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Economic Loss of Zinc Materials from Air Pollution and Corrosion -- a Case Study of Kunming City

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In this paper, the method for estimating the economic loss of atmospheric corrosion of materials is introduced briefly. And the Kunming city is selected as a representative area. The corrosion loss of zinc materials was estimated quantitatively by using the response function of corrosion damage and the calculation formula of service life. The results showed that the annual direct economic loss caused by atmospheric pollution corrosion damage to zinc materials was about 56 million yuan, which is about 0.16% of GDP of the same period. Among them, the contribution rate of dry settlement to total economic loss is between 67% and 95%, and the mean value is 91%.

1. Introduction

So far, there are both international and domestic groundworks on atmospheric corrosion field (Henriksen and Mikhailov, 2002; Chico et al., 2005; Veleva et al., 2009; Ma et al., 2015). Tidblad J et al. adopted the market value method to measure the losses caused by atmospheric pollution in Nepal on the buildings based on the measurement-response relationship (Tidblad et al., 2016). Domestic insight into losses from air pollution emerged as early as 1984 when Guo Xiaomin et al. made an estimation on it throughout the country. Zheng Yisheng measured the losses caused by pollution harms to human health and the direct economic losses of it to agricultural products, as well as the household cleaning outgoings incurred by it in China. Later, on this basis, these efforts have been improved and borne fruits. Xu Wenxuan et al. analyzed the behaviors and socio-economic impacts of urban air pollution in China (Xu et al., 2018). Qi Dongmei discussed the atmospheric corrosion mechanism of Cu and its alloys. He focused on the dominant factors that affect the atmospheric corrosion of them and several common approaches for studying atmospheric corrosion, and looked ahead to the future trends (Qi et al., 2014). Liang Chenghao conducted a 400-day outdoor atmospheric exposure experiment on the AZ31 magnesium alloy and pure magnesium samples in the marine climate of Dalian. In the meanwhile, the corrosion kinetics equation was calculated by image method and the composition of the corrosion product was also analyzed (Liang et al., 2013). Wang Zhenyao et al. explored the atmospheric corrosion behaviors on the P265GH and Q235 steels under cyclic dry-wet leaching conditions (Wang et al., 2014). Li Zhijun et al. made the analysis on the environmental monitoring theory and proposed the countermeasures against air pollution problems (Li et al., 2018)
Kunming lies in the central part of Yunnan Province, where the terrain is high in the north and low in the south. It is surrounded by mountains on three sides and borders on the Dian Lake in the southwest, 1891m above sea level in the center. Kunming is an inland city where there are the population, city size and GDP per capita approximate to other capital cities. In Kunming, therefore, it is of great practical significance to conduct a survey on the material corrosion caused by air pollution. In order to quantitatively evaluate what is the corrosive damage caused by air pollution in Kunming City to the materials, this paper takes zinc material as an example to estimate the economic losses caused by atmospheric pollution and corrosion on it with well-established response functions. In this paper, the method for estimating the economic loss of atmospheric corrosion of materials is introduced briefly. And the Kunming city is selected as a representative area. The corrosion loss of zinc materials was estimated quantitatively by using the response function of corrosion damage and the calculation formula of service life.

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2. Estimation method of economic loss of material corrosion damage

2.1 Estimation on economic losses

Up till now, there are two commonly used methods for estimating economic losses at home and abroad: comparative and analytical methods.

The comparative method compares the corrosive damage to the materials under different air pollution levels and the economic loss caused by them, based on which the relationship between air pollution and economic loss is available. Analytical method means that the dosage-response functions are used to calculate the losses of economic and aesthetic values caused by corrosive damage to the materials. Although the analysis method seems more cumbersome, it has a greater guiding function for the real things. Choosing the Kunming city as a sample, we analyze what is the economic loss caused by the atmospheric corrosion to zinc materials. On the one hand, it is because the city is large, and on the other hand, only aiming at zinc materials can greatly reduce the difficulty of data survey and improve data accuracy.

2.2 Estimation with the analytical method

The calculation process of analytical method is shown in the figure below.

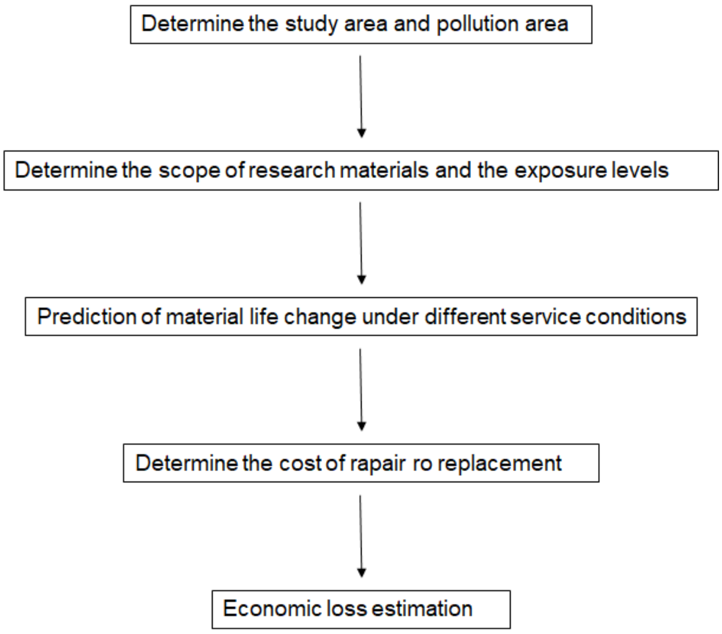

Figure 1: Computational flowchart

In general, the direct economic loss of material corrosion damage mainly refers to the additional repair or replacement costs incurred by air pollution. According to this concept, the formula for estimating the economic losses in the figure can be derived.

$$K_P = \frac{K \times S \times \left(L_P^{-1} - L_c^{-1}\right)}{*MERGEFORMAT} \qquad (1)$$

Where K_p is the additional repair or replacement cost incurred by the damages of atmospheric pollution to the materials, i.e. the economic loss; K is the repair or replacement cost of the material per unit area; S is the material exposure area. $L_p^{-1}$is the material repair or replacement cycle under the pollution conditions, i.e. the service life. $L_p^{-1}$is the material repair or replacement cycle under pollution free conditions (i.e. background points).

3. Steps for estimating the economic loss of material corrosion damage

3.1 Determination and pollution division of survey scope

There are 14 prefectures in Kunming, they are as follows:

Municipal districts: Wuhua District, Panlong District, Guandu District, Xishan District, Dongchuan District
County: Chenggong County, Puning County, Fumin County, Yiliang County, Shilin Yi Autonomous County, Songming County, Luquan Yi and Miao Autonomous County, Xundian Hui and Yi Autonomous County
Escrow: Anning City.
Considering the concentration of industrialization level and population density, this paper selects five municipal districts as sample partitions. The population is concentrated, the buildings are relatively dense, and the metal exposure is high. These five samples have a higher realistic significance.

3.2 Range of estimated materials

Outdoor exposure materials are complex and diverse and subjected to different pollutants. Due to the limited types of materials exposed to the field, it is almost impossible to calculate all materials. In general, only materials that are substantial, extensive, and relatively easy to quantify the losses can be chosen as representative materials for estimating the economic losses. Based on the previous experience, zinc materials and other zinc structures as applicable to outdoors exposed materials in Kunming are chosen for measuring the economic losses of atmospheric corrosion.

3.3 Exposure of materials contaminated in different areas

Since materials are usually used in the area where humans live, it is generally believed that the exposure to materials has direct bearing on the population distribution. The total exposure of the materials in the study area can be determined in such a way that the per capita usage of a material is counted up. Then the total exposure of the material in the area is as follows.

$$S = \frac{N \times S_a}{*MERGEFORMAT} \quad (2)$$

Where N is the total population of a polluted area, which is available from the Kunming Statistical Yearbook. Sa is the per capita usage of a material. As evaluated for the per capita usage of materials, the following recommended values are available based on extensive surveys and statistical analysis: the per capita usage of galvanized steel is 1.6㎡/person, and the per capita usage of other zinc structures is 1.5㎡/person.

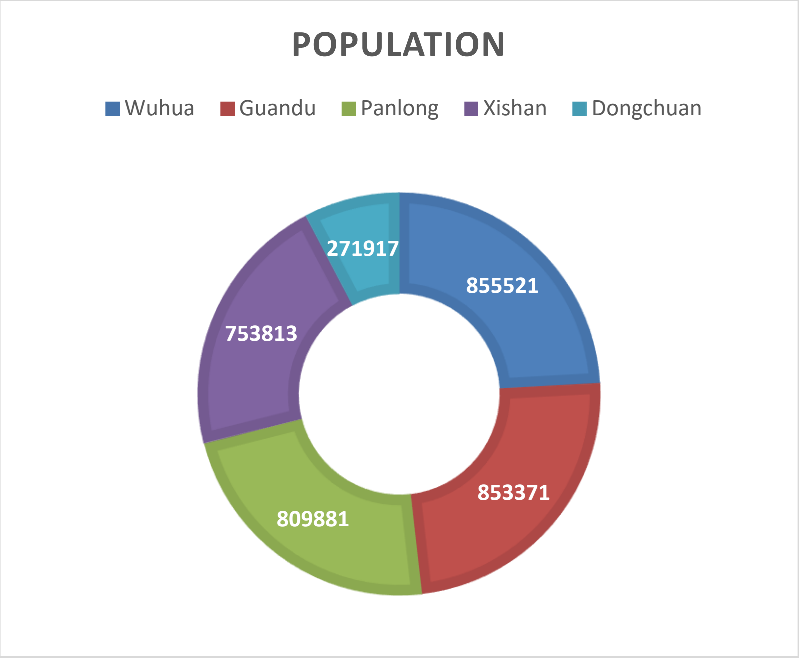

Figure 2: The population of the 5 Zones of Kunming

3.4 Determination for maintenance or replacement unit price

Generally, based on data available from the material survey, when there are multiple repair or replacement unit prices for a certain material, the weighted average method can be used to obtain the average repair or replacement unit price. In this estimation, we adopt the maintenance unit price as determined by Zhao Gantao et al. on galvanized steel and other zinc structures according to the China's practical situation and the difference in special price indicator in these areas (Zhao et al., 2018).

3.5 Service life of material in different pollution conditions

Assume there is not air pollution conditions, that is, at the environmental background points, the zinc material repair or replacement cycle is L_c, and calculated by the formula

$$L_c = \frac{S_{CDL}}{Y_c} \Big/ \text{*MERGEFORMAT} \tag{3}$$

Where L_c is the empirical life of the zinc material at the background point; S_{CDL} is the corrosion damage threshold, while the thresholds for galvanized steel and other zinc structures are 20 μm and 60 μm, respectively. Y_c is the corrosion rate of zinc material at the background point, whose value is 1.95/(g*m2*a).
The zinc material repair or replacement cycle L_p at a particular atmospheric pollution level is

$$L_P = \frac{S_{CDL}}{Y_P} \Big/ \text{*MERGEFORMAT} \tag{4}$$

Where L_p is the empirical life of zinc material at a specific pollution level; Y_p is the corrosion rate of zinc material at a specific pollution level, which can be calculated from the dosage response function. To estimate these values, it is required to further derive the dosage response function expressed as the thickness loss of zinc material, as shown below

$$\begin{aligned} Y_p = Y_{dry} + Y_{wet} &= 1.142 \times C_{SO_2}^{0.207} \times C_{NO_2}^{-0.258} \times t_{TOW}^{0.744} \\ &+ 0.0033 \times P_{rain} \times C_H \,/\text{*MERGEFORMAT} \end{aligned} \tag{5}$$

Where, Y_{dry} is the corrosion thickness loss caused by dry deposition; Y_{wet} is the corrosion thickness loss caused by wet deposition; C_{SO2} $C_{NO2}^{-0.25}$ is the mass fraction of SO_2, NO_2, respectively; t_{TOW} is the total surface wetting time, indirectly calculated from the annual average relative humidity and temperature. P_{rain} is the amount of atmospheric precipitation; C_H is the mass fraction of H+ in precipitation.

4. Economic loss estimation results and analysis

4.1 Results from overall economic estimation

Take 2014 as the base year for estimation, the above steps are finished according to the flow process shown in Fig. 1, the economic losses of different pollution area in Kunming can be calculated according to the formula (1). The results are shown in Table 1 and Fig. 3.

Table 1: Total loss of zinc due to atmospheric pollution (million yuan)

Material	Zone				
	Wuhua	Guandu	Panlong	Xishan	Dongchuan
Zinc plated copper	12.387	12.252	11.068	10.792	4.78
Other zinc structures	1.458	1.238	1.073	1.016	0.351
Total zinc materials	13.845	13.49	12.141	11.808	5.131
proportion	0.245	0.239	0.215	0.209	0.091

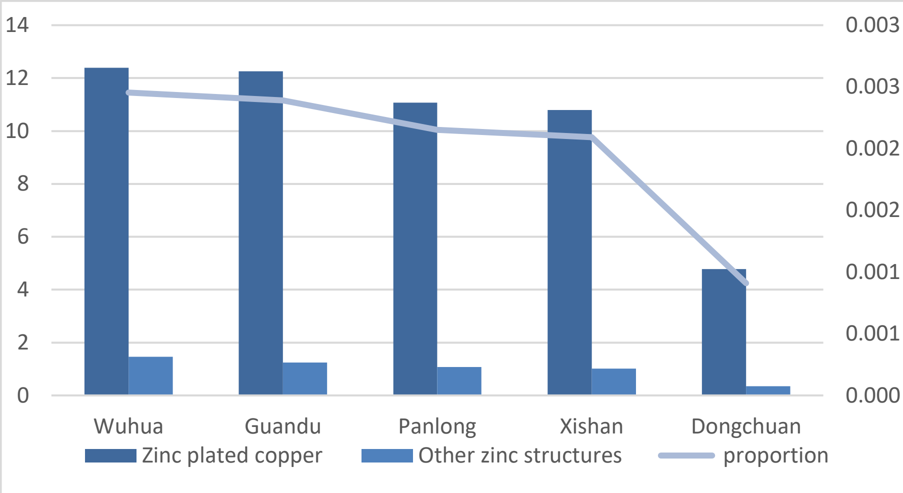

Figure 3: Total loss of zinc due to atmospheric pollution(million yuan)

4.2 Contribution rate of dry deposition to total economic loss

In order to quantitatively distinguish the contribution rate of dry and wet deposition to corrosion damage of materials, the contribution rate of dry deposition is defined.

$$\alpha = \frac{K_{dry}}{K_P} \times 100\% \quad \text{/*MERGEFORMAT} \tag{6}$$

Where, α is the economic loss caused by dry sedimentation corrosion destruction material; K_{dry} is the total economic loss caused by atmospheric pollution corrosion destruction material; K_{dry} is the contribution rate of dry sedimentation. Based on the atmospheric corrosion dosage of zinc-response function formula (5), the economic loss estimation formula (1) and service life formulas (3) (4), it can be derived

$$\alpha = \frac{1.142 \times C_{SO_2}^{0.207} \times C_{NO_2}^{-0.258} \times t_{TOW}^{0.744} - Y_c}{1.142 \times C_{SO_2}^{0.207} \times C_{NO_2}^{-0.258} \times t_{TOW}^{0.744} + 0.0033 \times P_{rain} \times C_H - Y_c} \quad \text{/*MERGEFORMAT} \tag{7}$$

According to the formula (7), the contribution rate of dry settlement of different pollution areas in Kunming to total economic losses can be calculated. The results are shown in Fig. 4 and Table 2 .

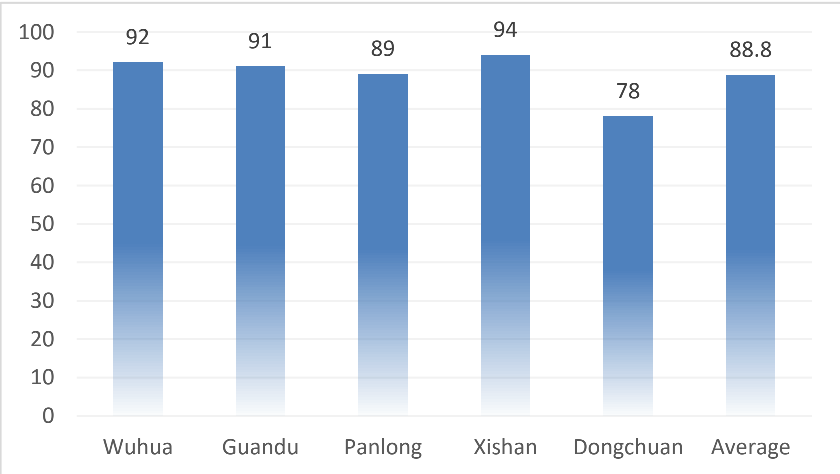

Figure 4: Contribution rate of dry deposition to total economic loss of zinc materials

Table 2: Contribution rate of dry deposition to total economic loss of zinc materials

Material	Zone					Average
	Wuhua	Guandu	Panlong	Xishan	Dongchuan	
α	92	91	89	94	78	88.8

5.Conclusion

In conclusion, the annual direct economic loss caused by the corrosion of zinc by air pollution in five districts of Kunming city is about 56.41 million yuan, accounting for about 1.6% of the regional GDP in the same period, and the actual loss may be even higher.

The contribution rate of dry subsidence to the economic loss of corrosion destruction of zinc materials is between 78% and 94%, and the mean value is 88.8%, indicating that the influence of acidic dry subsidence is greater than that of acidic wet subsidence (mainly refers to acidic precipitation, which is mainly due to the relatively high concentration in the central area of the main city, long dry period and high dry subsidence intensity. On the other hand, the humid period is short and the precipitation acidity in urban areas is not particularly strong under the buffer of large alkaline particles.

This research selects Kunming city as a representative city for analysis, and the results are of practical significance. It can help relevant departments to make economic decisions and promote the sustainable development of the economy. With the acceleration of urban construction and the continuous development of industry, energy consumption will be increasingly large, and the energy consumption structure dominated by coal is unlikely to be greatly changed in the short term. Therefore, from this research, we can come to the conclusion that if effective measures are not taken to control acid deposition atmospheric pollution caused by coal burning, the economic losses caused by material atmospheric corrosion damage will be larger and larger.

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