

Soil Assessment in South and North Kuwait Oil Fields: A Baseline Study

Dhari Al-Anjari¹, Aisha Al-Baroud² and Sherifah Al-Hashash³

Kuwait Oil Company, Ahmadi, Kuwait.

Corresponding Author: Sherifah Al-Hashash.

Received: September 17, 2026 / Accepted: September 28, 2026 / Published: Vol. 11, Issue 10, pp. 1-12, 2026

Abstract: Kuwait's primary oil-field sectors in North Kuwait (NK) and South Kuwait (SK) suffered extensive soil contamination and physical disturbance during the 1990–1991 Gulf War. Although hydrocarbon impacts have declined significantly over the past three decades, persistent soil chemical alterations continue to limit plant establishment in these arid ecosystems. Soil properties comprise inherent qualities determined by parent material, climate and biological factors, and dynamic qualities that respond to management. This study evaluated dynamic soil properties across 35 monitoring plots in NK and SK during the winter and summer 2024 campaigns to establish a baseline for monitoring and identify specific soil limitations to revegetation. Plots represented five site categories: reference, control, revegetation, effluent-pit control, and effluent-pit revegetation. Utilizing USDA (United States Department of Agriculture) & Natural Resources Conservation Service (NRCS) protocols, dynamic soil health was evaluated via Electrical Conductivity (EC_e), Sodium Adsorption Ratio (SAR), Chloride (Cl^-), Organic Matter (OM) and Saturated Infiltration Rate, with group and seasonal variations analysed through non-parametric tests.

Results reveal that SK effluent-pit plots are chemically and physically distinct; most are moderately to strongly saline, and exceed the sodicity threshold, with elevated chloride levels imposing severe ionic stress on establishing vegetation. Elevated OM may partly reflect residual petroleum-derived carbon rather than solely biological recovery, while higher infiltration rates may reflect physical disturbance associated from past remediation. Residual salinity, sodicity, chloride toxicity, and physical soil disruption represent the primary bottlenecks to successful revegetation. These outcomes emphasize the necessity of tailored site management and continuous long-term surveillance to track soil recovery and guide effective ecological restoration.

Keywords: Kuwait oil fields; Soil properties; Baseline monitoring; Revegetation.

1. Introduction

Kuwait is a hyper-arid country on the north-western edge of the Arabian Peninsula, covering about 17,818 km². The country's climate is characterised by long, hot summers with typical maxima of 42-48°C, milder winters, and annual rainfall of 75-150 mm. Under these conditions, the soils are dominantly Aridisols, which are generally water-deficient and low in organic matter, and Entisols, which are deep, undeveloped sandy soils [2]. Plants cover on these soils is naturally sparse, and once it is lost or degraded, the soil is exposed to wind erosion, salinisation and further degradation.

On these fragile soils, Kuwait's oil-field environments have been further shaped by the 1990-91 Gulf War. During the war, an estimated 700 oil wells were ignited, creating about 300 oil lakes over 110 km² of desert; heavy crude penetrated the soil to varying depths and left a widespread residue of weathered, long-chain hydrocarbons. Following an award from the United Nations Compensation Commission of over \$2 billion to clean up the oil lakes, large-scale remediation has taken place in Kuwait over the last three decades [3]. This is being conducted by the Kuwait Oil Company (KOC) through the Kuwait Environmental Remediation Programme (KERP). KERP includes oil-field areas in both North Kuwait (NK), including the Raudhatain and Sabriya fields, and in South Kuwait (SK), centred on the Greater Burgan field. KOC's sites include former effluent pits, engineered features originally constructed as lined or unlined bermed pits for oil-field water and brine waste disposal [4]. These pits were later decommissioned and remediated, and the plots form part of the larger KERP programme.

Within the remediated areas do not constitute a uniform landscape, as soil characteristics vary according to the remediation techniques employed and the nature of the contamination at each site [5]. Because revegetation success is primarily determined by soil condition rather than the extent of hydrocarbon removal, comparative evaluation of KERP-remediated soils with undisturbed reference soils is essential to assess their suitability for revegetation.

2.0 Soil Health and the Basis for Baseline Assessment

2.1. Soil Health and Key Soil Parameters

This comparative assessment is based on a working concept of soil health that is applied through a defined set of parameters. Soil Health can be defined as the soil's capacity for supporting plant life, maintaining ecosystem functions and allowing native species to recolonise. Successful revegetation is assessed based on the restoration of soil function and not simply on a reduction in contaminant levels in the soil.

Restoring soil function is not a single-property problem: two levels of soil properties shape soil functioning. The first is inherent and formed over time through the interaction of parent material, climate, landscape features, and biological activity. For the surveyed areas of Kuwait, this inherent layer has been classified as Entisol and Aridisol. The two orders cover most of the studied area in Kuwait and provide the basis for assessing the inherent ability of each site [2]. The other level is dynamic and varies depending on disturbance and management practices.

On this dynamic layer, the five parameters below determine whether native vegetation can re-establish in KERP's revegetated areas (Fig. 1).

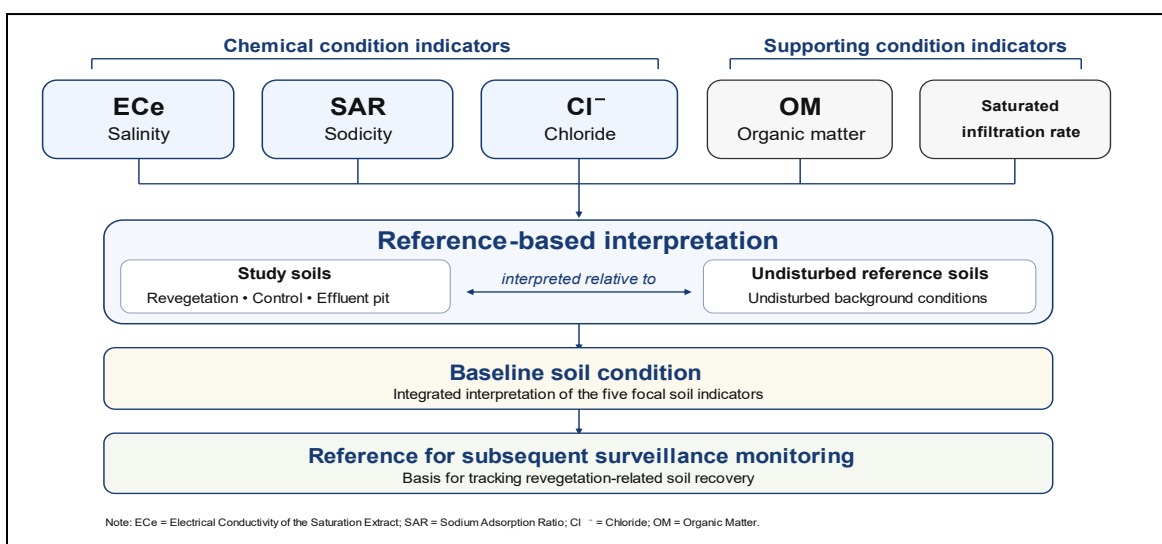


Fig. 1. Conceptual framework for baseline soil condition assessment

The Electrical Conductivity of the Saturation Extract (EC_e) measures the overall amount of salt in the soil, which primarily governs plants' access to water in arid soils. The Sodium Adsorption Ratio (SAR) is an index of soil sodicity. If SAR rises, it will increase instability in the soil structure, and when the soil is wetted, it will reduce roots' ability to penetrate. Chloride (Cl⁻), one of the major soluble anions in saline soils, was included as a supplementary indicator of salt loading [7]. Soil organic matter (OM) reflects the level of biological activity going on in the root zone, along with the nutrients available to the roots. When remediation has taken place, OM is often depleted, while associated compaction may reduce root penetration and infiltration. Once infiltration has occurred, it then regulates both salt leaching and water recharge in the root zone under arid conditions. This makes up the final component of the parameter set. Together, these five parameters anchor the comparative assessment used against undisturbed reference conditions throughout this study.

2.2. Distinct Post-Remediation Soil States

The different approaches used to remediate KERP sites have varying effects on the soil, post-remediation conditions cannot be represented by a single soil condition [5]. These differences persist following hydrocarbon removal, manifesting across the physical, chemical, and biological properties of treated soils compared to undisturbed reference areas [6]. This variability is evident across the five site categories evaluated in this baseline study with effluent-pit settings offering a clear example. Soils within the SK field sites, particularly in the Greater Burgan region, remain sandy, characterized by minimal organic matter and high salinity in the arid environment [4]. Consequently, vegetative limitations at these sites extend beyond residual hydrocarbon levels to include widespread salt-affected soil conditions [3 & 7].

Because of this heterogeneity, each non-reference plot type is assessed separately using the same five parameters and compared against corresponding undisturbed reference plots (Fig. 2). This assessment establishes a baseline from which the long-term impact of revegetation on soil properties can be evaluated over time.

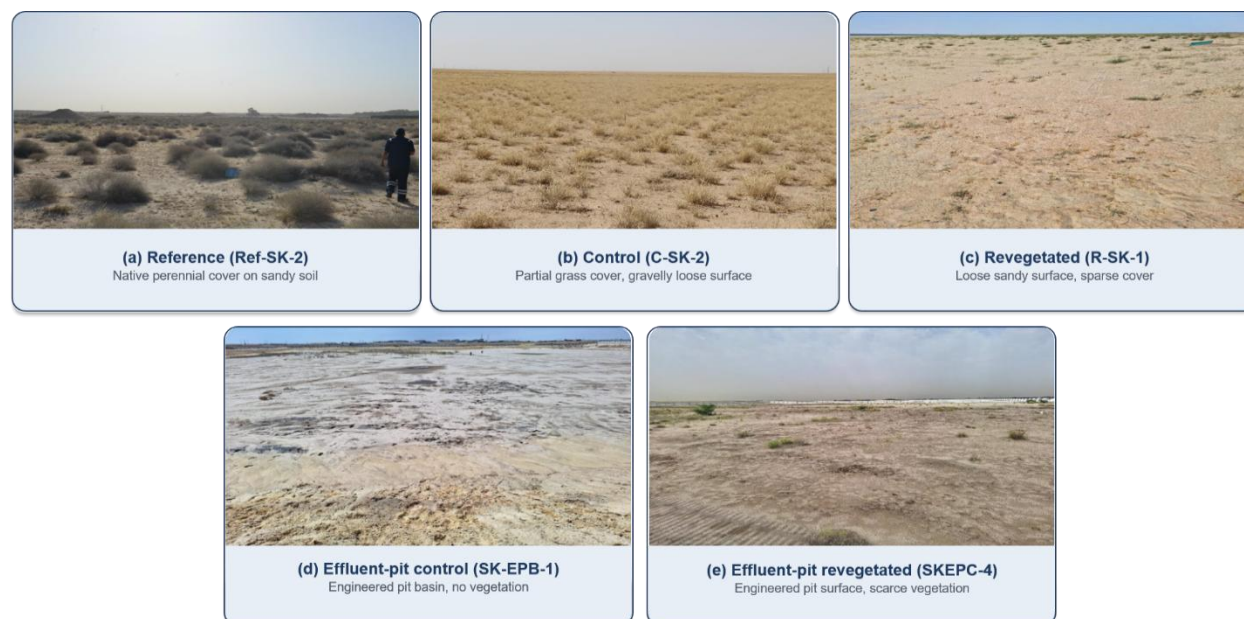


Fig. 2. Representative field views of the five site categories used in the baseline study

3. Materials and Methods

As part of the ecological surveillance monitoring programme implemented by KOC in the NK and SK oil-field areas (Raudhatain–Sabriya and Greater Burgan), a baseline soil investigation was conducted during the winter and summer campaigns of 2024. This baseline provides the reference point that will be used to monitor soil conditions throughout the surveillance activity to measure the level of soil recovery for revegetation.

3.1. Study Area and Plot Network

The network comprised 35 monitoring plots, 12 in NK and 23 in SK. Each plot measured 20 m × 70 m and was assessed in both campaigns. Plots were categorised into five types: reference (undisturbed background), control (un-revegetated), revegetation (actively planted), effluent-pit control (remediated effluent-pit soil, not revegetated) and effluent-pit revegetated (remediated effluent-pit soil, revegetated). All effluent-pit plots were located in SK. There were a total of five investigation points per plot, giving 175 points across the network. Fig. 3 shows a map of the general locations of the plots and the number of soil samples collected on each plot type during each campaign.

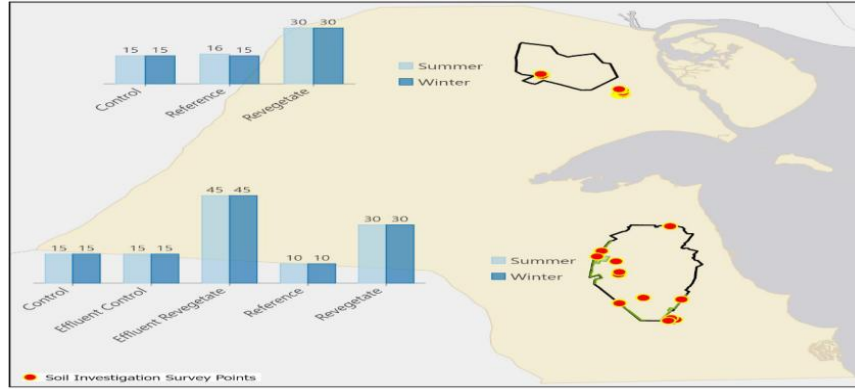


Fig. 3. Distribution of soil investigation sampling points across the North Kuwait (NK) and South Kuwait (SK) study areas.

3.2 Field and Laboratory Assessment

Soil samples were obtained at each of the five sampling locations in each of the plots during both campaigns. At each point, one composite sample of about 1 kg was taken from the upper 15 cm using a specially designed sampling tube. At each point, one composite sample of about 1 kg was taken from the upper 15 cm using a specially designed sampling tube. The interval of 0 – 15 cm was chosen based on an ecological monitoring sampling plan to provide a uniform baseline of surface soil conditions relevant to seedling growth and initial revegetation for all plots and campaigns. The sampling was not intended to delineate the full vertical extent of residual contamination. All analyses at the KISR (Kuwait Institute for Scientific Research) soil laboratory followed USDA-NRCS protocols [8]. Although the broader investigation measured additional soil properties, this paper focuses on five parameters selected to represent the principal dynamic chemical and physical conditions relevant to revegetation: salt loading (EC_e and Cl^-), sodicity-related structural risk (SAR), organic condition (OM) and soil-water movement (saturated infiltration rate). Salinity and sodicity classifications for the soils in this paper use the thresholds shown in Table 1 [1].

Table 1. Classification thresholds used to interpret soil salinity and sodicity.

Property	Class	Range	Interpretation
Soil salinity — EC_e ($mS\ cm^{-1}$)	Non-saline	< 2	Salinity effects mostly negligible
	Very slightly saline	2 to < 4	Yields of very sensitive crops may be restricted
	Slightly saline	4 to < 8	Yields of many crops may be restricted
	Moderately saline	8 to < 16	Only salt-tolerant crops exhibit satisfactory yields
	Strongly saline	≥ 16	Only a few very salt-tolerant crops show satisfactory yields
Soil sodicity — SAR ($(mmol\ L^{-1})^{0.5}$)	Non-sodic	< 13	No sodicity hazard
	Sodic	≥ 13	Sodicity hazard;

Sources: Salinity class boundaries adapted from the USDA Soil Survey Manual (Soil Science Division Staff, 2017); salinity-related crop responses, the $SAR \geq 13$ sodicity threshold and gypsum-management interpretation adapted from Zaman et al. (2018).^{7,9}

4. Results

Table 2 presents the observed ranges of the five key soil parameters across the five site categories during both baseline monitoring campaigns. The following subsections provide a detailed description of the distribution of each parameter and its variation among the different site types.

Table 2. Baseline ranges of the five focal soil parameters across the five site categories in the winter and summer 2024 campaigns.

Site category (region)	Season	EC _e (mS cm ⁻¹)	SAR ((mmol L ⁻¹) ^{0.5})	Cl ⁻ (meq L ⁻¹)	OM (%)	Sat. infiltration (mm h ⁻¹)
NK non-effluent (Ref, Con, Reveg)	Winter	0.85–3.05	0.29–0.68	0.39–4.29	0.42–0.96	90–151
NK non-effluent (Ref, Con, Reveg)	Summer	0.74–2.96	0.29–1.07	0.67–7.94	0.43–1.04	120–240
SK non-effluent (Ref, Con, Reveg)	Winter	0.39–1.68	0.26–1.46	0.37–6.58	0.25–0.83	90–270
SK non-effluent (Ref, Con, Reveg)	Summer	0.47–1.18	0.18–1.11	0.58–4.40	0.47–1.49	120–300
SK effluent-pit control (SKEPB-1-1C to -3C)	Winter	19.37–22.09	27.52–33.02	169.0–210.0	0.59–0.90	180
SK effluent-pit control (SKEPB-1-1C to -3C)	Summer	12.88–21.65	19.39–30.55	116.2–218.5	0.93–2.23	180–210
SK effluent-pit revegetated (9 plots)	Winter	1.18–56.00	0.45–22.94	1.5–615.4	0.34–2.24	210–540
SK effluent-pit revegetated (9 plots)	Summer	1.16–72.33	0.47–33.85	1.4–840.8	0.70–3.44	180–480

Values are minimum–maximum ranges across all plots in each site category. EC_e, Electrical Conductivity of the Saturation Extract; SAR, Sodium Adsorption Ratio; Cl⁻, Chloride; OM, Organic Matter. SAR values ≥ 13 meet the sodic threshold shown in Table 2.⁷

4.1 Salinity, Sodicity and Chloride

The spatial distribution of the three principal parameters throughout the monitoring plot network during each campaign is presented in Figures 4 to 6. There is a similar trend with respect to all three: the effluent-pit plots sit well above the low end of the scale, while the NK and SK non-effluent plots are grouped together. Soil salinity levels were generally low across all non-effluent plots. In the NK plots, EC_e values ranged from 0.85 to 3.05 mS cm⁻¹ during the winter campaign and from 0.74 to 2.96 mS cm⁻¹ during the summer campaign. Similarly, the SK non-effluent plots remained within the non-saline class, with salinity levels that were, in some cases, lower than those recorded in the NK plots. EC_e values in these plots ranged from 0.39 to 1.68 mS cm⁻¹ during both the summer and winter campaigns.

Soil Assessment in South and North Kuwait Oil Fields: A Baseline Study

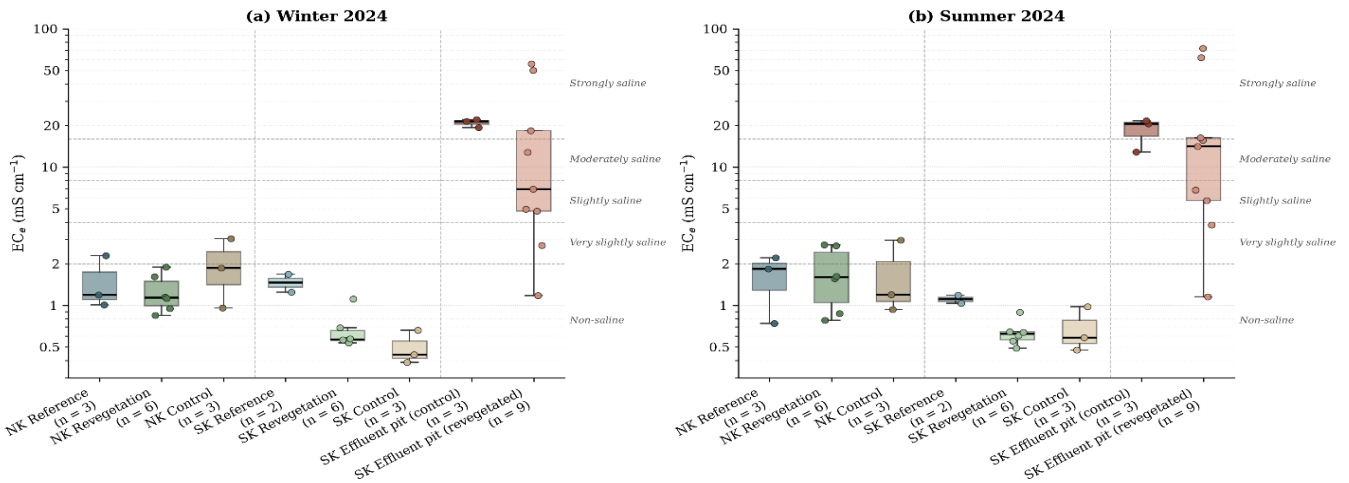


Fig. 4. Electrical conductivity of the saturation extract (EC_e , $mS\ cm^{-1}$) across the eight plot categories in (a) winter and (b) summer 2024.

In contrast, the control plots associated with the KOC's effluent pits (SKEPB-1-1C to SKEPB-1-3C) consistently exhibited strongly salinity, with EC_e values ranging from 12.9 to 22.1 $mS\ cm^{-1}$ across both campaigns. The nine revegetated effluent-pit plots displayed wider range of salinity levels, varying from 1.2 to 72.3 $mS\ cm^{-1}$. The highest salinity values were recorded in plots SKEPC-4-2R and SKEPC-4-3R (Fig. 4). A similar pattern was observed for soil sodicity. SAR values in the NK plots remained low, never exceeded 1.1 ($(mmol\ L^{-1})^{0.5}$) during either campaign. Likewise, SAR values in the and for the SK non-effluent plots, did not exceed 1.46 during the winter (recorded at REF-SK-1), and 1.11 during the summer campaign. In contrast, all three effluent-pit control plots recorded SAR values above the sodic threshold of 13, ranging from 19.4 to 33.0 across the two monitoring campaigns. Among the revegetated effluent-pit plots, all SAR values exceeded the sodic threshold, with the exception of plot SKEPC-4-1R, which remained below the threshold during both sampling events (Fig. 5).

Chloride concentrations exhibited a pattern similar to that observed for salinity and sodicity. In the NK plots, chloride concentrations ranged from 0.39 to 4.29 $meq\ L^{-1}$ during the winter campaign and from 0.67 to 7.94 $meq\ L^{-1}$ during the summer campaign. The SK non-effluent plots showed a comparable range, with chloride concentrations varying from 0.37 to 6.58 $meq\ L^{-1}$ across both monitoring periods. In contrast, the three effluent-pit control plots recorded substantially elevated chloride concentrations, ranging from 116 to 220 $meq\ L^{-1}$.

The nine revegetated effluent-pit plots had the greatest variability. The highest chloride was measured in plots SKEPC-4-2R and SKEPC-4-3R, reaching 615 $meq\ L^{-1}$ during the winter campaign and 841 $meq\ L^{-1}$ during the summer (Fig. 7). These concentrations indicate a substantial chloride load and potential plant-growth concern.

Seasonal differences were generally limited. The chloride concentrations remained relatively stable between both campaigns, with little change observed in overall plot rankings. The main seasonal effect in the SKEPC-4 plot series was a slight increase from winter to summer.

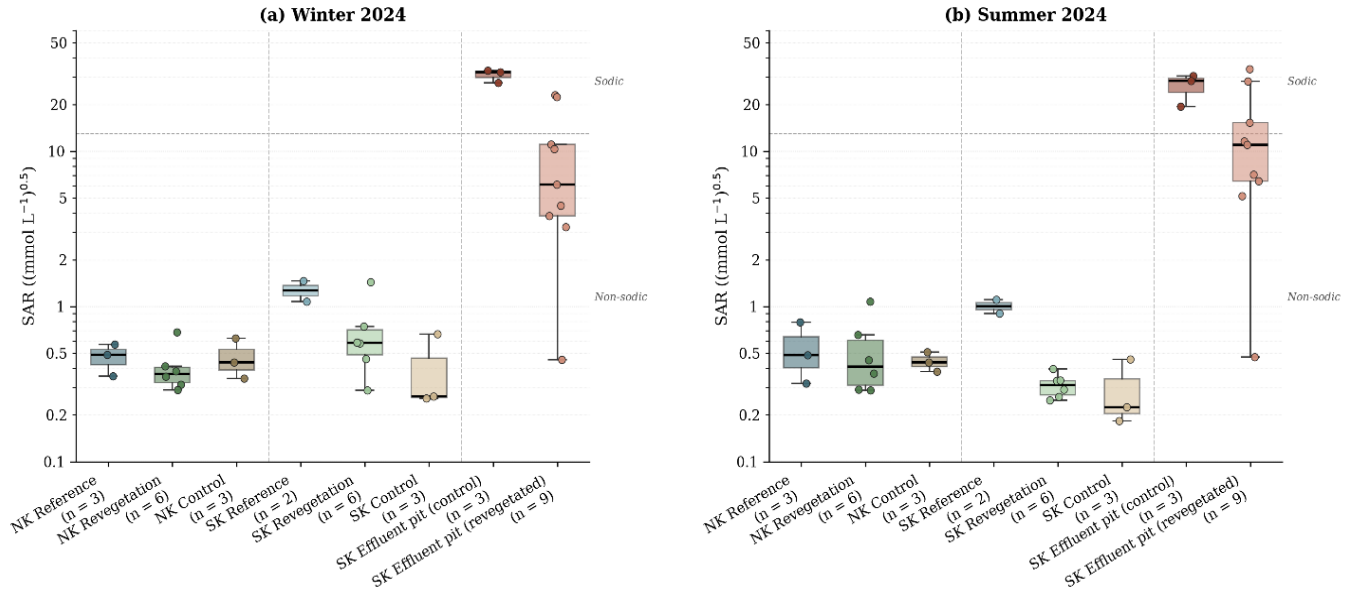


Fig. 5. Sodium adsorption ratio (SAR, $(\text{mmol L}^{-1})^{0.5}$) across the eight plot categories in (a) winter and (b) summer 2024.

4.2 Organic Matter

A similar pattern was observed for organic matter (OM), although it differentiated the effluent-pit areas from the rest of the network at a finer scale than the salinity parameters (Fig. 6). During the winter campaign, OM concentrations in the non-effluent plots of North Kuwait (NK) and South Kuwait (SK) generally ranged between 0.25% and 1.0%, while summer values ranged from 0.43% to 1.49%. Within the non-effluent group, the control and revegetation plots were comparable with the corresponding undisturbed reference plots. The three effluent-pit control plots (SKEPB-1-1C to SKEPB-1-3C) reached 0.59–0.90% in winter and 0.93–2.23% in summer. However, the highest OM values were consistently observed in the nine revegetated effluent-pit plots during both monitoring campaigns. These plots exhibited OM concentrations ranging from 0.34% to 2.24% in winter and from 0.70% to 3.44% in summer, with the maximum value recorded at site SKEPC-4-3R. Seasonal variation in OM was more pronounced than that observed for the salinity parameters and there was a general upward shift from winter to summer for OM in all of the effluent-pit plots.

Soil Assessment in South and North Kuwait Oil Fields: A Baseline Study

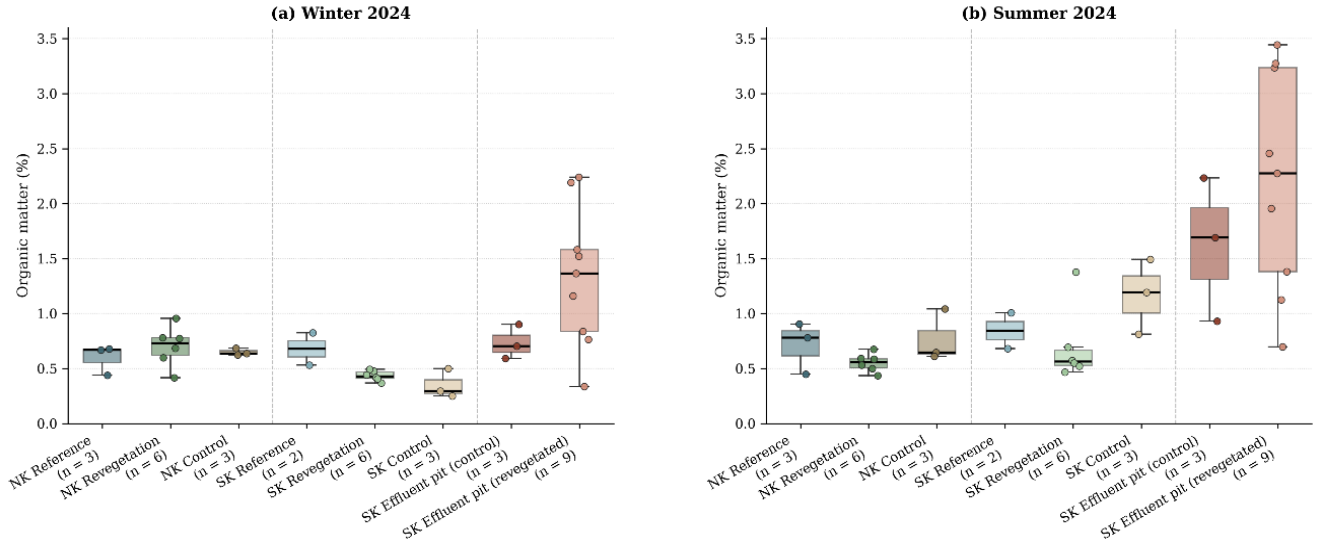


Fig. 6. Soil organic matter (OM, %) across the eight plot categories in (a) winter and (b) summer 2024.

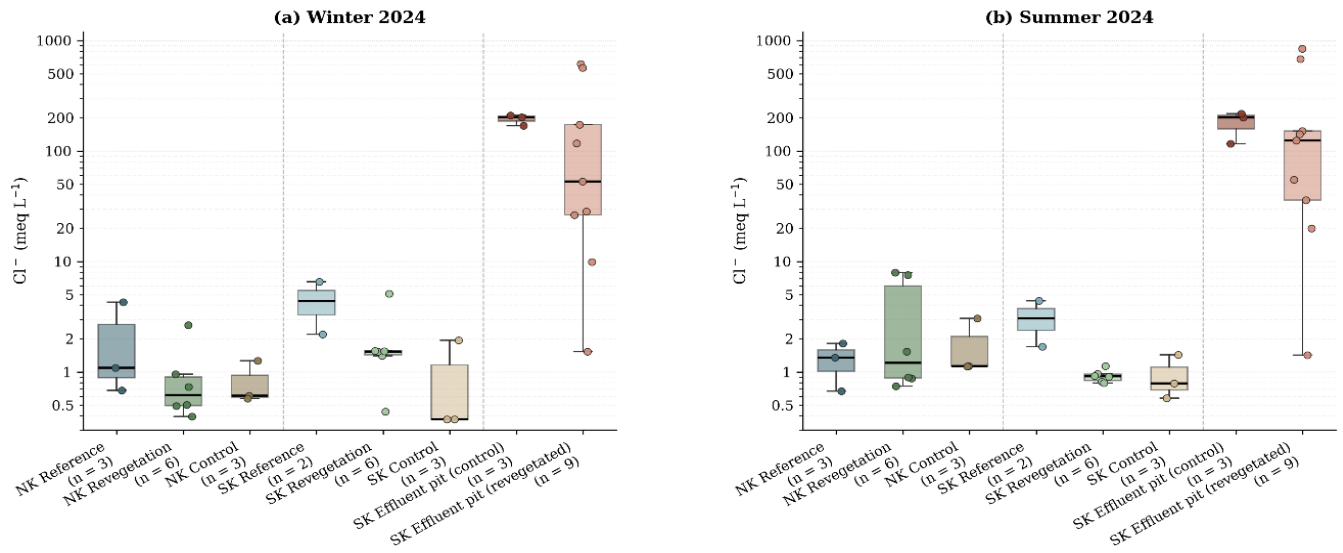


Fig. 7. Soluble chloride concentration (Cl^- , meq L^{-1}) across the eight plot categories in (a) winter and (b) summer 2024.

4.3 Saturated Infiltration Rate

Infiltration also differentiated the effluent-pit plots from the remainder of the monitoring network; however, the pattern was not as pronounced as that observed for the chemical parameters (Fig. 8). In the NK and SK non-effluent plots, saturated infiltration ranged from 90 to 270 mm h^{-1} during winter and from 120 to 300 mm h^{-1} during summer, within this group, the control and revegetation values overlapped with those measured in the corresponding undisturbed reference plots. All three of the effluent-pit control plots measured 180 mm h^{-1} during

each of their respective winter measurements and 180 to 210 mm h⁻¹ during the summer measurements. All nine effluent-pit revegetated plots exhibited the highest infiltration rates in both field campaigns, ranging from 210 to 540 mm h⁻¹ in winter and from 180 to 480 mm h⁻¹ in summer, with the peak recorded in the three SKEPB-2 plots (all at 540 mm h⁻¹ in winter). The plots with the highest SAR, the SKEPB-1 controls, did not exhibit the lowest infiltration rates, while the highest infiltration occurred in the SKEPB-2 plots, which had lower SAR. Thus, the expected inverse relationship between SAR and infiltration was not evident in this dataset. Moreover, unlike the salinity and OM characteristics, the seasonal variability in infiltration was minimal and inconsistent; the non-effluent plots exhibited slightly greater infiltration in summer than in winter, whereas the effluent-pit revegetated plots showed a slight decrease.

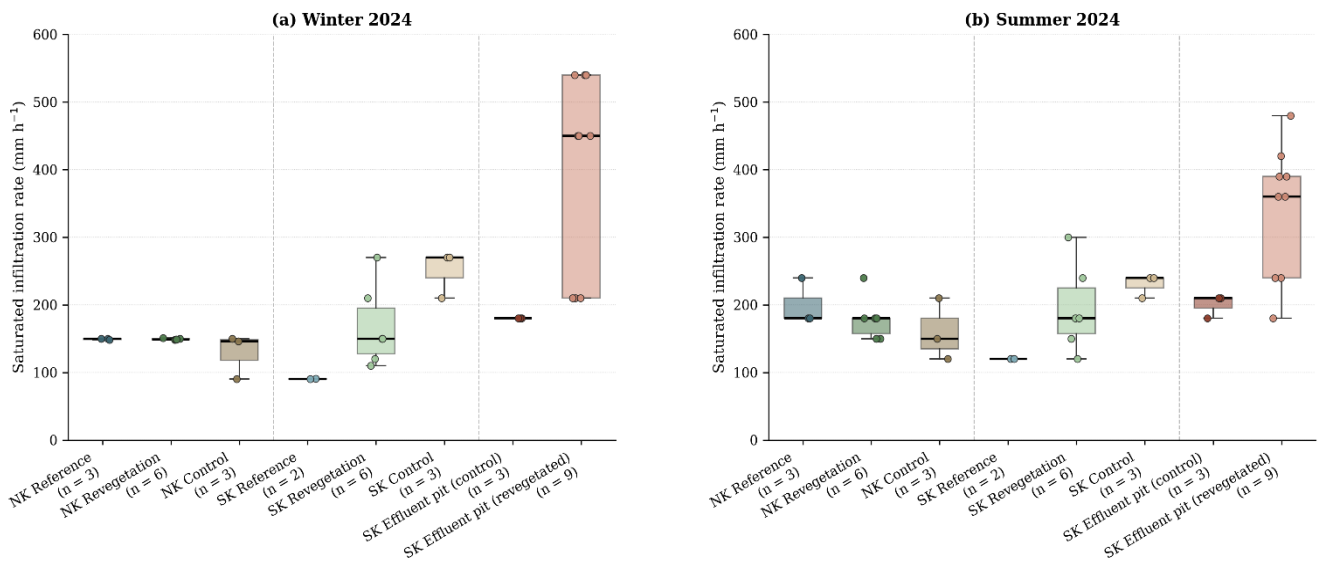


Fig.8. Saturated infiltration rate (mm h⁻¹) across the eight plot categories in (a) winter and (b) summer 2024.

5. Outcomes

The baseline assessment showed that the SK effluent-pit plots were markedly different from all other site categories, while the revegetation and non-effluent control plots in both NK and SK exhibited soil characteristics similar to the undisturbed reference plots. Statistical analysis identified effluent-pit status as the primary factor influencing soil variation, with all five measured parameters showing significant differences between SK effluent and non-effluent plots. In contrast, seasonal and regional effects were limited and inconsistent. The effluent-pit plots were characterized by high salinity, sodicity, and chloride concentrations, creating a chemically stressful environment for vegetation establishment. ECe values indicated moderate to strong salinity, while SAR exceeded the sodic threshold in several effluent-pit plots, posing risks to soil structure and plant growth. Elevated chloride levels further increased stress on plants. Although organic matter (OM) concentrations were higher in the effluent-pit plots, these results should be interpreted cautiously because OM measurements may include residual petroleum-derived carbon in addition to biological organic matter. Therefore, elevated OM levels should not be

considered definitive evidence of biological recovery or improved soil health. The elevated infiltration rates observed in the effluent-pit revegetated plots should be interpreted with caution, as they are likely a result of soil disturbance caused by remediation activities such as excavation, backfilling, and mixing rather than an improvement in soil quality or plant water availability. The lack of the expected inverse relationship between SAR and infiltration supports this interpretation.

The findings indicate that non-effluent plots in both NK and SK do not exhibit significant chemical or physical constraints to revegetation. In contrast, effluent-pit plots remain affected by residual salinity, sodicity, chloride accumulation, and soil structural.

6. Conclusion

The baseline assessment of 35 monitored sites established a robust reference framework for future ecological monitoring within the KOC monitoring programme. Results indicate that non-effluent, control and revegetation plots are comparable to undisturbed reference sites, suggesting no significant soil-related constraints to revegetation. Results showed that non-effluent, control, and revegetated plots were comparable to undisturbed reference sites, indicating no significant soil-related constraints to revegetation. In contrast, the South Kuwait (SK) effluent-pit sites remained affected by elevated salinity, sodicity, chloride levels, altered infiltration characteristics and physical disturbance which continue to limit successful revegetation. Continued seasonal monitoring is recommended to track recovery, evaluate the effectiveness of site-specific management measures and assess progress toward sustainable ecosystem restoration.

Acknowledgements

The authors acknowledge the Kuwait Oil Company for providing support for this paper.

References:

1. Baseline Ecological Monitoring Report (M3 – deliverable, Doc. No: 22058659-KSR-EN-REP-00003-Rev-E) submitted to Kuwait Oil Company (KOC) by KISR (Kuwait Institute for Scientific Research) in Jan 2026.
2. Shahid, S.A. and Omar, S.A.S. (2022) *Kuwait Soil Taxonomy*. Cham: Springer. <https://doi.org/10.1007/978-3-030-95297-6>
3. Al-Mebayedh, H., Niu, A. and Lin, C. (2023) ‘Strategies for cost-effective remediation of widespread oil-contaminated soils in Kuwait, an environmental legacy of the first Gulf War’, *Journal of Environmental Management*, 344, article 118601. <https://doi.org/10.1016/j.jenvman.2023.118601>
4. Al-Rashed, M., Mukhopadhyay, A., Al-Senafy, M., Ghoneim, H. and Abbas, A. (2010) ‘Contamination of groundwater from oil field water disposal pits in Kuwait’, *Arabian Journal for Science and Engineering*, 35(1B), pp. 105–123.
5. O’Brien, P.L., DeSutter, T.M., Casey, F.X.M., Wick, A.F. and Khan, E. (2017) ‘Evaluation of soil function following remediation of petroleum hydrocarbons: A review of current remediation techniques’, *Current Pollution Reports*, 3(3), pp. 192–205. <https://doi.org/10.1007/s40726-017-0063-7>

Soil Assessment in South and North Kuwait Oil Fields: A Baseline Study

6. Domínguez-Rodríguez, V.I., Adams, R.H., Vargas-Almeida, M., Zavala-Cruz, J. and Romero-Frasca, E. (2020) 'Fertility deterioration in a remediated petroleum-contaminated soil', *International Journal of Environmental Research and Public Health*, 17(2), article 382. <https://doi.org/10.3390/ijerph17020382>
7. Zaman, M., Shahid, S.A. and Heng, L. (2018) *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*. Cham: Springer. <https://doi.org/10.1007/978-3-319-96190-3>
8. Soil Science Division Staff (2017) *Soil Survey Manual*. 4th edn. Edited by C. Ditzler, K. Scheffe and H.C. Monger. Washington, DC: Government Printing Office, USDA Handbook No. 18.