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A FIELD STUDY OF THE DRILLING FLUID'S DISCHARGE IN SOUTH CHINA SEA

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ABSTRACT

Drilling fluid is one of the primary contaminants produced in the offshore drilling operation, which would pollute the water column if it is directly discharged into the ocean. In view of the insufficient far-field research on drilling fluid's discharge in the Chinese offshore area, a field study of the influence on the marine environment is conducted based on an oil field in South China Sea. At a constant rate, the water based fluid is pumped into the seawater vertically from a pipe on the bottom of the platform. A relative large monitoring range at distances up to 2000 meters from the discharge source is determined in the light of the results from the previous study and the environmental impact assessment report. The water quality and the sediment solids are measured by the field monitoring under different stations and water depths. To obtain the particle size, the drilling fluid to be discharged is sampled and taken back to the laboratory for a statistics test. The single index method is introduced to assess the environmental quality in this field and the suspended solids, total mercury and cadmium are chosen as the evaluation factors. The monitoring results show that, the influence of the drilling fluid's discharge is very small on the water quality for the surrounding sea areas. The concentration distribution of the suspended solids presents a trend of spreading outward from the discharge source and the monitoring results can be attributed to the natural fluctuation of the background value. There are only small deviations between different water depths for the suspended solids and mercury, while the amount of the cadmium is relatively great in the surface layer of the water column. In this monitoring field, none of the concentrations of the total mercury and cadmium exceed the standard value, which meet the national primary standard of the seawater quality. The results of this study contribute to the understanding of the drilling fluid's dispersion in South China Sea and the field data can provide references for the marine environmental prediction and evaluation.

Keywords: Drilling fluid, Discharge, Field monitoring, Marine environmental impacts

1 INTRODUCTION

In the development process of offshore oil and gas field, the drilling fluid and cutting are the primary pollutants generated in the drilling operation (Liu and Zhang, 2014). The waste drilling fluid mainly refers to the fluid abandoned during the drilling process, after completion or the fluid that cannot be used (Zhu, 2018). Drilling fluid can be divided into water-based, oil-based and synthetic-based, and the impact of the discharged fluid on the marine environment varies greatly due to different components (Liang, 2010). In general, the water-based fluid is advocated to be used in the offshore drilling. Under the present condition, if the water-based fluid is non-toxic and harmless without any oil, it will be discharged into the surrounding areas directly as the general treatment (Zhang, 2003). The suspended sand discharged by the non-oil-based drilling fluid in the construction stage is one of the primary negative influences on sea water quality, bottom substrate and marine ecology.

The influence of drilling fluid's discharge on the marine environment is affected by various factors such as the hydrological and meteorological conditions of the ocean and the discharged type, quantity, velocity and depth of the fluid (Koh and Chang, 1973). It is shown that, after the drilling fluid is discharged into the sea, clay particles will rapidly flocculate and form larger particles to sink due to the hydrodynamic action of the ocean and 95% of the fluid settles to the seabed within the range of 150 meters around the drilling platform (Xie and Tian, 2017). Because of the dilution and diffusion in the sea water, the suspended solids concentration in the distance of 100 meters from the discharge point decreases by four to five orders of magnitude compared to the concentration in the center, and the increments of suspended solids concentration do not exceed 10 mg/L at most. The suspended solids concentration drops to background level at 500 meters from the discharge point (Xie and Tian, 2017). Laboratory studies of total suspended solids concentrations at different water depths and distances had also shown that the drilling fluid would dilute extremely quickly in a distance of 50 times the discharge tube diameter from the discharge source and the dilution ratio could be up to 1000 within a range of

400 times the discharge tube diameter (Davis et al., 1989). Meanwhile in another near-field study, it was found that the distribution of the suspended solids concentration had extremely high difference, and the fluid was rapidly diluted after discharging into the marine environment. The suspended solids concentration was decreased by 200 to 5,500 times when it was 10 meters away from the discharge source and 2,900 to 7,700 times when it was 100 meters away from the discharge source. In this near field case, the suspended solids concentration decreased with the increase of the water depth and also decreased with the increase of the distance from the discharge point (O'Reilly et al., 1988; Smith et al., 2004).

In the process of the abandoned drilling fluid's discharge, a high concentration of the suspended solids will be formed as a source of pollution and it will migrate to the surrounding sea area in the form of plume under the action of marine convection and diffusion. In the water environment with stratified flow, the fluid plume will go through three different phases: the convective descent, dynamic collapse and passive diffusion phase (Davis et al., 1989). The convective descent phase is a high-mixing-rate region between the discharge pipe and the point of neutral buoyancy. The dynamic collapse phase is the transition region where the plume collapses at the level of neutral buoyancy due to ambient stratification or at the bottom if it is not trapped. In this region any vertical momentum is converted to horizontal momentum and the plume flattens due to pressure forces above and below the plume. The last phase is the passive diffusion phase where plume momentum has dissipated and mixing is due primarily to ambient turbulence. The former two stages belong to the near field and the last stage is a far field phenomenon. At present, the study is primarily focused on the range within 100 meters (Brandsma, 2004), and the related analysis is very limited for suspended solids' diffusion in larger sea area. Experts such as Davis et al. suggested that the far field monitoring study should be carried out when conditions permit and be compared with the model calculation (Davis et al., 1989). In the meanwhile, to the authors' knowledge, the field monitoring has been carried out in different sea areas such as the Gulf of Mexico, eastern Pacific Ocean (Smith et al., 2004) and central Atlantic Ocean (Ayers et al., 1982). However, the field monitoring of the drilling fluid's discharge in Chinese offshore areas has not been seen yet.

Above all, in view of the insufficient far-field research on drilling fluid's discharge in the Chinese offshore area, a field study of the influence on the marine environment is conducted based on an oil field in South China Sea. The water quality and the sediment solids of different stations and water depths are obtained by the field monitoring method. To obtain the particle size, the drilling fluid to be discharged is sampled and taken back to the laboratory for a statistics test. The single index method is introduced to assess the environmental quality in this field and the suspended solids, total mercury and cadmium are chosen as the evaluation factors.

2 MONITORING METHOD

Platform A is located in the eastern North Gulf of the South China Sea, about 25 km away from Wushi Harbor, Leizhou Peninsula, Guangdong Province. The tracking and monitoring of drilling fluid's discharge of Platform A were carried out in the range of 100 m~2000 m from the platform, based on the prediction results given in the EIA report. The investigation time was from 09:08 to 14:22 in September 27th, 2017.

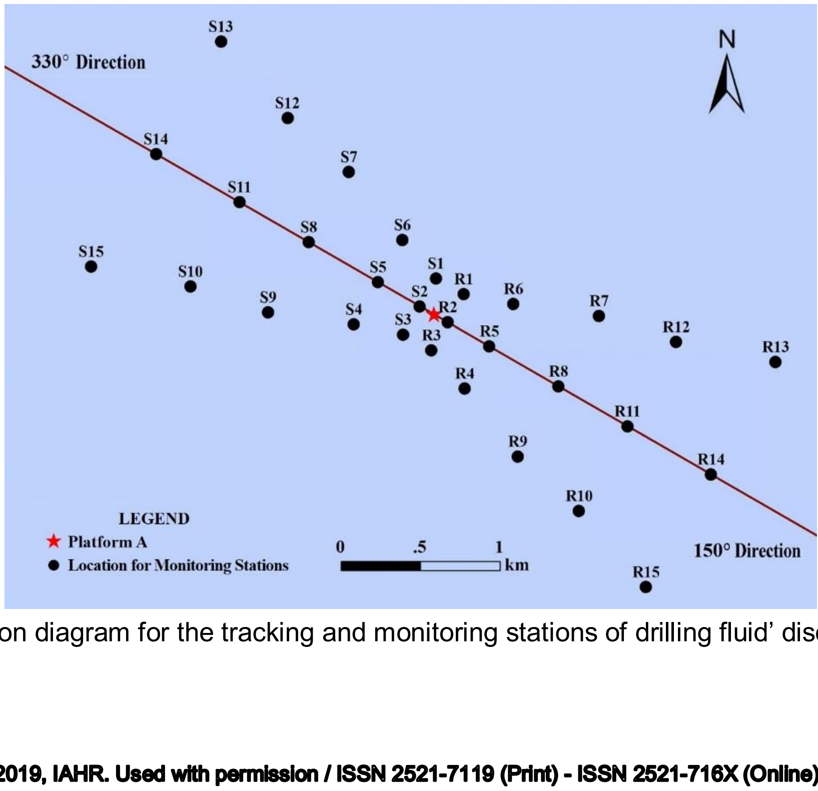

Figure 1. The location diagram for the tracking and monitoring stations of drilling fluid' discharge of Platform A

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2.1 Set-up of monitoring stations

According to the current forecast data, the current in the monitoring sea area is the reciprocating current. The direction of the falling and rising tide are 150 degrees and 330 degrees, respectively. The location diagram for the tracking and monitoring stations can be seen in Figure 1. The rising tide period (330 degrees direction) was selected for the observation in this monitoring, and the series of the tracking and monitoring stations were from R3→R2→R1 to S1→S2→...→S15 with a numerical sequence. Among them, the distances from the platform to S2, S5, S8, S11 and S14 were 100 m, 400 m, 900 m, 1400 m and 1900 m successively. The distance from S1 to S2, from S5 to S6, from S7 to S8, from S11 to S12 and from S13 to S14 were 200 m, 350 m, 500 m, 650 m and 800 m, respectively. The background concentration was monitored at a station 3 km away from the platform.

2.2 Requirements for sampling

The monitoring items of the water quality for the drilling fluid included Hg, Cd, suspended solids, water temperature and salinity. Hydrological and meteorological monitoring items included temperature, wind speed, wind direction, sea condition, weather condition, current velocity and flow direction. Some points were sampled in parallel.

(1) Sampling layers of water quality for the drilling fluid: the surface layer (0.5 meters), the middle layer (0.5H) and the bottom layer (2 meters from the bottom).

(2) Sampling layers of flow velocity and flow direction: the surface layer (0.5 meters), the middle layer (0.5H) and the bottom layer (2 meters from the bottom).

(3) The observation station of flow velocity, flow direction and water quality were synchronized.

(4) The sampling of water quality was completed during a rising tide period (330°).

2.3 Hydrological and meteorological conditions

During the field operation, a hydrological and meteorological observation at the platform was carried out on September 27th. The weather conditions are cloudy and the sea conditions are level 2; the temperature is ranged from 29.3°C to 31.6°C, and the average temperature is 30.3°C; the sea-level pressure is ranged from 1012.9 hPa to 1015.0 hPa, with an average of 1014.2 hPa; the wind speed is ranged from 1.8 m/s to 2.4 m/s, and the average wind speed is 2.1 m/s; the wind speed is small, and the northeast wind is the primary wind.

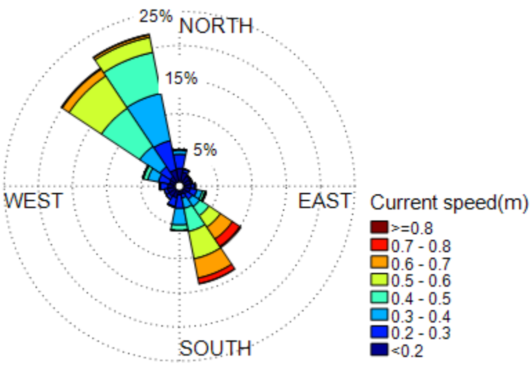

Figure 2. The rose diagram of the current in the sea area of Platform A

The tidal current is strong in the sea area around Platform A, and the diurnal tide is the main component in the sea area; the current here is mainly rectilinear stream, which is roughly in line with the shoreline trend, and the main direction of the tidal current is NW and SSE. The rose diagram of the current in the sea area of Platform A is shown in Figure 2.

Table 1. The observation statistics on the tidal current of drilling fluid's discharge of Platform A

Layer \ Velocity	Maximum velocity (cm/s)	Flow direction at maximum velocity(°)	Minimum velocity (cm/s)	Flow direction at minimum velocity(°)	Mean velocity (cm/s)	Mean flow direction (°)
Surface	35	176	10	142	17	168
Middle	25	179	7	171	14	166
Bottom	9	163	3	146	5	166

During the monitoring period of the drilling fluid’s discharge from the platform, the current in the investigated sea area was also measured. The observation statistics on the tidal current of drilling fluid’s discharge are shown in Table 1. In the field of drilling fluid’s discharge, the falling current was observed, and the tidal current velocity decreases gradually from the surface to the bottom. The maximum current velocity in the surface layer is 35 cm/s and its direction is 176°; the maximum current velocity in the middle layer is 25 cm/s and its direction is 179°; the maximum current velocity in the bottom layer is 9 cm/s and its direction is 163°. The observed mean current velocities of the surface, middle and bottom layers are 17 cm/s, 14 cm/s and 5 cm/s, and the flow directions were 168°, 166° and 166°, respectively.

3 EVALUATION METHOD

3.1 Single index method

Single index method is used for the environmental quality assessment.

The calculation formula is：

$$Q_{ij} = C_{ij} / C_{oi} \qquad [1]$$

Among them, Q_{ij} is the standard index of *i* evaluation factor of station *j*; C_{ij} is the measured value of *i* evaluation factor of station *j*; C_{oi} is the standard value of *i* evaluation factor.

3.2 Evaluation criterion

The evaluation criterion adopts the Sea Water Quality Standard (GB3097-1997) in China, as shown in Table 2.

Table 2. The Sea Water Quality Standard

Evaluation factors	Primary standard	Secondary standard	Tertiary standard	Quaternary standard
The suspended solids*	≤10 mg/L		≤100 mg/L	≤150 mg/L
Total mercury	≤0.05 μg/L	≤0.2 μg/L		≤0.5 μg/L
Cadmium	≤1 μg/L	≤5 μg/L	≤10 μg/L	

*Artificially increased quantity

3.3 Evaluation factors

The primary evaluation factors are the suspended solids, total mercury and cadmium.

4 RESULTS AND DISCUSSION

4.1 Source intensity of drilling fluid’s discharge

The drilling fluid’s discharge condition of the platform during the tracking and monitoring period is shown in Table 3. The one-time discharge amount of drilling fluid is 132.0 m^3, and the emission duration is 1 hour. Among them, the mercury content was 0.026 μg/g and the cadmium content was 0.132 μg/g.

Table 3. Drilling fluid’s discharge of Platform A

Parameter / Monitoring	Disposable discharge (m^3)	Emission duration (h)	Drilling fluid density (g/cm^3)	Drilling fluid properties	Mercury concentration (μg/g)	Cadmium concentration (μg/g)
On-site emission	132.0	1	1.25	water-based	0.026	0.132

4.2 Classification statistics of drilling fluid’s particle size

Samples of drilling fluid discharged from Platform A have been collected for laboratory analysis. The statistical data is shown in Table 4 and Table 5.

Table 4. The statistics of the mass percentage of particles with different diameters of the drilling fluid discharged from Platform A

Gravel	Sand	Silt	Clay
＞2 cm	0.063~2 cm	0.004~0.063 cm	＜0.004 cm
0.0%	8.8%	77.7%	13.5%

Among them, Table 4 is the statistics of the mass percentage of particles with different diameters in drilling fluid discharged from Platform A; Table 5 shows the mass percentage of silt with different diameters in drilling fluid. As shown in the two tables, the particle size component of the drilling fluid is mainly composed of silt, followed by clay and sand, and there is no gravel. The type is named silt, and the median diameter is 0.0098 mm.

Table 5. The mass percentage of silt with different diameters of the drilling fluid from Platform A

Layer (cm)	**Silt** (%)			
	0.063-0.032	**0.032-0.016**	**0.016-0.008**	**0.008-0.004**
0-5	10.2	14.1	25.3	28.1
	19.0	33.1	58.4	86.5

4.3 Monitoring results

According to the results of monitoring factors of the water quality, the suspended solids content in the surface layer of the seawater of the monitoring area varies between 0.4 mg/L and 12.6 mg/L, with an average of 9.3 mg/L; the suspended solids content in the middle layer varies between 3.0 mg/L and 14.6 mg/L, with an average of 9.7 mg/L; the suspended solids content in the bottom layer varies between 6.4 mg/L and 15.8 mg/L, with an average of 9.8 mg/L. The content of suspended solids varies widely among different stations in the sea area, and there are small deviations in suspended solids content between the surface, middle and bottom layers. The variation characteristics of suspended solids content in the monitoring area are shown in Figure 3~5. As can be seen from the figures, the distribution characteristics of the surface and middle layers are similar, which shows that the concentration in the northwest sea area of the platform is higher; there is no obvious law of distribution in the bottom layer, and the section of S7~S8 station is relatively high.

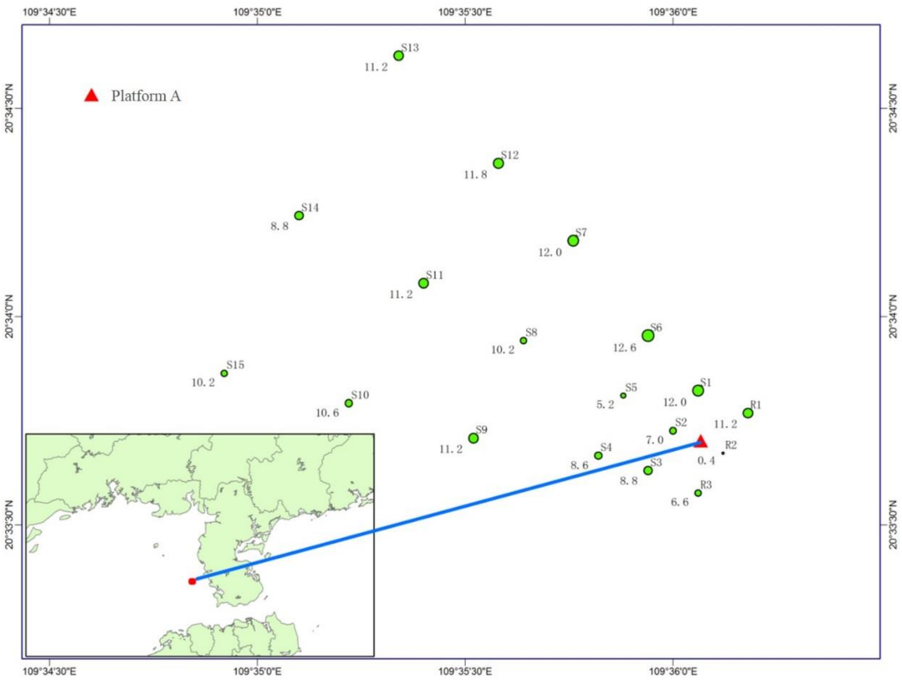

Figure 3. The distribution diagram of suspended solids concentration in surface layer after the drilling fluid discharged from Platform A

As to the mercury content of the seawater in the monitoring area, the range in the surface layer is from 0.017 µg/L to 0.023 µg/L, with an average of 0.020 µg/L. The range and the average of mercury content in the middle and bottom layer are the same with that in the surface layer, which is from 0.017 µg/L to 0.023 µg/L with an average of 0.020 µg/L. The mercury content in the whole sea area is low, and the average mercury content in the surface, middle and bottom layers are not significantly different, and there is no obvious distribution rule.

Table 6. Monitoring results of various items of seawater quality after drilling fluid discharged from Platform A

Items		**Surface layer**	**Middle layer**	**Bottom layer**
Mercury µg/L	Range	0.017~0.023	0.017~0.023	0.017~0.023
	Average	0.020	0.020	0.020
Cadmium µg/L	Range	0.25~0.78	0.19~0.80	0.27~0.76
	Average	0.50	0.45	0.45
Suspended solids mg/L	Range	0.4~12.6	3.0~14.6	6.4~15.8
	Average	9.3	9.7	9.8

For the cadmium in the monitoring area, the range of cadmium content in the surface layer is from 0.25 µg/L to 0.78 µg/L, with an average of 0.50 µg/L; the range of cadmium content in the middle layer is from 0.19µg/L to 0.80µg/L, with an average of 0.45 µg/L; the range of cadmium content in the bottom layer is from 0.27µg/L to 0.76µg/L, with an average of 0.45 µg/L. There are some deviations for the cadmium content among different stations in the sea area. The surface layer has relatively high cadmium content, while the content of the middle and the bottom layer have small deviations. The distribution characteristics of cadmium content in the surface, middle and bottom layers are similar. Generally, the cadmium content in the sea area around the platform is relatively low, while that in the peripheral sea area is relatively high. All the monitoring results of various items of water quality are shown in Table 6 above.

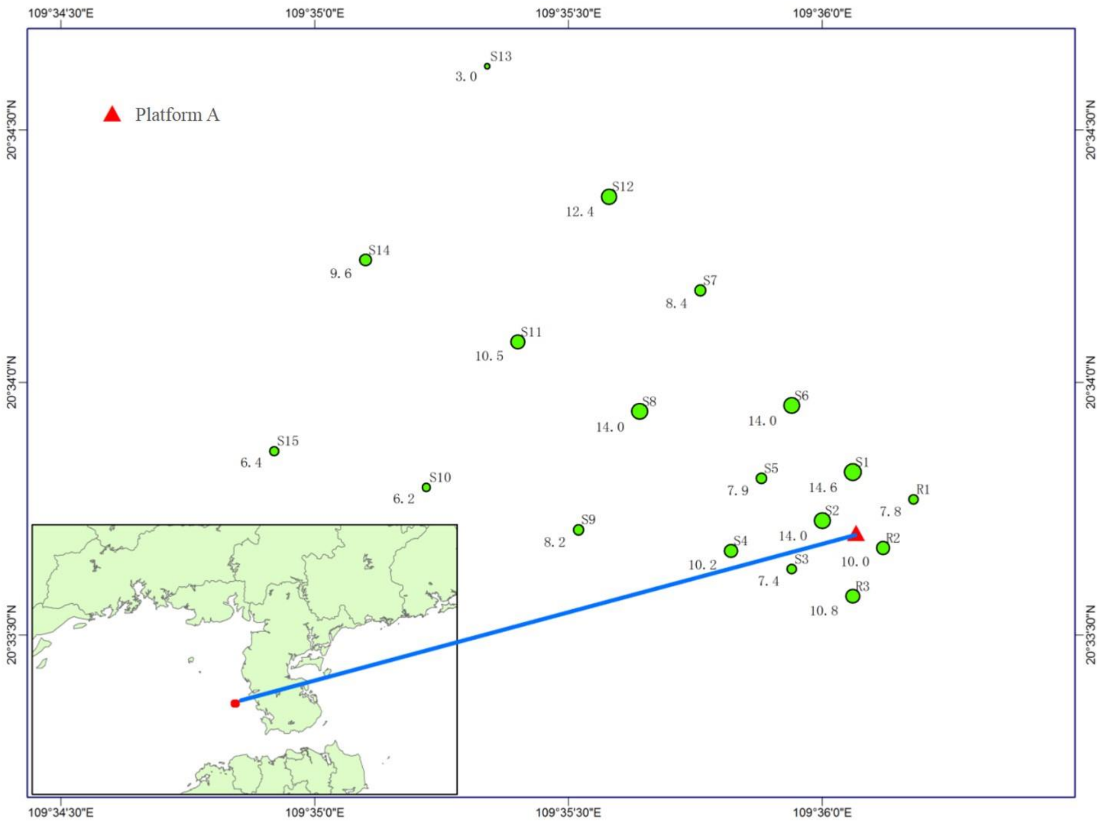

Figure 4. Distribution of suspended solids concentration in the middle layer of the seawater after drilling fluid discharged from Platform A

The monitoring of the drilling fluid's discharge were started after 1.5 hours of the one-time discharge of the drilling fluid. It can be seen from the spatial distribution of pollutants that the pollution diffusion has reached a stable level at this time. The background values of the suspended solids concentration in the surface, middle and bottom layers for the surrounding sea area around the well A were 7.1 mg/L, 8.0 mg/L and 7.8 mg/L, respectively. Compared with the background values, the concentrations of the pollutants at all the monitoring stations are equivalent to the background value, and the overall spatial distribution is irregular. Meanwhile, O'Reilly et al. (1988) and Smith et al. (2004) found that the fluid was rapidly diluted after discharging into the marine environment, the suspended solids concentration was decreased by 200 to 5,500 times when it was 10 meters away from the discharge source and 2,900 to 7,700 times when it was 100 meters away from the discharge source. Therefore, it can be derived that the suspended solids of the drilling fluid is quickly diluted by the seawater after being discharged into the water body and the monitoring results can be attributed to the natural fluctuation of the background values. In this far field case that the minimum distance from the monitoring station to the well A was 100 meter, there was no significant effect on the concentration of suspended solids in the surrounding seawater.

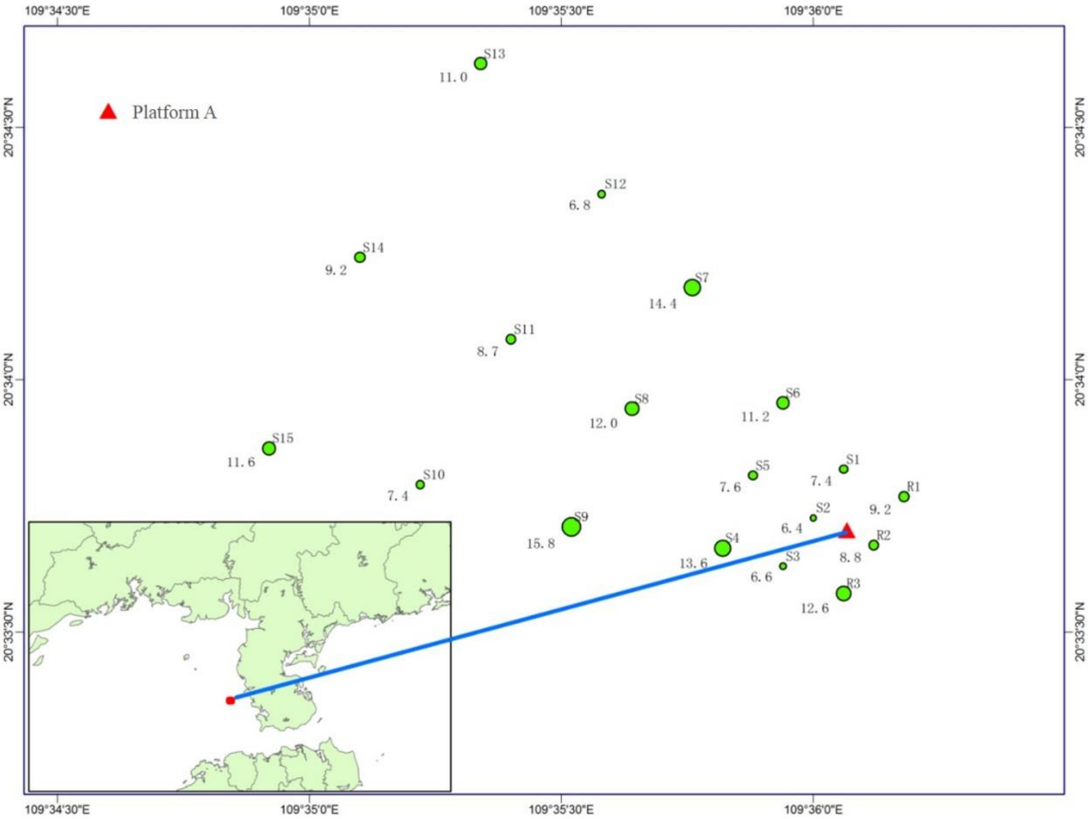

Figure 5. Distribution of suspended solids concentration in the bottom layer of the seawater after drilling fluid discharged from Platform A

The results of this monitoring show that the concentrations of the suspended solids, mercury and cadmium in this monitoring field all meet the national primary standard of the seawater quality. It indicates that the drilling fluid discharged during the drilling of Platform A has a low impact on the surrounding sea area and meets the requirements of marine development management. The drilling fluid's discharge of Platform A has little impact on the water quality of the surrounding sea area, especially heavy metals such as the mercury and cadmium. The distribution of the suspended solids show a tendency to spread outward from the platform, and the monitoring results can be attributed to the natural fluctuation of the background values.

5 CONCLUSIONS

Based on the influence of drilling fluid's discharge on the marine environment in a certain oilfield in South China Sea, the measuring of water quality and sediments at different stations and water depths were carried out by field monitoring, particle size statistics and single index method.

Within the scope of the investigation, the mercury content in the whole sea area is low, and the average mercury content in the surface, middle and bottom layers are not significantly different, and there is no obvious distribution rule. There are some differences in cadmium content among different stations, the surface layer has relatively high cadmium content, and the distribution characteristics are as follows: the cadmium content in the sea area around the platform is relatively low, while that in the peripheral sea area is relatively high. The content of suspended solids varies widely among different stations, while there is little difference for suspended solids content between the surface, middle and bottom layers. The distribution characteristics of the surface and middle layers are similar, which shows that the concentration in the northwest sea area of the platform is higher; there is no obvious law of distribution in the bottom layer, and the sections of S7~S8 station are relatively high. Overall, the drilling fluid's discharge during the drilling of Platform A has a low impact on the surrounding sea area, and the monitoring results can be attributed to the natural fluctuation of the background values.

The work which has been done here is a preliminary investigation for the field study of the drilling fluid's discharge. The results of this study contribute to the understanding of the drilling fluid's dispersion in South China Sea and the field data can provide references for the marine environmental prediction and evaluation.

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