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Phytosociology and antioxidant profile study for selecting potent herbs for phytoremediation of crude oil–contaminated soils

Tridip Boruah · Paramita Chakravarty · Hemen Deka

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Abstract Crude oil exploration activities affect the surrounding vegetation. The present investigation deals with the study of phytosociology and biochemical profiles of the herbaceous community in the active and abandoned oil drilling sites of crude oil–explored area. For comparison, a similar investigation was also carried out in control sites where oil exploration activities were not evident. At first, a phytosociological investigation was carried out and based on the results obtained antioxidant enzyme profiles of dominant herbs were studied to understand their defense mechanism to crude oil–associated stress. A total of 69 plant species belonging to 20 families were recorded in the studied sites and the family Cyperaceae was the most dominant in the crude oil–contaminated sites. The results revealed that the plants growing near the oil-explored-contaminated sites exhibit a higher level of DPPH and H_2O_2 radical scavenging activities as compared to control plant samples. For DPPH assay, the lowest IC_{50} value was exhibited by *Cyperus rotundus* which was recorded to be 31.49 and 55.31 respectively for the samples of contaminated and control sites. Again, in the case of H_2O_2 scavenging activity assay, *Parthenium hysterophorus* showed the lowest IC_{50} values of 27.48 and 63.07 for the samples of contaminated and control sites respectively. As a whole, the findings confirm the superior defense mechanism of some dominant herbs of the contaminated sites that include *Torenia flava*, *Croton bonplandianus*, *Eclipta alba*, *Cyperus rotundus*, *Cyperus brevifolius*, and *Parthenium hysterophorus* and their suitability for use in phytomanagement practices.

Keywords Phytomanagement · Biochemical defense · DPPH · Vegetation · Ecological indices

Introduction

Crude oil pollution is a burning problem around the globe. Usually, soil contaminations take place during drilling/extraction, processing, transportation, and refining process of crude oil (Abbaspour et al. 2020). The activities of crude oil exploration create negative impacts on surrounding environments causing serious hazards to plants and animals including human beings. For example, drill cuttings that are released in massive amounts during oil drilling operations contain both organic and inorganic contaminants such as petroleum hydrocarbons, polychlorinated biphenyls, and heavy metals (Motamedimehr and Gitipour 2019). Besides, several previous studies have confirmed the presence of toxic and carcinogenic polycyclic aromatic compounds (PAHs) in crude oil–polluted sites (Douglas et al. 2018; Kiamarsi et al. 2019; Patowary et al.

T. Boruah · P. Chakravarty · H. Deka (✉)
Environmental Botany and Biotechnology Laboratory, Department of Botany, Gauhati University, Guwahati, Assam 781014, India
e-mail: hemendeka@gauhati.ac.in

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2018). Considering these, remediation of oil exploration–affected habitats has become an utmost important issue among the oil-producing nations around the globe.

Several chemical and physical methods have been developed for decontamination of crude oil–polluted soils but most of these methods are costly and have side effects (Liu et al. 2018a, b; Patra et al. 2020). Recently, biological methods such as phytoremediation have come out as an alternative, cost-effective, and environment-friendly technique for remediation of crude oil–contaminated sites. In phytoremediation, which is the utilization of joint interaction of green plants and beneficial soil microbes (Ashraf et al. 2019), some resistant plant species are grown in polluted sites for removal/reducing the concentration of toxic contaminants from the polluted soils (Liu et al. 2018a, b; Yadav et al. 2018). However, the success of phytoremediation depends on the type of plants used in the process, and besides in most cases it is site-specific. The better adaptability is supported by their fibrous root systems; herbaceous and/or annual plants of contaminated sites are reported as suitable candidates for remediation of crude oil–contaminated soils. Besides, despite their tolerant mechanism and fast acclimatization potential, the herbaceous plants also show response to sudden short-term or long-term stressors with reduced cell activities and stunted plant growth or even plant mortality (Gilliam et al. 2016). The uses of herbs for phytoremediation of crude oil–polluted habitats have been heavily reported in the literature (Pandey et al. 2018; Yavari et al. 2015; Ziarati et al. 2019). Nevertheless, several factors such as bioavailability of the contaminants, intra- and interspecific competition among the plants, and reduced microbial biomass ultimately hamper the uptake of pollutants from contaminated soils. Therefore, on-field investigation on phytosociology and enzymatic defense systems of herb community of the contaminated site is necessary to select suitable plants as well as to end the lacunas of phytoremediation.

Applications of monoculture of very fast growing non-native plant species for speedy removal of contaminants and/or reclamation of contaminated soil are a well-known trend of present-day phytoremediation practices. During such practices, improvement aspects of soil qualities are ignored, which is one of the very essential requirements for any eco-restoration process (Helga et al. 2018). Besides, use of non-native or exotic plants is not encouraged as they are associated with removal of indigenous biota. Therefore, applications of native or indigenous plants are mostly preferred nowadays. For this, a well-designed field/phytosociological investigation is needed in order to select dominant indigenous herbs that are better adapted to the particular contaminated sites. Moreover, it has been reported that restoration practice of degraded land usually gets disturbed due to the lack of basic information on the variety and variability of dominant native plant species (Hatami et al. 2019) in the contaminated sites. These observations have established that phytosociology is an important parameter for selecting plant species for developing proper phytoremediation strategies. Again, the plants that are growing in the crude oil–contaminated habitat always remain in oxidative stress conditions. Antioxidant defense of plants is an important mechanism to survive in oxidative stress conditions and considered as an essential criterion for the selection of suitable plants for phytoremediation (Saleem et al. 2018). Thus, this study has been designed for studying the phytosociology of herbaceous community of crude oil drilling/contaminated sites. Besides, antioxidant enzyme analysis of the dominant herbs was carried out to understand the enzymatic defense mechanism of the plants in the adverse conditions created due to crude oil contamination.

Materials and methods

Study area

The study location selected for this investigation was the Lakowa oil field in Assam, India. The map showing the study area is presented in Fig. 1. These sites/locations are situated between latitude 27.0136° N and longitude 94.8572° E with an elevation of 86.6 m above sea level. Lakowa has several active oil wells, abandoned drilling sites, and crude oil–contaminated areas including human household and tea gardens. The annual temperature ranges from a minimum of 8 °C in winter to a maximum of 35 °C in summer. The area is highly humid with average annual precipitation of 2432 mm. The physicochemical profiles of the study sites are presented in Table 1, indicating the deterioration in soil conditions due to higher concentrations of petroleum hydrocarbon pollutants including polycyclic aromatic hydrocarbon

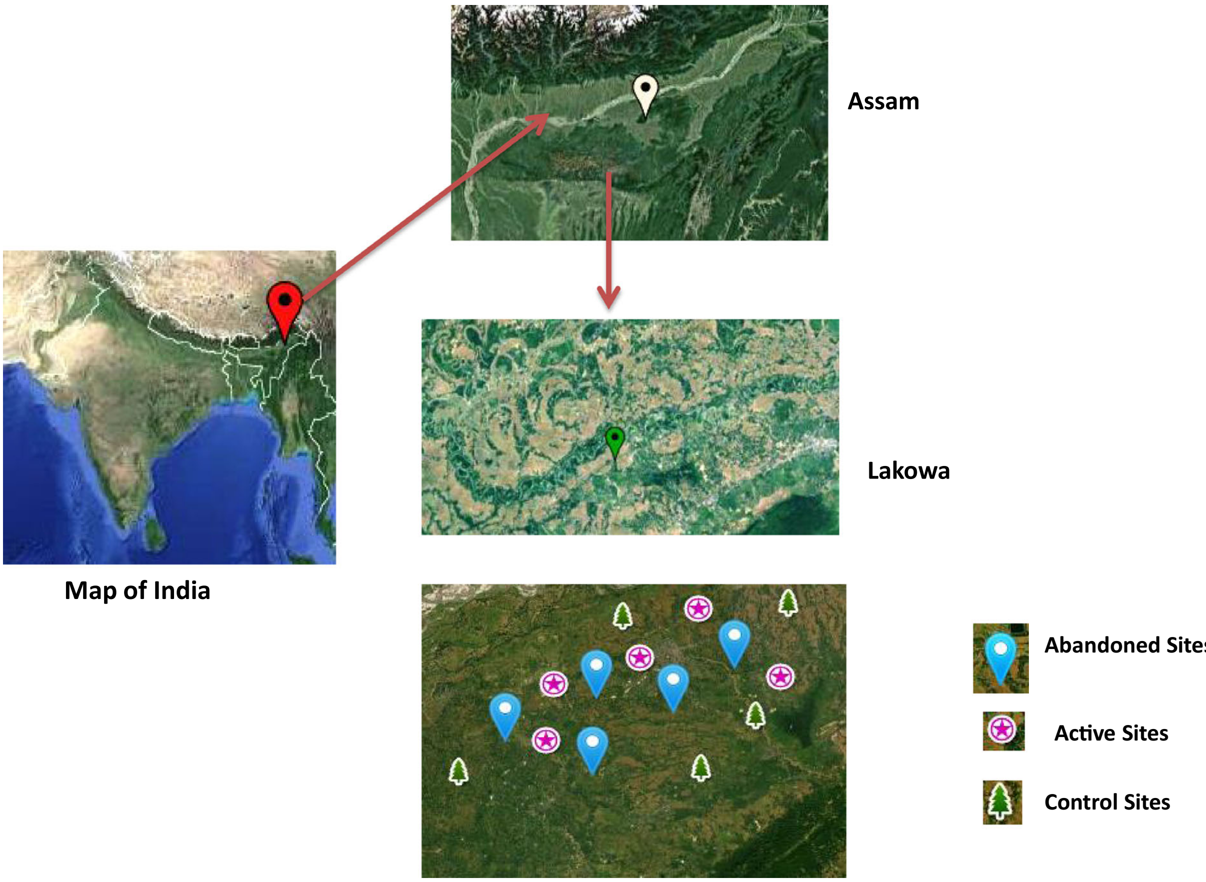

Fig. 1 Map of the study area

(PAH) compounds such as anthracene, fluoranthene, benzo[a]anthracene and benzo[a]pyrene.

Primary phytosociological methods

The quadrat method as suggested by Mishra (1968) and Kershaw and Looney (1985) was used for the sampling of all the study sites (Mishra 1968; Kershaw and Looney 1985). Twenty quadrats of 50 × 50 cm^2 size each were laid randomly at all the sites starting from the drilling point towards the periphery up to 100 m in all directions. The herb species were recorded in each quadrat sampling for primary ecological analysis and taxonomic confirmation was carried out by consulting the herbarium of the Botany Department, Gauhati University (GUBH), Guwahati, Assam. The primary ecological analysis includes parameters such as density, frequency, abundance, and relative basal area from which the important value index (IVI) was calculated to figure out the dominance of a plant species in the community (Phillips 1959; Curtis 1959).

Secondary phytosociological methods

To understand the diversity of herbaceous plant species in the community, six indices were estimated. Simpson (1949) was calculated to measure the con-

Table 1 Physicochemical, total petroleum hydrocarbon (TPH), and polycyclic aromatic hydrocarbon (PAH) content of oil-contaminated soils

Parameters	Control site	Contaminated site
pH	6.88 ± 0.22	4.77 ± 0.58
Conductivity (dS/m)	2.0 ± 0.23	0.672 ± 0.11
Total organic carbon (%)	3.33 ± 0.45	22.67 ± 1.43
Water holding capacity (%)	64.15 ± 2.3	16.02 ± 2.7
ΣTPH (mg/kg)	ND	13,238.92 ± 97.8
ΣPAH (mg/kg)*	ND	2160.91 ± 16.7

Mean values ± SD; *ND*, not detected

*Total values of anthracene, fluoranthene, benzo (a) anthracene, and benzo (a) pyrene centration of dominance (Simpson 1949). The Shannon and Wiener (1963) was used to measure the species diversity of the area (Shannon and Wiener 1963). The species evenness and species richness were computed according to Pielou (1966) and Menhinick's index (1964) respectively (Menhinick 1964; Pielou 1966). The beta diversity between the communities was estimated by Sorensen (1948). The spatial distribution pattern of the species was calculated by using the Whitford (1949).

Biochemical analysis

Based on IVI values, the herbaceous plant species finalized to study the biochemical parameters were *Torenia flava* Buch.-Ham. ex Benth., *Croton bonplandianus* Baill., *Eclipta alba* (L.) Hassk., *Cyperus rotundus* L., *Cyperus brevifolius* (Rottb.) Hassk., and *Parthenium hysterophorus* L. The 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical scavenging assay was carried out by following the analytical method given by Saral et al. (2016). H_2O_2 radical scavenging activity was estimated by the method outlined by Ruch et al. (1989). Ascorbic acid, butylated hydroxytoluene, and alpha-tocopherol were selected as standards for comparing the results of IC_{50} values in order to determine the validity of antioxidant assays. If the standards give positive results, then the method is considered as a valid method (Ruslan et al. 2018).

Statistical analysis

A paired *t* test was performed to carry out plant community analysis of the study sites. An ANOVA LSD test ($P < 0.01$) was used to compare the distribution pattern and diversity indices of the study sites. All the statistical analysis was carried out in SPSS software (version 2018).

Results and discussion

Plant community analysis

Plant community is the association of various plant species growing together in a particular habitat. Plant community analysis is an important parameter to understand the functional aspects and vegetation pattern of an area (Altieri 2018). The distribution pattern of some of the dominant plant families as revealed in the present study has been presented graphically in Fig. 2. A total of 69 plant species belonging to 20 families were recorded in all the three studied sites that include abandoned oil drilling, active oil drilling, and control sites. A total of 25, 23, and 21 numbers of herb species respectively were recorded in the active oil drilling, abandoned oil drilling, and control sites. The families Cyperaceae, Poaceae, and Asteraceae were found to be the most dominant in the abandoned and active oil drilling sites. Out of 4286 individuals of Cyperaceae family, 2270 individuals were present in abandoned oil drilling sites; 1970 and 46 individuals were recorded in the active oil drilling and control sites respectively. From a total of 3491 individuals of Poaceae family, 1571 and 1281 were found in the abandoned and active oil drilling sites, whereas control recorded 639 individuals at the time of the investigation. The family Asteraceae has emerged as the third highest contributor to the species richness in

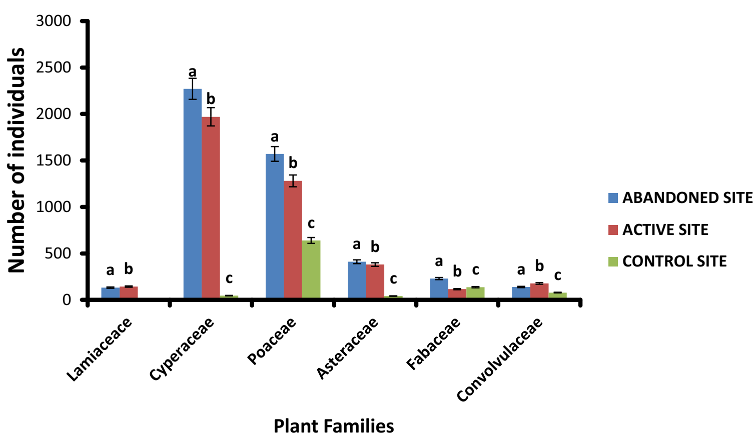

Fig. 2 Distribution pattern of dominant plant families of the study sites. Values are mean, $n = 3$, bars indicate SD. Significant differences are indicated by different letters

the studied sites. The results showed 411 and 381 numbers of individuals in the abandoned and active oil drilling sites as against the 41 individuals of control sites. The members of Cyperaceae and Poaceae such as *Cyperus brevifolius* and *Cynodon dactylon* (L.) *Pers* have been reported to be present dominantly in large numbers in the crude oil–contaminated habitats and their remediation potential against oil pollutants was also studied (Basumatary and Bordoloi 2016; Bordoloi and Basumatary 2016). A recently concluded study revealed that the plant species belonging to Cyperaceae and Poaceae utilize available soil nitrogen more efficiently, allowing them to be more dominant over other plant families in the contaminated ecosystem (Zhang et al. 2020). Poaceae and Cyperaceae are among the pioneer colonizers of a degraded land which might also contribute significantly to their dominance in the crude oil–contaminated land (Vitova et al. 2017). Again, the dominance of plant species belonging to Cyperaceae and Poaceae over Asteraceae could be attributed to their ability to withstand crude oil contamination through their fibrous root system that spread across a large surface area. The same logic can be applied to justify the presence of large numbers of individuals in the oil-drilled sites. Besides, the less number of species/individuals of dominant families in control sites as compared to contaminated habitats could be attributed to biotic pressure posed by herbivores (Moreira et al. 2018). From our observation, we hypothesize that in the contaminated habitats, plant species remain intact as these sites are avoided by grazing animals. Nevertheless, further planned studies are required to prove this hypothesis.

Distribution pattern

The abundance to frequency ratio (A/F or Whitford index) is a good indicator to understand the distribution pattern of species in a community. The A/F value less than 0.025 signifies regular, 0.025–0.05 random, and above 0.05 contiguous pattern of distribution. The random distribution pattern is comparatively unusual in nature, occurring in a very uniform environment and there is no inclination towards aggregation with other species; regular distribution can occur where both intra-specific competition and interspecific competition among individuals are rigorous, and positive antagonism is evident; contiguous distribution is the most common pattern of vegetation which is represented by varying degrees of clumping (Zhang et al. 2018). The distribution pattern of herbaceous plant species of the studied sites is presented in Fig. 3. The maximum number of species showed contiguous distribution followed by a random distribution pattern. Both contiguous and random patterns were found to be dominant in the abandoned oil drilling sites. The number of species that showed contiguous distribution was found within the range of 11–16, whereas only 3 herb species showed random distributions in the abandoned oil drilling sites. Nevertheless, the herb species *Mimosa pudica* L. was found to be the only plant that showed a regular distribution pattern in the abandoned oil drilling sites. The same pattern of distributions was found among the herb species of active oil drilling sites. The number of herb species that showed a contiguous distribution pattern in the active oil drilling sites was found in the range of 9–12 although no random and regular distribution was

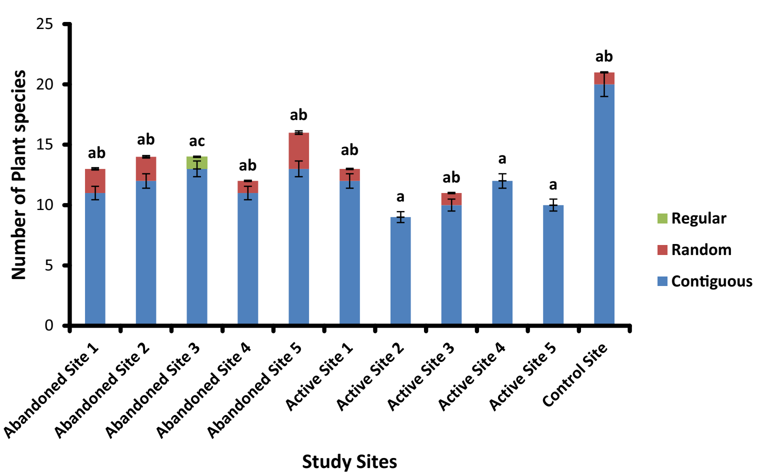

Fig. 3 Distribution pattern of plant species in the study sites based on the Whitford index. Values are mean, $n = 3$, bars indicate SD. Significant differences are indicated by different letters

recorded. Out of the 21 species of the control sites, contiguous distribution was shown by 20 species and only one species performs random distribution. Like active oil drilling sites, regular distribution was not prevalent among the studied herb species of control sites.

The results can be justified by the works of previous researchers who have reported about the contiguous distribution pattern of species followed by random and regular distribution in the disturbed areas (Shadangi and Nath 2005; Shameem et al. 2010). The dominance of contiguous distribution in the study area could be attributed to the reproductive strategies where most of the species reproduce vegetatively in addition to sexual reproduction (Alhassan et al. 2006). Besides, it has been suggested that contiguous distribution is the most common type of distribution in the areas that show significant variation in prevailing environmental conditions (Odum 1971). Here, it is inferred that the life history strategies of the herbaceous plant species are responsible for the pattern of distributions. The maximum species in the area are "r" selected and as a result, they invest their maximum energy to grow rapidly and produce a large number of offspring eliminating other species that ultimately results in the contiguous distribution pattern in the studied sites.

Vegetation attributes

The important value index (IVI) of the top ten plant species of the studied sites is presented in Fig. 4. *Cyperus brevifolius* was found to be the most dominant species in the contaminated habitats. The IVI value of the species was found to be 71.01 and 73.29 for abandoned and active oil drilling sites respectively. Besides, the results also showed that *Axonopus compressus* (Sw.) P.Beauv. was the most frequent species in all the studied sites. The IVI value of the species was found to be 48.51 and 52.66 in abandoned and active drilling sites, whereas in control sites it was recorded 33.29. The order of dominancy based on IVI was found as *Acmella paniculata* (Wall. ex DC.) R.K.Jansen > *Leucas aspera* (Willd.) Link > *Cynodon dactylon* in the abandoned oil drilling sites. On the other hand, the dominancy order of plant species was recorded as *Chromolaena odorata* (L.) R.M.King & H.Rob. > *Cyperus rotundus* > *Evolvulus nummularius* (L.) L. in the active oil drilling sites.

The IVI is a common parameter used in ecological studies to understand the ecological importance of a particular species in an ecosystem (Kacholi 2014). The maximum numbers of species that predominate the vegetation of crude oil–contaminated sites exhibit a fibrous root system that allows them to spread across a large surface area for deep penetration to the contaminated soil. Previous reports have suggested that the plants possessing this quality are regarded as the good candidates for combating the adverse stress in the crude oil–contaminated sites (Idris et al. 2013). The higher IVI value of the herbaceous plants reported in this study could be attributed to the better tolerance level of the species to the crude oil pollutants.

Diversity indices

All total six diversity indices were used to analyze the herbaceous vegetation of crude oil–contaminated sites. The diversity indices recorded in all three study sites are presented graphically in Fig. 5. The results showed that the Simpson index was 0.21 and 0.25 for the abandoned

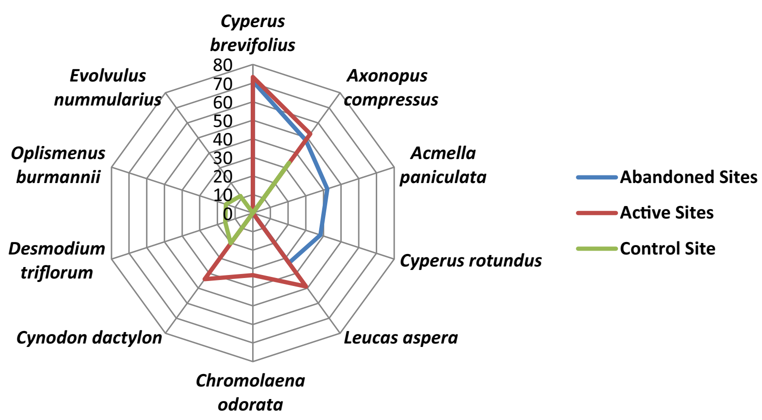

Fig. 4 Diagrammatic representation of top ten plant species based on their IVI values

and active oil drilling sites, whereas it was 0.12 in the control field. The Shannon-Wiener index was 1.84 for both the abandoned and active oil drilling sites and in control, it was 3.11. Similarly, Pielou's evenness index was found to be 0.48 and 0.66 in the abandoned and active oil drilling sites as against 1.02 of control. Menhinick's index was recorded as 0.47 and 0.40 in the abandoned and active oil-drilled sites and 0.61 in the control. The species richness index or Margalef index was found to be 1.89 and 1.51 in the abandoned and active oil-drilled sites, whereas the value was 2.83 in the control. The Sorensen similarity index of species composition was found to be 0.176 for all the three distinct habitats studied.

The present findings corroborated with the previous works (Jahantigh and Efe 2010) who have reported about the effect of wastewater irrigation on the phytosociology of an area. The fluctuation of Simpson's index in all the studied sites can be correlated to the differences in anthropogenic activities and livestock grazing in different sampling locations. Similar results were obtained for the Shannon-Wiener index in a study conducted by Ramadan et al. (2018), where they have reported about higher values of Shannon-Wiener index in the control site as against the polluted site. Here, it is emphasized that crude oil contamination reduces the water holding capacity and nutrient composition/concentration in soil resulting in lower diversity in the contaminated sites as compared to the control habitat. The results obtained for Pielou's evenness index can be justified by citing the work of Johnston and Roberts (2009) where they have reported a decrease in species evenness values with the increase in the concentration of contaminants. Further variation in species evenness between control and contaminated sites can be attributed to the fact that control sites contain plant species which were more or less evenly distributed, whereas in the contaminated sites, one or two species become more dominant due to their better acclimatization in the prevailing environment. The results obtained for Menhinick's index can be corroborated with studies of Singh (2012) which had described the vegetation pattern around sewage drains. Here, it is interpreted that the decrease of Menhinick's index in abandoned and active oil-drilled sites as against the control is associated with both the level of contaminants in the soil and tolerance ability of different herb species in the adverse environment. Besides, the lower species richness in the oil-contaminated sites can also be attributed to many factors including metal tolerance level of plant species, livestock grazing, and different biotic and abiotic disturbances of the study area (Conesa et al. 2007). The results recorded for the Sorensen similarity index was found to be significantly lower and it falls in the line with the previous works (Carpenter et al. 1990). Similar plant species cannot occupy both contaminated and non-contaminated land together; some species are cosmopolitan in distribution and some species are restricted to specific climatic and edaphic conditions based on which the diversity and the similarity of distribution of plant species differ in the studied sites.

DPPH assay

DPPH instantly decolorizes in the presence of any antioxidants which makes it a reliable assay for determination of scavenging activity (Zaman and Khalid 2015). The results obtained from the DPPH assay have been presented graphically in Fig. 6a–f. The results are

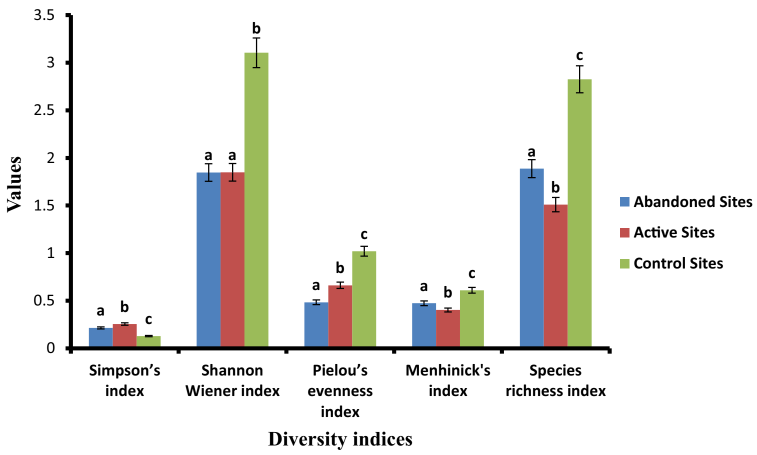

Fig. 5 Different diversity indices of the study sites. Values are mean, $n = 3$, bars indicate SD. Significant differences are indicated by different letters

expressed in terms of the IC_{50} values and IC_{50} for free radical scavenging activity indicates the concentration of a sample or standard required to inhibit 50% of that free radical (Ruslan et al. 2018). The IC_{50} values of ascorbic acid, butylated hydroxytoluene (BHT), and alpha-tocopherol were recorded to be 27.056, 38.720, and 24.381 respectively and used as standards for comparing the results obtained from the studied plant samples. The IC_{50} value of *Torenia flava* collected from the control sites was found to be 49.34 as against 42.19 of the contaminated sites. The IC_{50} value of *Croton bonplandianus* was 63.46 in control samples and 62.13 in the sample from contaminated sites. *Eclipta alba* growing in the control sites exhibits an IC_{50} value of 122.87 and 65.83 in the contaminated sites. For *Cyperus rotundus*, IC_{50} value was 55.31 and 31.49 in the samples from control and contaminated sites respectively. *Cyperus brevifolius* of control sites exhibits an

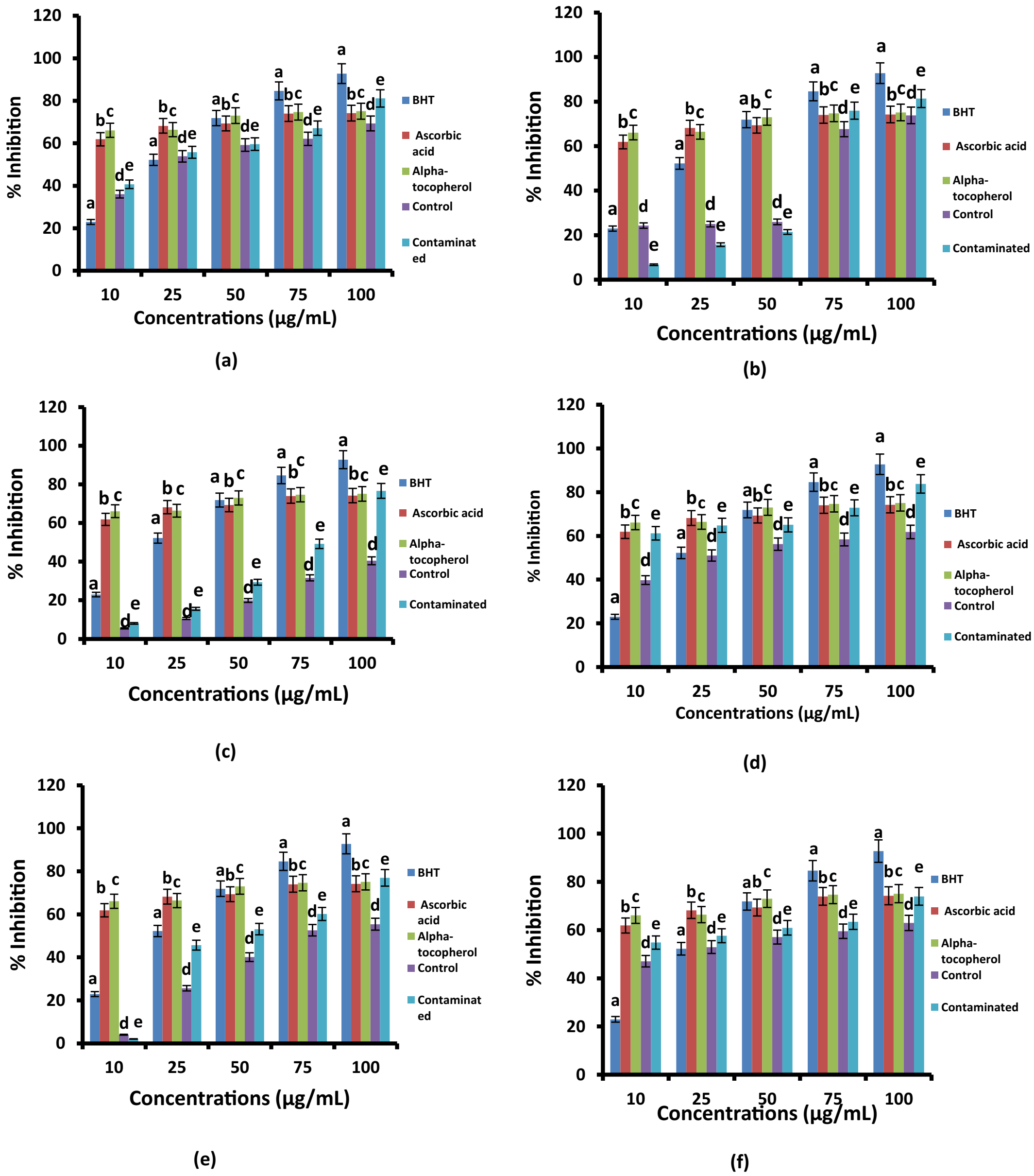

Fig. 6 DPPH radical scavenging activity of methanolic extracts of herbaceous plant species collected from contaminated and control sites. Values are mean, $n = 3$, bars indicate SD. Significant differences are indicated by different letters. (**a**) *Torenia flava*, (**b**) *Croton bonplandianus*, (**c**) *Eclipta alba*, (**d**) *Cyperus rotundus*, (**e**) *Cyperus brevifolius*, and (**f**) *Parthenium hysterophorus*

IC_{50} value of 77.88, whereas it was found to be 59.02 in the plant samples collected from contaminated sites. The IC_{50} value of *Parthenium hysterophorus* was recorded to be 51.13 in the control and 39.68 in the contaminated sites.

A concentration-dependent DPPH scavenging activity was observed in the studied plant samples. Percentage inhibition of methanolic plant extracts increased with increase in concentration. A similar trend was observed in the case of plant extract of *Leea macrophylla* Roxb. ex

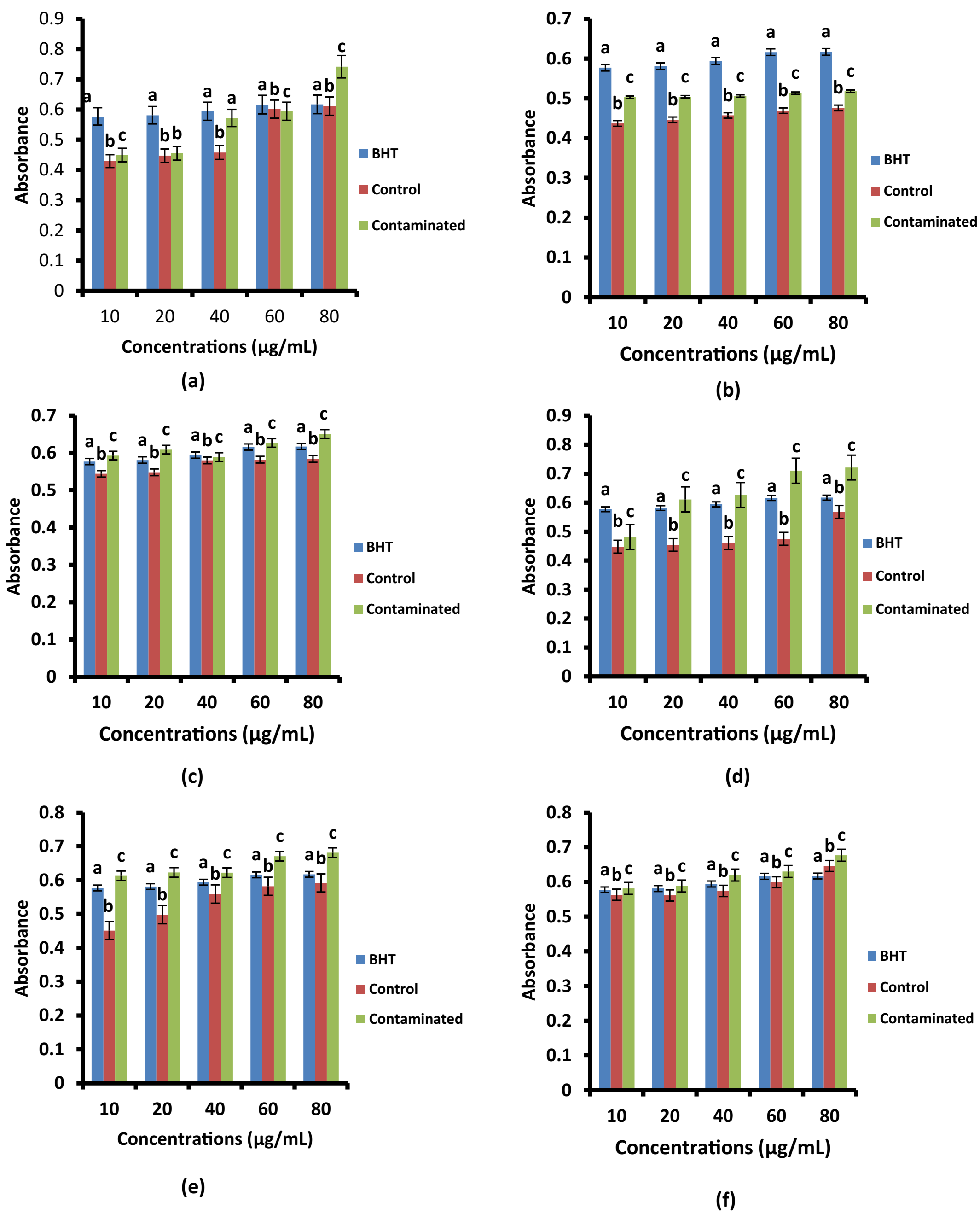

Fig. 7 H_2O_2 scavenging activity of methanolic extracts of herbaceous plant species collected from contaminated and control sites. Values are mean, $n = 3$, bars indicate SD. Significant differences are indicated by different letters. (**a**) *Torenia flava*, (**b**) *Croton bonplandianus*, (**c**) *Eclipta alba*, (**d**) *Cyperus rotundus*, (**e**) *Cyperus brevifolius*, and (**f**) *Parthenium hysterophorus*

Hornem. (Ahmed et al. 2018). The present investigation falls in line with the previous findings where it was reported that plants growing in the contaminated/stress environment shows lower IC_{50} values as compared to those that grow in non-contaminated conditions (Bouterfas et al. 2016; Đogić et al. 2017; Ulusu et al. 2017). The lower IC_{50} values are directly associated with the higher free radical scavenging activity of the herbaceous plants growing in contaminated soil (Mongkhonsin et al. 2018). Pollutants present in the crude oil can create oxidative stress in plants and to overcome this stress condition, plants utilize their antioxidant defense systems (Han et al. 2016; Odukoya et al. 2019). The increasing antioxidant activity of the plant species in the contaminated environment may trigger the cellular defense systems that can be crucial for the plants to cope up with the pollutants and to protect the cells from internal injuries (Ruslan et al. 2018). In this investigation, it is emphasized that the herbaceous plant species growing in crude oil–contaminated soil exhibits a superior defense mechanism against crude oil–associated abiotic stress through enhanced DPPH radical scavenging activities. It further confirms the fact that oxidative stress can be controlled by an increased level of DPPH antioxidant activities in the herbaceous plants growing in crude oil–contaminated sites (Saeed et al. 2016).

H_2O_2 radical scavenging activity

The H_2O_2 radical scavenging activity of the methanolic plant extracts is presented graphically in Fig. 7a–f. Butylated hydroxytoluene (BHT) was taken as a reference compound for comparison of results. The IC_{50} value of the reference was recorded as 2.431. The herb species *Torenia flava* of the control site showed an IC_{50} value of 70.04, whereas it was 37.79 in the case of samples collected from contaminated sites. In the case of *Croton bonplandianus*, IC_{50} value was found to be 71.94 and 34.9 for the samples of control and contaminated sites respectively. The IC_{50} value for *Eclipta alba* growing in the control site was 68.961, whereas it was 35.236 in the samples of the contaminated site. Again, in the case of *Cyperus rotundus*, the IC_{50} values were found to be 75.22 and 49.24 for the samples of control and contaminated sites respectively. For *Cyperus brevifolius*, the IC_{50} values were 84.42 and 41.55 respectively in the control and contaminated sites' samples. Finally, the herb *Parthenium hysterophorus* showed IC_{50} values of 63.07 and 27.48 for the samples collected from control and oil-contaminated sites respectively.

The present investigation showed that plants collected from crude oil–contaminated sites exhibit lower IC_{50} values as against their counterpart collected from control sites. This indicates that herbaceous plants growing in crude oil–contaminated sites have higher H_2O_2 scavenging activity than the plants growing in control sites. The finding corroborated with the studies of previous workers in this field (Cui et al. 2016; Norouzi et al. 2020; Piscitelli et al. 2020). The collective increase in H_2O_2 scavenging activity in the plants growing in the crude oil–contaminated site could be accredited to the fact that H_2O_2 free radicals react with reactive oxygen species to limit oxidative stress by inhibiting lipid peroxidation and develop improved resistance power to survive in the adverse condition (Sabahi et al. 2018; Saleem et al. 2020). The oxidative stress resulting from the crude oil contamination also disrupts the carbohydrate metabolism of the plants and it passively contributes to the higher level of H_2O_2 scavenging activity in the plants (Norouzi et al. 2020). Here, it is hypothesized that the increased H_2O_2 scavenging activity of plants collected from crude oil–contaminated sites is directly related to the signal transduction pathway of the herbs that eventually contributes to the plant defense mechanism against the stress exerted by crude oil contamination.

Conclusion

This investigation revealed that the crude oil–contaminated sites are dominated by herbs *Axonopus compressus*, *Cyperus brevifolius*, and *Cyperus rotundus*. Investigation on DPPH and H_2O_2 scavenging activities of *Cyperus brevifolius*, *Cyperus rotundus*, and *Parthenium hysterophorus* has explored their defense mechanism in stress environment and confirms its superiority as a potential candidate for phytoremediation. Furthermore, the study has also explored the tolerance ability of *Torenia flava*, *Croton bonplandianus*, and *Eclipta alba* in crude oil–polluted habitat and can be further tested for phytomanagement practices.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10661-020-08721-4.

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Data availability All data generated or analyzed during this study are included in this article itself.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Code availability Not applicable

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