes, 0 = no)	0.67	0.47
Religious	Does the respondent have faith? (1 = yes, 0 = no)	0.11	0.32
Health	Respondent rate his/her health as (1 = very bad, 5 = very good)	3.51	0.79
Discrimination	Does the respondent have been discriminated in daily life? (1 = yes, 0 = no)	0.33	0.47
Lonely	Does the respondent feel lonely in daily life? (1 = yes, 0 = no)	0.29	0.46
Hotline	Does the respondent know the environmental complaint hotline? (1 = yes, 0 = no)	0.21	0.41

Table 2 Sample distributions of variables

Variables		Frequency	%	Variables		Frequency	%
AIR	Extremely serious	56	14.1	Income	10,000–30,000 Yuan	114	28.8
	Very serious	157	39.6		30,000–60,000 Yuan	225	56.8
	Moderately serious	141	35.6		60,000–100,000 Yuan	40	10.1
	Slightly serious	38	9.6		100,000–200,000 Yuan	16	4.0
	Not at all serious	4	1.0		> 200,000 Yuan	1	0.3
Age	< 30 years;	93	23.5	Health	Very bad	5	1.3
	30 ~ 40 years;	79	19.9		Bad	25	6.3
	41 ~ 50 years;	71	17.9		Good	163	41.2
	51 ~ 60 years;	75	18.9		Pretty good	169	42.7
	> 60 years	78	19.7		Very good	34	8.6
Variables				Frequency		%	
Education	Elementary school			3		0.8	
	Junior high school			57		14.4	
	Senior high school			93		23.5	
	Secondary Technical School			66		16.7	
	> college			177		44.7	

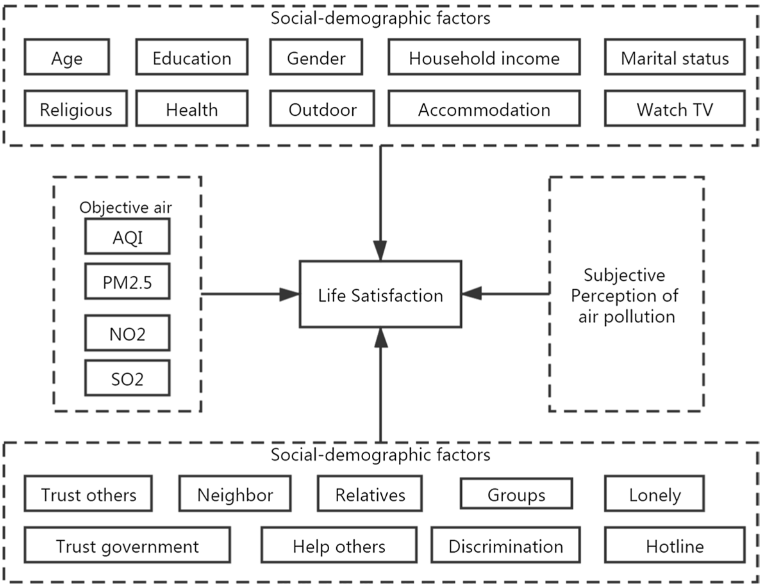

Fig. 2 LS-perception-objective air quality model (Variables are defined in Table 1)

Table 3 Air quality category in China mainland

Level	AQI	Average per 24 h. SO_2 (μg/m^3)	Average per 24 h. NO_2(μg/m^3)	Average per 24 h. PM2.5(μg/m^3)
Good	0 ~ 50	0 ~ 50	0 ~ 40	35
Moderate	51 ~ 100	51 ~ 150	41 ~ 80	75
Unhealthy for sensitive groups	101 ~ 150	151 ~ 475	81 ~ 180	115
Unhealthy	151 ~ 200	476 ~ 800	181 ~ 280	150
Very unhealthy	201 ~ 300	801 ~ 1600	281 ~ 565	250
Hazardous	301 ~ 500	1601 ~ 2620	566 ~ 940	350 ~ 500
Beyond index	> 500	> 2620	> 940	> 500

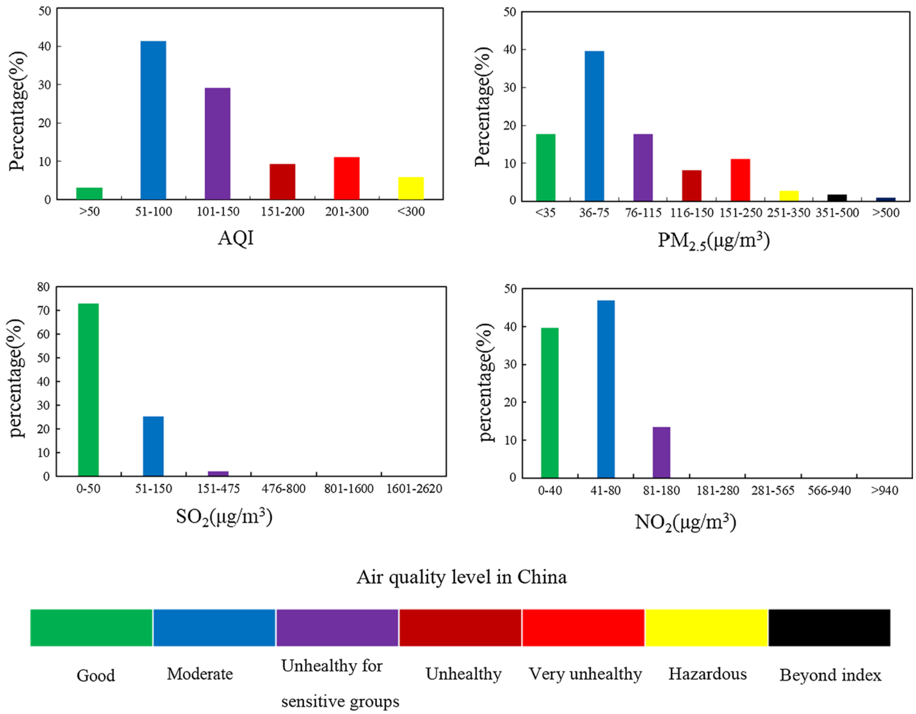

Fig. 3 Frequency Distribution of AQI and concentration of PM 2.5, NO_2, and SO_2 in Xi'an City

AQI range is between 23–500. Only 3.11% of AQI is less than 50 and 41.38% of AQI is between 51 and 100. The average annual AQI is 136.97, which exceed the annual pollution benchmark. SO_2 concentrations range between 22.84 μg/m^3–59.44 μg/m^3. 70.89% of SO_2 is lower than 50 μg/m^3, and 29.11% of SO_2 is between 51–150 μg/m^3.

$PM_{2.5}$ concentration frequency distribution peaked at 36–75 μg/m^3 and only 15.51% of the data are below 35 μg/m^3. $PM_{2.5}$ concentration exceeded 250 μg/m^3 is more than 4.43% of sampling days. The range of NO_2 concentrations are 33.58 μg/m^3 and 63.37 μg/m^3.

31.96% of NO_2 concentration is lower than 40 μg/m^3, and 56.65% of NO_2 concentration is between 41–80 μg/m^3. 10.76% of NO_2 concentration is between 81–120 μg/m^3, whereas 0.63% of NO_2 concentration is above 120 μg/m^3.

The average annual concentrations of SO_2, $PM_{2.5}$, and NO_2 are 40 μg/m^3, 158.1 μg/m^3 and 53.07 μg/m^3, respectively. All of these indices exceed the maximum average annual pollutant concentrations of WHO guideline (Mackerron & Mourato, 2009).

3.2 Air pollution perception

Across the response scale perceptions of air pollution were distributed: 39.6% of respondents perceive that air pollution is serious in their districts or blocks, and even 14.1% of respondents state the air pollution is very serious. Whereas, 35.6% of respondents believe air pollution is general. In addition, there are 9.6% of respondents who argue air pollution is light. Furthermore, only 1% of respondents hold that air pollution is not a problem at all. The results indicate that the majority of locals considered air quality is not good.

The relation between the air pollution perception and objective measures of air pollution (mean concentration of pollutants) is presented in Table 4. It is obvious that a high mean concentration of pollutants corresponds to a higher perception of air pollution. The results also echo the previous studies because the perception is based on the objects in the real world (Liao et al., 2015).

3.3 Life satisfaction

The mean value of LS is 3.31 in Xi'an City. For comparison, the mean LS was 3.41 which was conducted in 18 cities in China (Cao, 2011) and the mean value of LS was 3.29 which was conducted in Taiwan (Liao et al., 2015). The patterns of LS are shown in Fig. 4, which shows 3 as the first and 4 as the second most common.

Eight ordinal logistic regression models of LS were estimated, as shown in Table 5. Hair et al. (1998) think the smaller 2 log likelihood values are the better model fit. Thus, all eight ordinal logistic regression models indicate a good fit. Statistically, the significant variables of all models include trustgov, income, married, health and discrimination. Model 1 shows that neighbor has a significant positive impact on LS. Model 1, 3, 5, and 7 show that AQI, SO_2, NO_2, and $PM_{2.5}$ are significantly and negatively associated with LS, when the AIR is not considered. When AIR is considered in the model 2, 4, 6 and 8, it is found that AIR as an explanatory variable has a significant effect on LS. However, all the significant effects of AQI, NO_2, SO_2, and $PM_{2.5}$ become insignificant in the above models, respectively.

Table 4 Crosstable of Perception and objective measures of air pollution

Perception of air pollution	AQI	SO_2(μg/m3)	NO_2(μg/m3)	PM2.5(μg/m3)
Extremely serious	140.88	33.26	62.49	125.27
Very serious	137.84	34.19	62.94	122.76
Moderately serious	137.06	33.90	62.64	121.41
Slightly serious	133.89	32.08	62.92	121.90
Not at all serious	133.03	33.26	59.70	119.45

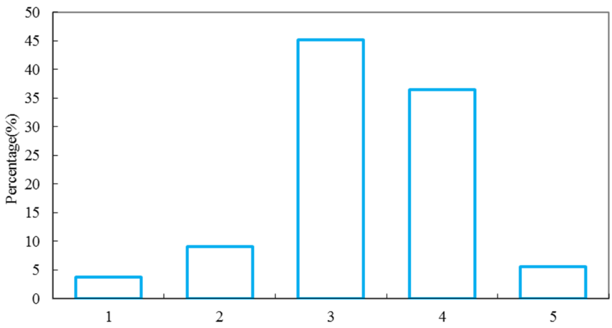

Fig. 4 Life satisfaction ratings

4 Discussion

4.1 Social–demographic factors effect on LS

Statistically, income, married and health have significant positive implications on LS, which are easy to understand and in line with the previous researches on LS (Chen & Yue, 2001; Daraei & Mohajery, 2013; Yi & Wang, 2007).

Many studies have proved that there is a significant relationship between income and LS (Clark et al., 2008). The new study finding has revealed that other factors beyond income also significantly affect people's LS, including marital status, employment, and health (Dolan et al., 2008). Probably because of the household budget limitation, people with low household income may obtain nothing or less from social progress. In modern societies, nevertheless, people who have a high income can have posh cars, take a vacation to alien countries, buy the newest high technology goods and enjoy extravagant leisure time (Ferrer-I-Carbonell, 2005). Thus, income has a positive correlation with individual LS (Frijters et al., 2004).

Marriage can improve the health and promote the financial satisfaction (Stack & Eshleman, 1998). Previous studies also suggest that unmarried people are less satisfied and unhappier with their lives than married persons (Mikucka, 2016; Verbakel, 2012). The adverse impacts of air pollution on human beings can reduce the levels of local residents' LS directly and separately. Therefore, linking LS and air pollution, health may be one of important pathway (Mackerron & Mourato, 2009).

The results also establish that neighbor is a significant positive determinant of LS, which is consistent with the result revealed by Sirgy and Cornwell (2002). Communicating with neighbors can improve residents' LS. The higher the frequency of neighborhood communication, the higher the LS is (Sirgy & Cornwell, 2002). Trust in government (Trustgov) also has a positive effect on LS. Local residents hold that it is the responsibility of the government departments to improve the quality of people's lives. In the field survey, most people hope the government can put more efforts on life improvement. In accordance with the legal requirements in China, only the government can announce the pollution data and make full use of the supervision to avoid environmental pollution by implementing administrative regulations. If the government departments can take into account people's expectations and requirements, the level of local residents' LS will be improved.

Table 5 Estimated parameters for life satisfaction models

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Air	–	−0.370**	–	-0.356**	–	−0.373**	–	−0.369**
Trust	0.093†	0.111	0.082	0.099	0.100	0.117	0.099	0.114
Trustgov	0.347**	0.270**	0.347**	0.277**	0.340**	0.267*	0.477***	0.358**
Neighbor	0.126†	0.127†	0.118	0.118	0.132†	0.131†	0.125†	0.125†
Relatives	0.089†	0.078	0.081	0.070	0.091	0.079	0.089	0.078
Groups	0.229	0.259	0.212	0.242	0.238	0.267	0.227	0.257
Help	0.353†	0.392†	0.346	0.345	0.345	0.346	0.360†	0.356†
Outdoor	0.102	0.152	0.063	0.111	0.087	0.136	0.105	0.152
Gender	0.209	0.243	0.226	0.257	0.212	0.244	0.205	0.240
Age	0.008	-0.009	0.003	-0.013	0.006	-0.010	0.011	-0.007
Education	0.044	0.047	0.055	0.058	0.048	0.051	0.047	0.049
Income	0.074*	0.079*	0.066*	0.071*	0.073*	0.078*	0.073*	0.078*
Home	0.171	0.208	0.201	0.237	0.148	0.192	0.166	0.207
TV	0.199	0.179	0.245	0.223	0.191	0.170	0.197	0.177
Married	0.846**	0.798**	0.849**	0.805**	0.868**	0.819**	0.851**	0.802**
Religious	0.190	0.185	0.188	0.183	0.215	0.205	0.192	0.185
Health	0.607***	0.525***	0.611***	0.568***	0.627***	0.581***	0.603***	0.561***
Discrimination	−0.387†	−0.398†	−0.438†	−0.446†	−0.396†	−0.406†	−0.386	−0.398†
Lonely	−0.358	−0.371	−0.347	−0.361	−0.331	−0.347	−0.357	−0.371
Hotline	0.016	0.012	0.030	0.026	0.040	0.033	0.015	0.010
AQI	−0.062*	−0.041	–	–	–	–	–	–
SO_2	–	–	-0.042*	-0.038	–	–	–	–
NO_2	–	–	–	–	-0.031*	-0.027	–	–
PM2.5	–	–	–	–	–	–	-0.034*	-0.022
-2 log likelihood intercept only	946.156	959.286	878.483	896.951	1190.649	1206.594	946.652	981.748

Table 5 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
-2 log likelihood final model	816.192	821.727	790.851	799.680	964.603	966.087	823.173	831.740
Chi-square	119.964	124.429	97.975	97.554	130.743	129.534	92.889	90.647
Degree of freedom	19	20	19	20	19	20	19	20
Significance	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Cox and Snell R^2	0.288	0.236	0.276	0.315	0.294	0.242	0.283	0.219
Nagelkerke	0.314	0.270	0.303	0.429	0.381	0.335	0.306	0.282
N	396	396	396	396	396	396	396	396

† $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

As expected in this study, perceived discrimination has a negative effect on LS. The negative impact of perceived discrimination on the health and life satisfaction of people has been widely reported (Pascoe & Smart-Richman, 2009; Urzúa, et al., 2018). Bjørnskov et al (2007) also suggest that people are more pleased with their lives when society becomes more equal.

4.2 Air quality effect on LS

Empirical evidences have supported the negative influence of air pollution on LS (Luechinger, 2010). In this paper, we find that AQI, SO_2, $PM_{2.5}$, and NO_2 are significant depressors of LS.

Regretfully, we still have few studies to place our result of the effect of $PM_{2.5}$ concentration on LS in a specific context. Ferreira and Moro (2010) find the similar effects of PM_{10} on LS with the regional data of Ireland. In addition, Orru et al. (2015) consider that even a comparatively lower concentration of PM_{10} can reduce subjective well-being evaluation on account of the potential results of greater physical and psychological stress, annoyance and frustration. China's annual average $PM_{2.5}$ standard, U.S. EPA's annual average $PM_{2.5}$ standard, and WHO's annual average $PM_{2.5}$ standard are 35 μg/m^3, 12 μg/m^3, and 10 μg/m^3, respectively. In the last 10 years, substantially, the average annual $PM_{2.5}$ concentration is up to 167 μg/m^3 in Xi'an city, which is far beyond the average annual $PM_{2.5}$ standards of any country and organization (Gao et al., 2015). Therefore, the public is extremely concerned about the air pollution of Xi'an city nowadays. In addition, they can easily complete online inquiry of $PM_{2.5}$ value and AQI at any time.

Earlier studies often took the SO_2 concentrations as an objective air quality index. The previous relative analyses show that SO_2 concentration has a negative effect on the subjective LS (Menz & Welsch, 2012; Tella & MacCulloch, 2008). Based on the air quality data from 30 cities in China, Smyth et al. (2008) highlight that SO_2 emission has an obvious negative effect on self-reported well-being. Similarly, we also reveal that there is an obvious negative relationship between SO_2 concentrations and the LS of local residents in Xi'an city.

Moreover, NO_2 is one of the critical damaging pollutants to one's health in modern cities. Our findings confirm the effect of NO_2 on LS. Mackerron et al. (2009) also identify a significant negative association between NO_2 concentration and LS.

4.3 Perception of air pollution effect on LS

The results establish that the perception of air pollution has a significantly negative effect on LS, which also is identified (Rehdanz & Maddison, 2008) in Germany, Taiwan (Liao et al., 2015), and English (MacKerron & Mourato, 2009). The public air perception is shaped by tangible and observable features of air pollution. The air pollution can lead to more frequent hazes which directly affect the visible range easily perceived by the public, so it can be treated as a visible indicator of air quality.

However, when the perception of air pollution affects LS significantly, the effects of objective air pollution ($PM_{2.5}$, $NO_{2,}$ SO_2 and AQI) become insignificant. This result is similar to the previous study by Liao et al. (2015) who reveal that the indicators of air quality have an indirect effect, but no direct effect on individual LS. As Liao et al (2015) explain, "Taiwanese respondents usually practice the Taoism in their daily life, which could lead to this consequence." However, this explanation needs to be supported in the future study.

Air quality consists of one part of the local environment, which can be easily perceived by respondents, so there is a high correlation between the perception of air pollution and the objective measures. This is one reason why the pollutant´s terms in the models lose the statistical significance including subjective measure.

5 Conclusion

Nowadays, air pollution is the main environmental problem in developing countries as a result of the development of industry and infrastructure and rapid increase in population, which may last for a long period. The studies concerning the subjective well-being suggest that LS has a notable relation with environmental quality and available public services. However, there are still few studies on the impact of the subjective and objective environmental factors on the self-reported well–being in China (Gu et al., 2015; Zhang et al., 2011).

This paper investigates the effects of the subjective and objective air quality on individual LS. The ordinal regression logistical analysis results suggest that residents report lower levels of LS with high air pollution. Furtherly, the real-time objective air pollution indices have a negative association with LS. However, when the subjective perception of air pollution is considered in the regression models, our results show that the subjective perception of air pollution has a significant negative impact on LS, while the $PM_{2.5}$, NO_2, SO_2, and AQI effects become insignificant to the LS, of which the reason maybe there is a high correlation between the perceived air pollution and the objective measures.

All the average annual concentrations of air quality indicators (AQI, SO_2, $PM_{2.5}$, and NO_2) exceed the WHO guideline maximum average annual pollutant concentrations in Xi'an city. The continuous environmental degradation of Xi'an city is threatening this area's sustainable development and is likely to agitate the local residents. Thus, our research results imply that the notable gains to improve LS can be achieved by reducing air pollution in Xi'an city.

There has been an increasing interest in the facts of LS among policy-makers to directly refer to design of policy in recent years. Our findings suggest that policies of improving the LS should be adopted in an integrated way with the social and economic development policies and regulations. Xi'an municipal government sets up a leading group on governing the haze weather. And a series of policies and regulations have been issued to reduce air pollution. For example, the policy of traffic restriction has been implemented daily based on the last digit of license plate numbers. Our results reaffirm the standards and goals of the Environment Protection Measure for Ambient Air Quality (2014) and suggest that the Atmospheric Pollution Prevention and Control Law of Shaanxi Province is a useful initiative. By 2030, Xi'an's atmospheric environment is expected to meet standards in accordance with the new national standards. Xi'an municipal government is putting forward more other actions to clean the air, but there are no any measures about subjective well-being. Our study indicates that it is important to incorporate objective measurement of atmosphere quality and subjective perception in understanding their effects on an individual's LS. When the city development policies are formulated, not only do the subjective perception of air pollution should be treated as an advanced guiding principle, but also the specific standards of the city development need to be set gradually based on the widely accepted subjective well-being indicators. It is important and crucial for policy-makers to realize that.

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