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Ergas SJ, Schroeder E, Chang D, Scow K, (1994) Spatial distributions of microbial populations in biofilters. In: Proceedings of the *78th Annual Meeting and Exhibition of the Air and Waste Management Association*, pp. 19-24, Cincinnati, OH.

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Research Paper

The Removal of N-nitrosodimethylamine, Trihalomethane, and Halonitromethane Precursors by RO Membrane from Water

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Abstract: Reverse osmosis (RO) has been proven to be effective for removing disinfection by-products (DBPs) precursors from different water sources during conventional water treatment processes. However, polymeric RO membranes have the potential to leach DBP precursors, which can introduce a bias in the true performance evaluation of these membranes during bench, pilot, and full-scale operations. This study first examined the NDMA precursor leaching potential of one commercially available virgin RO membrane. Following a cleaning procedure, the efficiency of the RO membrane was tested for the rejection of N-nitrosodimethylamine (NDMA), trihalomethane (THM), and halonitromethane (HNM) precursors from surface water and wastewater treatment plant effluents. While the leaching potentials of RO membranes for NDMA precursors were up to 370 ng/L, the leaching potential of membrane's decreased as the filtered volume of water increased. In the tested water samples, the RO rejection efficiencies ranged from 78 to 91%, 81 to 97%, and 63 to 78% for NDMA, THM, and HNM precursors, respectively. The results also showed that the background water quality did not have a considerable influence on the rejection of NDMA, HNMs, and THM precursors by the RO membrane. While the correlation between NDMAFP, HNMFP and THMFP, and total dissolved nitrogen (TDN) removals were weak (r^2 ranged from 0.02 to 0.3), the removals of DBPFP were correlated well with DOC removals (r^2 ranged from 0.6 to 0.89).

Keywords: *DBP precursors, Leaching, Disinfection By-products*

Introduction

High-pressure reverse osmosis (RO) membranes have emerged as the preeminent technology for the rejection of salts, natural organic matter, and emerging contaminants from water sources. During manufacturing processes, polymer-based RO membranes are, in general, made from either cellulose acetate or polysulfone coated with aromatic polyamides through a method called phase inversion, where the selected polymers are dissolved in water-soluble solvents. The manufacturing process involves in use of varying types of polymers, additives, and surface-coating materials. During membrane filtration, loosely bound chemicals and additives may be released into the permeate and serve as a precursor for emerging contaminants (Ersan *et al*., 2015).

Although chemical disinfectants (such as chlorine, chloramine, ozone, and permanganate) have been used to kill harmful pathogens in drinking water supplies, these oxidants can react with precursors (organic matter, bromide [Br^-], iodide [I^-], and other anthropogenic pollutants) and result in the occurrence of unintended disinfection by-products (DBPs) in the treated waters. Trihalomethanes (chloroform, dichlorobromomethane, dibromochloromethane, bromoform) and haloacetic acids (monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid) are among the major and regulated DBPs of chlorination (U.S. EPA, 2006). To mitigate the formation of regulated DBPs (THMs and HAAs), the water reclamation facilities have been switching to alternative oxidation strategies such as ozone, chlorine dioxide, UV photolysis, and chloramine. Among these, chloramine is one of the most used disinfectants in water reclamation facilities in the US. Although the formation of THMs and HAAs is minimized during chloramination of finished waters, this can facilitate the formation of other problematic unregulated DBPs, such as halonitromethanes (HNMs), haloacetonitriles (HANs), and nitrosodimethylamine (NDMA) (Chen & Valentine, 2006; Ersan *et al*., 2016; Krasner *et al*., 2006). While NDMA is reported as a potential human

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carcinogen and has been detected mainly in chloraminated waters (Russell et al., 2012), HANs and HNMs have higher cyto- and genotoxic potency than the regulated THMs and HAAs (Plewa et al., 2004). Although NDMA has been listed in the toxic pollutant category, there is no federal maximum contaminant level (MCL) has been issued for drinking water. Though, some of the states, i.e., California, has been issued notification limit of 10 ng/L for NDMA (CDPH, 2014). On the other side, there is no health-based advisory level or regulation exists for HANs and HNMs. Because of their pervasiveness in engineered and aquatic systems, alternative strategies for controlling their formation have been critical in protecting public health from the harmful effects of these contaminants. Several treatment techniques, such as activated carbon, anion exchange resins, enhanced coagulation, and nanofiltration (NF) and reverse osmosis (RO) membranes, have been used at the conventional scale to control the occurrence and formation of DBPs (Beita-Sandí *et al*., 2016; Boyer and Singer, 2005; Ersan et al., 2016; Gan et al., 2013; Krauss *et al*., 2010; Miyashita et al., 2009; Schmidt and Brauch, 2008; Snyder *et al*., 2007; Uyak *et al*., 2007). Among these, RO membranes have been a proven technology in water and wastewater treatment, seawater desalination processes, and brackish water treatment due to their ability to remove organic constituents from water, such as organic matter, bacteria, viruses, and harmful trace organics. However, previous research studies have reported NDMA precursors leach from membranes, anion exchange resins, and various materials (gaskets, rubber seals, etc.) (Ersan et al., 2015; Gan et al., 2013; Morran *et al*., 2011; Teefy *et al*., 2011). For example, in one of our previous studies, we demonstrated that nanofiltration (NF) membranes can leach from 130 to 450 ng/L of NDMA precursors regardless of their polymer type or manufacturer (Ersan et al., 2015). Therefore, the possibility of DBP precursor leaching from RO membranes raises questions about the true performance evaluation of these membranes for the removal of NDMA during bench, pilot, and full-scale applications. As a result, it is necessary to investigate whether polymeric RO membranes also contain precursors of NDMA, and then perform a DBP removal test after the precursors have been removed from the RO membranes.

The main goals of this study are to (i) examine the leaching of NDMA precursors from RO membranes and (ii) investigate the rejection of unregulated (i.e., NDMA and HNMs) and regulated (THMs) precursors by RO membranes from municipal WWTPs effluents and surface water sources. To the best of our knowledge, this is the first study reporting NDMA precursor leaching potential from RO membranes and providing a true evaluation of NDMA, THM, and HNM precursor removal efficiency of RO membranes.

Materials and Methods

Leaching experiments

A commercially available composite polyamide CPA2 (Hydranautics) RO membrane was used during the experiments (Table 1). All filtration experiments were conducted at 25 ± 1 ºC under constant operating pressure of 500 psi using SEPA II crossflow filtration cell described elsewhere (Ersan et al., 2016), and a schematic diagram was presented in Figure S1. The surface area of the membrane coupon was 140 cm^2. 500 ml of sample was withdrawn from the effluent side of the membrane system at the predetermined distilled and deionized (DDI) water volume to surface area ratios (L/m^2), and NDMA formation potential test (NDMAFP) was carried out.

Table 1. Characteristics of RO Membrane

Designation Manufacturer Polymer type	Molecular weight cutoff (Da)	NaCl Rejection (%)	pH range (25 ^{0}C)	Typical flux (m^3/day)
Composite Polyamide	300-500	99.7	2-10	37.9

Filtration Experiments

The water samples were collected from treated effluents of surface water sources (SW-A and SW-B) and wastewater treatment plants (WWTP-A and WWTP-B). The collected samples were passed through a pre-rinsed 0.2µm Whatman Polycap TC 150 capsule filter and characterized for ultraviolet absorption (254nm), dissolved organic carbon (DOC), total dissolved nitrogen (TDN), conductivity, ammonia (NH_4^+), nitrate (NO_3^-), bromide (Br^-), and pH. The formation potential (FP) concentrations of disinfection by-products (DBPs), nitrosodimethylamine (NDMA), halonitromethane (HNM; trichloronitromethane, TCNM), and trihalomethanes (trichloromethane, bromodichloromethane,

dibromochloromethane, and tribromomethane) were measured according to slightly modified standard methods, discussed below. The water qualities of studied water sources are given in Table 2.

The removal efficiency, R (%) was calculated as shown in *eq 1*.

$$R = \left(1 - \frac{Cpermeate}{Cfiltrate}\right) * 100 \quad (1)$$

where $C_{permeate}$ and $C_{filtrate}$ are the concentration of permeate and feed, respectively.

Table 2. Characterization of selected water sources

Parameters	WWTP-A	WWTP-B	SW-A	SW-B
UV_{254nm}	0.083	0.047	0.283	0.059
DOC (mg/L)	5	1.99	7.62	3.01
$SUVA_{254}$ (L/mg/m)	1.7	2.4	3.7	2.0
TDN (mg/L)	8.5	8	0.78	0.83
Conductivity (µs/cm)	572	80.1	48	44.9
NH_4^+ (mg/L)	0.02	0.04	0.01	0.02
Ca^{2+} (mg/L)	18.5	4.8	4.1	5.0
NO_3 (mg/L)	38	35	3	4
Br^- (µg/L)	50	30	<MRL*	18
pH	7.8	7.3	7.1	7.2
NDMAFP (µg/L)	1049	164	179	106
HNMFP (µg/L)	36	13	17	10
THMFP (µg/L)	218	136	1325	206

*Bromide MRL= 10 µg/L

Analytical methods

To ensure that all the precursors were converted to their respective DBPs, NDMAFP, HNMFP, and THMFP tests were performed with an excess of oxidants. The details of the analytical methods used in this study were provided in the literature (Ersan et al., 2016). Briefly, 10 mM phosphate buffered was used to buffer the samples at pH 7.8 before the addition of the oxidants. For NDMAFP, 100 mg/L (as Cl_2) of chloramine was spiked to both raw water and treated source water samples and reacted for 5 days. For THMFP, 50 mg/L of chlorine was added to the samples and hold for 5 days. For HNMFP test, the samples were spiked with ozone followed by chlorine. Ozone stock solution (~20-30 mg O_3/L) was produced using a lab-scale ozone generator (Model GTC-1B, Griffin Technics, NJ). The samples were initially ozonated at a mass ratio of 1:1 (O_3:DOC) for 5 min. Then, the samples were reacted with 50 mg/L of Cl_2 for 24h. After 24h, the oxidant residuals were measured, and residual Cl_2 was quenched at a 1:1 molar ratio with sodium thiosulfate before the analysis.

NDMA samples were extracted according to USEPA Method 521. (USEPA, 2004). Before the solid phase extraction, N-nitrosodimethylamine-d6 (NDMA-d6) was added as a surrogate compound to the quenched samples. Later, the extracted samples were spiked with an internal standard, N-nitrosodi-n-propylamine-d14 (NDPA-d14) and measured by Varian GC 3800-MS/MS equipped with an RTX-5MS (Restek 30 m, 0.25 mm, 0.25 mm) column.

The analysis of THM and HNM samples was performed according to USEPA Method 551.1 with minor modifications. A liquid-liquid extraction (LLE) procedure was followed for the extraction of the samples in accordance with the USEPA 551.1 method. Briefly, samples were transferred into extraction vials (50mL) which was followed by transferring 3 ml of MtBE and 10g of overnight (at 105 °C) dried sodium sulfate (Na_2SO_4) into the vials, respectively. The extraction vials were then shaken at 300 rpm for 30 minutes. After 30 minutes, the samples were placed on a flat surface for 10 minutes to allow for phase separation. MtBE phase was extracted and analyzed on an Agilent 6890 GC outfitted with a DB-1 column (J&W Scientific 30 m x 0.25 mm x 1 µm) and an electron capture detector (ECD). The details on the analytical methods are summarized in Table S1.

Results and Discussion

NDMA Precursor Leaching Potential of RO Membrane

The NDMAFP leaching potential of the CPA2 RO membrane is shown in Figure 1 as a function of the DDI water volume passed through the membrane. The initial NDMAFP leaching potential in the RO

permeate was up to ~313 ng/L, which gradually decreased as the passed volume of water increased up to 1070 L/m^2. Even after flushing the membrane with 1070 L/m^2 of water, the leaching potential was still well above (60 ng/L) the background NDMAFP concentration (DDI= 12 ng/L). In our laboratory, we also tested NDMA precursor leaching potential of a point of use under sink RO membrane. The results showed that the initial permeate NDMA leaching potential from the membrane was 370 ng/L (Figure S2). Like the CPA2 RO membrane, the leaching potentials decreased with the increasing volume of water passed. This indicates the importance of flushing home-type RO filters for the initial operation to eliminate the exposure of residual chemicals from these filters. In another study, authors reported NDMA precursor leach from nanofiltration (NF) membranes (Ersan et al., 2015). The authors examined the leaching potential of NDMA precursors from NF membranes made from various polymeric materials (i.e., polyamide [PA], cellulose acetate [CA], and polypiperazine amide [PPA]) and manufactured by various companies. Their findings indicated that membrane leaching was not limited to a single membrane type or manufacturer. This may indicate that the precursors may be originated from manufacturing impurities (i.e., dimethyl formamide [DMF] or other chemical additives) that remained in the membrane structure after the manufacturing process. Two confirming results, from this study and the previous study, indicate that the leaching potential was significantly reduced after passing a large amount of water per surface area (m^2) of the membrane. From the application point of view, although it is likely to reduce the precursor leach from the membranes, this may raise a concern about water and energy consumption at the initial startup of these systems. According to Schreiber et al. (2007), the addition of free chlorine reduced NDMA formation by deactivating its precursors (Schreiber and Mitch, 2007). Thus, in this study, we investigated the effectiveness of chlorine on the deactivation of NDMA precursors from RO membranes. As discussed in our previous study, the RO membrane was first flushed with 1 mg/L (as Cl_2) chlorine-exposed DDI water. As a result, the leaching potential from the RO membrane was significantly reduced and reached levels comparable to those observed in DDI water (Figure 1).

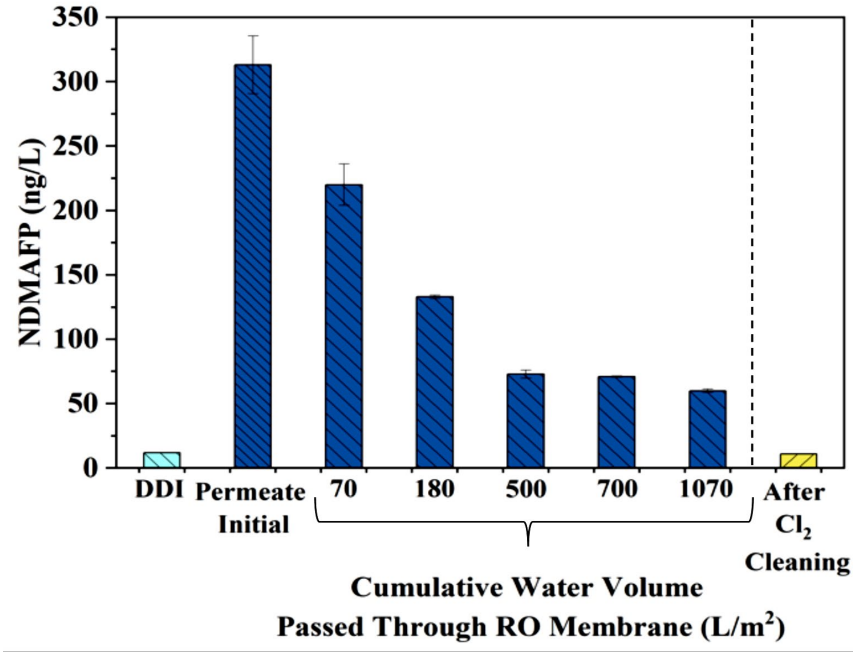

Figure 1. NDMA leaching potentials of RO Membrane

The current study demonstrated that NDMA precursors leach from RO membranes; therefore, it is critical to monitor such precursor leaching in laboratory-scale studies as well as industrial and home-type membrane applications. Previous research studies evaluated NDMA precursor leaching potentials of various polymeric materials and chemicals (i.e., resins and coagulant aids)(Gan et al., 2013; Teefy et al., 2011). The results showed that using these polymeric-based chemicals and materials during water treatment increased the occurrence of NDMA precursor concentrations in treated water effluents, ranging from low levels (20 ng/L) to very high levels (600 ng/L). The reported NDMA precursor leaching concentrations in the previous studies were comparable to the concentrations found in our study

(60-313 ng/L). The results from these studies suggest that it is likely to wash out the residual precursors after long operating hours. However, special attention should be given to the formation of NDMA at the startup period of membrane systems if chloramine is used as the primary oxidant.

Because of the proven leaching potential of NDMA precursors from RO membranes, we used a cleaning procedure described in a previous study (Ersan et al., 2016, 2015) to eliminate NDMA precursor leaching from RO membranes and thus make a true evaluation of RO membranes for removing NDMA precursors from different water sources.

The control of NDMA precursors from RO membrane

Figure 2 depicts the removal efficiencies of the CPA2 RO membrane for NDMA precursors. When the formation potentials of NDMA were compared between feed and permeate formation potentials, 78-91% of NDMA precursors were removed by the RO membrane. These results suggest that the primary mechanism that controlled the rejection of precursors by the RO membrane was size exclusion. Other factors, such as the physicochemical properties of the precursors (i.e., hydrophilicity, hydrophobicity, charge, etc.), may also have an impact on the overall NDMA removal process.

Figure 2 shows that precursor removals from various sources occurred in the following order: WWTP-A > SW-A > SW-B > WWTP-B. Among the tested waters, municipal WWTP-A effluents had higher NDMA precursor removals than SW-A-B and WWTP-B effluents. This finding suggests that either relatively large precursors or particle-associated NDMA precursors were present in WWTP-A. (Mitch and Sedlak, 2004). The lower NDMA precursor removals observed in SW-A, SW-B, and WWTP-B can be attributed to the presence of small molecular size NDMA precursors in these sources. These findings imply that NDMA precursors derived from various sources and treatment facilities may differ in terms of molecular size (or possibly other properties), which affects the rejection efficiency of RO membranes.

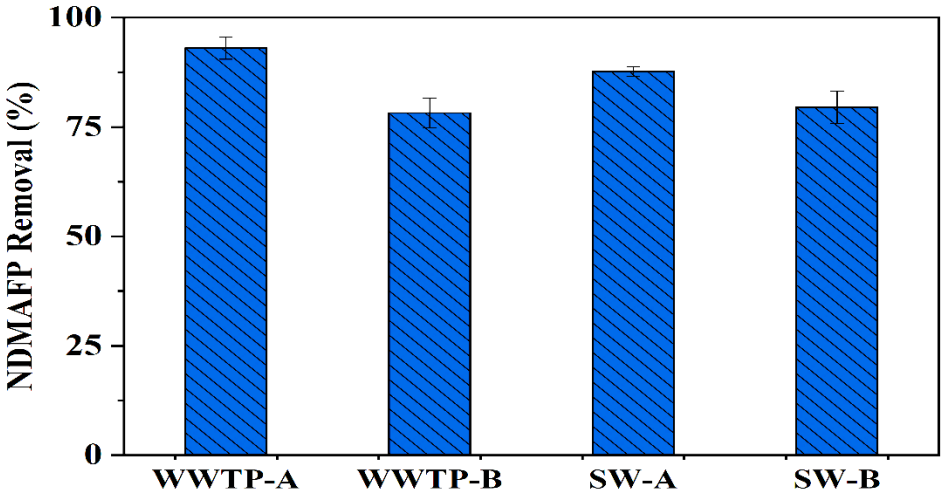

Figure 2. The removal efficiency of NDMA from RO membrane in different water sources

Furthermore, while it is preferable to measure the precursors directly rather than relying solely on FP tests, the structure of precursors is not well understood, limiting direct measurements of these precursors in different sources. However, bulk water parameters, such as DOC and TDN, can be used as surrogate parameters to predict DBPFP removals in different sources. Therefore, in this study, we correlated the removal of NDMAFP with DOC and TDN removals in these sources. Overall, the rejection of DOC and TDN by RO membrane in the studied source waters ranged from 87 to 95% and 79 to 93%, respectively (Figure 3). When the percent removal of NDMAFP was plotted versus the percent DOC and TDN removals (Figure S3), there was a good correlation between NDMAFP and DOC removals (r^2=0.60). However, the correlations between NDMAFP and DON removals (r^2=0.04) were significantly low.

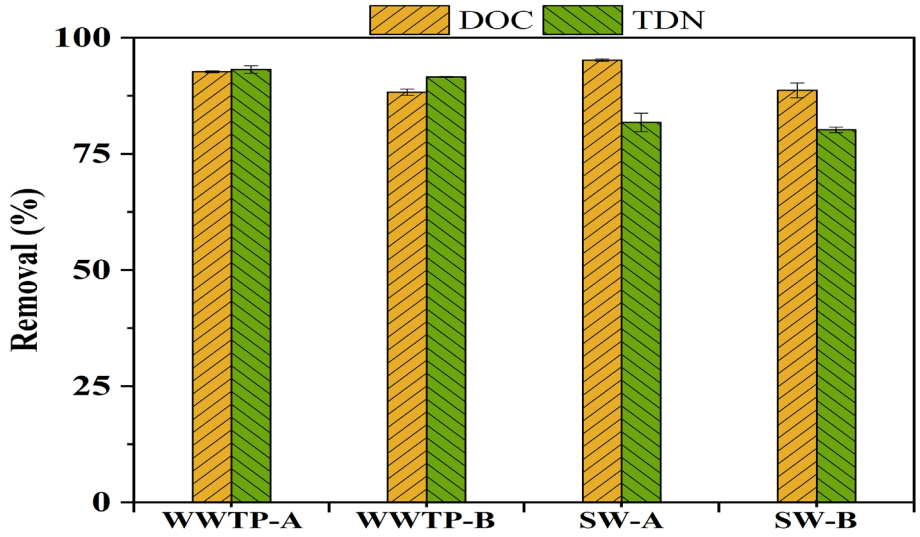

Figure 3. Percent removals of DOC and DON by RO membrane from different water sources

3.3. The control of HNM precursors from RO membrane

The removal efficiencies of HNMFP by CPA2 RO membrane from different water matrices are shown in Figure 4. When the feed and the permeate HNMFP concentrations were compared, HNMFP removal efficiencies by RO membrane ranged from 63 to 78%. As compared to NDMAFP removals, the removal of HNMFP by RO membrane was much lower than NDMAFPs. Lower efficiencies may be attributed to the smaller size of HNM precursors compared to NDMA precursors, resulting in lower rejection by the CPA2 RO membrane. On the other hand, the removal of HNM precursors by the CPA2 RO membrane may be also altered by the physicochemical characteristics of HNM precursors. According to Figure 4, precursor removals from different sources followed the order of SW-A > WWTP-B > WWTP-A >SW-B. Among all types of source waters, there was slightly higher HNM precursor removal observed for the SW-A source. This may be attributed to the presence of larger molecular weight HNM precursors in the SW-A source (Ersan *et al*., 2016).

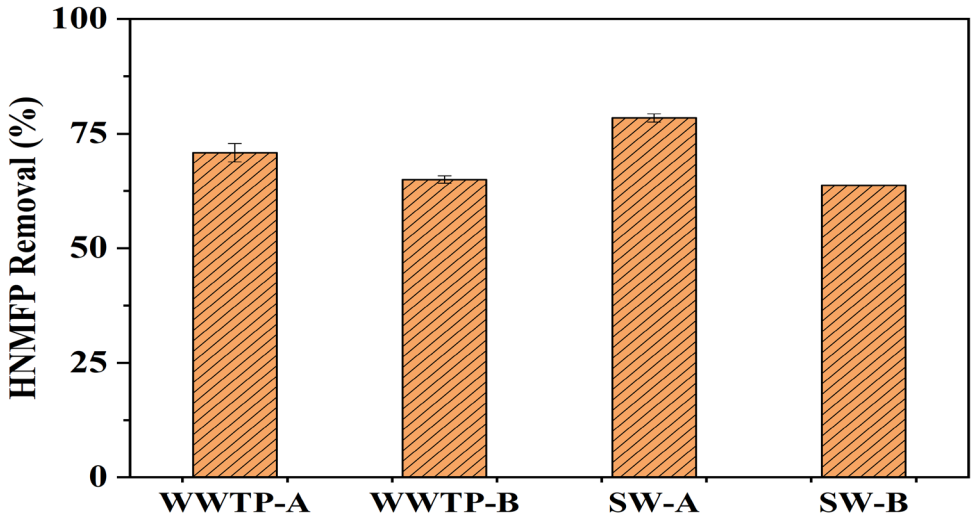

Figure 4. The removal efficiencies of HNM from RO membrane in different water sources

In addition, in Figure S4, the removal of HNMFP was plotted against DOC removals in all the sources. The results suggest that there was a good correlation between HNMFP and DOC removals (r^2= 0.89) for the tested water sources. On the other side, a weak correlation was obtained between HNMFP and TDN removals (r^2=0.02) (Figure S4). This may suggest that DOC can be used as a surrogate parameter to predict the removal of HNMFP from waters with similar water quality.

The control of THM precursors from RO membrane.

The removal of THMFP from different sources by CPA2 RO followed the order of SW-A > WWTP-A ≈ SW-B > WWTP-B, as shown in Figure 5. For all the tested water sources, the removal of THMFP ranged from 86 to 97%. Overall, the RO removal efficiencies for THM precursors were higher than NDMA and HNM precursors. The results indicate that THM precursors are relatively larger than NDMA and HNM precursors. Among the water sources, RO removal efficiency for THM precursor from SW-A was the highest, which may be due to existing of larger size precursor molecules in this source. Previous studies found that NF membranes removed 41-98% of THM precursors (Ángeles et al., 2008; Chellam, 2000; Ersan et al., 2016; Golea et al., 2016; Lin et al., 2006), which is comparable with RO membrane results in the present study. In the literature, generally, the rejection of THM precursors was much higher than NDMA and HNM precursors due to the larger molecular size/weight of THM precursors (such as natural organic matter) than NDMA precursors, which has been linked to small molecular weight compounds of anthropogenic origin (Ersan *et al*., 2016; Mitch & Sedlak, 2004).

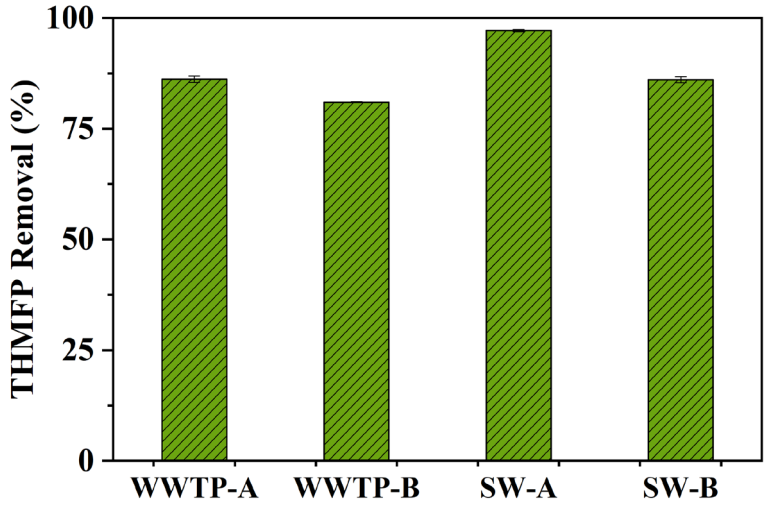

Figure 5. The removal efficiency of THM from RO membrane in different water sources

When the percent THMFP removal was plotted against the percent DOC and DON removals (Figure S5), there was a strong correlation (r^2=0.70), implying that the percent DOC removals can be used as a surrogate parameter for THM precursor removals. On the other hand, a weaker correlation (r^2=0.32) was observed between THM precursor and TDN removals.

Conclusions

In this study, we investigated the leaching of NDMA precursors from RO membranes as well as the removal of NDMA, HNM, and THM precursors from various types of water/background matrices. For the first time, NDMA precursor leach from RO membranes was reported. The leaching potentials from both CPA2 and under-sink RO membranes were up to 370 ng/L. These findings highlighted the importance of flushing/cleaning RO membranes before use in both scientific research and drinking water production to eliminate bias in RO unit performance evaluations. As a result, the CPA2 RO membrane was tested in this study after being cleaned with a low dose of chlorine. To the best of our knowledge, this is the first study in the literature to report the true efficiency of RO membrane at the initial operation for removing NDMA precursors from the surface and treated wastewater backgrounds. In addition to NDMAFP removals, the removal of other DBPs by RO membrane, HNM, and THM, was also investigated. Overall, the removal efficiencies for NDMA, HNM, and THM precursors in the studied sources ranged from 78 to 91%, 63 to 78%, and 81 to 97%, respectively. These results showed that among the tested background sources, THM precursor removals by CPA2 RO membrane were always higher than those of NDMA and HNM precursors. The background water characteristics of the water sources (SW vs WWTP effluent) did not have a considerable impact (within 10% when % removals in WWTP compared with SW) on the removal of NDMA, HNMs, and THM precursors. While DBPFP removals correlated well with DOC removals (r^2=0.6-0.89), there was a weak correlation with TDN (r^2=0.02-0.32) in this study. This could imply that the bulk parameters, such as DOC, can be used as surrogate parameter for predicting the removal of DBPFP by RO membranes.

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Review Paper

Impact of Financial Support Mechanisms on Renewable Energy Deployment: Turkey as a Case Study

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Abstract: In this study, the link between state financial support mechanisms for renewable energy sources (RES) and renewable energy deployment success in Turkey is inquired. The study particularly focused on the electricity sector. Deployment success for renewable energies is defined using several indicators: number of new participants to the RES financial support scheme, their installed capacity, their electricity generation, the amount of RES payments in the given year, the increase in overall renewable energy capacity, and the increase in the share of renewable energies within overall electricity generation of the country. The study starts by reviewing state regulations and financial incentives that promote renewable energy investments in Turkey. The effectiveness of this policy is tested by using yearly renewable energy statistics for the period 2014-2020. Methodologically, correlation analysis is applied to test the research hypotheses. The research results showed significantly positive correlation coefficients between the tested variables within the study period, and therefore, validated the positive impact of the use of state financial incentives on the promotion of renewable energy capacity, and thereby, on the increase in the share of renewable energies in the overall electricity mix in Turkey.

Keywords: *Renewable energy, financial incentives, investments, feed-in tariff, Turkey*

Introduction

In the post-Covid 19 pandemic period, in the global scale, states and societies increasingly faced with energy supply insecurity and price volatility problems. The conventional energy sources also bring about environmental pollution and warming problems. To prevent these negative effects on environment, economy, and society, the governments focus on the ways of reducing fossil fuel use and increasing the share of renewable and environmentally friendly energy sources. The renewable energy sources have many advantages over the conventional energy sources. They have less environmental impact, they are infinite and flexible, and they have decentralization possibility. They also contribute to other sectoral goals such as reducing greenhouse gas emissions, developing the related manufacturing sector, and creating new jobs for the society. The overall positive impacts of the renewable energies would be a significant contribution to the sustainable development goals of the countries. There are many studies in the academic literature that confirm these positive impacts. For instance, Dincer provided that sustainable development requires a sustainable supply of energy resources, and in this context, renewable energies are sustainably available at reasonable cost (Dincer, 2000). To encounter the negative consequences of the fossil fuel use and of the dependence on energy imports, many states focus on policies to increase the share of renewables in their energy generation and benefit from these resources in a secure, economic, and sustainable way in the longer term.

However, many developing countries encounter problems of finding efficient and sustainable ways of abandoning fossil fuels and investing in renewable energies. Especially for those countries that are traditionally dependent on conventional energy sources, energy transition is a complicated process implying major changes in the existing energy structures. Turkey is one of such examples with its dependence on imported fossil-fuel based energy sources. A quick analysis of national statistical data shows that conventional energy sources dominate the energy mix of Turkey in electricity generation. IEA database shows that fossil fuels dominate the total primary energy supply (TPES) in Turkey as their share has been stable at around 90% since 2000 (IEA, 2021). In 2019, the share of fossil fuels in TPES was 83%, which ranked the ninth-highest ratio among IEA member countries. In terms of electricity generation in 2019, coal constituted the biggest share (34.5%), followed by hydro energy (25.4%), natural gas (22.5%), and wind energy (8.03%). Even though Turkey has a growing production capacity

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in RES, the choice of electricity production remains heavily on the side of the conventional energy sources due to their being considered as a reliable power supply. This situation not only limits the country's options in economic development and foreign policy, but also exacerbates its environmental problems.

Turkey recognized the need to promote the production and use of renewable energies, and thereby, to change its energy mix. The Eleventh Development Plan of Turkey (2019-2023) set forth national energy targets with a target of 38.8% share of renewable energy sources in electricity production in 2023. It is obvious that this political target can be achieved through effective government policies that would provide supportive legal and financial framework for the new renewable energy investments. In many developing countries, a big obstacle to renewable energy deployment is its high upfront capital costs because the renewable energy projects require high initial investment before the start of production and this investment cost is generally borne by investors. For this reason, many states try to promote the deployment of renewable energies with enabling policy frameworks including different financial support measures.

Therefore, this article inquires the implementation of renewable energy deployment in Turkey through enabling financial measures. The focus is on the relationship between state's various financial incentives and the increase in renewable energy investments, and the resulting increase in the share of renewable energies in the overall energy generation. Most of the existing literature on the subject have affirmed the triggering effect of state financing mechanisms on the new renewable energy investments. In the same vein, this article inquires the role and efficiency of state financial incentives for renewable energies in Turkey on deployment success.

In this article, state's financial incentives are defined as allocation of financial resources in the energy sector with an aim to guide the capital flow into renewable energy investments. In the global context, the impacts of financial incentives on renewable energy investment efficiency have been empirically analyzed by several academic studies. As an example, scholars studied the intermediary effect of bank loans, short-term loans, and long-term loans in China and found that short-term loans have few intermediate effects on investment efficiency, while long-term loans have no intermediary effect (He et.al., 2019). These authors suggested that the government should construct the green financial system through appropriate policies and regulations (He et.al., 2019).

There are several studies on the impact of financial mechanisms for an effective utilization of renewable energy sources in Turkey. In 2017, scholars analyzed the renewable energy utilization in Turkey and concluded that although electricity was mainly generated by using fossil energy resources, renewable energies showed a significant increase as well (Ugurlu and Gokcol, 2017). The authors attributed this increase to the renewable energy law in 2005 which regulated the sector and provided financial incentives for the new renewable energy investments. To achieve full utilization of the renewable energy potential of the country, they suggested to remove the barriers to new investments via laws, regulations, and financial incentives (Ugurlu and Gokcol, 2017).

A number of studies focused on the role of enabling government policies and financial support mechanisms in triggering the deployment of renewable energies (Haas 2011). In this context, several scholars underlined the need for government financial incentives for the deployment of renewable energies in Turkey. This need mainly arises from the fact that renewable energy technologies have high initial capital costs. Particularly, this holds true for the solar PV electricity, hydropower, and wind energy. Due to high investment costs, poor people or communities may find it difficult to afford investments without government's financial support (Kaygusuz, 2011). For this reason, the high initial costs of investing in renewable energies should be overcome by state mechanisms via financial, technical, and organizational intermediation (Kaygusuz, 2011).

Similarly, other scholars analyzed government policies in Turkey for the promotion of renewable energy investments and argued that the introduction of the Renewable Energy Law of May 2005 boosted the new renewable energy investments via the introduction of tariff support for renewable electricity (Benli, 2013). The amendments of this law in May 2007 and in 2010 increased the level of the support, however, the author considered this support low in comparison to other European countries (Benli, 2013).

In the literature, energy policy legislative framework and financial incentives in Turkey were also analyzed to find out the institutional barriers for the development of renewable energies. This research depicted these barriers as high taxes, inadequate market conditions and private sector participation, and risks and costs associated with the renewable energy investments (Simsek and Simsek, 2013). The authors concluded that implementation of a successful renewable energy policy should be the priority

of Turkey's energy policy, and it should be facilitated by an intense collaboration between government agencies, the private sector, and the consumers via appropriate financial incentive mechanisms (Simsek & Simsek, 2013).

Researchers also showed a correlation between the development level of financial markets and new renewable energy investments. It was found that the renewable energy sectors grow disproportionately faster in countries with developed financial markets. Since renewable energies are highly dependent on external financing, they demonstrate a higher deployment level in more developed financial markets (Kim and Park, 2016).

The financing methods of renewable energies were also analyzed in developing countries to find out the ultimate method of achieving sustainable development. The researchers have shown that in Africa, governments promote renewable energies to foster economic development and they implement various financing mechanisms to achieve anticipated level of deployment of renewable energies. These governments mostly focus on end-user finance for individual households, business finance for small and medium enterprises (SMEs), and small-scale project finance for energy communities (Oji et.al., 2016). However, in Africa, the problem associated with the support for large projects is that although they provide an increase in electricity production, they do not provide an increased energy access for the whole society. Therefore, the authors suggested that it is better for the governments to support individual households and SMEs in terms of new renewable energy investments, if they seek to achieve energy transition and sustainable development (Oji *et.al*., 2016).

Several policy experts and scholars share the argument that feed-in tariffs are the most convenient and efficient financial support mechanism to reach wider sections of society. In a comparative analysis among several countries, researchers analyzed the impact of feed-in tariffs (FIT) for the deployment of renewable energies in China, India, and South Africa, particularly for the solar PV sector (Becker and Fischer, 2013). The authors argued that FITs provide investment security by increasing investor's ability to plan the future of the business, and by this way, accelerate deployment of the targeted renewable energies, whereas low tariffs and competitive auctions limit the deployment of solar PV projects (Becker and Fischer, 2013).

As a conclusion, government financial mechanisms are inevitable for the increase in renewable energy investments in all countries, although the mix of financial measures might vary depending on different political, economic, and social contexts.

Policy Analysis

In this study, it is argued that the energy transition process begins with supportive governmental policies such as creating a sound regulatory framework and employing financial mechanisms. These policies are implemented by many countries with an aim to create enabling conditions for new renewable energy investments and promote the use of renewable energies by individuals, energy communities, and the private sector. The outcome of such policies reduces business risks and increases the confidence of investors and markets. Turkey combines different forms of financial support measures for the renewable energy investments. This section provides an overview of these financial support mechanisms. This analysis serves as the validation of a determined governmental policy for the promotion and the use of renewable energies.

In Turkey, Renewable Energy Support Mechanism (YEKDEM) regulates the feed-in tariffs (FITs) for renewable energy facilities since 2011. The terms and conditions to receive FITs are firstly specified in 2005 with Law No:5346. An amendment to this law was provided in 2011 with Law No:6094 on the utilization of renewable energy sources in electricity generation. This law regulated the incentives to renewable energy sources according to source type and locality rate and determined the details of the Renewable Energy Resources Support Mechanism. According to this law, the legal entities who wish to apply for support mechanism must hold a valid license for renewable electricity generation and obtain a RES certificate. For this purpose, they must apply to the Energy Market Regulatory Authority (EPDK). The FIT support is given in Turkey for the first ten years of operation starting from the commissioning date of the facility. Law No.5346 provided a fixed FIT support for all renewable energies, but later, Law No.6094 differentiated the FIT support for each renewable energy sector (See Table 1).

Law No. 5346 also provided local content support for domestically manufactured equipment used in the renewable energy generation facility. This type of support is an extra bonus that is added to the FIT price. The basic requirement is that at least 55% local content ratio must be met to receive the incentive. The law stated that the amount of this support would be between 0.4 USD and 3,5 USD per kWh depending on the types of local components and machinery (See Table 1). This support is provided

for five years from the starting date of operation of the renewable energy facility.

There is another financial support mechanism, that is termed as land usage fee incentive. This mechanism was designated for the land that is privately owned by the Treasury or placed under state disposal to be utilized for renewable energy generation. The renewable energy projects that are granted this incentive are entitled to a discount of 85% for permission, lease, easement rights, and servitude right fees for the first ten years of operation.

Renewable energy facilities in Turkey can also benefit from a reduction in license and system usage fees. The system usage fees are reduced by 50% for the renewable electricity generation facilities for the first five years of their operation, while the annual license fees are annulled for the first eight years of operation.

Pursuant to the Council of Ministers' Decision No. 2012/3305 on the "State Aids for Investments" the renewable energy generation facilities can benefit from the General, Regional, and Strategic Investment Incentive Schemes. These schemes include different incentives, such as VAT exemption, customs duties exemption, corporate tax reduction, social security premium support, and interest rate support. These support schemes have been successful in driving sizeable new investments in renewables within the period of their implementation.

Table 1. Feed-in tariff and local content support provided for renewable energies in Turkey

Renewable energy sector	Feed-in-tariff (US Dollar cent/kWh	Local content support (US Dollar/kWh)
Hydro energy	7.3	1.0 – 1.3
Wind energy	7.3	0.6 – 1.3
Solar PV energy	13.3	0.5 – 3.5
Geothermal energy	10.5	0.7 – 1.3
Biomass	13.3	0.4 – 2.0

The literature on the analysis of the deployment of renewable energies in various countries affirmed that effective design as well as transparent and extensive use of state financial support schemes result in a successful energy transition. Upon a closer investigation, the brief analysis here demonstrated that Turkey carefully designed and adjusted financial support mechanisms to ensure investor interest in renewable energy projects and provided a positive climate for new investments. These financial support mechanisms are important to attract new actors to the market and stimulate new investments in renewable energies. Only through implementing such measures states can acquire a growth in renewable energy installation and generation.

Materials and Methods

Methodology

The aim of this analysis is to find out the impact of the financial support mechanisms on the renewable energy deployment success in Turkey in the examined time period (2014 – 2020). The selected time series starts with 2014 due to data availability because statistical data regarding YEKDEM mechanism has been provided constantly since 2014.

Regarding the renewable energy investments, particular attention is given to six variables: number of new participants to the RES support scheme, their installed capacity, their electricity generation, the amount of RES payments to these participants, overall renewable electricity capacity in the country, and the share of renewable energies in the country's electricity mix. These aspects are called together as "deployment success". Detailed descriptions of all variables are provided in Table 3. The statistical data for these variables are acquired from the annual reports of Energy Market Regulatory Authority (EPDK) and Energy Markets Operation Company (EPİAŞ) of Turkey. This data is tested, when applicable, using the annual statistical reports of the International Energy Agency (IEA).

A correlation analysis is applied for these hypotheses. The statistical expectation is that if the correlation coefficient is closer to +1, it indicates a positive (+1) correlation between the variables. If the correlation coefficient is closer to -1, it indicates a negative (-1) correlation between the variables. Positive correlation means that when the values of one variable is increasing, the values of other variable increase as well. Negative correlation means that when the values of one variable is decreasing, the values of other variable decrease as well. If the correlation coefficient is closer to 0, it indicates no or weak correlation. The results of empirical analysis are given in the next section.

Table 2. Description of variables

Symbol	Definition	Unit
PART	New participants to YEKDEM scheme in a given year	Number
INST	New installed renewable electricity power in the context of YEKDEM in a given year	MW
GEN	Generation of renewable electricity power in the context of YEKDEM in a given year	MWh
PAYM	Annual YEKDEM payments each year	TL
YEAR	Year	Time
CAP	Overall renewable energy capacity in the country	MW
SHARE	Share of renewable energies to the overall energy capacity in the country	Percent

The hypotheses in this study are:

H1 = New participants in RES support scheme (PART) positively impacted on the increase in the installed capacity in renewable electricity (INST)

H2 = New participants in RES support scheme (PART) positively impacted on the increase in renewable electricity generation (GEN)

H3 = New renewable electricity installations (INST) in the context of RES support scheme positively impacted on the increase in overall renewable electricity capacity (CAP)

H4 = RES incentives (PAYM) positively impacted on the overall renewable energy capacity (CAP)

H5 = New participants in RES support scheme (PART) positively impacted on an increase in the share of renewable energy capacity in the country (SHARE)

Empirical Analysis and Discussion

A data set from 2014 to 2020 is used to examine the relationship between financial incentives and renewable energy growth (See Table 3). The preliminary argument is that the growth in the share of renewable energies in a country is highly reliant on supportive government policy; this argument is tested by using a correlation analysis. There are several ways to measure renewable energy's development in the literature, such as through installed capacity and electricity generation. The capacity increase is used to examine the links between available financial incentives and the actors' decision to invest in renewable energy installations. To the extent that the state financial support is an effective policy for promoting renewable energy growth in a country, annual financial payments to renewable energy investments is used to capture the link between the policy dependence and growth in renewable energy deployment.

Table 3. Data set for the variables

YEAR	PART	INST	GEN	PAYM*	CAP	SHARE
2014	93	1798.0	5874.769	1207044	27945.0	40.2
2015	234	5423.6	17944.514	4045866	31520.8	43.1
2016	556	15082.7	45830.502	11015263	34449.6	43.9
2017	647	17399.9	50496.769	13869442	38751.1	45.5
2018	708	19266.3	62505.431	21945656	42264.0	47.7
2019	777	20921.5	76668.087	37996703	44395.5	48.6
2020	821	21146.1	73482.227	46323195	49202.2	51.3

* Data for 2014, 2015, 2016 are taken from EPİAŞ online information platform (Exist). Data for 2017, 2018, 2019, 2020 are taken from EPDK annual reports.

Table 4. Hypothesis testing: correlation coefficient between the selected variables

Hypothesis	Variable 1	Variable 2	Correlation coefficient
1	PART	INST	0.998286
2	PART	GEN	0.98797
3	INST	CAP	0.921618
4	PAYM	CAP	0.959867
5	PART	SHARE	0.924408

** significant at alpha = 0.05

As can be seen from Table 4:

H1: The impact of new participants in RES support scheme on the installed capacity in renewable electricity is significant (0.998286), thus the correlation between these variables is tenable.

H2: The direct effect of new participants in RES support scheme on the renewable electricity generation is significant, and the coefficient is 0.98797, which shows that increasing number of participants in the RES support scheme increases the renewable electricity generation.

H3: The effect of new renewable electricity installations in the context of RES support scheme on overall

renewable electricity capacity is significant (0.921618); this shows that a contributing effect of supported renewable energy facilities on the overall energy capacity exists.

H4: The impact of RES incentives on the overall renewable energy capacity is significant (0.959867), thus the correlation between these variables is tenable.

H5: The direct effect of new participants in RES support scheme on the share of renewable energy capacity in the country is significant, and the coefficient is 0.924408, which shows that increasing number of participants in the RES support scheme increases the share of renewable energy in the country.

The results show that within the study period (2014-2020), state financial support for the renewable energies increased the renewable energy capacity and generation in Turkey. In practice, this capacity and production increase within the RES schema improved the share of renewable energies in the overall energy mix and brought a positive development on the way of energy transition. To maintain this positive trend in renewable energy deployment, government, financial institutions, and private enterprises must continue coordinating with each other in this policy framework.

Conclusion

In this article, the use of financial incentives and the deployment success in renewable energies in Turkey is analyzed, and a positive correlation is found between the financial incentives and the renewable energy capacity increase.

The preliminary assumption of this research is that effective governmental policies for the promotion of renewable energies positively impact on new renewable energy investments, and thereby, they trigger energy transition from conventional energy sources to renewable energy sources. The conclusion of data analysis showed that in Turkey, supportive financial incentives for renewable energies provided an effective method to maintain new investments and contributed to the increase in the share of renewable energies in the overall energy capacity. Therefore, supportive financial incentives provided a useful mechanism for the achievement of Turkey's renewable energy targets.

There is still a high potential for renewable energy resources in Turkey, so, an economic growth opportunity can be triggered by greater investments in the renewable energy sectors. These investments are expected to provide positive socio-economic consequences as well. Although dominant policy objective for the promotion of the renewable energies is mainly the reduction of import dependency on oil and gas, a sustainable economic growth opportunity is also significant for Turkey. The achievement of both goals of energy transition and sustainable economic growth would be in line with the EU's policy goals and objectives. These achievements would be a decisive move for this EU candidate country to associate itself more closely with the EU member states.

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Research Paper

An Industry Perception and Assessment of Oil and Gas Pipeline Third-Party Interference

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Abstract: The world population is growing at an alarming rate and human needs for technology and easy lifestyles drive dependency on oil energy into excessive demand, resulting in more pipelines, pipelines that are often subjected to various form of abuse. The aim of this research is to investigate the perception of oil and gas pipeline third-party interference from government agencies, professional bodies, academia, pipeline service providers and private companies' representatives. This paper attempts to identify types of third-party interference; the severity of interference; various preventive and detection tools; and examination of how the pipeline industry manage interference. The study population consisted of members of the pipeline industry, including health and safety engineers, pipeline engineers, pipeline service providers, and pipeline project engineers. The methodology for this study was formed by qualitative data, via open-ended questionnaire. The study shows that application of proper standard and procedures; greater awareness campaign to all stakeholders; and more Research and Development are the best procedures in preventing pipeline third-party interference. In organisational procedures to preventing third-party interference during and after pipeline installation, surveillance frequency as determined from risk assessment is the most effective. The study revealed that right-of-way encroachment is the most prevalent activities organisations presently monitor to avoid third-party pipeline damage. The result of the study also showed that communications with all stakeholders is more effective in preventing intentional pipeline interference, and government's social responsibility to communities as the major factor influencing occurrence of intentional pipeline damage; and land use and human activities as the most ranked factor for consideration in mitigating intentional third-party damage. The study also outlined what governments and the industry can and should do to help better manage risk and effectively reduce the risk of pipeline third-party damage.

Keywords: *Content Analysis; Country comparison; Pipeline management*

Introduction

The world population is growing at an alarming rate and human needs for technology and easy lifestyles drive dependency on oil energy into excessive demand. The global energy demand will rise by as much as 54% over the next two decades and oil consumption makes up 40% of this energy demand (EIA, 2007). This increased demand for more oil encourages exploration and production of more petroleum resources and simply means more pipelines (Jing et al., 2013; Yao et al., 2015). This energy infrastructures and maritime transportations (*e.g.* pipelines, truck tankers, refineries and oil and gas terminals) are potential target of terrorists and saboteurs. Third-party interference is a threat in the pipeline industry, and with limited attention within research literature (Hayes & McDermott, 2018; Kraidi, et al., 2021). For example, plenty of studies on pipeline failures have addressed various types of failures such as corrosion and mechanical failures. However, few studies have addressed theoretical and methodological issues of third-party damage, especially intentional pipeline damage (sabotage, theft, and terrorism threats); and many studies and reports have identified this potential (e.g. Nwankwo and Ezeob, 2008; Parfomak, 2008; McKinley, 2007; Houreld, 2007; GAO, 2005; Yao, Xu, Zeng, & Jiang, 2015; Popescu & Gabor, 2021). A considerable amount of literature published on third-party interference suggested it is the leading causes of pipeline failures (CONCAWE, 2007; La & Li, 2005; Parfomak, 2008; Sljivic, 1995; Jager et al., 2002; Re & Colombo, 2004; Palmer-Jones et al., 2004;

Jaffrey et al., 2002; Daco et al., 2000). Cross-country analysis recorded by relevant bodies, for example, UKOPA's Pipeline Fault Database (PFD) covering pipeline loss incidents from 1962, also showed third-party interference as the largest single cause of damage to pipelines in the UK (UKOPA, 2002; UKOPA, 2008).

Technological advancement has made inevitable many companies digging millions of utilities holes across the world (Hayes & McDermott, 2018; Kraidi, et al., 2021). Hence, third party interference becomes inevitable, and the consequences can be devastating for people and the environment. Papadakis (2005) for example, reviewed tragedies that involved twenty-four people who died with several causalities, and others hospitalised with severe burns when a Major Accident Hazard Pipeline (MAHP) near Ghislenghien in Belgium operated at a pressure of 70 bars failed due to third-party activities. Similarly, a third-party damage tragedy occurred in California in 2004 resulting in the death of five utility workers when an excavator digging a ruptured a high-pressure petroleum pipeline. CONCAWE's (1994) detail of how over 500 people died in 1998 when attempting to lift oil product from a pipeline under its jurisdiction failed. Besides this, it also recorded how in 1993 how 51 people were burnt to death when a gas pipeline failed in Venezuela. In the United States, in1994 a 36-inch pipeline in New Jersey failed, resulting in the injuring of more than 50 people (US Department of Transportation, 1995). Parfomak (2008) also reiterated how *"a 1999 gasoline pipeline explosion in Bellingham, Washington, killed two children and an 18-year-old man, and caused $45 million in damage to a city water plant and other property. In 2000, a natural gas pipeline explosion near Carlsbad, New Mexico, killed 12 campers, including four children".*

The knowledge and understanding of third-party interference is important in pipeline management to overcome the problem of third-party pipeline failures (TRB, 2004; Jaffrey et al., 2002; Gallacher, 1996). Third-party interferences are sometimes due to political instability and socio-economic depravity, where proliferation of arms and ammunitions, militia groups, hostage taking and kidnapping go with this act. For example, rebels have bombed the Caño Limón oil pipeline in Colombia over 600 times since 1995 and similarly detonated several bombs along Mexican natural gas pipelines in July 2007. The U.S President's Commission on Critical Infrastructure Protection (1997) and Parfomak (2008) reports how London police foiled a plot by the Irish Republican Army to bomb gas pipelines and other utilities across the city. In June 2007, the U.S. Department of Justice arrested members of a terrorist group planning to attack jet fuel pipelines at the John F. Kennedy (JFK) International Airport in New York (U.S. Dept. of Justice, 2007).

In Nigeria, militants have repeatedly attacked pipelines and related facilities involving great loss of life and property. Interestingly, the Nigerian National Petroleum Corporation (NNPC) documented over 13,000 cases of vandalism between 2000 and 2008 (Punch, 2008). In 2000 about 250 villagers burned to death in Jesse, Delta State, while scooping fuel from vandalised pipeline. Similarly, in 2003, a foiled attempt of oil theft led to exploding pipelines in a village near *Umuahia*, Abia State; about 125 people died. Another example is the September 2004 third-party interference, where dozens of people died in a pipeline explosion in Lagos after thieves tried to siphon oil product from a pipeline. In May 2006, a pipeline explosion at *Inagbe* Beach on the outskirts of Lagos killed more than 250 people and in December, another 269 recovered burned bodies from the scene of pipeline fire in *Abule Egba*, a suburb of Lagos because of pipeline third-party interference. Recently, Nwankwo and Ezeob (2008) recount how Nigeria has experienced increased pipeline vandalism including a simultaneous bombing of three oil pipelines in May 2007. In addition, on December 26, 2007, over 45 people burned to death in Lagos when fuel they were siphoning from a buried pipeline caught fire. In May 2008, at least 100 people died, and hundreds injured when fuel from a pipeline ruptured by an earthmover explodes in a village near Lagos. Overall, attacks made on the pipeline most time cripples oil production eventually having a multiplier effect on the international oil price. For example, the total destruction of oil pipelines in *Isaka* and *Abonema*, both in Rivers State barely 72 hours after crippling the *Adamakri* crude flow line belonging to Shell Petroleum Development Company (SPDC) affected the price of oil barrel in 2008 (Nwankwo & Ezeobi, 2008). The objective of the study is to gather information from various stakeholders in the oil and gas industry to gain a better understanding of the problem of third-party interference on pipelines. The study aims to assess the perception of the industry towards third-party interference and to evaluate the measures currently in place to prevent, detect, and respond to such incidents.

Materials and Method

Survey Procedure and Sampling

Questionnaires create many nonrespondents, and therefore getting the right people to participate is important. There is need in survey to select the right sample (group) from the population to represent the entire population. Samples are determined using either probability or nonprobability sampling techniques. Nonprobability sampling is nonrandom, and includes systematic sampling, convenience sampling, quota sampling, and snowball sampling (Thomas, 2004). This questionnaire survey utilised the quota recruited nonprobability method of sampling. This method is similar to the stratified probability (random) sampling where identified subgroups (*e.g*. pipeline industry of the oil and gas sector) are sample frame. The recruited sample identifies respondents enlisted from the subgroups via e-mail and are provided with the URL of a web-based questionnaire. The data collection instrument consisted of a self-administered web-based survey to assess respondents' demographic characteristics, opinions, management experience, and perception on pipeline third-party interference from 229 respondents. Thirty-eight (38) countries participated in the study, and many of these responses included opinion and views of representative from DOT and PHMSA, TransCanada PipeLines Limited, SHELL, Subsea7, Exxonmobil, ConocoPhillips, British Pipeline Agency Ltd, and many others.

Coding Open-Ended Questions

Qualitative data, like open-ended questions are nonnumerical records, commentary, description, feedbacks that produce an immediate understanding with further processing. Open-ended questions are unanswerable directly with, for example, a simple "yes" or "no", detail specific comments or answers are required. Coding is therefore the process of converting such qualitative data into numerical records, referred to as multiple response analysis (Kent, 2001). In the study, maximum number of responses to a particular open-ended question was determined from the collated questionnaire after the survey. SPSS statistical software for analysis (version 15) was used for data management and analysis, where responses are defined as variables.

Instrument

The result of this study was part of a larger study on third-party interference using questionnaire survey, and we report here only the open-ended questions about third-party interference. The following were the question's items:

a) Respondents' general opinion about preventing and monitoring pipeline third-party interference.
b) Preferred methods for direct physical protection of pipeline networks
c) Preferences of pipeline damage prevention measures that will mitigate damage cause by third-party activity during and after installation.
d) Suggestion of method most effective for pipeline damage prevention
e) Respondents' opinion about factors influences the occurrence of intentional pipeline damage.

In addition to the above, respondents were asked to select three factors that are most important that could be used to weigh the potential for third-party interference and rank them from 1 to 3 (with 1 as the most important). These items were:

(1) Land use and human activities
(2) Socio-economic conditions of population living near a pipeline
(3) Accessibility to pipeline network (proximity of roads, rivers, streams)
(4) Socio-political factors (*e.g.* literacy rate, political stability, and violence
(5) Depth of pipeline (exposed pipeline provide criminal opportunities)
(6) Other factor in respondents' opinion not mentioned above.

The study is interested in knowing what third-party activities organisations presently monitor, and the items(activities) were: (a) Direct pipeline vandalism; (b) Theft of product and pipeline facilities; (c) Sabotage to pipeline network; (d) Guerrilla attacks; (e) Likelihood of terrorism against pipeline; (f) Intrusion to aboveground facilities; (g) Right-of-way encroachment; and (h) Cyber-attack/potential hijack of network facilities (Muhlbauer, 2004).

Multiple Response Analysis of Open-ended Questions

Multiple response analysis is one of the most used methods of analysing open-ended questions in a questionnaire survey. The goal of using open-ended question in the research is to identify salient theme for analysis by eliciting understanding of the subject from respondents. In addition to closed question in a survey, open-ended questions give respondents the liberty to express replies, comments, and observation from their personal experience. Open-ended questions are qualitative data, and are source of rich description and diagnosable explanations in a context that could generate a research theme (Kent, 2001). The study analysed the patterns of the response to the open-ended questions and frequency from respondents' unique experiences that are organisation specific. The appropriateness of open-ended questions for this research is because of the following (Coakes, 2005; Kent, 2001):

a) The question survey is international, and third-party interference are country specific, hence it was considered inappropriate to *close* some question by specifying only eligible options.
b) Open-ended questions are more engaging and avoid the likelihood of pre-judgement and biasness that might result when responses in a survey is suggested to respondents.
c) An open-ended question captures all view and perception that have not been consider as part of the closed questions of a survey questionnaire.

Results

This study analysed two hundred and twenty-nine (229) responses from 38 countries and was geographically balanced: 50 responses from Africa, 24 from Asia Pacific region, 92 from Europe and 63 from America region. Most respondents (51%) are from the private companies (pipeline consultants and contractors), 17% from government agencies, 8% from the academia, and 4% from professional bodies (Figure 1). Thirty-nine percent (39%) of the respondents are pipeline engineer and 25% are pipeline service providers, also, approximately quarter (25%) of those surveyed are pipeline service providers (Figure 2).

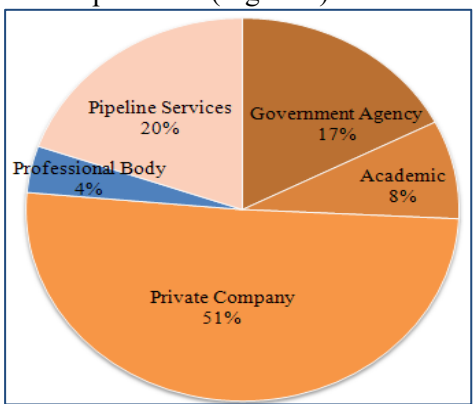

Figure 1. Organisation of Respondents

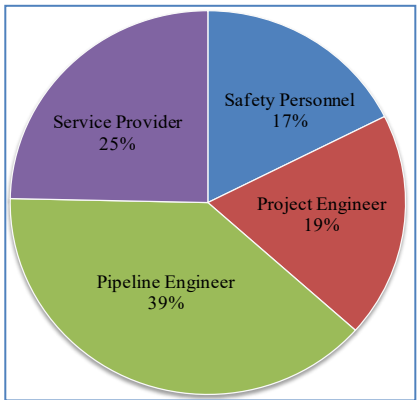

Figure 2. Occupation of Respondents

Preventing and monitoring pipeline third-party interference

Respondents' views about method of preventing and monitoring pipeline third-party interference showed four numbers of maximum responses and twenty possible methods of preventing third-party interference (TPI) identified. Using SPSS, frequency analysis of the multiple responses of respondents' view was examined for distribution. The overall response of the open-ended question showed that 45% of respondents expressed one or more views about preventing third-party interference (Table I).

The frequency table of the multiple responses set indicates that (1) a*pplication of proper standard and procedures* (13.80%); (2) *greater awareness campaign to all stakeholders* (12.20%); and (3) *more Research and Development* (10.60%) are the most frequently referenced view of respondents. In an analysis by location undertaken (Table II), respondents from Africa frequently indicated *use of modern technology* and *evaluation of social and environmental impact*. Respondents from Europe mostly indicated *greater awareness campaign to all stakeholders,* and *application of proper standard and procedures* was frequently indicated by respondents from North America. Similarly, in a cross-tabulation analysis by organisation, respondents from government agencies frequently indicated a*pplication of proper standard and procedures,* while respondents from the professional bodies

frequently indicated *more Research and Development.* One participant referred to how more research in third-party interference is necessary: *"In a recent report that was issued by the EU Commission on safety of pipeline transportation systems, the main findings included: Third part damage is the main cause of pipeline incidents and therefore should receive the main focus and the availability of an effective Pipeline Integrity Management system is one of the key elements in controlling the risks".*

Table 1. Frequency table of the multiple responses to preventing and monitoring TPI

Category label from respondents' view	*Responses*		*Percent of Cases*
	N	Percent	
Impact alert system	1	0.50%	1.00%
Greater awareness campaign to stakeholders	23	12.20%	22.30%
Use new Modern technology, e.g. Optical fibre	16	8.50%	15.50%
Enforcement of strict safety requirements	16	8.50%	15.50%
Improve rapid response capability	5	2.60%	4.90%
Address motivations of causes	6	3.20%	5.80%
Accurate collation of pipeline database	5	2.60%	4.90%
Install fence along ROW	1	0.50%	1.00%
Better land use planning guidelines	7	3.70%	6.80%
More Research and Development	20	10.60%	19.40%
Intensive surveillance on Hotspots	9	4.80%	8.70%
Evaluate Social and Environmental Impact	8	4.20%	7.80%
Statutory Punishment to offenders	9	4.80%	8.70%
Increase burial depth	2	1.10%	1.90%
Remote monitoring	8	4.20%	7.80%
Application of proper standard and procedures	26	13.80%	25.20%
Prevent all activities near Pipelines	4	2.10%	3.90%
One-Call Systems	8	4.20%	7.80%
Engage community cooperation	9	4.80%	8.70%
Education on consequences of pipeline failure	6	3.20%	5.80%
Total	**189**	**100.00%**	**183.50%**

Table 2. Open-ended analysis by respondents' location on to preventing and monitoring TPI

		Geographical Location of Respondent						
		Africa	Asia	Europe	North America	South America	Oceania	Total
Impact alert system	Count	1	0	0	0	0	0	1
Greater awareness campaign to	Count	4	1	10	7	1	0	23
Use new Modern technology, e.	Count	7	0	6	3	0	0	16
Enforcement of strict safety	Count	3	1	2	8	0	2	16
Improve rapid response	Count	2	0	1	2	0	0	5
Address motivations of causes	Count	4	0	0	2	0	0	6
Accurate collation of pipeline	Count	0	0	2	2	1	0	5
Install fence along ROW	Count	0	1	0	0	0	0	1
Better land use planning	Count	2	0	4	1	0	0	7
More Research and	Count	5	1	6	7	1	0	20
Intensive surveillance on	Count	3	0	1	3	1	1	9
Evaluate Social and	Count	6	0	1	1	0	0	8
Statutory Punishment to	Count	2	0	2	5	0	0	9
Increase burial depth	Count	1	0	1	0	0	0	2
Remote monitoring	Count	3	0	3	1	0	1	8
Application of proper standard	Count	3	2	9	11	0	1	26
Prevent all activities near	Count	1	0	2	1	0	0	4
One-Call Systems	Count	0	1	1	5	0	1	8
Engage community cooperation	Count	4	0	2	2	0	1	9
Education on consequences of	Count	1	0	1	4	0	0	6
	Count	29	5	32	31	3	3	103

Procedures for Preventing TPI during and after pipeline installation.
Respondents' perceptions were assessed of what damage prevention measures, organisation representative that will mitigate damage cause by third-party activity during and after pipeline installation. The frequency table of the multiple responses analysis indicates that *surveillance frequency by risk assessment* is the most frequently indicated measures. The maximum number of responses obtained from a respondent was two, and the respondent (Table III) identified ten possible methods.

Table 3. Frequency table of responses to procedures for preventing third-party

Responses to open-ended question	*Responses* N	Percent	*Percent of Cases* N
1. Education of Third parties	2	7.70%	10.00%
2. Fibre optic cable	2	7.70%	10.00%
3. Jet grouting protections to vulnerable portions	3	11.50%	15.00%
4. Material selection against external load	1	3.80%	5.00%
5. Community Investment Strategy	3	11.50%	15.00%
6. One call notification system advertised	3	11.50%	15.00%
7. Coating, possibly concrete	1	3.80%	5.00%
8. Sufficient Burial depth	1	3.80%	5.00%
9. Satellite monitoring	2	7.70%	10.00%
10. Surveillance frequency by risk assessment	8	30.80%	40.00%
Total	**26**	**100.00%**	**130.00%**

Effectiveness of Preventive Methods against Intentional Interference
Respondents were asked what method they would suggest as most effective to prevent pipeline third-party damage from intentional interference. The frequency table of the multiple responses set indicates that *communications with all stakeholders* (16.80%) is the most frequently recommended preventive measure by respondents. *Increase pipe wall thickness* is the least recommended measures (Table 4).

Table 4. Frequency distribution of open-ended question about effectiveness of Preventive Measures

Suggested prevention methods for intentional pipeline. damage by respondents	*Responses*		*Percent of Cases*
	N	**Percent**	**N**
Punishment of offenders to deter others	3	1.90%	3.00%
Maximum pipeline burial with addition protection	19	11.80%	19.00%
Involvement of specialist security organisations	8	5.00%	8.00%
Electromagnetic detection and acoustics	8	5.00%	8.00%
Public education/ Awareness of pipeline location	19	11.80%	19.00%
Direct physical protection of vulnerable segments	13	8.10%	13.00%
Remote and aerial surveillance	21	13.00%	21.00%
Alignment based on Risk/Consequence design	6	3.70%	6.00%
Customised solution tailored to fit the environment	14	8.70%	14.00%
Increase pipe wall thickness	5	3.10%	5.00%
Involve the community to guard pipelines	18	11.20%	18.00%
Communications with all stakeholders	27	16.80%	27.00%
Total	**161**	**100.00%**	**161.00%**

In an analysis by location undertaken (Table 5), respondents from Africa frequently indicated *involve the community to guard pipelines*, while majority of responses from Europe recommended *communications with all stakeholders*. Respondents from North America mostly recommended *public education/ awareness of pipeline location*. Similarly, in a cross-tabulation analysis of respondents'

organisation and the open-ended question, respondents from government agencies frequently recommended *communications with all stakeholders.*

Table 5. Cross-tabulation analysis by location

	Geographical Location of Respondent (count)					
	Africa	Asia	Europe	North America	South America	Oceania
Punishment of offenders to deter others	1	0	0	2	0	0
Maximum pipeline burial with addition protection	2	1	7	7	0	2
Involvement of specialist security organisations	2	1	3	1	1	0
Electromagnetic detection and acoustics	1	0	4	2	0	1
Public education/ Awareness of pipeline location	2	1	7	8	0	1
Direct physical protection of vulnerable segments	2	2	5	4	0	0
Remote and aerial surveillance	3	0	9	7	0	2
Alignment based on Risk/Consequence design	0	0	2	3	0	1
Customised tailored solution for the environment	2	1	4	4	2	1
Increase pipe wall thickness	0	0	5	0	0	0
Involve the community to guard pipelines	10	0	5	3	0	0
Communications with all stakeholders	7	1	12	6	0	1
Total	19	4	40	30	2	5

3.4. Factors Influencing Occurrence of Intentional Pipeline Damage

Respondent were asked what factors in their opinion influence the occurrence of intentional pipeline damage. The frequency distribution of responses indicates that *government and social responsibility to communities* (20.60%) is the most frequently commentary factor perceived by respondents that influence the occurrence of intentional pipeline damage (Table 6).

Table 6. Frequency distribution of factors Influencing Occurrence of Intentional Pipeline Damage

	Responses		*%(Cases)*
	N	Percent	N
1) Petroterrorism	17	17.50%	29.80%
2) Political reasons	11	11.30%	19.30%
3) Burial depth of pipeline	4	4.10%	7.00%
4) Strict penalty to offenders	1	1.00%	1.80%
5) Public education and communication	13	13.40%	22.80%
6) Absence of laws for pipeline security	7	7.20%	12.30%
7) Ignorance of the consequences of failure	7	7.20%	12.30%
8) Government and social responsibility to communities	20	20.60%	35.10%
9) Economy situation of a country (*e.g.* theft of product)	17	17.50%	29.80%
Total		**100.00%**	**170.20%**

The next most frequently commentary factor perceived by respondents was *petroterrorism* (all associated activities that interfere with maritime transportation) and *a country's economy*, for example poverty and theft of product. In the more specific comments about occurrence of intentional pipeline damage, the following extracted comment from the survey expresses the opinion of two respondents: *"The reasons for damage can vary by location, e.g. in FSU it is 100% economic (oil theft). In Nigeria, it is a mixture of economic and protest. In Colombia, it was 100% protest. Protest (terrorism) probably cannot be prevented but should be of limited impact. Economic will remain endemic until the political system has the will to stop it as this does not usually seriously damage the pipeline"; and "In Australia intentional interference is not such an issue, rather unintentional interference brought about by deficiencies in the risk assessment in the first instances failing to identify the threat and relevant controls of such interference. I disagree with the any inference that third parties would intentional seek to damage a pipeline; unless of course it is in a politically unstable environment e.g. Iraq and Afghanistan."*

Table 7. Cross-tabulation analysis by location

		Geographical Location of Respondent					
		Africa	Asia	Europe	North America	South America	Oceania
Petro-terrorism	Count	3	1	6	3	1	3
Political reasons	Count	4	1	2	2	1	1
Burial depth of pipeline	Count	0	0	3	1	0	0
Strict penalty to offenders	Count	1	0	0	0	0	0
Public education and	Count	5	1	3	3	0	1
Absence of laws for pipeline	Count	1	0	2	4	0	0
Ignorance of the	Count	1	0	2	4	0	0
Government/Social	Count	7	0	8	5	0	0
Economy situation of a	Count	7	0	5	4	1	0
	Count	15	2	21	14	2	3

In a cross-tabulation analysis by location undertaken (Table VII), respondents from Africa frequently indicated *government/social responsibility to communities* and *economy situation of a country* (*e.g.* poverty and theft of product). In support of the above findings, most comments from Africa (mostly Nigeria) are from respondents' organisation experiencing intentional third-party interference as the following two comments illustrate: "*Failure of government commitment to the people of the oil producing communities in Nigeria, and resentment of government policy implementation expressed as vandalism to company pipeline assets for economic gains",* supported by another respondent, that*: "Poverty/purchasing power of nearby population in relation to value of product in pipelines; and socio-political factors - wealth distribution, employment opportunities, absence of effective community development programs, environmental pollution etc.".* Respondents from Oceania countries mostly indicated *petroterrorism.* Similarly, *petroterrorism* was the most frequently indicated factor by pipeline engineers compared to other profession, for example, pipeline project engineers whose majority indicated g*overnment and social responsibility to communities*.

Ranking of Factors for Potential for Third-Party Interference

Respondents were asked to select the three factors that are most important that could be used to assess the potential for third-party interference and rank them from 1 to 3 (with 1 as the most important). The study shows that *land use and human activities* was the most selected and thus the most ranked factor for consideration in mitigating intentional third-party damage. The second most ranked factor is *depth of pipeline* and followed by *accessibility to pipeline network* (Table 8).

Table 8. Frequency distribution for ranking of factors for potential for TPI

	Land use and human activities		Socio-economic conditions of population living near a pipeline		Accessibility to Pipeline Network (proximity of roads, rivers, streams and rail)		Socio-political factors (e.g. literacy rate, political stability, and violence		Depth of Pipeline (exposed pipeline can often provide criminal opportunities)		Other factor in your opinion not mentioned that influence intentional pipeline	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
None Selected	80	34.9%	118	51.5%	132	57.6%	137	59.8%	105	45.9%	198	86.5%
1st Most Important	86	37.6%	40	17.5%	19	8.3%	30	13.1%	29	12.7%	4	1.7%
2nd Most Important	36	15.7%	42	18.3%	27	11.8%	41	17.9%	52	22.7%	6	2.6%
3rd Most Important	27	11.8%	29	12.7%	51	22.3%	21	9.2%	43	18.8%	21	9.2%
Total	229	100.0%	229	100.0%	229	100.0%	229	100.0%	229	100.0%	229	100.0%

Third-party activities organisations presently monitor to avoid damage.

The survey research examined what activities organisations currently monitor to avoid third-party interference. SPSS multiple dichotomy analysis provided frequencies and percentages for the survey

items and determine the most often suggested activities. Analysis of the demographic characteristics of respondents' choice based on occupation, organisation and location were examined using cross tabulation and showed most respondents (97.4%) indicated more than one item, and the frequency distribution showed that *right-of-way encroachment*, followed closely by *direct pipeline vandalism* are the most frequently chosen in the survey (Table 9).

In a cross-tabulation analysis by location, respondents from Africa, North America and Oceania most frequently indicated direct *pipeline vandalism* as the main priority of their surveillance program (Table 9). Respondents from Asia and Europe indicated *right-of-way encroachment*; only South American respondents indicated *theft of product and pipeline facilities*. In likewise manner, frequency analysis by organisation, majority of respondents from the academia and professional bodies indicated *no opinion*, while the respondents from government agencies indicated *direct pipeline vandalism* and *right-of-way encroachment*. Interestingly, respondents from the private companies and pipeline services indicated *right-of-way encroachment* as the most preferred surveillance activities to mitigate intentional third-party interference.

Table 9. Frequency distribution party activities organisations presently monitor to avoid damage.

	Responses		
	N	Percent	Percent of Case
Direct Pipeline Vandalism	108	14.6%	48.4%
Theft of product or facilities	101	13.7%	45.3%
Sabotage to pipeline network	101	13.7%	45.3%
Guerrilla attacks	39	5.3%	17.5%
Likelihood of Terrorism against pipeline facilities	72	9.8%	32.3%
Intrusion to above ground facilities	100	13.6%	44.8%
Right-of-Way Encroachment	116	15.7%	52.0%
Cyber attack and potential hijack of network facilit	32	4.3%	14.3%
No Opinion	69	9.3%	30.9%
Total	738	100.0%	330.9%

Discussion

Standard and procedures, and Research and Development

The study showed that application of proper standard and procedures; greater awareness campaign to all stakeholders; and more Research and Development are most effective in preventing pipeline third-party interference. The findings shows that besides engineering design of pipeline being carried out in line with international best practices, preventing third-party interference also depends primarily in utilising the opportunities created by research and development of pipeline project, for planning, design, installation, and maintenance(Williamson & Daniels, 2008). Education and awareness campaign about the risk and consequences of pipeline failure from third-party interference presented in an accommodating way to stakeholders, youth and communities help prevent third-party interference. One respondent outlined their opinion of preventing pipeline third-party interference:

"The prevention of third party interference is also reliant on the application of standards and procedures by the operating company. In countries where these are regulated it is easier to draw conclusions or state opinions, but in the Middle East for instance, there is a lack of formal regulation and in some cases, this can result in a lack of understanding in the need to enforce and ensure the proper preventative measures are taken".

In the last decades, environmental, political and financial awareness and consciousness about the negative aspects of pipeline failures has led to development of various national policies to reduce such failures. This development have lead to different legal framework and actions taken to promulgate appropriate environmental protection laws; harmonise the existing protection legislation, and make it a constitutional duty of any responsible stakeholders to safeguard petroleum pipeline. Pipeline failures not only impede financial and world energy supply of oil, but also cause death and environmental damage that demean a normal comfortable living environment. Therefore, important effective regulation and legislation for prevention and remediation of pipeline damage from third-party interference cannot be over emphasised.

Table 10. Cross-tabulation of respondents' geographical location

		Geographical Location of Respondent					
		Africa	Asia	Europe	North America	South Americ	Oceania
s Direct Pipeline Vandalism	Count	27	5	34	29	6	7
	% within $S3_Question	25.0%	4.6%	31.5%	26.9%	5.6%	6.5%
	% of Total	12.0%	2.2%	15.1%	12.9%	2.7%	3.1%
Theft of product or facilities	Count	24	4	35	25	8	5
	% within $S3_Question	23.8%	4.0%	34.7%	24.8%	7.9%	5.0%
	% of Total	10.7%	1.8%	15.6%	11.1%	3.6%	2.2%
Sabotage to pipeline networl	Count	28	3	31	28	5	6
	% within $S3_Question	27.7%	3.0%	30.7%	27.7%	5.0%	5.9%
	% of Total	12.4%	1.3%	13.8%	12.4%	2.2%	2.7%
Guerrilla attacks	Count	14	2	10	11	2	0
	% within $S3_Question	35.9%	5.1%	25.6%	28.2%	5.1%	.0%
	% of Total	6.2%	.9%	4.4%	4.9%	.9%	.0%
Likelihood of Terrorism against pipeline facilities	Count	14	3	25	24	3	3
	% within $S3_Question	19.4%	4.2%	34.7%	33.3%	4.2%	4.2%
	% of Total	6.2%	1.3%	11.1%	10.7%	1.3%	1.3%
Intrusion to above ground facilities	Count	18	5	42	26	4	5
	% within $S3_Question	18.0%	5.0%	42.0%	26.0%	4.0%	5.0%
	% of Total	8.0%	2.2%	18.7%	11.6%	1.8%	2.2%
Right-of-Way Encroachment	Count	27	7	43	28	5	6
	% within $S3_Question	23.3%	6.0%	37.1%	24.1%	4.3%	5.2%
	% of Total	12.0%	3.1%	19.1%	12.4%	2.2%	2.7%
Cyber attack and potential hijack of network facilities	Count	5	1	12	12	1	1
	% within $S3_Question	15.6%	3.1%	37.5%	37.5%	3.1%	3.1%
	% of Total	2.2%	.4%	5.3%	5.3%	.4%	.4%
No Opinion	Count	15	6	31	16	3	0
	% within $S3_Question	21.1%	8.5%	43.7%	22.5%	4.2%	.0%
	% of Total	6.7%	2.7%	13.8%	7.1%	1.3%	.0%
	Count	50	15	90	51	11	8
	% within $S3_Question						
	% of Total	22.2%	6.7%	40.0%	22.7%	4.9%	3.6%

Surveillance Frequency

In any procedure for preventing third-party interference after pipeline installation, surveillance frequency determined from risk assessment is the most effective strategy, as also confirmed by this study. Periodic surveillance can help security analysts to assess any unusual trend that could be damaging to the pipeline and identify illegal activities within a pipeline's right-of-way or intrinsic to the pipeline, achievable using GPS mounted helicopter and small wing airplane (Riquetti et al., 1996; Gallacher, 1996). Aerial surveillance could be a reminder to the population beneath, that there is a pipeline on their land and this sometimes could serve as a deterrent. The major reason of disadvantage in high usage frequency and some modes of surveillance (*e.g.* helicopter surveillance) remain the high costs associated with capital, operation, and maintenance.

Communications with Stakeholders

Communications with stakeholders is another organisational representative recommended preventive measure by respondents. Sljvic (1995) recognises third-party interference as the most single probable cause of pipeline failure caused by landowners, utility companies, contractors, and

local authorities. He studied relationship between third-party activities and its influence towards pipeline damage, and encouraged increased contact by pipeline operator with potential third parties through quality dissemination of information, this view was supported by Lu and Li (2005). In addition, an earlier companion paper by Hovey and Framer (1993) also confirms the likelihood of a spill along a pipeline is the primary responsibility of the pipeline managers and not the influence of socio-economic factors. He encourages collaborative communication between the operators and the landowners. In all responses to question of preventive, *increase pipe wall thickness* is the least recommended measure compared to education of third parties; installation of fibre optics; jet grouting protections to vulnerable portions, material selection against external load; one call warning systems; and satellite monitoring. This finding was unexpected; an implication of this is the possibility that engineering design with increased thickness of pipeline in vulnerable segment might be unnecessary.

Occurrence Factors of Intentional Pipeline Damage

Another important finding was that governmental social responsibility to communities and *economy situation of a country* (*e.g.* poverty and crime rate) are the most commentary factor perceived by respondents that influence the occurrence of intentional pipeline damage. One participant referred to how governmental social responsibility to communities as a necessary consideration:

> *"Avoid vulnerable areas, and work with local communities by making them feel responsible for the pipeline"; and "Maintaining excellent and mutually beneficial relationships with the host communities (this is relevant only for prevention of wilful damage), in addition to pipeline surveillance technology for all the pipeline networks, the host communities should continuously be educated about dangers in pipeline vandalization and as well engage them for local surveillance".*

This study revealed that the prevalence of third-party interference in Africa is associated with socio-political and socio-economic status of the region. The findings from the survey highlight the need for stakeholders to consider: (1) creation of quality practice with high levels of commitment to communities; (2) development of programs and supports to optimize risk mitigation strategies; and (3) the benefits and understanding of various modern technologies applicable for prevention of third-party interference. Literature suggests that people from poor and deprived area are more likely to damage a pipeline intentionally than those from an area that is more affluent. For example, Bennett (1991) found that theft rate are related directly to gross domestic product per capita of a region, supported by Blau and Blau (1982) who also show how poverty and deprived economic empowerment can result in the frustration, thus leading to higher rates of crime.

Ranked Factors for Potential for Third-Party Interference

The study shows that *land use and human activities* is the most ranked factor for consideration in mitigating intentional third-party damage. The second most ranked factor is *depth of pipeline* and followed by *accessibility to pipeline network* (Table VIII). A participant acknowledged that without proper land use planning, security of pipeline would be a problem: *"...the risk of third-party interference is considered from an unintentional point of view. That is, resulting from poor risk mitigation measures adopted by Pipeline Company such as failing to adequately identify land use and hence put in appropriate and effective controls."* However, the most striking result to emerge from the study about methods of preventing pipeline third-party interference is that *depth of pipeline*; contrary to literature review, is least ranked compared to with *land use and human activities*.

These findings have challenged many study's claim, for example a pioneering study by Knight and Grieve (1974), cited by Mather *et al*., (2001) providing a comprehensive overview of the depth of cover as an influence to damage from third-party. It complements the review by (Neville, 1981), also cited by Mather *et al*., (2001) that incidences to pipeline are low with high depth of cover. Also, the findings of the study do not support previous research that identified depth of pipeline as one of the major dominant factor in third party failures (Muhlbauer, 2004; TRB, 2004; Jager et al., 2002; Taylor et al., 1984; Andersen and Misund, 1983). Therefore increasing pipeline depth of cover could prevent third-party damage, for example, researches have also shown that the probability of damage to a pipeline is reduced by 90% if the pipeline depth is doubled (Hopkins et al., 1999; Hopkins, 1993; Potter, 1985; Taylor et al., 1984). Exposed or shallow pipeline provides criminal opportunities because it is easy to vandalise or create illegal valves for stealing the pipeline content. Brantingham and

Brantingham (1981) term the above scenario as *crime generator*, as they provide places where crimes are likely to happen.

Current Third-party Activities been Monitored by Organisation

It is interesting to note that in all eight cases (Direct pipeline vandalism; Theft of product and pipeline facilities; Sabotage to pipeline network; Guerrilla attacks; Likelihood of terrorism against pipeline; Intrusion to aboveground facilities; Right-of-way encroachment; and Cyber attack/potential hijack of network facilities) *right-of-way encroachment*, followed closely by *direct pipeline vandalism* are the most current activities of intentional third-party interference being monitored by organisations. All participants identified right-of-way and direct pipeline vandalism as one of the factors influencing intentional third-party interference, and recommends regular patrolling on the pipeline right-of-way; for example, two participants outlined their opinion on right-of-way:

> *"Make it difficult to dig into the right of way. Grasscrete grids at the surface make the area look like a green field but make it very difficult to dig. This also spreads out the load of a vehicle driven on the right of way. Cost is an issue and gresscrete can only be used on the highest risk areas*", and *"Public education about pipelines that run through their neighborhood; what activity they might normally see on the ROW, what type of equipment they might see, learn to report any suspicious activity to the local authorities".*

Selected General Remarks about the Questionnaire Survey

The questionnaire survey asked respondents about any feedback or observation about pipeline third-party interference not covered by the survey questionnaire. These are some selected responses:

- *"Industry here held a meeting with various governmental entities to discuss the issue of possible terrorist acts against pipelines, platforms, etc. The lead agency in these discussions was the FBI. FBI recognized that no effective means exists that can prevent a terrorist act. Their desire was that industry set up video surveillance on its facilities with the intent that were such an act to take place that they could retrieve the video for use in investigation of the crime. Industry did not view this favourably in that the approach was tantamount to FBI requesting a "black box" recorder to investigate a disaster after the fact. In other words, FBI accepts the fact that facilities and personnel are in fact helpless to prevent such an attack and as such can only serve to provide possible evidence of the crime after it has been committed. Moreover, even if industry were to set up its own security measures, such measures would not be effective it that no effective counter-response capability exists. Industry representatives even went so far as to suggest that it be allowed the use of firearms to protect it pipeline and associated assets, e.g. offshore platforms. Government did not like this suggestion. Note: it is illegal to possess firearms on such properties. Industry effectively responded that government was powerless to stop industry from arming itself. Government effectively has turned a blind eye to industry's intentions in this regard. As to pipeline yet to be installed; burial, i.e. "hiding" these assets is the most effective means by which to lessen the possibility of their being compromised. Markers are also effective as is membership in a "Dig Alert" organization. Markers however have the disadvantage of advertising placement of pipelines. While your study is very well intentioned and may even provide some positive fruit, it is generally felt here that pipelines are at greatest risk from terrorist activity over which no control or preventative measure is possible. This is not fatalistic viewpoint; it is the reality of the world at this juncture. Joint governmental/industry continued cooperation does exist as regards reacting to reported suspicious activity. However, this is not a pro-active stance. It merely serves the purpose of being able to state that something is being done; no matter how impotent it really is. The recognized truth the matter is the tacit acknowledgement that an attack on a pipeline may be affected with virtual impunity".*
- *"Intentional damage is only likely where there is civil unrest or unhappiness for some reason. Where people wish to vandalize pipelines, there will be little you can do to stop them. There are however many very effective measures that can be taken to avoid accidental pipeline hits, e.g. mapping, One-Call system, legislation, and effective enforcement"*
- *"In Canada we have not seen a large presence of terrorism or other types of activities related to pipeline damage. There have been some pockets of criminal activities within the pipeline community however the greatest threat we face is from within our own ranks. That is a contractor or landowner*

who performs a ground disturbance without calling for locates and hits a pipeline or other buried infrastructure".

- *"The importance of ensuring that Risk assessment is always conducted with the number of increasing events demonstrated the importance of reviewing the pipeline controls for reduction in third-party interference. This is normally by way of neglect in searching land title for easements coupled with no delineation of the pipeline on District Council Maps. With designation secured the pipeline will be shown on District Council Maps and must be reported to any member of the public seeking a LIM (Land Information Management) Report for development or work"*
- *"Third-party damage is typically not an act of sabotage but rather an unintentional interference with the pipeline caused by local activity. The solution is avoidance. Avoidance requires design and construction techniques that identify the pipeline and detection technology on excavating equipment. Where avoidance is not possible then monitoring is required. Solutions must be cost effective".*
- *"Although third-party interference is the single main cause for pipeline damage, the cases of major pipeline incidents (on transmission pipelines) is so rare that additional safety measures are not required at all. Major incidents mainly occur on the distribution networks close to the buildings, mainly caused by manipulation of the supply connection directly. e.g., as an attempt of steeling gas, or due to the design for low pressures (plastic pipes)"*
- *"The cause and solution to the problem of third-party damage to pipelines in Nigeria are well known. There seems to be a reticence on the part of government to address the root causes. The oil companies themselves support local communities in which they work but the government does not support them in the appropriate manner".*
- *"You seem to have overlooked the issue of parochial business interest of some actors, underpinned by corruption. In one of my (field study) interaction with some local people where some Nigeria\'s oil pipelines transverse they argue that some firms or personnel that specialize in repair of pipelines connive with some vandals to puncture these pipes to achieve their mutual interest. The vandals benefit from this through siphoning of the products, while the firms/personnel gain from the award of contracts to effect repairs".*
- *"New technologies to detect buried pipelines and others like Broadband-in-Gas from NETHERCOMM could be more explored".*
- *"For the past 15 years Virginia government has been involved helping our pipeline industry reduce excavation damage to our pipelines. Our efforts have resulted in reducing these damages by more than 50% while miles of underground pipelines have increased by more than 30%. This has been done by effective public education, use of technology and strong and fair enforcement".*
- *"Intentional damage is not a problem in NA at least not yet. Most damage is due to contractors not using one call or facilities not being properly marked (which could go back to good records of the location of the pipeline). We need to make it very convenient for contractors to use first call and very painful if they don't use it".*
- *"Lack of awareness, information and knowledge about the pipeline damage risk, become a major factor of improper design, construction and maintenance, and cause many problems in the field".*

Conclusion

The ability to understand pipeline third party interference (TPI) is a valuable knowledge for stakeholders in the oil and gas industry, and for millions of people who live near petroleum the over two million kilometres of pipelines worldwide. The inadequacy of the usual traditional monitoring via regular patrolling of the rights-of-way, airborne or land-borne is in no doubt (Parfomak, 2008). Therefore, this study recommends that pipeline operator solicits stakeholders' participation at individual and group levels. At the individual level, questionnaires are developed and used for survey of local residents and officials. At group level, public meetings are organised with representatives of the national and local government stakeholders, and local non-governmental organisations. Public meetings held to provide feedback about the scope of the pipeline project, where findings and recommendations of the process will be incorporated into the engineering design (Hopkins et al., 1999; Day, 1998). This strategy will also identify and evaluates the positive and negative impacts likely to result from a pipeline project to enable assigning technical values to curb the impacts. This will enable stakeholders to expectedly recommends practical and cost-effective measures to prevent or

reduce significant negative impacts of third-party interference to an acceptable level within a locality (Muhlbauer, 2004).

The study showed that government and social responsibility to communities, petroterrorism and a country's economy are the most frequently commentary factor perceived, that influence the occurrence of intentional pipeline damage. Unfortunately, the limited amount of published literature on intentional pipeline third-party interference makes the questionnaire survey generic. This study has explored the pipeline industry perceptions of third-party interference, and data analysis revealed nine themes: proper standard and procedures; greater awareness campaign to all stakeholders; Research and Development; surveillance frequency as determined from risk assessment; right-of-way encroachment; communications with all stakeholders; government and social responsibility to communities; land use and human activities; and a country's economy. The study would contribute to the development of a more comprehensive and effective approach to preventing and managing third-party interference incidents on oil and gas pipelines, which can enhance the safety and security of pipeline operations and protect the environment and public health.

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Review Paper

Biochar – an Essential Component for Soil Enhancement, Plant Development and Environmental Cleanup

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Abstract: Biochar is a solid, carbon rich product produced by thermal decomposition of organic matter in the absence of oxygen. It is persistent and beneficial to the soil. This review systematically analyzed and summarize the beneficial aspects of biochar for soil quality improvement, plant growth and environmental remediation. Also, this review provides an overview of the research conducted on biochar till data in Nepal. Study reported the effects of biochar depend on the quality of materials and the type of soil where it is going to be utilized. If site-specific soil limits and nutrient/water limitations are reduced by proper biochar formulations, crop yields significantly rise. The application of biochar in carbon sequestration should be further investigated at similar experimental conditions to obtain consistent results. A study suggested that the effect of biochar on soil microbes should be further investigated to elucidate the dominant reason for the improvement of soil fertility based on different soil and feedstock. In summary, biochar has a wide application prospect in environmental remediation and should be further investigated.

Keywords: *biochar, carbon sequestration, plant growth, soil fertility*

Introduction

Soil fertility is critical as it can influence the crop yields and their development. The fertility can be improved through organic and inorganic fertilizers in the soil. It incorporates a number of soil characteristics (biological, chemical and physical), all of which have an impact on the availability and dynamics of nutrients either directly or indirectly. Since the "green revolution", inorganic fertilizer have significantly increased agricultural productivity (Liu et al. 2010); nevertheless, they are not a sustainable option for the maintenance of crop yields (Vanlauwe et al. 2010). Mineral fertilizer used excessively over time may increase soil acidification, impacting both soil biota and biogeochemical processes, posing a risk to the environment and reducing agricultural yield (Aciego Pietri and Brookes 2008). Therefore, organic additives like compost and biochar may be helpful in preserving and improving soil fertility and crop yield.

Biochar is a black, stable, carbon-rich material thermochemically converted (slow, intermediate, and fast pyrolysis or gasification) in an oxygen-limited environment. A variety of feedstocks, including agricultural and forestry wastes, may be used to make it, including straw, nutshells, rice hulls, wood chips and pellets, tree bark, and switchgrass (Sohi et al. 2009). Biochar can be used as a possible tool for removing toxicity from soil and help in climate change mitigation (Ennis et al. 2012; Stewart et al. 2013). Several studies have shown that biochar application to soil can (i) improve soil's physical and chemical properties (Sohi et al. 2010; Mukherjee and Lal 2013) (ii) enhance plant nutrient availability and correlated growth and yield (Jeffery et al. 2011; Biederman and Stanley Harpole 2013) (iii) increase microbial population and activities (Lehmann et al. 2011; Jaafar et al. 2014), and (iv) reduce greenhouse gas emissions through C sequestration (Crombie et al. 2015). Studies have shown that combined applications of biochar with organic or inorganic fertilizers could lead to enhanced soil physical, chemical, and biological properties, as well as plant growth. Several composted materials in particular offer a sustainable supply of nutrients that might promote plant development while improving the physicochemical and microbiological qualities of the soil (Schulz and Glaser 2012; Liu et al. 2012).

According to Liu et al. (2012), compost and biochar applied together exhibit a beneficial synergistic effect on soil nutrient levels and water-holding capacity under field conditions.

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Also, the use of biochar in conjunction with compost has shown to be effective in stabilizing soil structure, increasing soil nutrient content, and enhancing water retention capacity (Schmidt et al. 2014; Agegnehu et al. 2015). Moreover, these studies highlight how the combination of compost and biochar might improve the qualities of compost, resulting in a greater added value and a far better potential for carbon sequestration because of the long-term stability of biochar (Schulz and Glaser 2012).

However, research indicates that depending on the types of feedstock used, the production and the application process used, can differ soil biophysical-chemical characteristic and plant growth and yield (Bernal et al. 2009). The review provides a overview of importance of biochar as a key component for the improvement of soil and crop production.

Biochar for soil enhancements

Biochar is a carbon-rich material that contains organic matter, inorganic salt (humic and fluvic substance), N, P, and K that may be used as fertilizer and taken up by plants and microbes. According to Lin et al (2012), humic levels in biochar made from *Acacia saligna* at 380 ^{o}C and sawdust at 450 ^{o}C were 17.7 and 16.2%, respectively. Biochar made from *Lantana camara* at 300 ^{o}C contained available P (0.64 mg kg^{-1}), available K (711 mg kg^{-1}), available Na (1145 mg kg^{-1}), available Ca (5880 mg kg^{-1}) and available Mg (1010 mg kg^{-1}) (Masto *et al.* 2013). Similarly, fresh biochar had the potential for nutrient availability and could release large amounts of N (23 – 635 mg kg^{-1}) (Mukherjee & Zimmerman 2013). Biochar not only increases nutrient content but also increase available water capacity, soil porosity (Nelissen et al. 2015) and increase crop production and prevent soil degradation (Amézketa, 1999). Lu et al., (2014) showed an increase in soil aggregation (8 to 36%) and soil pore structure (20%) after the application of rice husk biochar. These studies show that biochar has great potential to be utilized as nutrient-rich organic fertilizers.

Enhanced physicochemical characteristic of soil

Application of biochar to soil can increase soil aeration, bulk density, porosity, and packing, as well as increase net soil surface area (Chan and Xu 2012; Palansooriya et al. 2019). Additionally, through improving soil aggregate stability, soil preparation workability, water infiltration, and water holding capacity, biochar directly modifies the connection between soil and water (Qambrani et al. 2017; Purakayastha et al. 2019). This improvement in soil quality is made possible by the movement of water, heat, and gases on soil and the decrease in bulk density and rise in soil porosity (Lian and Xing 2017). Moreover, biochar affects soil pH, which is particularly beneficial in reducing soil acidity by enhancing cation exchange capabilities (K, Ca, Mg, and Na from biochar), through functional group effects (–COO– and -O- contribute greatly to biochar alkalinity) and increase the availability of primary and secondary nutrients like K, P, Ca, Mg (Kookana et al. 2011). According to (Laird et al. 2010), biochar increased cation exchange capacity, amount of nutrients that are available to plant roots, which promotes microbial activity and quickens chemical reaction in the rhizosphere.

Improvement in soil fertility

Through the cycling of soil organic matter, biochar has been proven to alter soil biological qualities in addition to improving soil physicochemical properties (Liang et al. 2010). It can optimize nutrient cycles, increase pore space, and improve soil structure, all of which will lead to nutrient retention and immobilization and eventually promote plant development (Warnock et al. 2007). By cycling soil organic materials, microorganisms like rhizosphere bacteria and fungus may directly promote plant development. According to Domene et al. (2014), the addition of 30 t ha^{-1} biochar might cause an increase in microbial abundance from 366.1 to 730.5 μg C g^{-1}. Similarly, for the various preincubation durations (2 – 61 days), microbial abundance rose by 5 – 56% with the rise in maize stove biochar rates (from 0 to 14%) (Domene et al. 2015). The possible reason for the increase in microbial abundance is due to higher availability of nutrients, less competition, increased habitat suitability and refuge with the addition of biochar.

The kind of soil and the amount of biochar have an impact on the microbial community in the soil. Biochar may include certain organic pyrolytic products that are toxic to soil microbes, such as phenolics and polyphenolics. After the application of biochar, a research by Warnock et al (2007) revealed a reduction in mycorrhizae and overall microbial biomass. Microbial abundance and activities are reduced due to the retention of heavy metals and pesticides released from biochar (Gell et

al. 2011). Additionally, certain biochar may directly risk the soil biota and their functions, resulting in lower crop yields (Liesch *et al*., 2010). Clover plant leaves have reportedly been discolored as a result of biochar application without sufficient washing to remove organic and inorganic contaminants (Turner, 1955).

More research is needed on fundamental mechanisms and the utilization of biochar is poorly understood. Therefore, research should focus on the following aspects.

- Studying how soil microbes and biochar interact, with a particular emphasis on how much CH_4 and $N_2O$the soil release as greenhouse gases.
- Many factors restrict the use of biochar and soil and its application rates; therefore, field trials should be conducted by selecting a suitable variety to understand the interaction between biochar, soil, microbes, and plant roots.
- Since the life cycles of biochar in the soil are not well known, we should focus more on how quickly biochar decomposes in the soil.

Biochar for environmental remediation

Biochar can be used as a remediation product to lessen soil pollution in addition to enhancing soil fertility. For the purpose of cleaning up polluted soils, biochar in soil exhibits a variety of interactions with inorganic and organic contaminants (Younis *et al*., 2016).

Removal of heavy metals

Heavy metals are an environmental pollutant and is hazardous when they accumulate in the organism. It has been proposed to utilize biochar to remove heavy metals from polluted water. Removal mechanisms vary depending on the valence state of the target metal at different solution pH (Li *et al*., 2017). Numerous studies have demonstrated that the capacity of biochar to reduce pollution is due to a variety of functional groups and inorganic ions contained in the biochar, which may greatly aid in stabilizing metals in soils in addition to the surface sorption (Xu et al. 2013; Wang et al. 2018). A study by Zhang *et al*. (2015) showed that there was almost an equal amount of sorption of Cd and total released cations (Na, K, Mg, Ca) from the biochar, indicating the cation exchange has a leading role in Cd sorption. Zhou et al (2013) showed that the biochar modified by chitosan had favourable removal efficiency for three heavy metals (Cd^{2+}, Pb^{2+}, and Cu^{2+}) from solutions. Two dyes used in wood carpet dyeing (Lanasyn Orange and Lanasyn Gray) could be highly sorbed on nanoporous biochar derived from bamboo cane (Pradhananga *et al*., 2017).

Removal of pesticides

Biochar can be used to remediate pesticide pollution in a novel way, restoring ecological balance and enhancing human health (Dai et al. 2019). According to Klasson et al. (2013), almond shell biochar has 102 mg g^{-1} sorption capacity for the nematode pesticides dibromochloropropane. Thiacloprid was reported to be absorbed by biochar made from maize straw through pore-filling and hydrophobic interaction (Zhang *et al*., 2018). Sawdust char helps to eliminate more than 89% of Tetracycline (Zhou *et al*., 2017).

Removal of antibiotics

Pharmaceutical wastewater is classified as an emergent environmental concern since it takes a long time for it to break down naturally (Carvalho & Santos, 2016). The research was conducted on reducing the toxicity of antibiotics by biochar. Humic acid-coated magnetic biochar derived from potato stems and leaves sorb three typical fluoroquinolones (FQs) i.e. enrofloxacin (ENR), norfloxacin (NOR), and ciprofloxacin (CIP) by hydrophobic, electrostatic, and formation of hydrogen bonds (Zhao et al. 2019). To enhance sand biofilters, Mohanty *et al*. (2014) added 5 wt% biochar to increase the *Escherichia coli* removal capacity and prevent their mobility during continuous, intermittent flows.

Nepali biochar research efforts

In Nepal, there has been some study and there is some understanding about the use of biochar. There are very few peer-reviewed journal papers based on extensive biochar experiments in Nepalese soils. Nepali farmers are traditionally practicing open-burning of agricultural wastes before the cropping

season with a belief that ashes of biomass help enrich soils. There are many researchers conducted by Nepalis researchers in temperate climate countries of Asia (especially in China, Indonesia, and Japan), Europe, Australia, the USA and South America but they are not based on Nepalis soils. Also, field experiments conducted in one part of the world could not be the same in others due to diverse soils and climates. According to Mukherjee and Lal (2014), biochar advocacy is growing worldwide without adequate scientific knowledge on basic soil processes and cost-benefit analysis of biochar application to soil. Therefore, more research on biochar is needed despite its beneficial effects on the soil environment particularly to assess its effectiveness in different soil profiles, climatic conditions and crop varieties. In Nepal, there is a volume of renewable feedstock from agriculture and forest which is critical sources for promoting biochar. We can choose the feedstock which is underutilized biomass available from farm fields, households, and markets of agro-processing mills. As our focus is on the hill economy, we can choose available forest litter and invasive species of grass and shrubs as also ricks husks and wooden dust from mills. The feedstock can be chosen depending on seasons and ecological conditions.

Table 1: Agencies undertaking biochar programs in Nepal.

Agency	Types of activity	The funding source, program areas, years, and key interventions
Asian Development Bank in collaboration with Nepal Agriculture Research Council and Nepal Academy of Sciences and Technology	Action research, piloting	Nordic Development Fund, 3 eco-regions – high mountains, mid-hills and Terai, 2014 -16, production tests, trials on soil amendment, carbon sequestration, and energy-saving stoves.
Department of Environment Science and Engineering, Kathmandu University	Action research	Helvetas Intercooperation, Sindhupalchok, Kavre and Lalitpur of Nepal, 2013-15
Multi-stakeholders Forestry Programme	Community support	Jointly funded by Swiss, UK and Finland, 2013-14, support communities of smallholding farmers for livelihood improvement
Nepal Agroforestry Foundation	Scientific research	Norwegian Geotechnical Institute and the Norwegian University of Life Sciences, 2012 onwards. Nepal is one of the 4 countries where the project has been launched.
Local Initiative for Biodiversity Research and Development	Action research, piloting	DanChurchAid, 2014-2016, support for livelihood improvement among low-income households

Prospects for using biochar

Biochar is not widely applied and is still in the test stage of research. Due to a lack of an industrial chain and public awareness, biochar utilization is still undeveloped in developing nations. Therefore, laborious research work should be carried out to address potential environmental issues and broaden the uses of biochar. Despite being plentiful and widely accessible, feedstock/biomass must be properly ground, cleaned, and pyrolyzed to produce biochar. Therefore, to reduce the cost, future research should attempt to find a compromise between optimizing the production process and maximizing the applicability of biochar. To get biochar with improved performance, study should also be done on the careful selection of feedstocks, manufacturing circumstances, and modification techniques. More efforts would be needed to link biochar properties to soil and crop responses in both climate-controlled environments and in the field.

Conclusion

The addition of biochar to soil has enormous promise for enhancing soil fertility, fostering plant development, and cleaning up the environment. To comprehend biochar true function in soil fertility and biomass output, the type of biochar sued should be flexible. The study demonstrated the biochar has a significant surface area, an intricate pore structure, and levels of exchangeable cations and nutritional components. Therefore, biochar should be considered as catalyzers, not as a fertilizer. Biochar offers an alternate method for increasing agricultural land productivity as well as for sequestering carbon through increased organic matter in soil that has been locked for generations.

Lastly, biochar research could provide very positive effects in improving soil quality and crop productivity in Nepal as the agriculture and forest sector offers a huge number of resources.

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