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ENVIRONMENTAL IMPACT ASSESSMENT OF DRILLING OPERATIONS WASTEWATER IN PETROLEUM FIELDS

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ABSTRACT

Drilling is a large process that generates large amounts of waste and can have negative impacts on the environment. The drilling process produces both water and drilling waste, which can have harmful effects on the environment and human health. Drilling waste must be managed properly to avard its impact on the environment and people. The present study has been undertaken to assess the environmental impacts of wastes, and to evaluate the approoch to solve the wastes problem. In this work Rapid Impact Assessment Matrix (RIAM) technique was used to select the best drilling wastes management sgotem. The study recommended that choice of disposal partly underground as the most binificail technique for wastes disposal, most reasonable for environmental pollution, as the other options for waste management were time and high environmental impactmy.

Results obtained from this work indicate that theramal treatment was an important prosess in drilling treatment unit to manage the drilling wells wastes. Also, results revealed that there are three environmental options for waste management i. Above ground disposal; ii. Total underground disposal; iii. Partially underground disposal. Using RIAM as a modern technique for best alternative selection, proved that the second technique (total underground disposal) had the most positive outcome and least negative impacts on environment.

It can be demonstrate that the wastes produced in the oil fields have great negative impacts on environment, so it must be disposed using the seconde option. Finally, using modern techniques like RIAM helps to find the best alternatives and stronglly recommended to use in other cases.

Key Words: Wastewater; Drilling Operations; North Kuwait; RIAM program; EIA

INTRODUCTION

Drilling is the major operation that generates a significant volume of waste that can potentially negative impact the environment. Drilling operations in oil and gas fields will generate a large amount of highly polluted and difficult to degrade drilling wastewater **(Le Zhang, *et al.*, 2024)**. Drilling waste includes drill cuttings, drill mud, and drilling wastewater. In the process of drilling a well, drilling fluid is supplied to lubricate and cool the tool, compensate for down-hole pressure, reduce the intensity of cavern formation, strengthen the walls of the well, and bring the drilled rock to the surface **(Silva, 2023)**.

Drill cuttings are formed after the exit of used drill mud with particles of the drilled rock at the surface resulting from its subsequent cleaning. When the drilling site, drilling equipment, and tools are flushed, drilling wastewater is generated **(Pereira *et al.*, 2022).** They have potential adverse effects to environment and human health. The drilling wastewater must be properly managed to ensure no negative impacts to the environment and humans **(Abdul Razak *et al.*, 2017)**.

The composition of produced water and drilling wastewater constituents have heavy metals, phenol, oil, and poly-aromatic hydrocarbons (PHAs). Characteristics of produced water and wastewater are important requirements of disposal or reuse. Types of drilling waste differ mainly in their composition and application including multiple factors such as safety, economic considerations, technical performance, and environmental impact **(Pereira *et al.*, 2022)**. Most of the drilling wastes sources in the oilfields are oil-based mud (OMBs) and oily cuttings associated with them. Unfortunately, lack of demanding regulations regarding drilling waste discharge leaves room for drilling companies to leave the waste in the nature without treating them **(Kazamias and Zorpas, 2021)**.

Environmental impacts Assessment (EIA) of drilling operations and searching for the methodologies to protect nature and resources against negative impacts of environment has become an interesting topic during the last thirty years in upstream petroleum industry **(Zoveidavianpoor *et al.*, 2012)**. Environmentally responsible actions require an understanding of the characteristics of these wastes and how they are generated to minimize their environmental impacts by known environmental protection methods **(Ilinykh *et al.*, 2023)**.

Produced water and drilling wastewater assessment are necessary to assess effluent quality, meet higher treatment requirements, ability of handling higher hydraulic and organic loadings. Performance of treatment is effective in generation of additional data using accurate sampling and laboratory analysis **(APHA, 2023).** These data can be used for design procedures improvement **(Guven *et al.*, 2019)**.

The present study was aimed to evaluate the produced water and wastewater quality in Sabriyah field - North Kuwait and suggest best solution for hazardous waste disposal and treatment using rapid impact assessment matrix (RIAM) technique.

Study Area

The study area is Sabriyah field - North Kuwait, which considered as the home to oil gathering centers, and one of the five key assets of Kuwait's oil production **(Aladwani and Ahmed, 2022).**

Kuwait's total area is approximately 18,000 km2 and the country lies between latitudes 28.45°N and 30.05°N, and longitudes 46.30°E and 48.30°E. It is located in the Arabian Peninsula, at the northern edge of the Arabian/Persian Gulf, bordering Iraq to the north and Saudi Arabia to the south, and has approximately 300 km of coastline to the east. The Kuwaiti oil fields of Sabiriyah (Fig.1) are situated on the western flank and crest, respectively, of the N-trending Kuwait Arch **(Anwar Al-Helal *et al*., 2023)**.

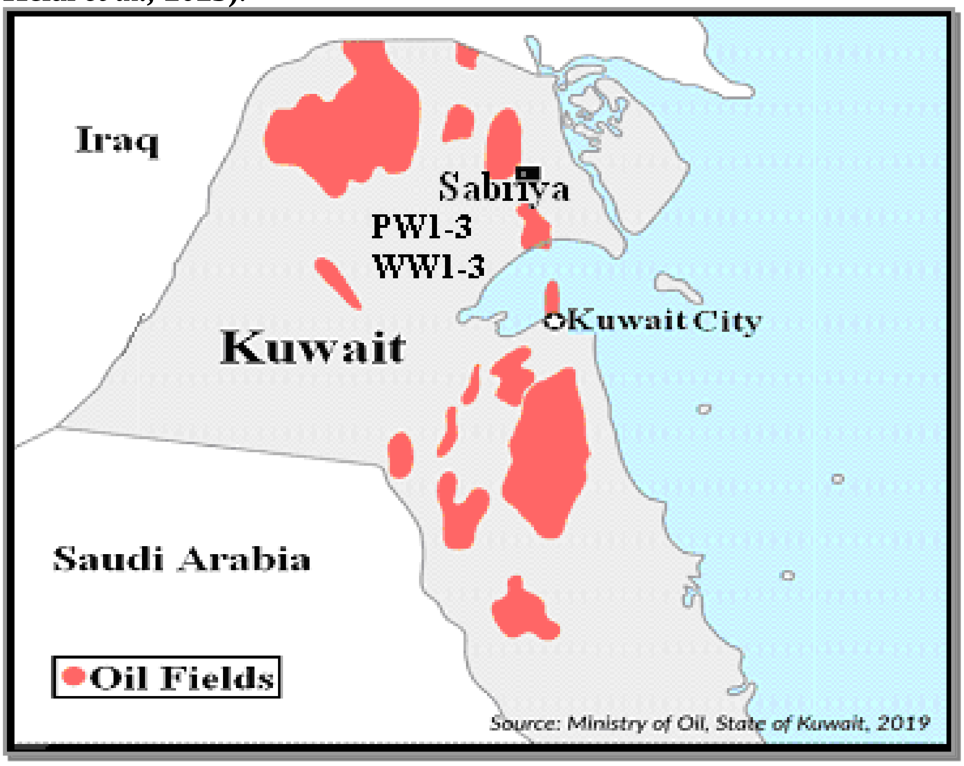


Fig.1. Map location of sampling sites along oil field in north kuwait

Methodology

First step in the study is to assess the waste water quality produced from studied area, six water samples represented produced water (PW1, PW2, PW3) and oilfield wastewater (WW1, WW2, WW3) as shown before in Fig.1 are collected and perserved according international standard methods for examination of water and wastewater**.** Main components and analytical methods for drilling waste water samples shown in Table (1). These samples were selected to assess characterization of produced water and wastewater along different oil field in Sabriyah Field-North Kuwait including various chemical and bacteriological measurements.

Characterization of Oil-Field Wastewater

In order to explain the environmental problem in this studied area, it mostly dirved from the wastewater that produced from oil wells. In the next section all analytical results obtained in the oil field will illustrate in spite of used it in this work of not, just for give a full review of the waste water characters. Produced water associated with surface hydrocarbon resource, subsurface hydrocarbon reservoirs and production operations **(USEPA, 2012).** So, produced water and large volumes of wastewater can be recycle to solve water scarcity, potential subsurface disposal limitations, and regional linkages proplems in Sabriyah field-North Kuwait.

Table (1): Main Components and Analytical Methods for Drilling Waste Samples

No.	Component	Analytical Method
1	pH	Method 4500-H using WTW inolab pH level-1 (Ref. APHA)
2	EC(mmhos/cm)	Method 2520 B using WTW Model Multi Hand Held (Ref. Brown, 2015)
3	TDS	Method 2540 C, Gravimetric (Ref. Godson, *et al.*, 2013)
4	Heavy Metals	Method 3120, 3500 using ICP-ES Perkin Elmer optima 3000 (Ref. Anwar, *et., al.* 2019)
5	COD	Colorimetric, method 5220D using Huch DR-3900 (Ref. Lenore *et al.*, 1998)
6	BOD	Respirometry system (model TS 606/2), method 5210B, 5210D (Ref. Lenore *et al.*, 1998)
7	Total Oil and Grease	Partition gravimetric, method 5520B
8	Phenol	Chloroform extraction method, 5530C, 5530D
9	Total Petroleum Hydrocarbon	Partition gravimetric, method 5520E + 5520F (silica gel treatment); Agilent GC/FID model 7890A
10	Poly Aromatic Hydrocarbons (PAHs)	Liguid/liquid extraction and analysis by Gas Chromatograph system (GC-MSD-HS 7890B) (ref. Qazi, *et al.*, 2021)
11	TC and FC	Membrane filter method 9222B

The characterisation of produced water confiremed with **Alsalem and Thiemann, 2022; Jiang *etal.*, 2022** as listed in Table 2.

Table (2): Environmental Measurements (mg/l) in Oil Field Water Samples

Parameters	PW1	PW2	PW3	WW1	WW2	WW3
pH	7.5	7.79	7.9	7.3	7.5	7.6
E.C(mmhos/cm)	11.2	11.9	12.9	11.09	11.26	13.1
TDS	10689.6	11862.6	12113.4	10689.3	10685	13081.8
Al	1.78	2.11	2.2	2.78	3.11	4.2
Ba	1.445	1.557	1.755	1.545	2.557	3.557
Cd	0.002	0.0024	0.0028	0.004	0.0042	0.0088
Cr	0.066	0.078	0.095	0.076	0.087	1.05
Cu	0.495	0.596	0.659	0.549	0.596	0.933
Co	0.013	0.015	0.016	0.042	0.051	0.0631
Fe	6.43	6.7	7.3	7.34	7.6	7.83
Mn	0.193	0.209	0.239	0.319	0.409	0.623
Pb	0.256	0.345	0.459	0.526	0.435	0.596
Ni	0.028	0.031	0.038	0.068	0.081	0.098
Mo	0.047	0.055	0.076	0.077	0.098	0.107
Zn	0.302	0.352	0.402	0.372	0.523	0.602
BOD	1206	1955	2770	1326	1458	2115
COD	3310	4315	6220	3972	4965	6620
Phenol	1.678	1.84	2.013	2.134	2.52	3.011
TOG	58.071	71.805	85.71	136.33	166.33	206.23
TPH	41.6	51.80	59.31	90.88	110.8	137.4
PAHs	66.30	75.09	83.71	91.12	98.92	107.59
TC (CFU/100ml)	$20X10^3$	12000	$9 X10^3$	$23 X10^3$	$26 X10^3$	$28 X10^3$
FC(CFU/100ml)	$9 X10^3$	$6 X10^3$	$4 X10^3$	$8 X10^3$	$10 X10^3$	$12 X10^3$
Total Hardness	2040.7	2313.9	2452.5	2040.06	2040.06	2494.7
SAR Ratio	95.05	98.93	97.85	95.06	95.02	105.31

Rapid Impact Assessment Matrix (RIAM)

The data of hazard pollutants did not agree with the approval limits for United States Environmental Protection Agency **USEPA 2012** standards for produced water and drilling reuse **(Badawi *et al.*, 2023)**. Therfore, some procedures were done to solve the waste problems. Rapid Impact Assessemet Matrix (RIAM) algorithm was used to assess the most technique could used to solve the waste problem with minimum impacts on environment. RIAM presents a transparent and eternal record of the evaluation process while on the identical time organizing the EIA manner, which in turn considerably reduces the time taken in executing EIAs **(Pastakia 1998)**.

The importance of the evaluation criterion used in RIAM is divided in two groups: criteria relative to the degree of the relevance of the condition, and that individually can alter the resulting classification (A); criteria relative to the development of the condition but individually is not capable of altering the obtained classification (B).

For organization A, the general citation machine is composed in multiplying the marks attributed to every criterion. The principle of multiplication insures that the burden of each criterion intervenes at once. For group B, the overall quotation machine is composed in including the marks attributed to every criterion. This insures that a mark taken in isolation can not affect a good deal the overall end result. The technique is for that reason expressed through the subsequent set of equations **(Jensen, 1998)**:

$$\textbf{(k1) X (k2)} = \boldsymbol{a}\textbf{T} \quad (1)$$

$$\textbf{(v1) + (v2) + (v3)} = \boldsymbol{v}\textbf{T} \quad (2)$$

$$\textbf{(kT) X (vT) = ES} \quad (3)$$

Where,

(k1) and (k2):	Person criteria ratings which can be of significance to the circumstance (organization A), and which could in my view trade the rating obtained;
(vl) to (v3):	Individual standards ratings which might be of value to the situation (institution B), but individually must not be able to changing the rating acquired;
kT:	The result of multiplication of all (A) ratings;
vT:	The result of summation of all (B) ratings; and
ES:	The assessment scores for the situation.

RESULTS AND DISCUSSION

According to the chmical and biological analysis of oil field waste water, Figure (2a) shows the values ranged from 7.3 to 7.9 mg/l with mean value is 7.59 for produced water and drilling wastewater that within **USEPA 2012** limits (6-9) and confirmed with oil fields ranging (6 to 7.7) as reported by **Dawoud *et al.*, 2021**. There are two types of conductivity: intrinsic conductivity due to the mentioned factors or extraneous conductivity due to ion’s concentration already existing in the sample such as chloride, calcium, sodium, magnesium, and other ions. It was noted that the conductivity of produced water and drilling wastewater field was in the range of 11–13 mmhos/cm **(Fillo and Evans, 1992)** as reported in Table (2). Salinity can be described as TDS that vary in conventional oil and gas well produced waters from 1000 - 400,000 mg/l **(Alsalem, and Thiemann, 2022)**. Total dissolved salts for produced water and drilling wastewater concentrations ranged from 10689.6 to

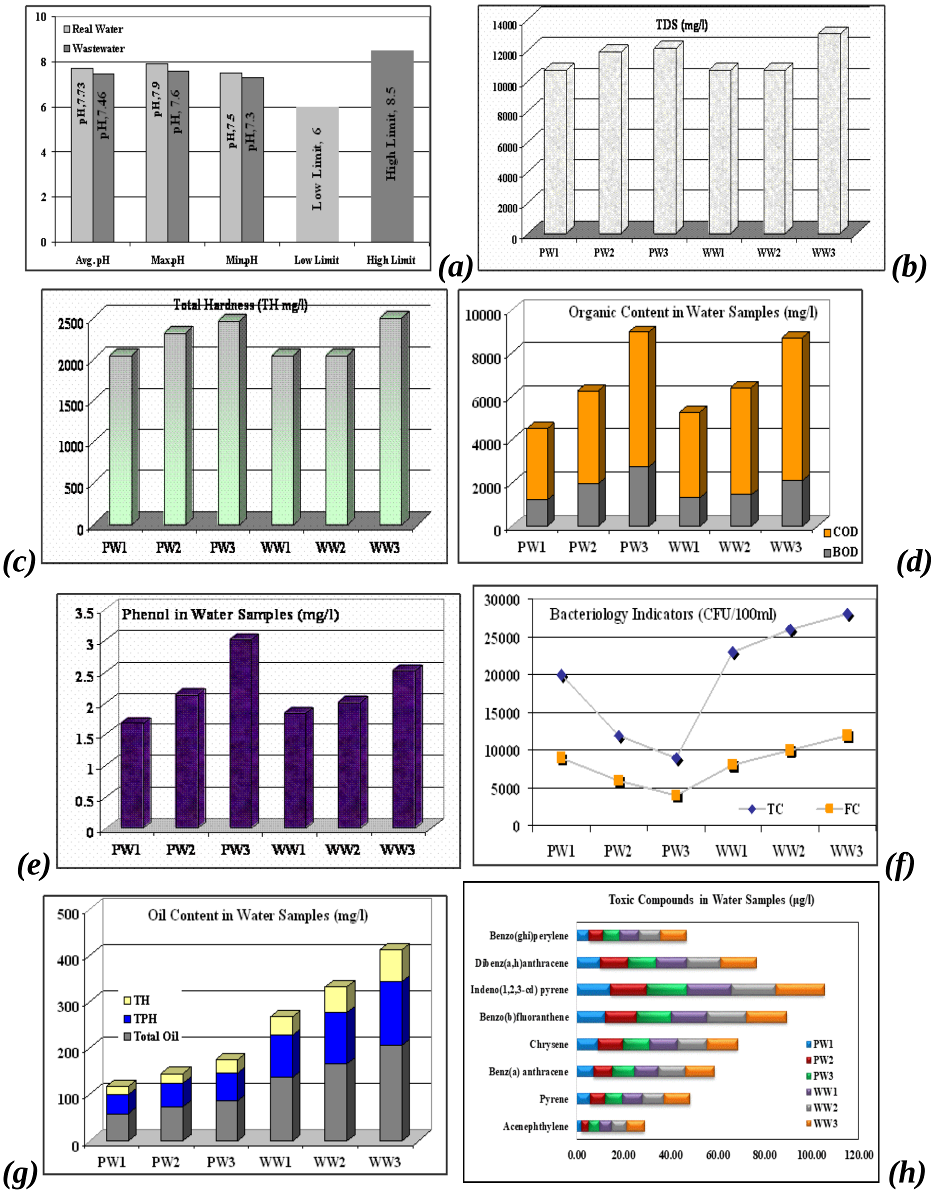
13081.8 mg/l that fell in TDS standard for sea water (500 to 30,000mg/l) **(Razak *et al*., 2022)** and more than (2000 mg/l) limits for wastewter reuse for irrigation **(Gabr, 2019 and FAO, 2023)** and drinking water **(WHO, 2017)** as shown in Fig.2b.

In the present study, hardness of oilfield for produced water and drilling wastewater varied from 2040.7 to 2494.7 mg/l as $CaCO_3$ (>180 mg/l-very hard permissible limit) as listed in Table 2 and Fig.(2c). These results clarified oilfield produced water and drilling wastewater can not be use for irrigation applications and drinking water**.** So, the study suggest all soild suspends must be removed.

Recent studies clarified ecological effects (TDS, COD, BOD and TC) are indirect indicators **(Slavov, 2017)** that can be used for produced water and drilling wastewater identification hazards risks **USEPA, 2012** and **USEPA., 2019** standards. Fig.(2d) described the variation trend of organic matter including BOD (1206 to 2770 mg/l) and COD (3310 to 6220 mg/l) that is more than 30mg/l **(USEPA 2012)**.

High phenol concentrations in all samples (1.678 to 3.01 mg/l) might be due to the use of additive chemicals as shown in Fig.(2e) which industrial manufactures reveal all phenol values are unacceptable limits for drinking water use **WHO, 2017** and environmental protection **(EPA, 2012)** (<0.002mg/l) for wastewater reuse. The present results demonstrate microbial charcterization for produced water and drilling wastewater that recorded the mean value of the total coliform (TC: $9X10^3$ to $28X10^3$ CFU/100ml) and fecal coliform (FC: $4X10^3$ to $12X10^3$ CFU/100ml), as shown in Fig.(2f). These values are inacceptable for drinking water and irrgation vegatables (>200 CFU/100ml **USEPA 2012** and **WHO, 2017**).

The differences of data that are not approved with **USEPA 2012** for water reuse are attributed to qualify nature of organic loads, the type of the operational conditions in the study. As can be seen in Table 2, produced water and drilling wastewater had levels of organic load, heavy metals, and hydrocarbons (Fig.3). This underpins the need for proper physicochemical characterization of concretes wastewater with thermal treatment (pre-treatment) drill cuttings before putting them to the intended use.

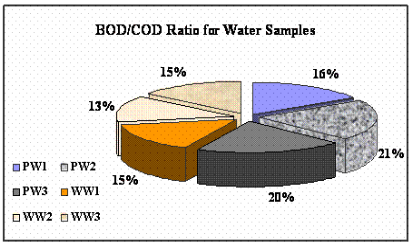


Figs.(2a,b, c, d, e, f, g, h): Variation trend of different environmental measurements H, TDS, TH, BOD, COD, Phenol, TC & FC and for drilling Wastewater

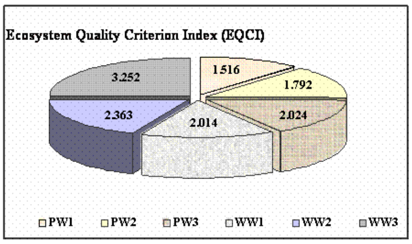
Table 2 recorded petroleum hydrocarbon concentrations which is a combination of hydrocarbon containing mostly four groups: BTEX (volatile aromatic compounds: benzene, toluene, ethylbenzene, and xylene), phenols, polycyclic aromatic hydrocarbons (PAHs ranged from 66.30 to 107.59 µg/l) and NPD (naphthalene, phenanthrene, and dibenzothiophene). The total petroleum hydrocarbons values ranged from 41.6 to 137.4 mg/l for produced water and drilling wastewater as shown in Fig.(2g, h). While oil and grease values ranged from 58.071 to 206.23 mg/l for produced water and drilling wastewater that confirmed by **Eldos *et al*., 2022**.

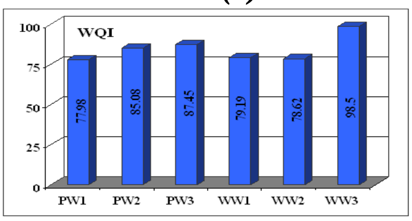
Figure 3c clarified the water quality of produced water and drilling wastewater for irrigation purposes associated with major ions concentrations that affect on soils and plants. For instance, high salt concentration as described by SAR ratio (Table 2) in irrigation water (**FAO, 2023:**>9) can be harmful to crops by changing soil structure, and plant metabolic processes, decreasing plant growth rates and promoting salt accumulation in soil profiles **(Chidiac etal., 2023)**.

(a)



(b)





(c)

Fig.(3a,b,c): Trend of WQI for produced water and drilling wastewater

Results of Rapid Impact Assessment Matrix (RIAM)

To determine the best way of wastes management in the current study area, there are four different methods to select,

1. No action (NA); or manage the wastes by:
2. Above-ground disposal
3. Partially-underground disposal
4. Totally-underground disposal

Scoring, evaluation and assessment criteria in line with the influences of the water sources management issues beneath four distinctive additives have been assessed and given rankings on the basis of the standards indicated in Table 3.

Physical/Chemical (PC): Environmental aspects those are physical and chemical.

Biological/Ecological (BE): Environment's biological components.

Sociological/Cultural (SC): Environmental aspects related to humans.

Economic/Operational (EO): Impacts of environmental change on the economy.

The program then computed the ratings to arrive on the very last Environmental scores (ES) from which the range bands indicated in Table 3 were decided on.

Table 3: Environmental Scores (ES)

Environmental Score	Range Bands	Description of Range Bands
+72 to +108	+E	Major positive change/impacts
+36 to +71	+D	Significant positive change/impacts
+19 to +35	+C	Moderately positive change/impacts
+10 to +18	+B	Positive change/impacts
+1 to +9	+A	Barely high quality change/affects
0	N	No alternate/fame not applicable
-1 to -9	-A	Slightly negative impacts
-10 to -18	-B	Negative impacts
-19 to -35	-C	Moderately negative impacts
-36 to -71	-D	Significant negative impacts
-72 to -108	-E	Predominant bad impacts

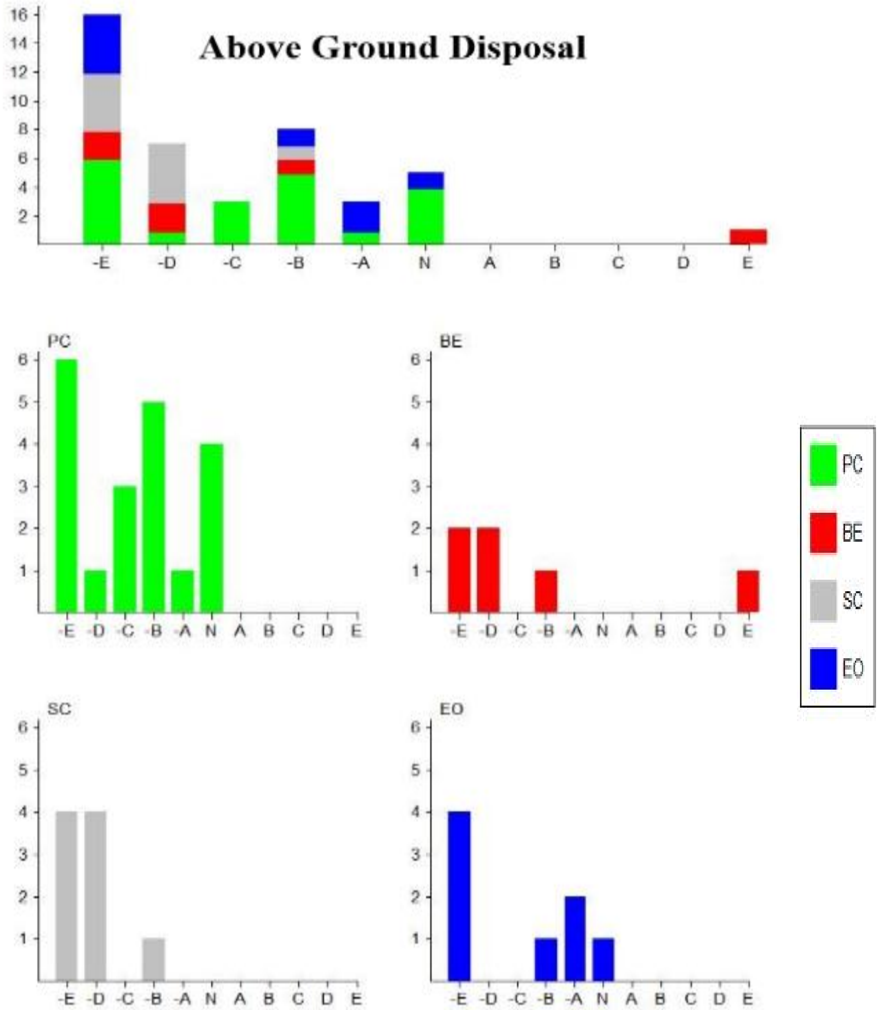
Table 4 shows impacts of produced wastewater management problems on environmental signs including thermal treatment, open system pond, storage underground, and partially storage under ground.

Table 4: Impacts of water control troubles on environmental indicators

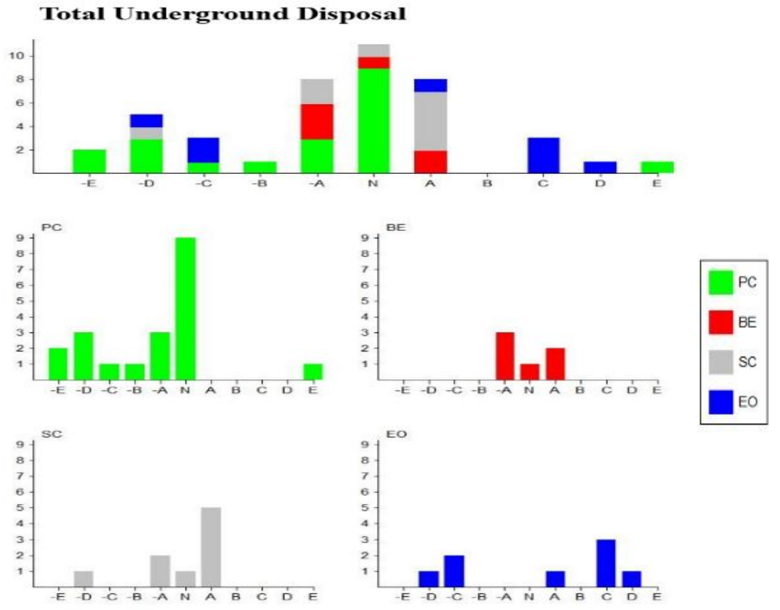
1-No action (NA)	Assuming that no action is to be taken / or the waste disposal operation will continue the same traditional way without implementing the landfill site.
2- Above-ground disposal	Assuming that waste disposal is totally above the ground surface / or the waste disposal operation will be in a form of piling up huge piles or heaps without excavating the landfill pit. So all the waste will be on the ground surface, however, covered at time intervals and capped at the end.
3-Partially-underground disposal	Assuming that a part of the waste disposal is above the ground / or the waste disposal operation will take place in partially excavated wedges inscribed in ground taking advantage of the level differences (topographic variations) of the ground at the project site.
4- Totally-underground disposal	Assuming that waste disposal is totally below the ground surface / or the waste disposal operation will take place in an excavated pit with all necessary measures and precautions needed to be taken for constructing a sanitary landfill, as described before.

Figures 4a, b,c illustrated the conceptual steps of prioritizing produced water and wastewater resources management problems implementation of this alternative. It is concluded that the option that has the most positive impact on environment is thermal treatment that is expected to be the most expensive option. A choice of disposal partly underground, no action and partially above the ground would be most reasonable for environmental pollution, waste time and high environmental cost for land and ground water.

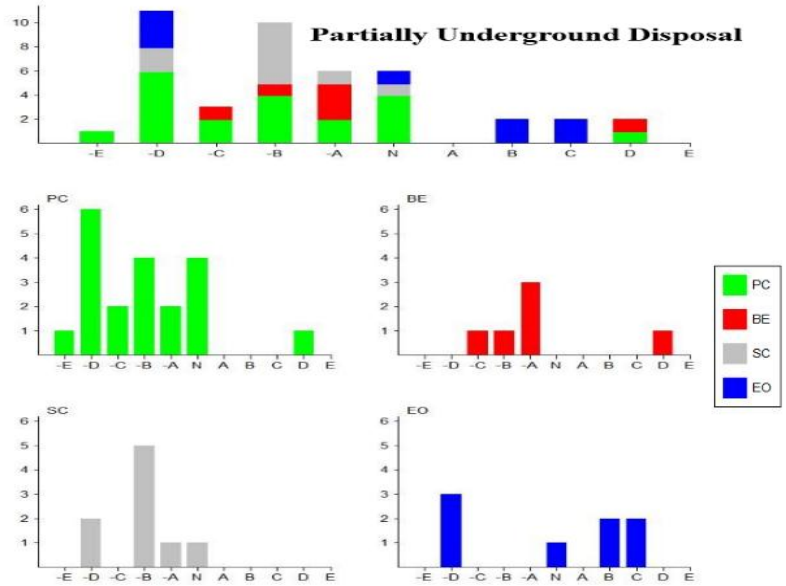
As the option "no action" were a non-suitable option, and not agree with the EEAA, it was excluded from options.



A



B



C

Fig 4(a.b.c): The conceptual steps of prioritizing produced water and wastewater

The results from RIAM showed some facts:

1. In the first option "above ground disposal", the physical environmental component (green) have a high negative impacts on environment with no positive impact at all. While the biological environmental impacts (red) have one high positive impacts, but has negative impacts triple the positive value; for the social and culture component (grey) and the economic and operation component (blue) have almost the same negative impacts with no positive impacts at all on environment.
2. In the second option "total underground disposal", the physical environmental component (green) have a high negative impacts on environment with only one positive impact. While the biological environmental impacts (red) and the economic and operation component (blue) have relatively the same low positive and negative impacts; for the social and culture component (grey) have some negative impacts with higher positive impacts with moderate values on environment.
3. In the last and third option "partially underground disposal", the physical environmental component (green) have a high negative impacts on environment with only one positive impact. While the biological environmental impacts (red) have equal negative and positive impacts; for the social and culture component (grey) have only negative impacts. The economic and operation component (blue) have some negative impacts with high positive impacts on environment.

The results indicate that all the options have negative impacts on environment. So, the key to select the best option is how those negative impacts could mitigated. Some impats that could not diminished so the option could not used. While if the negative impacts in option that could mitigate allow us to select and use this option.

The "partially underground disposal" option found to be the best option as all its negative impacts (like it costs some funds, it consume some effort and time, it need sutable piece of land to be used as a dump area) could excuted and achieved.

CONCLUSION AND RECOMMENDATION

Wastewater needs to identify hazards pollutants and assess associated risks for tolerance on an ongoing basis using USEPEA standards and guidelines. Three drilling wastewater samples along Sabriyah Field-North Kuwait are chosen for hazard pollution examination. The water chemistry results exceeded **USEPA 2012, FAO, 2023** standards limits which reported their wastewater quality must have suitable treatment. Therefore, the study assessed their consideration analysis (COD, BOD and COD/BOD). The results reported had differences attribute to qualify nature of organic loads, the type of the operational conditions and mainly the dissimilarity of drilling wastewater Sabriyah Field-North Kuwait in the present study.

The data of hazard pollutants did not agree with approval limits for **USEPA 2012** standards for produced water and drilling reuse **(Badawi etal., 2023)**. Therfore, RIAM provides a transparent and permanent document of the evaluation technique whilst at the identical time organizing the EIA manner, which in turn drastically reduces the time taken in executing EIAs **(Pastakia 1998)**. The study recommended that theramal treatment can play key role in drilling treatment unit. A choice of disposal partly underground, no action and partially above the ground would be most reasonable for environmental pollution, waste time and high environmental cost for land and ground water.

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تقييم الأثر البيئي لعمليات حفر مخلفات المياه السائلة في الحقول النفطية

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تنتج عملية الحفر كميات كبيرة من النفايات التى تشمل المياه ومخلفات الحفر ويمكن أن يكون لها آثار سلبية على البيئة وصحة الإنسان. لذا تتطلب إدارة مخلفات الحفر بشكل صحيح إجراءات لضمان عدم وجود أي تأثير على البيئة والناس.

أجريت هذه الدراسة لتقييم الآثار البيئية للنفايات، وتحديد الطريقة المثلى لحل مشكلتها . وقد تم استخدام تقنية برنامج تقييم الأثار البيئية (RIAM) كتقنية حديثة لاختيار أفضل البدائل لإدارة مخلفات الحفر من بين ثلاثة خيارات بيئية لإدارة النفايات هي اولا (التخلص من فوق

سطح الأرض؛ ثانيا. إجمالي التخلص تحت الأرض؛ ثالثا. التخلص جزئيا تحت الأرض). كما كشفت النتائج التي تم الحصول عليها من هذا العمل إلى أن المعالجة الحرارية هي عملية مهمة في وحدة معالجة الحفر لإدارة مخلفات آبار الحفر. وتبين أن النفايات الناتجة في حقول النفط لها آثار سلبية كبيرة على البيئة، لذا يجب التخلص منها باستخدام الخيار الثاني. وأخيرًا، فإن استخدام التقنيات الحديثة مثل RIAM يساعد علي تحديد أفضل البدائل ويوصى بشدة باستخدامها في حالات أخرى.

أوصت الدراسة بأن اختيار التخلص جزئيا تحت الأرض هو الأسلوب الأكثر فعالية للتخلص من النفايات، والأكثر معالجه للتلوث البيئي.