The impact of expressway snowmelt agent usage on the environment in an extreme freezing snow and sleet condition

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Abstract. During Jan 11-Feb 2, 2008, affected by cold air, a rare cryogenic sleet and snow weather process occurred in the southern China. To cope with this extreme weather condition, and to secure the expressway safety, for the first time some expressways used snowmelt agent in large areas. In order to make quantitative impact assessment for the snowmelt agent usage on roadside ecological environment under these extreme sleet and snow condition, field sampling surveys were conducted on the North Guangdong section and the Hunan Leiyi section of Beijing-Hong Kong-Macao Expressway, where the most snowmelt agent used on, in March 2008. The results showed that the snowmelt agents were dominated by salts, of which the main components are sodium chloride (NaCl) and sodium sulfate ($NaSO_4$). After deicing, the concentrations of chloride, sulfate and sodium ions in water sampling from drainage edge ditches were (19.89±19.11) mg·L^{-1}, (45.73±29.67) mg·L^{-1} and (14.41±16.65) mg·L^{-1}, respectively, which is 3.07 times, 2.08 times and 8.58 times that in the water outside the ditches; and these ion concentrations outside the ditches are slightly higher than that in the river nearby. The concentrations of these ions in the soil within 20 meter range of vertical distance from road exhibited a downward trend with the increase of distance from road. In the soil close to expressway (0.5-2.5 m), the main components of snowmelt agents accumulated within the depth of 10-20 cm; and soils a little bit far from expressway are not affected. In some road section, snow residue containing snowmelt agents were concentrated on roadside plant growth area, where the vegetation were killed by salt damage.

1. Introduction

In winter, severe weather conditions such as snowfall are often encountered in northern China. When there is a continuous low temperature, snow is very difficult to melt, and ice and snow consolidation would appear, making the road wet and slippery, causing frequent traffic accidents in winter. Nowadays, expressway is taking more traffic demand pressures from freight and travel. In order to ensure the smooth and safe expressway traffic in rain and snow weather, a variety of snow and ice removal methods, such as mechanical snow removal, snowmelt agents [1,2] and electrothermal snow removal [3,4] have been commonly applied, both domestic and international. In general, snowmelt agents are most widely used. Snowmelt agents could be divided into two main categories: one is chlorinated salts, containing sodium chloride, calcium chloride, magnesium chloride, potassium chloride, etc., commonly known as “deicing salts”; the other contain potassium acetate as its main component. Currently, the most widely used snowmelt agents are chlorinated salts (mainly is sodium chloride). Research showed that long-term use of deicing salts could have adverse effects, such as concrete corrosion and deck cracking/peeling, on road infrastructure [5,6]; reinforced concrete structures of bridge would be corroded faster because of the electrochemical process produced [7]; chlorinated deicing salts could affect the integrity and emulsification of asphalt pavement [8]; the road performance of asphalt binder could be negatively affected [9], making the bituminous concrete pavement more fragile [10]. Meanwhile, use of deicing salts could have serious adverse effects on the roadside ecological environment: germination rate of plant seeds could be decreased [11]; cell membrane of roadside plants could be damaged, affecting the plant growth and death [12,13]; underground and surface water could be contaminated [14-16]; salt concentration in soil could rapidly accumulated, causing long-term environmental problems such as soil compaction and salinization [17].

At present, abnormal events of global climate change are frequent. At the end of January 2008, southern China suffered a snow and sleet disaster which is rare in the history. When that severe weather happened, transportation department, followed the road secure experience applied in northern China, used a lot of snowmelt agents, forming salt-water solution with lower freezing point, to increase the traffic capacity and safety during the sleet and snow weather. According to reports, within a week, more than 1,500 tons of snowmelt agents (deicing salts) were accumulatively sowed on the North Guandong section and Hunan Leiwei secton of Beijing-Hongkong-Macao Expressway, with a spreading quantity of 50g m^{-2} [18]. Lots of research had been conducted on the cumulative influence of long-term snowmelt agents use on transportation infrastructure and roadside ecological environment. However, the impact of large scale and short time usage of snowmelt agents on the roadside environment has not been commonly studied. In this research, based on field investigation and sampling of roadside surface water, soil and plants during the ice and snow disaster happened in southern China 2008, the impact of expressway snowmelt agent usage on the roadside ecological environment under an extreme freezing rain condition were studied; and corresponding mitigation countermeasures were promoted, providing reference for protecting the roadside environment when using snowmelt agents.

2. Materials and methods

2.1. Research area profile

During March 10-15 2008, after snowmelt agents were sowed, project team conducted a field investigation and sampling on roadside environment condition. Locations were chose at North Guandong section and Hunan Leiwei secton of Beijing-Hongkong-Macao Expressway. Figure 1 shows the measurements location. At 9 typical subsections, where the weather condition was most severe and snowmelt agents were mostly used, water and soil were sampled from roadside drainage ditches, surface water and nearby areas. Table 1 shows the specific location of these sampling points.

Table 1. Basic situation of expressway for water and soil sample.

Sampling point	Road section	Pile No.	Location of sampling point	Sampling
1#	North Guandong	K42+500	Right side ot expressway	Water and soil
2#	North Guandong	K41+800	Right side ot expressway	Water and soil
3#	North Guandong	K40+500	Right side ot expressway	Water and soil
4#	North Guandong	K33+300	Right side ot expressway	Water and soil
5#	North Guandong	K30+900	Left side ot expressway	Water and soil
6#	Hunan Leiyi	K494+800	Left side ot expressway	Water and soil
7#	Hunan Leiyi	K502+900	Left side ot expressway	Water and soil
8#	Hunan Leiyi	K503+200	Right side ot expressway	Water and soil
9#	Hunan Leiyi	K494+900	Right side ot expressway	Water and soil

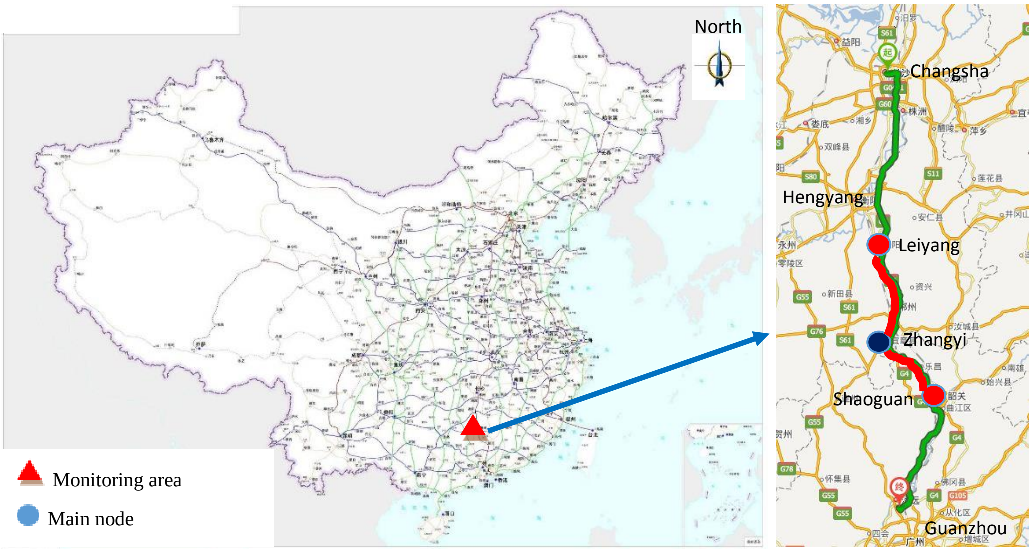

Figure 1. Measurements location.

2.2. Sampling and analysis method

Roadside water environment sampling. Sampling points were set up at the roadside drainage ditches, and at the water body a little bit far from expressway, respectively. Hard glass bottles and polyethylene bottles were used as sampling containers. Instantaneous water samples were collected and mixed well. Water sample analysis included pH, Cl^-, NO_3^-, SO_4^{2-}, Na^+, Ag^+, and As^+.

Roadside soil sampling. Three random sampling points, with area of 2 m × 2 m, were set up at the lower side slope of the highway, the central zone, and the areas with obvious plant death. Soil samples from the 3 random sampling points were mix up before test. Surface vegetation, grass root layer and large stone block were removed at each sampling points. And soil samples were collected in the depth of 0-10cm and 10-20 cm at each point. Quarries, garbage dumps and other special sites were avoided when choosing the sampling points. Soil samples were sieved through 100 mesh screening after being air-dried and grinded. Soil sample analysis included Cl^-, NO_3^-, SO_4^{2-}, Na^+, Ag^+, As^+.

ULTIMA inductively coupled plasma spectrometer and Diane 600 ion chromatograph were used for sample analyzing. Water samples were determined by the methods in *water and exhausted water monitoring analysis method*. pH values were tested by acid measurer; cations such as Na^+, Ag^+ and As^+ were tested by inductively coupled plasma spectrometer, after hydrofluoric acid- perchloric acid digestion. Anions such as Cl^-, NO_2^-, NO_3^- and SO_4^{2-} were tested by Diane 600 ion chromatograph. To ensure that the results of the analysis are reliable, parallel, blank test and sample control were applied for all the testing above.

3. Results and discussion

3.1. Components of snowmelt agents

Table 2 shows the sampling test results of snowmelt agents sowed on the expressway. The main component of snowmelt agent sample is sodium chloride, accompanied with a small amount of sodium sulfate and a trace of silver ions. Nitrite ions, nitrate ions and arsenic ions were not detected. It is obvious that the snowmelt agent used during this severe sleet weather is chlorinated salts, which had been applied in the United States since 1930s. Characterized with low ice point, abundant resources, affordable price (only one-tenth of organic snow melt agents), chlorinated salts have good snowmelt effect. However, these deicing salts could seriously damage soil and water environment [19].

Table 2. Test results of salt sprinkled on freeway (unit: mg·kg^{-1}).

Ions / Road sections and Related standards	Cl^-	NO_2^-	NO_3^-	SO_4^{2-}	Na^+	As^+	Ag^+
North Guangdong section	519100	—	—	4512.8	338112	—	0.58
Hunan Leiyi section	528268	—	—	5771.6	358136	—	0.01
GB/T 23851-2009《Road deicing and snowmelt agent》	—	—	—	—	—	≤5	—
GB/T 23851-2017《Snowmelt agent》	—	—	—	—	—	≤5	—

Notes: "-" Indicates that nothing detected or not limited in the standard

3.2. Impact on water environment

Figure 2 shows the testing results of water samples from roadside ditches and nearby water body.

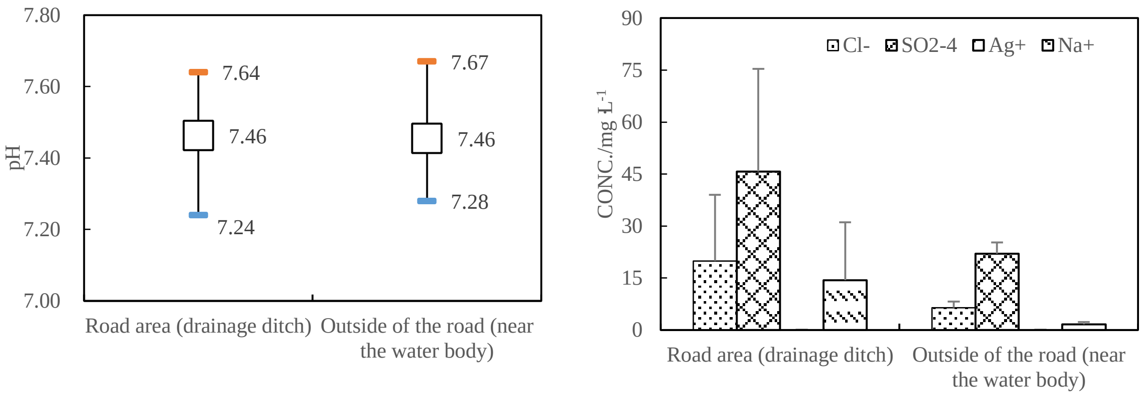

Figure 2. Comparison of ion concentration inside and outside the road area after the use of snow melt agent.

The pH values of sampling points from the two monitoring areas are between 7.24-7.67, with little differences. The concentrations of chloride, sulfate and sodium ions in water sampling from drainage edge ditches were (19.89±19.11) mg·L^{-1}, (45.73±29.67) mg·L^{-1} and (14.41±16.65) mg·L^{-1}, respectively, which is 3.07 times, 2.08 times and 8.58 times that in the water body outside the ditches. And the concentrations of chloride [(6.47±1.68) mg·L^{-1}], sulfate [(22.03±3.24) mg·L^{-1}] and sodium ions [(1.68±0.61) mg·L^{-1}] in the water outside the ditches is slightly higher than that in the river nearby, where the concentrations of chloride, sulfate and sodium ions are, 1.82 mg·L^{-1}, 13.12 mg·L^{-1}, and 0.85 mg·L^{-1}, respectively. Therefore, after the expressway snowmelt agents use under the severe sleet weather condition in Southern China, concentrations of main ions in the stormwater from roadside ditches are obviously higher than that from the water body outside. The snowmelt use could have much higher impact on the water environment within the road region (inside the ditches) than that on the nearby area. This is quite different with the influence of long-term snowmelt agent use to the rivers, lakes, plants and animals near expressway [20].

3.3. Impact on soil environment

Figure 3 shows the concentrations of main ions of soil samples from different distances to the expressway, and from various depth. The concentrations of the main ions, such as Cl^-, NO_3^-, SO_4^{2-}, Na^+, and Ag^+, in the soil exhibited a downward trend with the increase of distance from road. For chloride and sodium ions in the top soil with depth 0-10cm, the concentrations decreased from (10.97±3.67) mg·L^{-1} (for Cl^-)and (1456.87±485.48) mg·L^{-1} (for Na^+) to (6.09±3.78) mg·L^{-1} (for Cl^-

)and (900±214.3) mg·L^{-1} (for Na^+), when the distance to the expressway increased from 0.5 m to 20 m. The decline rate of chloride and sodium ions were 44.49% and 38.22%, respectively. These concentrations differed not much between the soil at 20 m and 80 m away from expressway. For chloride and sodium ions in the middle layer soil (10-20cm depth), the concentrations decreased from (18.84±17.8) mg·L^{-1} (for Cl^-)and (2199.29±2210.64) mg·L^{-1} (for Na^+) to (5.25±0.18) mg·L^{-1} (for Cl^-)and (476.97±202.69) mg·L^{-1} (for Na^+), when the distance to the expressway increased from 0.5 m to 20 m. The decline rate of chloride and sodium ions were 72.13% and 78.31%, respectively. The decline rate from middle layer soil is larger than that from top soil, but the general rule of change is basically the same.

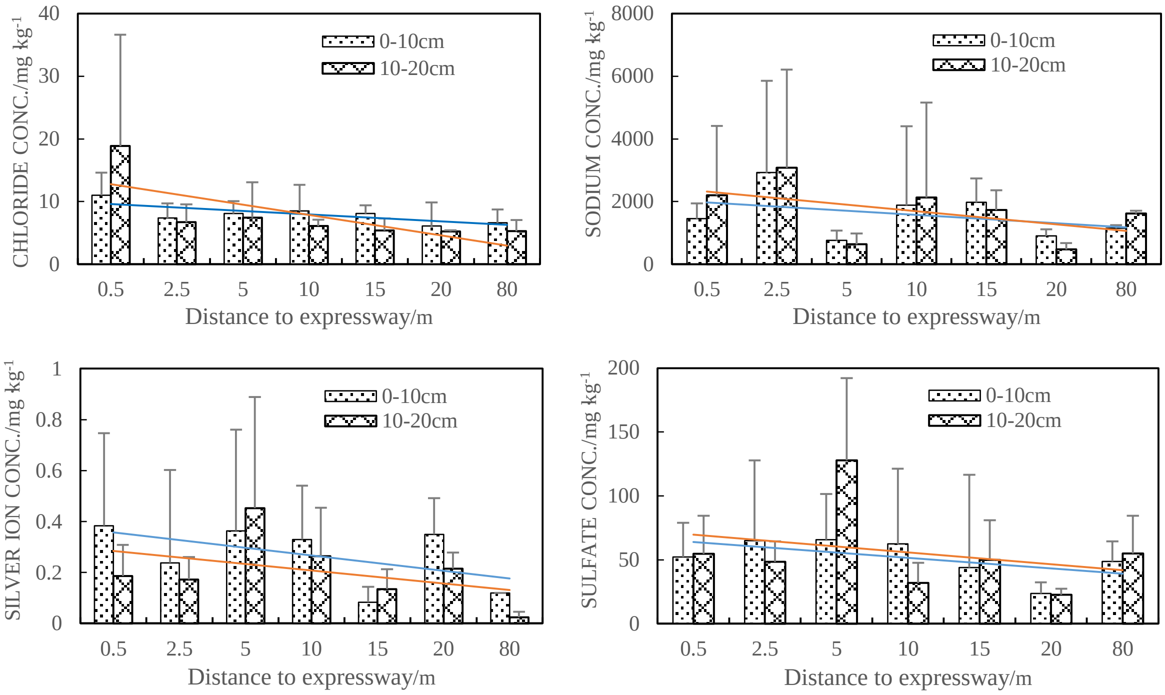

Figure 3. Comparison of ion concentration in soil at different distances from vertical roads.

In the nearer range of expressway (0.5-2.5 m), the main components of snowmelt agents showed a certain cumulative phenomenon in the depth of 10-20 cm, while the concentrations of Cl^- and Na^+ from soil in depth of 0-10cm are much lower. At the sampling point 0.5 m away from expressway, concentrations of Cl^- and Na^+ from the middle layer soil is 71.74% and 50.96% higher than that from top soil, respectively. At the sampling point 2.5 m away from expressway, concentrations of Cl^- and Na^+ from the middle layer soil is 8.68% lower and 5.25% higher than that from top soil, respectively. It could be concluded that the cumulative effect in the 10-20 cm soil is much apparent at soil nearer to the expressway (0.5 m) than the soil a little bit remote from the expressway (2.5 m). This indicates that sodium chloride, which is the main component of the used snowmelt agents, could be easily flushed by the melt snow water; and the greater the ion concentration is, the stronger leaching effect could be, and hence the snowmelt agents could be easier to get into deeper layer of soil. This explains diluted and cumulative effect of Cl^- and Na^+ in top layer (0-10 cm) and middle layer (10-20 cm) soil. The higher concentration of soluble sodium could have negative effect on the plants growth [21]. Expressway greening is dominated by herbs, which 90% number of roots exist in the soil of 0-30 cm depth. Woody plants usually chose for expressway greening are mainly with horizontal roots, which mostly exist in the soil of 20-30 cm depth [22]. Therefore the occasional use of snowmelt agents could also have negative effects on plants in the area 2.5 m close to expressway. Testing results showed that content of chloride and sodium ions were 3.41-59.25 $mg \cdot kg^{-1}$ and 252.11-8492.32 $mg \cdot kg^{-1}$, respectively, which were not a high value. Silver ion in the soil is very low, meaning that silver ions in snowmelt agents should not significantly affect soil. Based on the discussion above, after the expressway snowmelt agents use under the severe sleet weather condition in Southern China, concentrations of chloride and sodium ions in soil mainly increased in the area within 0.5-2.5 m close to expressway; and the area more remote to expressway should not have such effect.

3.4. Impact on plants

Figure 4 shows the condition of roadside plants under the impact of deicing salts usage; and it could be observed that this usage in some road sections have certain effect on those plants. This could be explained that, in the plant area where removed snow mixing with deicing salts were disposed at, the soil salt concentration could be much higher than other places. From lab tests, sodium ions in the soil from unaffected area (samples remote from expressway) are 400-1100 $mg \cdot kg^{-1}$, while the value from the disposed area could be as high as 8000 $mg \cdot kg^{-1}$. And research showed that, if the salt content in surface soil were higher than 0.6%, most plants, especially cultivated plants, could not grow normally or not even grow, except for some salt-tolerant species. If soluble salt content in soil were higher than 1%, only a little kinds of plant adapted to saline soil could grow [23]. Therefore the improperly disposal of removed snow after deicing is the major reason for the abnormal death of roadside plants. Research [24] showed that overabundance of soil salt could delay germination and hinder growth, leading to leaves blight and root decay. The severe condition could be plants death, and the area would be unsuitable for plants restoration and growth. Based on field investigation, Loropetalum chinense var. rubrum and Osmanthus fragrans were mainly affected.

The analysis shows that, after a severe freezing snow and sleet weather, the impact of extensive use of expressway snowmelt agents on roadside plants was sectional, which would be gradually reduced along with the influence of rainfall leaching. Most of the snow water containing snowmelt agents was discharged through roadside ditch during the melting process. The impact on plants concentrated in the area where snow water flowed, such as roadside ditches. The majority of ions accumulated at the bottom of roadside ditches [25], where the silt and humus make it easier to store up deicing salts.

Figure 4. Plants damaged by snowmelt salt.

3.5. Mitigations for negative impact of snowmelt agent

Using snowmelt agent provides a lot help for traffic safety under the severe snow and sleet weather condition; however, it brings negative impact on water and soil environmental along with expressway. Therefore it is very necessary to regulate and strengthen management of deicing salt use. 1) Reduce the use of snowmelt agent, and replace with mechanical and artificial snow removal. Develop snow removal method combined with both of these measures [26]. Use the asphalt pavement that could heat or automatically thaw ice and snow at environmentally sensitive road sections [27,28]. 2) Scientifically and quantitatively spread snowmelt agents, and remove the residue properly, reducing the harmful effect of concentrated ions to soil and plants. Avoid long-term disposal. Use organic snowmelt agent such as CMA, at environmentally sensitive road sections, because Ca^{2+} and Mg^{2+} from CMA are more helpful to maintain soil fertility and stability [29]. 3) Choose fixed location for remained snow storage and treatment. The remained snow contain high concentrated snowmelt agents, which could be harmful to plants and underground water. Therefore the disposal locations should be separate from environmentally sensitive area, such as surface water, water source, pond, etc. Collected snow should not be remained at plant isolation zone. 4) Use ecological drainage as roadside ditch [30], accumulating the snowmelt agent ions to ditches instead of leaking to outside environment.

4. Conclusion

- Main component of snowmelt agent sample is sodium chloride, accompanied with a small amount of sodium sulfate and a trace of silver ions. Nitrite ions, nitrate ions and arsenic ions were not detected. Concentrated and massive use of snowmelt agents could have certain impact on soil, plants, and water environment.
- The snowmelt use could have much higher impact on the water environment within the road region (inside the ditches) than that on the nearby area.
- Within the range of 20 m close to expressway, the concentrations of the main ions, such as Cl^-, NO_3^-, SO_4^{2-}, Na^+, and Ag^+, in the soil exhibited a downward trend with the increase of distance from road. Decreasing rate of chloride and sodium ions in middle soil layer (10-20 cm) are more obvious than that in surface soil layer (0-10 cm). Concentrations of chloride and sodium ions in soil mainly increased in the area within 0.5-2.5 m close to expressway; and the area more remote to expressway should not have such effect.
- Snowmelt agent usage in some road sections have negative effects on roadside plants, because remained snow were collected and disposed at roadside plant area. Snowmelt agent should be scientifically used and managed under the severe weather conditions such as extreme snow and sleet in southern China.

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