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Environmental impacts and social concerns - A case study associated with petroleum exploration activities from onshore Baram Delta, NW Sarawak

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Abstract: The onshore Baram Delta, located in NW Sarawak is the birthplace of petroleum production in Malaysia. The Miri oilfield was first discovered in 1910 and subsequently abandoned in 1972 with intermittent exploration activities in the late 1980's to early 1990's. To rejuvenate exploration interest and to identify remaining hydrocarbon potential of the study area, in 2009-2010 JX Nippon acquired gravity, then regional 2D seismic data, followed-by exploration well drilling from 2011-2014. This paper discusses the social-environmental impacts and concerns associated with these petroleum exploration activities, from acquisition of seismic where explosives and vibroseis were used as a source of propagating signals, to exploration drilling with petroleum chemicals such as water-based muds used to facilitate the drilling operations. Overall, the inquiry addresses operational challenges, security of explosive storage and concern for handling explosives in the field, the social-environmental impacts of seismic acquisition operations, as well as removal of drilling fluid chemicals and disposal of contaminated cuttings. Containment procedures and mitigation measures undertaken to alleviate these social-environmental impacts are discussed according to the guidelines and regulatory requirements provided by the Environmental Impact Assessment (EIA), in conjunction with PETRONAS Procedures and Guidelines for Upstream Activities (PPGUA) and the company's Health, Safety and Environment (HSE) Management System. In the final analysis, significant environmental and social challenges were certainly encountered while planning and conducting petroleum exploration activities in the study area. These challenges include problems related to topographic variabilities, permitting issues, compensations for affected lands and cash crops; layout constraints, drilling operations, well control measures for blowout prevention, traffic controls, potential damage to infra-structures, explosive and equipment transportation. However, with proper planning, effective communication with the local authorities, and awareness sessions conducted for the affected parties and stakeholders; together with the support of the local communities the operations have not only managed to mitigate these social and environmental concerns, the exploration activities also provided economic benefits such as hotel accommodation, logistics and transportation demands for local businesses, and short-term employment opportunities for the local people. Ultimately, the operations successfully acquired nearly 900-line km of seismic across many villages, longhouses, and in the city areas, with four exploration wells were drilled in the exploration block. We are glad to report that both seismic and drilling operations were conducted successfully and safely with minimal interruptions to people and environment, without untoward incidents or spills. With the mitigation measures in place, there were no damages other than land access, which were remediated, where incurred.

Keywords: Environmental impacts, Miri, NW Sarawak, petroleum exploration, seismic acquisition

INTRODUCTION

Our planet Earth is plagued by environmental issues that are depleting our natural resources and putting an enormous strain on our livelihoods. Some of the primary environmental issues that are affecting the general population today include climate warming, air pollution, waste disposal, water quality and supply issues, and degradation of farmland by desertification, among others. In the oil and gas industry, the broad environmental issues faced by the petroleum exploration companies are manifested at both local and global levels. In particular, onshore petroleum exploration activities pose the risk of noise pollution, unintended explosion, chemical spills and contaminations ruining environment, bringing potential harm to those who live, work and farm in the affected areas, as well as harming habitats critical to plants and animals. These explorations activities could result in freshwater discharges, chemical spills and groundwater contamination. If left unchecked, many of these issues will impact directly businesses and livelihoods.

Sarawak, and in particular Miri, have benefitted enormously from the presence of the oil and gas industry, thanks to which a modern infrastructure and a reasonable standard of living was achieved. However, during the last 20 years, awareness in respect of air pollution and atmospheric CO_2 contamination has developed into a mainstream subject. Although the industry produces far

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less pollutants in comparison with industrial coal mining and combustion, or forest fires, it has become a target of sometimes unfair criticism. Therefore, particular emphasis is given to clean field operations, carried out in the best possible way - respecting safety, health and environmental precautions for both company personnel and any other stakeholders. Good operational conduct is thus not only a prerogative but equally a license to operate in the future.

NW Sarawak, covering the onshore portion of Baram Delta, is the birthplace of the Malaysian petroleum industry where oil was first discovered by Shell in 1910 (Figure 1). The discovery of the Miri oilfield led to rapid development of Miri town, now called Miri Resort City, which played a paramount role on the economic development of the region located within the exploration Block SK333. After producing approximately 80 million barrels of oil, the field was abandoned in 1972 despite various enhancement efforts (Tan *et al*., 1999; Wannier *et al.*, 2011; Jong *et al*., 2017). To identify remaining prospectivity in the study area, JX Nippon acquired a regional 2D seismic dataset in 2009-2010 mainly in the southern portion of the Block SK333 Petroleum Sharing Contract (PSC), and also shot a number of test lines in the vicinity of Miri City in 2010-2011 (Figure 2). This was done to investigate if good quality seismic could be achieved. This was followed by the drilling of four exploration wells from 2011-2014, which resulted in one sub-commercial discovery in Adong Kecil West (AKW; Jong *et al*., 2017). This paper discusses the social-environmental impacts and concerns associated with these petroleum exploration activities, from the acquisition phase of seismic data where chemical explosives were used as a source of propagating signal (sound waves), to exploration drilling, where chemicals were also used to facilitate the drilling operations.

STUDY AREA AND INVESTIGATION METHODOLOGY

JX Nippon signed the study area of Block SK333 PSC, covering an area of *ca.* 3100 km^2, located in onshore portion of the Baram Delta on 7th December 2007 (Figures 1 and 2). The first 5 years exploration period was started on 7th December 2007 and ended on 6th December 2012. The exploration period was extended for an additional 2 years to 6th December 2014 to continue the exploration activities, and was extended further, for a month, to 6th January 2015 to complete administration work for the upcoming relinquishment. Due to the sub-economical outcomes of a feasibility study for further development and exploration, JX Nippon made the decision not to extend the exploration period and the whole area of Block SK333 was subsequently relinquished on 6th January 2015.

Twenty-eight (28, mainly exploration) wells, with more than 604 Miri field production wells, and approximately

Figure 1: Location map of the study area within Block SK333 (red polygon in index map) located in onshore Baram Delta, NW Sarawak with 2D seismic acquisition conducted mainly in the yellow box areas.

2200-line km of vintage 2D seismic lines were available for exploration studies before JX Nippon signed the PSC. The Miri and Asam Paya fields have discovered hydrocarbon in Cycle V sequences along Miri-Rasau anticline in the northern part of the block. JX Nippon fulfilled all commitment works during the exploration period and the extended exploration period as summarized in Table 1. Four wells were drilled by 2014. Oil and gas were discovered in the Cycle V section in Adong Kecil structure in 2012 by AKW-1/ST1/ST2, which was the 3rd exploration well drilled by the company. Other exploration wells (Miri East-1, Miri East-2 and Engkabang West-1 - see Jong *et al.*, 2016; 2017) could not confirm productive hydrocarbon accumulations.

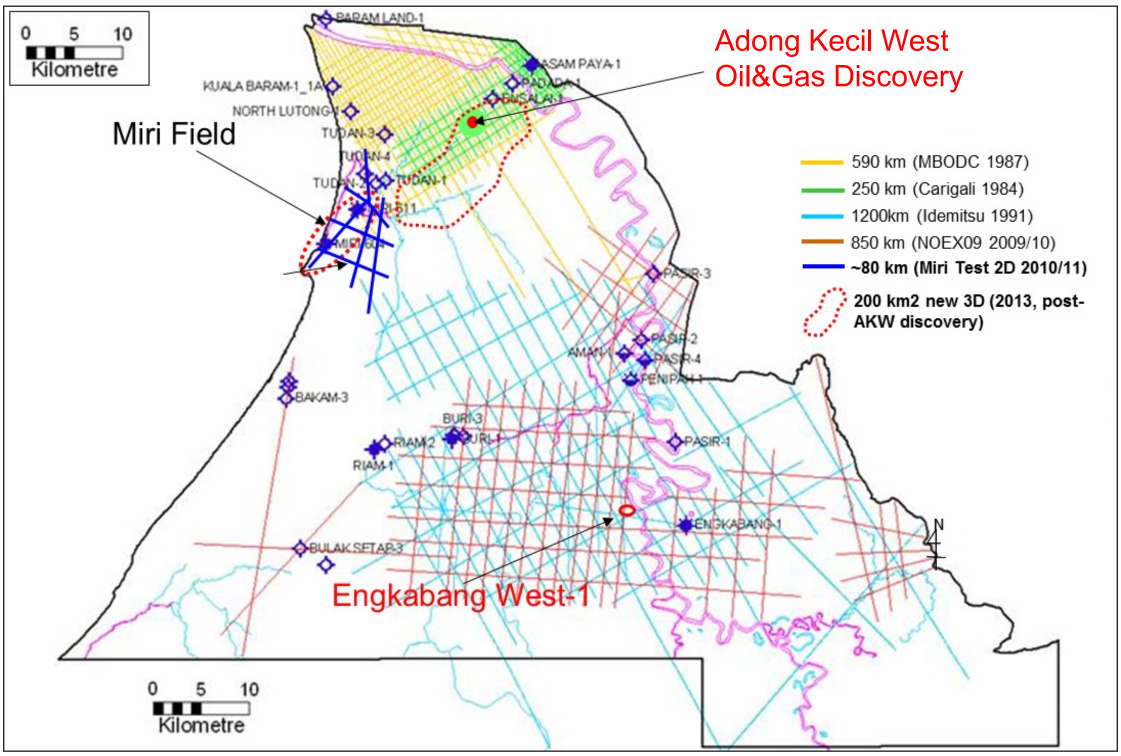

Figure 2: Existing well and seismic database (with ~3000-line km of 2D including the nearly 900-line km acquired during 2009/2010 acquisition campaign) in Block SK333. Shown also are the locations of two key exploration wells Adong Kecil West and Engkabang West (from Jong *et al.*, 2017).

Table 1: Summary of exploration activities in Block SK333, with seismic acquisition and drilling operations the subject of this paper.

Exploration Period	Work Commitments	Work Completion
5 Years Exploration Period (07 Dec 2007 – 06 Dec 2012) Extension (07 Dec 2012 – 06 Dec 2014)	High Resolution and Airborne Gravity and Magnetic Survey	Q4 2008
	Study on applicability for Enhanced Sniffer Survey - replaced with Gore Survey and High Resolution Microbial Survey	Gore survey – Q4 2010 High resolution Microbial survey – Q1 2010
	Test reprocessing of 100 km of existing 2D seismic data (if positive result, all available data)	Test reprocessing followed by total 1730 km of repro-cessing – Q3 2010
	Acquisition and processing of 500 km of new seismic data	Acquisition and processing of 851.5 km of new 2D seismic completed in 2011
	Drilling of 2 wildcat wells (total depth 4,000 m)	* Miri East-1, TD 1923 mMD – 2011 * Miri East-2, TD 1600 mMD – 2011 * Adong Kecil West-1, TD 3170MD – 2012 * Engkabang West-1, TD 4090 mMD - 2014

We investigate in this paper the environmental impacts and social concerns associated with the petroleum exploration activities, in particular those associated with seismic acquisition and drilling operations. Overall logistics planning included preparation for security bunker for explosives storage and transportation. There were precautions taken in case of onsite explosive detonation and mitigation measures for the environmental impacts of drilling fluid chemicals and contaminated cuttings disposal. Furthermore, procedures were developed according to the PPGUA guidelines provided by the regulatory body PETRONAS, in case formation overpressure was encountered to prevent a disastrous blowout. We will first discuss the environmental impact and concerns associated with these exploration activities and then outline the mitigation measures taken to minimize or alleviate their impacts.

ENVIRONMENTAL IMPACTS AND SOCIAL CONCERNS

In recent years, pollution and environmental issues have experienced great interest in the state of Sarawak and the local communities of Miri where the onshore petroleum exploration activities had rekindled during the years 2008 to 2014, after a lapse of more than 10 years (Table 1). The utmost social-environmental impacts and concerns include:

- Seismic data provide a great understanding and a good resolution of subsurface structures for exploration targets; therefore, seismic data are essential in any oil and gas exploration campaign. Seismic lines are designed to record data over the whole target area to each time the vibrator source is active or dynamite to be used for the survey (Figure 3). The activity required laying geophones to record seismic signals, and the generation of the signals using a vibration source contributes to the environmental impacts (IFC, 2007). For onshore seismic acquisition, proper planning of acquisition, especially near towns and populated areas needed to be carefully considered, as the operations might cause strong vibration, creating anxiety and resulting in structural damage to buildings. Noise from the combustion engines of vehicles and vibration source units might be an additional nuisance. Nonetheless, seismic acquisition hardly ever leads to any major damages, but can temporarily affect traffic circulation on roads as cars and inquisitive people passing by making unnecessary stops, look and inquire what is going on. Both dynamite and vibrator operations can disturb local wildlife habitats. In any seismic acquisition, the operator is in a weak position and will face both rightful and ridiculous claims of damage to the environment and land access fees that need to be dealt with.
- During acquisition, both dynamite and vibrators were used as the source (of sound wave), with dynamite commonly used in unpopulated jungle and plantation areas, whilst the vibrator was used mainly in the towns. Dynamite is dangerous and if not handled carefully (depending the quantity of explosives), it can cause havoc or cause significant damage to buildings and infrastructure. Seismic shot-hole drilling crews can hit pressurized gas or ground water zones given the optimum source-depth is normally located between 20 to 25 m. Such ground water pockets, with or without methane gas, can be found at such a depth, with the longest duration of pressurized water discharge of approximately 2 weeks. The potential mix of dynamite source and discharged shallow gas can be a disastrous

Figure 3: Seismic acquisition operations. a) The objective of seismic acquisition (2D or 3D), is to collect geophysical data on the subsurface hydrocarbon reservoirs within the study area to allow the subsurface targets to be characterised as potential further exploration prospects and for development of the discoveries. Sound wave signals generated by the seismic source travel though the various sub surface rock layers and at points where the rock type changes, reflect back to the surface (red and yellow lines). b) Onshore seismic operations rely on the use of an energy source (impulsive - explosive or non-impulsive) and receivers. The receivers are typically geophones (cables or nodes) which are placed at the surface to record the reflected energy following operation of the energy source. Non-impulsive energy sources include the use of vibrators or vibroseis trucks. Typically, a vibroseis survey involves the use of trucks with vibrating plates that stop at regular intervals along pre-determined survey lines. The truck vibrator plates are compressed against the ground using hydraulic power and vibrated to send energy waves into the sub surface. c) The gathered data is then processed for imaging the subsurface structures. The social and environmental impacts of the operations need to be carefully considered.

cocktail and can cause environmental damages to land, animal habitats, oil palms and fruit trees.

- Social-psychological impact on the native population. During land seismic operations, the issue of customary land rights and native ownership comes up. There are typically many cases of stolen equipment such as seismic cables, as well as damage and attempted extortion for access rights. This is commonly realized during the land operations. There is clearly a need to bring the rural population on board addressing the Ketua Kampung (village heads), and escorting authority, such as the district councillors and local police, which can be difficult in remote areas. The negotiation for compensation for the loss of cash crops and fruit trees should be agreed upfront before operation starts to avoid disruption and misunderstanding.
- The biggest safety concern of a land-based operation is the large fleet of vehicles and operator personnel in the field, which gives exposure to accidents. Road exposure is often under-estimated. Handling of dynamite (both storage and transportation) and operational detonation of the charges is a risky operation on its own and needs security escort, however strict safety practices have shown that this hazard can be well-controlled. Historical comparisons with other surveys have shown, that road transport is a far more dangerous business compared to dealing with dynamite. Increased traffic is also contributing to further background noise.
- The river transportation of a rig, heavy drilling equipment and construction materials to the drill site in the remote, difficult to access area near a river bank such as the Engkabang West location (Figure 4), could pose a risk for potential accidents and spillages of drilling chemicals that might result in environmental pollution and adversely affecting the wildlife habitats. Transporting equipment and goods to and from drill site by roads, due to the close proximity to people, poses issues for the environment between the well site and waste facilities, or water extraction points especially when they pass closer to more heavily populated areas.
- The process of drilling oil and gas wells generates large volumes of drill cuttings and spent muds and produces a variety of waste products. Most onshore wells are drilled with water-based or oil-based muds, these drilling fluids contain additives, organic and inorganic components that also leave marks on rock cuttings. Therefore, mud and cuttings must be stored in a safe way, such that no contact with groundwater is permitted. Onshore operators have a wide range of options for managing these drilling wastes. Depending on what environmental regulations allow and how costly those options are for the wells in question, some wastes are managed onsite whilst others are removed to offsite commercial disposal facilities. The onshore waste management options include land farming, land-treatment, evaporation, underground injection, incineration and other thermal treatment allowed under regulations, bioremediation and composting, and reuse and recycling (Veil, 2002). Waste burial onsite could be considered acceptable once the associated risks have been assessed.
- Appraisal wells are planned to determine the size and the extent of the field and confirm whether hydrocarbons can be extracted economically. The well is also designed for production testing for productivity, fluid properties, composition, flow, pressure, temperature and presence of contaminants in the crude. The crude and associated gas produced during testing are vented and flared (Figure 5). During venting and flaring, soil and groundwater

Figure 4: a) Drill site location of exploration well Engkabang West, near the bank of upstream Baram River, Marudi (photo credit: Mohamad Haffiz Hadran) where, b) crew changes and moving of rig, trucks, heavy machineries, cabins and logging tools were done by river transportation, which played a critical role in the drilling operations.

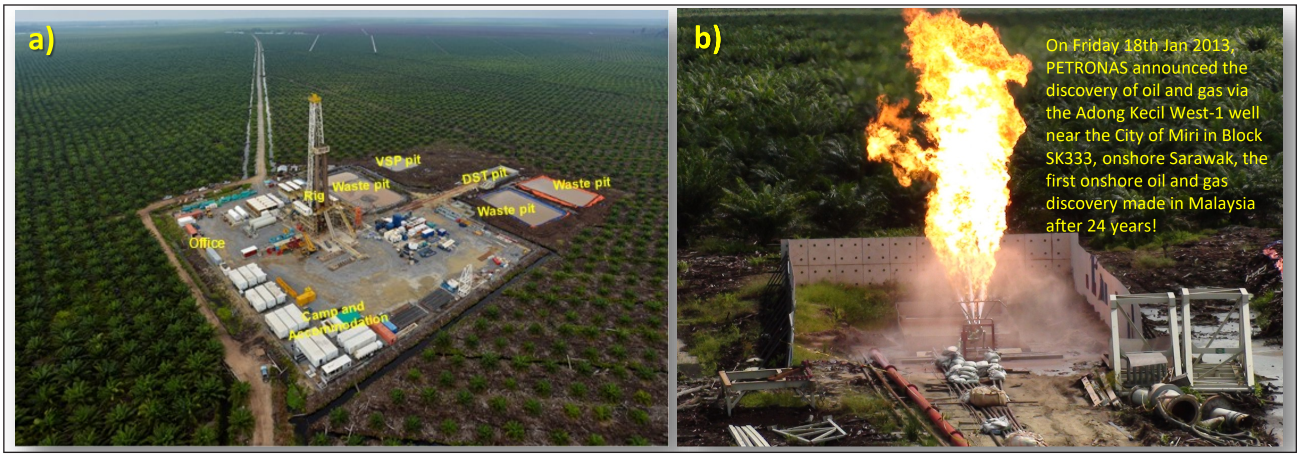

Figure 5: Onshore drilling operations can be risky. Accidents and work or traffic-related injuries, waste spillages, and damage to the environment are results of risks associated with onshore drilling operations that negatively influence the reputation of oil and gas industry. a) Based on the review of available G&G data and geochemical investigations, the Adong Kecil West location was identified for drilling to assess the hydrocarbon potential of the study area. In case of discovery of economically viable hydrocarbons, it can contribute to local work force, as well as the partial fulfilment of Sarawak energy requirements. b) Production testing conducted to establish well fluid properties, composition, flow, pressure, temperature and presence of contaminants in the crude. The produced crude and associated gas during testing were vented and flared with concrete mitigation measures to achieve minimal pollution and avoid environmental damages (from Jong *et al.*, 2013).

contamination and deterioration to local air quality associated with fuel related pollutant emissions might occur. An impact on community health and safety can arise due to the potential for fire and explosion during well testing. Disturbance of local residents and fauna by noise from generators, machinery and vehicles is another social concern.

- During drilling of vertical or deviated wells, drilling fluid or mud, which keeps the bit cool and lubricated is continuously circulated down the drill pipe and back to the surface equipment to balance underground hydrostatic pressure. The drilling fluid also functions to control formation pressures to prevent formation fluid flowing into the well and result in the loss of control, which if not carefully monitored, would result in a disastrous blowout (Figure 6). With a sudden increase in gas pressure and blowout prevention mechanism failure, the casing might be pushed out which may result in the well catching fire. The gushing flames could bring high temperatures that might affect the nearby oil palms or other cash crops, affecting local fauna habitats. Poisonous gases and emitting pollutants might cover a large area resulting in an emergency evacuation of the people living and working within a 2 km radius of the well site. Noise pollution levels could also be higher. In addition, gas migration and groundwater contamination, and leaks and spills of waste water and chemicals due to blowouts are also causes for concern especially in area where pipe water supply is limited for human consumption.

Figure 6: Blowout in Rasau field onshore Brunei neighboring Block SK333, which was discovered in 1979 with production began in 1983. A blowout of one of wells, Rasau-17 occurred in April 1989. The resulting fire lasted from 25th April to 8th May when it was finally extinguished. By the time the fire was put out, almost two weeks after it ignited, the drilling rig that had stood at the site had completely melted with nothing recognizable left (photo credit: Richard Davis).

REGULATORY AND COMPANY REQUIREMENTS

In the past, some operators used waste management practices that did not protect the environment and public health to the extent desired, and were later prohibited by regulatory agencies. Nonetheless, most countries do now have legislations, that forces operators to manage petroleum exploration activities consciously and responsibly. Over time, as state and federal regulatory requirements have become stricter, with advancement in drilling and mud system technologies, some companies have voluntarily adopted new waste management options that have even less environmental impacts than those in use today. Environmental planning, execution and remediation form a steadily growing field of activities, in which operators are encouraged to develop both plans and management systems that exceed government regulations. Environmental impact assessment (EIA), is a process of evaluating both beneficial and adverse likely environmental impacts of a proposed project or development by considering inter-related socio-economic, cultural and human-health impacts. In Malaysia, an EIA Report and approval from Department of Environment (DOE) is a regulatory requirement before conducting seismic and drilling operations.

The EIA guidelines in Malaysia consists of the updated guidelines prescribed by the Director General of Environmental Quality in order to fulfill the requirements under the provision of Section 34A (2c) of the Environmental Quality Act 1974, and later the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 2015 which has been gazette and enforced since 28th August 2015 (Abdul Rahman Mahmud, 2016). The purpose of this guideline is to guide the project proponent and qualified person (registered consultants by DOE) in the preparation of the EIA reports. The project proponent is required to appoint registered consultants and consults with the DOE about the proposal as early as at the project identification stage. This Guideline is also enhanced by providing guidance at pre, during and post stages of EIA Report submission. It also introduces guidance on self-regulation in the current practice by DOE to ensure the project proponent to be fully responsible and accountable in EIA project implementation. In this case study, a comprehensive EIA was conducted by Chemsain Konsultant Sdn Bhd (2007), following the guidelines prescribed by the Director General of Environmental Quality in order to fulfill the requirements of the Environmental Quality Act 1974, which was endorsed by Natural Resources and Environment Board of Sarawak (NREB). The EIA outlines the status of the environment in the affected area, provides a baseline for understanding the potential consequences of the proposed petroleum exploration activities, identifies positive and negative effects for the environment, and offers alternative actions, in relation to the proposed activities.

In addition, all upstream petroleum exploration activities are guided by the PETRONAS Procedures and Guidelines for Upstream Activities (PPGUA), which has been developed with consideration that the operator is professional and competent in executing upstream activities. The current Version 4.1 of PPGUA incorporates the latest procedures and guidelines covering the entire life of asset from exploration to abandonment, updated in line with circumstances and challenges faced by the upstream industry today. Operators are required to comply with the procedures when executing its operation and are expected to drive their upstream activities in a prudent, proficient and effective manner. Moreover, contractors are expected to exercise good self-governance over operations and shall ensure compliance to all the requirements stipulated (PETRONAS, 2021).

There are risks of health impairments, operational incidents and impact on the global environment in each stage of the oil and natural gas development business. JX Nippon positions the management of such risks concerning occupational Health, Safety and Environment (HSE) as a matter of the highest priority in the execution of its business, and have built an occupational HSE Management System (HSE-MS) that is compliant with international standards such as ISO14001 and OHSAS18001. The HSE-MS a system pursuant to the HSE policy instituted by JX Nippon's top management. It is a systematic platform to promote the company's HSE activities in effective and efficient manner including organizations, roles and responsibilities, HSE and Emergency Response plans, and management procedures in PDCA cycle (plan, do, check and act). Proper implementation of HSE-MS allows the company to minimize and mitigate the risks leading to incidents and operational troubles. The company operates an HSE-MS that extends across the entire organization, and continuously carry out improvement activities aimed at preventing occupational accidents and minimizing the environmental impacts (JX Nippon Oil and Gas Exploration Corporation, 2021).

CONTAINMENT PROCEDURES AND MITIGATION MEASURES

Historically, the first hundred years of oil exploration and production were marked by brutal and dangerous procedures, and many workers lost their lives due to poor equipment and insufficient training. Whilst health and safety measures gradually took root in the developing industry, the environmental angle came to focus and consideration merely in the last thirty years. Working with dangerous materials, exposure to harsh working conditions and road traffic are unavoidable in petroleum exploration activities but conscious efforts to contain and mitigate exposure are possible and necessary. These measures are part of a company´s commitment to society and also for reputation management.

Some of the most important aspects of the 2009-2014 seismic and drilling operations are listed below:

- We prepared a catalogue of hazardous goods and procedures, staff safety training and recommended appropriate actions and handling of dangerous situations and goods. This had to be prepared as a safety and environmental plan ahead of field activities. A daily staff briefing was undertaken before any field activity was conducted (Figure 7).
- Communication structure and communication plan. This was to inform all stakeholders in an operations theatre about the nature and timing of operations and to resolve permitting issues. These include regular briefing to local

Figure 7: Staff and drilling crew briefing and training. a) Public relation training on effective communication to local authorities and land owners. b) Procedure training to ensure work procedures were understood and correct working methods were put into practice. c) Line clearance training such as using the machete and the using of proper personal protective equipment for clearing shrubs and hand carrying of portable drilling rig. d) Explosive handling training before field work where special positions in the crew such as explosive handlers, doctor and medics are required to present their profession certification, diploma, work experience, license or additional document, which were verified by related authorities and filed in HSE documentation. e) First aid training was conducted at HSE safety induction to all personnel, including the use of the first aid kit and how to react when carrying out an emergency in the field. f) Jungle survival training in flooding events, which occur commonly during raining seasons in swampy area.

Figure 8: a) Restricted access and bunkered explosive magazine site, b) Security lookout post, c) Explosive store, and d) Battery handling area.

state government authorities and representatives such as the local state assembly men, Miri City Councillors, Head of Police and Head of Road Transport Division, Ketua Kampung and land owners. Hazardous tools (logging tools with radioactive and explosive sources) were kept safely and stored in well-guided and sheltered facilities.

- Explosives were stored in designated, a sheltered and bunkered depot with a 24 hours surveillance scheme and transported to operation sites with police escort (Figure 8).
- Traffic management. To minimize traffic interruption, the vibroseis operation in Miri's urban area was limited to a window from 0:30 am to 4:30 am. The acquisition area was cleared by police and guarded by dedicated

vehicles with flashing light and well-trained personnel to ensure the safety during the operation. A vibroseis road show was also conducted for local authorities to experience the working conditions.

- Waste handling. We identified the different types of waste originating from activities such as drilling and (to a lesser extent) seismic operations. The importance of drilling fluids, solids control, and waste management as a process designed to meet specific drilling conditions – the need could not be overemphasized. The process design was key to help improve economics and to minimize the environmental impact of drilling activities. In some locations, operators preferred a total fluids management approach that integrates fluids, solids control, and waste management to deliver a cost-effective wellbore in a safe and successful manner (Figure 9). Both solid and liquid waste contaminated by oils (mineral, hydraulic, other) must be disposed and shielded from ground water or, preferably, incinerated. In this case study, the drilling wastes were dehydrated and transported out of the drilling sites by appointed contractors to be disposed of in government approved facilities.

Drilling operations are limited to selected well sites with less complicated containment measures and hence less social-environmental impacts and concerns. Well equipment failure is less of a hazard today than it has been in the past as it became more reliable, and better well control practices have also resulted in the equipment being subjected to less strain and fatigue. Most blowouts occurred not because of faulty equipment but as a result of human error and poor practices. Blowout prevention is a frame of mind of the drilling crew and supervisory staff. The key to blowout prevention usually lies not in spending large sums of money on high pressure preventer equipment, but in teaching crews to identify foreign fluid entry into the wellbore at the very earliest time and then taking prompt action to remove this fluid from the well. A prepared plan of action for foreseeable eventualities, along with the necessary equipment, must be ready before the blowout occurs (Netwas Group Oil, 2020). With prudent kick control in place, it was reported that no major kicks were encountered during drilling operations in the study area.

Seismic operations, on the other hand covered vast areas from urban to jungle and swamp area (Figure 10), which required more detailed planning and execution of operations. The following mitigation procedures were undertaken by JX Nippon before, during and after operations for seismic acquisition operations.

Before the operations:

- To carry out EIA study by registered and qualified professionals to check and audit the activities during the survey and after completion of the survey.
- To carry out the scouting trip with all contractors to find out the best acquisition approach and suitable equipment for different terrains.
- To find out the location for explosive magazine and obtain approval from local police and all local agencies.
- To obtain seismic licenses for delivery, storage, and usage from Sarawak Police.
- To obtain the handling licenses for explosive detonators from the Sarawak Police.
- To find the suitable locations to build the temporary camps for workers.
- To build the temporary camps for workers in dedicated

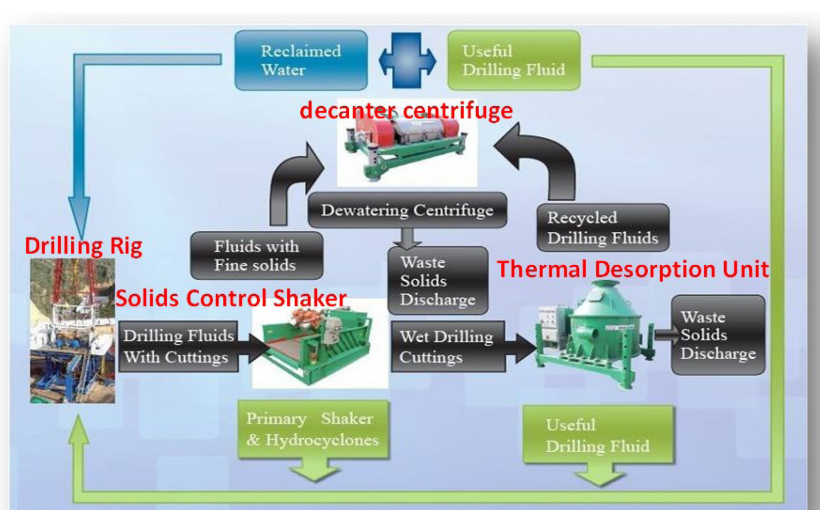

Figure 9: There is a wide range of options available for onshore drilling waste management, some wastes are managed onsite whilst others are removed to offsite commercial disposal facilities. Waste burial onsite can be considered acceptable once the associated risks have been assessed. The figure illustrates a waste management scheme where fluids and solids are separated with fluids recycled and waste solid discharged (from GN Solids Control, 2013).

area in the survey area.

- To provide training for all seismic crews.
- All of the vehicles are hired and checked.
- All of the seismic equipment is QAQC.
- Operation time: explosives are only used in jungle area and the daily operation time is 6:00 am to 5:00 pm. Vibroseis trucks are used in Miri urban areas and the operation time is 0:30 am to 4:30 am to minimise interruption to local traffic.
- To conduct the awareness sessions in all villages and Miri City public information sharing sessions before operations (with the support of District Office and local authorities) so that local people are aware of our activities.
- To contact all land owners and pay access and crop compensation before and during the survey, and to recruit local permit-men for crop compensation negotiation.
- To recruit local to work for seismic crews. With a high turnover rate, around 2000 short-term labourers were recruited for the survey.
- To provide dedicated training programs to all seismic crews, including HSE and job training (Figure 7).

During the operations:

- To avoid theft, explosives facilities were equipped with CCTV system and automatic alarms with police guarding at all time.
- The location of the explosive magazine and building design were selected and approved by Sarawak Chief Police and eleven other local government agencies. The construction was built under the supervision of Sarawak Police (authorized by District Chief Police).
- The daily explosive transportation window during the seismic survey was from 6:00 am to 5:00 pm. Thus, the vehicles could not leave the magazine earlier than 6:00 am and the vehicles returned to the storage not later than 5:00 pm. These vehicles were guarded by police at all time.
- The explosive handling and loading crews were well-trained by the professional trainers before the survey started and they all clearly understood the standard operating procedures.
- Contractor used the natural clay instead of bentonite as drilling mud for shallow pilot hole drilling to minimize the environment impact.
- Many HSE personnel were deployed to ensure the safety of seismic crew and local communities.
- All of the activities were supervised by qualified professionals to ensure the data quality and to protect the environment.
- No machines were used to clear the area for seismic lines to make sure that the trees are protected.
- Some seismic lines were deviated compared to plan when they were too close to houses or facilities to ensure the safety concern was addressed.
- Vibroseis safety distance limits were tested to protect the local housing and facilities.
- Daily safety briefings were conducted in the base camp, and in the field during the seismic survey.
- Clean water and food were supplied to seismic crews to ensure their hygiene and personal health.
- Local authorities and PETRONAS regularly visited the crew and operation site for environmental and safety audits.

Figure 10 shows some of the operational challenges encountered.

After the operations:

- All shot-hole and up-hole were restored to original conditions after the survey and certified by local authorities (including environment related matters as per EIA scope in the report).
- All seismic line localities were cleared and restored as original condition after the survey and certified by local authorities (including environment related matters as per EIA scope in the report).
- All worker camps (base camp, temporary camps) were restored as original condition, and then verified by local authorities and the land owners.
- Meetings with local authorities were held after the survey to update them on the status of the acquisition completion.
- All of the labourers returned home safely after operations.
- All contractors' equipment was transferred back safely to their place of origin.

LESSONS LEARNT

Although the 2009-2014 exploration campaign reached its objectives, it also demonstrated that seismic operations in relatively densely populated areas (urban and dispersed rural populations) can be challenging including accessibility in difficult terrains and permitting issues in the area of acquisition. Whilst drilling operations have profited from good infrastructure and access in the vicinity of Miri, they posed problems in the more remote inland areas where access roads to the drilling site were limited, and river transportation of the construction materials and drilling equipment was needed, thereby increasing the risk of potential accidents and spillages that might result in environmental pollution.

For urban seismic acquisition, it was not possible to convince the Miri City Council to allow explosives (even mini-charges) to be used in the greater urban Miri area, fearing damages to buildings and road surfaces. This forced the operator to use the far inferior vibroseis technology which led to inferior data quality. In addition, communicating in dispersed rural areas proved to be challenging. Some villages (kampung), as well as individuals in the field showed a hostile attitude, and there were cases of organized theft and

Figure 10: Seismic acquisition and operational challenges. a) Vibroseis operations at night, b) Laying geophones/hydrophones in swampy area, c) Bridging work with steep terrain in the hilly area, d) Fly camps for temporary living quarters, e) Up-hole drilling, and f) Shot-hole drilling.

sabotage of equipment, as well as attempts of blackmail and extortion. In hindsight, the company should perhaps put a greater effort in recruiting experienced permitting personal that is also able to speak the dialects of the respective villages.

JX Nippon has gained a lot of operational knowledge, as well as administrative experience from the discussed seismic acquisition and drilling operations. For planning of future onshore petroleum exploration activities, the following recommendations are worth considering for optimum seismic acquisition and drilling completion to minimize social and environmental impacts:

- √ To conduct awareness sessions in advance by senior management with local authorities, regulatory bodies, land owners and Ketua Kampung, and provide regular progress updates to the affected parties stakeholders.
- √ To establish a public relations team, staffed by experience liaison officers to maintain dialogues and good relations with the local authorities and discuss compensation with the affected land owners, and to have access agreement with oil palm companies in advance.
- √ To obtain all of required permits in advance, especially the explosive license, which could take up to a year for final approval.
- √ To employ local staff and assign them to work as QCs with each component/crew (shot-hole drilling and loading, flushing drilling, up-hole and geophone planting).
- √ To plan for assistance from Jabatan Pengangkutan Jalan (JPJ, Department of Road Transport), local police department and local council for traffic control for vibroseis operations and drilling equipment transportation in urban areas. In order to acquire data during the quietest periods and avoid heavy traffic flows, vibroseis operations should be conducted from mid-night to early hours of the morning (to 4.30 am).

Apart from the above lessons from operations, it should be highlighted that the petroleum exploration activities conducted in the study area have provided significant social-economic benefits to local businesses and communities in the greater Miri area. These benefits include short-term employment opportunities that boosted local spending such as increased activities at local restaurants, hotel stays, recreation facilities, logistics support and transportation demand, etc., during the period 2009-2014. In addition, formal and on-the-job trainings were also provided to the local people who were employed by JX Nippon, to equip them with the necessary knowledge and skills for potential job openings in the industry, that may arise in other states of the country with oil and gas operations once the exploration activities were completed.

CONCLUSIONS

Onshore seismic acquisition and drilling operations can be risky. Accidents and work-related injuries, waste spillages, and damage to the environment and wildlife habitats are some of risks associated with onshore petroleum exploration activities that could pose a danger to human life and negatively affect the reputation of oil and gas industry. The resulting impacts could be a potential threat to the future of the industry due to the potential social and environmental consequences associated with these exploration activities. These issues could lead to a loss of resources, medical compensation or a hike in insurance premiums for future operations, creating serious detriments.

In summary, significant technical and social challenges certainly were encountered while planning and conducting petroleum exploration activities in the study area. These challenges include problems related to topographic variabilities, layout constraints, drilling operations, well control measures for blowout prevention, traffic controls, permitting, potential damage to infra-structures, explosive and equipment transportation.

However, with proper planning, regular and effective communications with the local authorities and affected parties, and support of the local communities the operations have managed to mitigate these challenges and successfully acquired nearly 900-line km of 2D seismic across many villages, longhouses, and city areas, after which four explorations well were drilled successfully in the exploration block. We are glad to report that both seismic and drilling operations were conducted safety with minimal interruptions to people and environment.

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AUTHOR CONTRIBUTIONS

JJ: conceptualization, data compilation and analysis, writing original draft (lead); TQT: conceptualization, data compilation, writing (supporting); FLK: conceptualization, data analysis, writing (supporting).

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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