Linkage between herbaceous vegetation and soil characteristics along Rawal Dam Islamabad

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Abstract

This study provides an analysis of the soil, vegetation types and species distribution along Rawal Dam, Rawal Lake and its three tributaries (Bani Gala, Chattar and Bari Imam Streams and its tributaries), with a focus on the environmental factors that control species distribution. After identifying the study area’s herbaceous vegetation and analyzing the soil’s physical and chemical parameters, the variable data were connected into a relationship. TWINSPAN (Two Way Indicator Species Analysis) classified the herbaceous vegetation into seven different communities with which; the formulated groups in DCA (Detrended Correspondance Analysis) were coherent. CCA (Canonical Correspondance Analysis) produced the relationship of soil parameters such as pH, organic matter, Potassium, Manganese, Zinc, and Iron with the herbaceous vegetation. The most effectual and varied parameter was the Potassium and Manganese that was available among the heavy metals. Thus, this study analyzed the overall relationship among soil, vegetation and the species present at the selected site.

Key words: Vegetation, environmental gradient, ordination, heavy metals, rawal dam

1. Introduction

Vegetation is an area’s plant cover and plays an important role in the overall ecosystem. Vegetation that is found on land is categorized as a variety of forests; however, whenever it is present in (and alongside) a body of water, it is categorized as either emergent, submersed, floating leaves or floating plants. The world’s biomes contain many natural water bodies, but it is occasionally necessary to build an artificial water body reservoir to fulfill human needs. According to Sharma and Sharma (2008), these needs include irrigation, hydropower, water, flood control, navigation, fishing and recreational activities. Artificial reservoirs have their own environments and ecosystems because similar to the sea, they receive water from rivers, demonstrate vertical stratification, experience biological cycling and sedimentation and lose water through evaporation, thus controlling the distribution of species along
Soil-vegetation relationships have been documented in Australia (Bui and Henderson, 2003), Egypt (Abd El-Ghani and Amer, 2003; Abd El-Ghani and El-Sawaf, 2005), the USA (Omer, 2004), Iran (Jafari et al., 2004), and Spain (Rogel et al., 2001). Study results generally indicate that the soil’s moisture and available nutrients are important factors in controlling the distribution of vegetation (Rogel et al., 2001).

Many of the studies identifying the major environmental factors associated with vegetation patterns are just descriptive documentation of species and their classification (Liu et al., 2003). Modern synecological research has preferred a more subjective methodology for use at the local and sometimes regional scale, seeking to reduce the complexity of a field data set either by classification and/or ordination of floristic data and then relating results to environmental data, or by deriving vegetation habitat relationships from a single analysis of a combined floristic and environmental variable set. Recently, multivariate analyses including TWINSPAN (Two Way Indicator Species Analysis), DCA (Detrended Correspondence Analysis), CCA (Canonical Correspondence Analysis) and cluster analysis, have been used for analyzing soil vegetation relationship (Ahmad and Yasmin, 2011; Çakan et al., 2011; Malik et al., 2012; Zhu et al., 2011). Therefore, the present research was carried out i) to enrich knowledge about the vegetation and arrangement of plant communities providing the baseline data in ecologically important area and ii) to study the relationship between soil characteristics and herbaceous vegetation along Rawal lake and its tributaries in Islamabad, Pakistan using multivariate analyses.

2. Materials and Methods

2.1. Study area

This study was conducted from February through June, 2013 to survey the Rawal Dam (an artificial reservoir of Rawal Lake), Rawal Lake and its tributaries (including Bani Gala, Chattar and Bari Imam Streams) (Figure 1). Rawal Dam is located at 73° 13' N 33° 71' E in Islamabad at the foothill of Margalla and Murree Hills. It was constructed across the Korang Nullah in 1960 to supply water for domestic purposes to the twin cities of Rawalpindi and Islamabad. This 700-foot-long concrete dam has a storage capacity of 47,500 acre feet; it not only supplies drinking water to the twin cities but also irrigates a 500-acre area (Ali and Malik, 2010).

2.2. Vegetation sampling

For sampling purposes, various field surveys were conducted along Rawal Dam and its tributaries. The data collected were based on random sampling using a quadrat size of 1 m x 1 m. Fifty quadrats were randomly laid down in the field area. Within each quadrat, plant-cover values were recorded using the DOMIN scale (Kent and Coker, 1995). Plant species were deposited and identified in the herbarium of Fatima Jinnah Women University in Rawalpindi. The nomenclature used followed that of Nasir and Rafiq (1995).
2.3. Soil sampling and analysis

Three soil samples (0-50 cm) were collected from the root zone of each plot. These samples were then pooled together to form one composite sample. The soil was air-dried, thoroughly mixed, and passed through a two-mm sieve to remove gravel and boulders. The weight of the gravel in each soil sample was determined and expressed as a percentage of the total weight of the sampled soil. Soil portions that were smaller than two mm were kept for chemical analysis (Allen and Stainer, 1974), various physical and chemical parameters were analyzed, such as electrical conductivity, depth, pH, organic matter, available phosphorus, available potassium, moisture, and heavy metals as micronutrients. Electrical conductivity (EC) and pH were evaluated using a conductivity meter and a glass electrode pH-meter, respectively. The Allen method was applied to evaluate soil moisture (Allen and Stainer, 1974). The Nikolsky Method was used to test organic matter (Nikolsky, 1963). The Hua et al. (2008) method was applied to analyze the heavy metals, i.e., Zn, Fe, Cu and Mn.

2.4. Multivariate analysis

Both ordination and classification techniques were employed to obtain the effective analysis of vegetation and related environmental factors. To classify the species, we used Two-Way Indicator Species Analysis (TWINSPLAN), which was run through PC-ORD 5 software version (Abd El-Ghani and Amer, 2003). The species were clustered based on the samples’ classification following a divisive hierarchical clustering of sites. Species richness (alpha-diversity) within each separated TWINSPLAN vegetation group is calculated as the average number of species per site. The computer program CANACO was used for all of the ordinations. An indirect gradient analysis, DCA, plotted sites against axes based on species abundance and
composition. In the diagram, sites with similar structures were close to one another. A scatter plot was drawn to show the results of DCA. The CCA was then applied to quantify the relationship between vegetation and environmental variables (Berk, 1994). The soil variables included electrical conductivity, depth, pH, organic matter, available phosphorus, available potassium, moisture, and heavy metals. For the latter, an NMS scree plot demonstrated stress as a function of the dimensionality of the gradient model, where stress was an inverse measure of fit to the data. The NMS scree plot was drawn to demonstrate the significance of this study’s results.

3. Results

Overall, this study collected and identified 34 species belonging to 25 families. None of the species was present at all sites/sampling points. The largest families were Asteraceae (n=4), Brassicaceae (n=4), Fabaceae (n=3) and Poaceae (n=2), which represented 12%, 12%, 9% and 6% of the total flora, respectively. Figure 2 shows the frequency and number of species recorded at all sites. Some species were frequently present with high records, e.g., Cynodon dactylon, Cannabis sativa, Coronopus didymus, Melilotus indica, Euphorbia heiloscopia, Cyperus rotundus, Medicago polymorphus, Ranunculus arvensis, and Sonchus asper, whereas others were found in smaller numbers and were confined to a particular area.

3.1. Classification

3.1.1. TWINSPLAN analysis of vegetation data

Vegetation from five different sites of the study area has been divided into seven communities. Some of the plant species remained detached from communities but remained part of the main group, which was other six were subdivisions of A1, which was then divided into A1a and A1b, which in turn had different communities and only one species, respectively. A1a1 and A1a 2 were subdivisions of A1a. These divisions can be seen in Figure 3a, which identifies the various communities using different colors. Starting from the left, we see community I, which has the two dominant plant species, Medicago polymorphus and Parthenium hysterophorus (together, named Medicago-Parthenium). In community II, Scinchona iberica and Oxalis corniculata were the dominant species; accordingly, the name of that community was most prominent community and consisted of a large number of species, the most abundant of which were Ranunculus arvensis and Fumaria indica. Therefore, the name given to this community was Ranunculus-Fumaria. Malvastrum coromandelianum and Sisymbrium irio had the same abundance in that community. Community V was dominated by Sonchus asper. Coronopus didymus was the most abundant species in community VI. Community VII had two dominant species, Cannabis sativa and Euphorbia heiloscopia, and was named Cannabis-Euphorbia. Overall, three species collectively dominated the dendogram. The first and most abundant of those species was Cynodon dactylon, which leads the entire subgroup of Group A. However, that species was not found within any community. Cannabis sativa was the second species and was linked to community VII. The third species, Melilotus indica, also had no association with a community.

3.1.2. DCA analysis of vegetation data

DCA is an ordination method that ordiates the study area species in a specific manner. In Figure 3b, the herbaceous vegetation species of the study area sites have been arranged in an ordered form. The plant species were divided into three groups that were marked with a square shape; the outlier species were also found.
Figure 2. Total number and frequency of species recorded

Figure 3. (a) TWINSPAN analysis and (b) DCA analysis layout with demarcated communities and labeled outliers

Figure 3b is a scatter plot of the species. The star shape and the species names over the graph depict the presence of species. In addition, wherever these star-shaped symbols are close to each other, they indicate a group of plant species. Three main groups were formulated. Group 1 consisted of Anagalis arvensis, Convolvulus arvensis, Oxalis corniculata and Scinchona ibericathat; TWINSPAN also found those species in Group 1. The presence of Medicago polymorpha and Amaranthus viridis in Group 2 also demonstrated the similarity of the DCA groups and the TWINSPAN groups; similar to the Group 1 species, the two species in Group 2 were allocated to the same community by TWINSPAN. Similarly, in Group 3, Bambusa arundinacea and Rumex dentatus were located in the same community as that formulated by TWINSPAN. This association shows a similarity with part of the two-way cluster dendogram depicted in Figure 3a.
3.1.3. CCA analysis of vegetation and environmental data

CCA is another ordination technique that was used in this study to develop a linkage between the study area’s environmental variables and vegetation data. Therefore, it identified the presence, absence and/or occurrence of the individual species with respect to the various physical and chemical parameters of the soil. The soil characteristics with their means and standard deviation are given in Table 1. Various parameters were measured, and there was a high variation in the K values collected from different sites. The CCA biplot depicts the relation between soil variables and vegetation data. Each triangle in the plot denotes individual species. The arrow shows the extent of variation in the soil parameters. The longer the arrow is, the greater its effect on vegetation type is. In this study, the biplot based on the CCA results revealed that the soil’s K (available potassium) was the parameter or an environmental variable that greatly affected plant species composition (Figure 4a). Moreover, Bambusaa arudinacea, Diclyptera roxburghiana and Sonchus asper were frequently influenced by the K parameter. Melitotus indica and Mentha arvensis also might be affected by K. Moisture was another soil parameter that greatly affected Oxalis corniculata, Anagalis arvensis, Rumex dentatus and Ranunculus arvensis, Scinchona iberica and Cynodon dactylon. Organic Matter (OM) affected Cannabis sativa, Gallium asparine, Amaranthus viridis, Cyperus rotundus and Tramicum officinalis. Electrical conductivity only affected Medicago polymorphus. Conyza canadensis was the only plant species that might be affected by available phosphorus. pH had a major effect on Sonchus asper, Bambusaa arudinacea and Diclyptera roxburghiana. Other plant species (either individuals or in group form) were apparently not affected by any environmental variable. Similarly, the presence of heavy metals in soil determines the presence or absence of particular plant species. Figure 4b shows that some plant species’ relationships developed with the heavy metals that were present in soil of study area sites. The lengthiest arrow of manganese (Mn) indicated the stronger effect on Vicia faba. Anagalis arvensis and Malvastrum coromendelianum were somehow affected by the presence or absence of this metal in the study area’s soil. Zinc (Zn) affected Anagalis arvensis, Malvastrum coromendelianum and Melitotus indica. Iron (Fe) affected Cyperus rotundus, whereas Copper (Cu) affected Euphorbia helioscopia, Fumaria indica and Coronopus didymus. Other plant species were seemingly unaffected by these environmental variables.

3.1.4. T-value biplot

The T-value biplot is formulated to predict the negative or positive plant species response to any environmental variable; in this case, the soil parameters. In the diagram of the T-value biplot, the plant species are individually shown by arrows. There is also a pair of circles touching each other at the origin of the coordinate system, from which these arrows pass and depict the response. The circles are known as Dobben circles because the interpretation was first noted by H. Van Dobben (Ter Braak and Looman, 1991). Positive and negative responses are indicated by red and blue circles, respectively. As a regression biplot, the T-value biplot is used to approximate the individual regression coefficients of a multiple regression model, where the species can be referred to as the response variable and all of the environmental variables are used as predictors.

Generally it is assumed that available Potassium (K) is necessary for proper plant growth. The T-value Biplot enables the formulation of an association between this macronutrient and the plant species of the entire study area. In the Figure 5a, it can be seen that Melitotus

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Figure 4. CCA Biplot showing effect of (a) environmental variables and (b) heavy metals on plant species

<table>
<thead>
<tr>
<th>Soil Variables</th>
<th>Units</th>
<th>Mean values</th>
<th>F-ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>dSm⁻¹</td>
<td>0.98±0.1</td>
<td>1.46</td>
<td>0.17</td>
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<tr>
<td>pH</td>
<td>-</td>
<td>7.1±0.2</td>
<td>0.57</td>
<td>0.90</td>
</tr>
<tr>
<td>OM</td>
<td>%</td>
<td>0.64±0.04</td>
<td>6.01</td>
<td>0.001</td>
</tr>
<tr>
<td>Moisture</td>
<td>%</td>
<td>37.1±5.7</td>
<td>1.41</td>
<td>0.19</td>
</tr>
<tr>
<td>P</td>
<td>mgKg⁻¹</td>
<td>4.65±3.15</td>
<td>6.39</td>
<td>0.001</td>
</tr>
<tr>
<td>K</td>
<td>mgKg⁻¹</td>
<td>153.58±33.7</td>
<td>7.21</td>
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<tr>
<td>Zn</td>
<td>mgKg⁻¹</td>
<td>0.59±0.1</td>
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<tr>
<td>Fe</td>
<td>mgKg⁻¹</td>
<td>3.96±0.1</td>
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</tr>
<tr>
<td>Cu</td>
<td>mgKg⁻¹</td>
<td>0.13±0.04</td>
<td>4.61</td>
<td>0.002</td>
</tr>
<tr>
<td>Mn</td>
<td>mgKg⁻¹</td>
<td>2.22±0.1</td>
<td>1.38</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Table 1. Soil variables with mean, standard deviation and F-values collected from sampling sites

indica had a strong positive response for available Potassium; conversely Euphorbia helio had strong negative response. Other species passing from this circle were only slightly affected by this soil variable.

The linkage between soil organic matter and the various plant species found in the study area sites is given in Figure 5b. This is the soil parameter that has a direct impact on plant growth; however, the plant species in this study (for example, Malvastrum coromendelium) had a strong positive reaction to both the presence and absence of organic matter. Furthermore, other plant species (for example, Verbena officinalis and Stellaria media) also passed from the red circle, thus demonstrating their positive response to organic matter in the soil.
Conversely, *Cynodon dactylon* had a strong negative response as it passed from the blue circle. *Scinchoria iberica* and *Convolvulus arvensis* also had a negative response. The arrow of *Rumex dentatus* passed through the negative response circle, but its negative response was negligible. The rest of the species that passed through negative and positive response circles were scarcely affected.

The T-value biplot for soil pH presented species’ reaction to the soil’s changing pH. The *Cynodon dactylon* was the most dominant species and had a strongly positive response towards the soil variable, pH. *Scinchoria iberica* and *Convolvulus arvensis* were found near the positive response circle and reacted with the soil’s varying pH. *Malvastrum coromendelianum, Verbena officinalis* and *Stellaria media* had negative responses to soil pH. Other species had no reaction to changes (or lack thereof) in the soil variable (Figure 5c).

As the physical and chemical soil parameters of study area sites were analyzed, the presence of four heavy metals was examined in the soil samples. These variables’ T-value biplots and the study area’s vegetation were developed and interpreted. The T-value biplot drawn for Iron (Fe) shows a very strong positive reaction by *Cynodon dactylon* (Figure 5d). This indicated that presence of Fe had an effect on the presence and absence of this species. *Tramicum officinalis* and *Stellaria media* had a strong relationship with this soil parameter; they also passed through the positive response circle. *Conyza canadensis* and *Gallium asparagine* did not have a significant linkage. *Convolvulus arvensis* and *Oxalis corniculata* were equally and too negatively affected by presence of iron in soil. *Sonchus asper* was also strongly and negatively affected. The rest of the species in the graph were completely unaffected.

*Oxalis corniculata* had a strong negative response. The rest of the species were not strongly affected by this parameter.

*Cynodon dactylon, Stelleria media* and *Tramicum officinalis* were strongly affected by the Manganese (Mn) in soil and their growth, abundance and distribution also dependent on this parameter according to Figure 5f. *Oxalis corniculata* and *Convolvulus arvensis* were negatively affected by Mn in soil. The rest of the species on the graph had no response.

### 3.1.5. NMS scree plot

In the NMS (Non-metric multidimensional scaling) scree plot of Rawal Lake, Rawal Dam (its artificial reservoir) and its tributaries, the vegetation species were divided into four dimensions. The symbols of those individual dimensions were projected onto the line that lies perpendicular to the real data line. Those four lines, together with the symbols, were divided into three parts, representing the maximum, mean and minimum values of that species data. The diagram’s projection points were located in the order of the predicted increase in abundance of the particular species across the dimensions.

The scree plot shows stress as a function of the dimensionality of the gradient model. Stress is an inverse measure of fit to the data. The randomized data are analyzed as a null model for comparison (McCune and Grace, 2002).

In this study, the results were observed as more significant in this graph because the stress value of the randomized data ends at a stress value of 15 (Figure 6). According to Coulter (2008), the randomized data start from value >20 and end at value <20, which is considered significant, but whenever these values are not achieved, the result is considered an outfitted model.
According to Nagle (2005), the p-values are powerful indicators of the likelihood that an observed pattern has occurred by chance. Low p-values in this study for $p \leq 0.050$ indicate that the results are significant and have real meaning. The p values found in this study are shown in Table 2.
Soil and vegetation relationship along Rawal Dam

Figure 6. NMS Scree Plot showing the significance of present study results

Table 2. Stress in Relation to Dimensionality (Number of Axes)

<table>
<thead>
<tr>
<th>Axis</th>
<th>Stress in Real Data 50 run(s)</th>
<th>Stress in Randomized Data Monte Carlo test, 50 runs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>1</td>
<td>47.094</td>
<td>52.081</td>
</tr>
<tr>
<td>2</td>
<td>28.973</td>
<td>30.115</td>
</tr>
<tr>
<td>3</td>
<td>19.914</td>
<td>20.893</td>
</tr>
<tr>
<td>4</td>
<td>15.033</td>
<td>15.925</td>
</tr>
</tbody>
</table>
4. Discussion

Vegetation plays a significant role in a natural ecosystem; soil is a segment of the environment that both facilitates and is necessary for the continued existence of plant growth and life (Ghaemi et al., 2014). Soil is an abiotic factor that determines the diversity of vegetation in a specific space and time. In this study, the herbaceous vegetation of Rawal Lake, Rawal Dam and its tributaries was identified and then the relationship of those plant species was developed with the soil’s variable parameters. It was observed from the results that available potassium was the factor that strongly defined the presence of *Cynodon dactylon* in study area sites. Studies revealed that potassium is the necessary nutrient for the growth and survival of *Cynodon dactylon*. In another study, six alluvial soils were cropped to check the presence and reduction (or even absence) of potassium in soil after plant and *Cynodon dactylon* cultivation. The results showed that after harvesting, a significant decline was observed in soil potassium (Rasnake and Thomas, 1976). Thus, the availability of potassium in five study-area sites also determined the distribution of *Cynodon dactylon* grass.

Two other species also dominated the plant communities that were scrutinized by the TWINSPLAN classification technique. When we speak of dominance here, we are referring to the organism’s reaction to its habitat (Urooj et al., 2015). According to Trivedi (2004), the dominant species not only tolerate but also modify the environment’s harsh conditions (e.g., light, moisture, and space) for other organisms. Moreover, these species are prominent entities that formulate the major portion of a community’s living mass and provide the food, substrate and shelter for other individuals that live there. The most dominant species is *Cynodon dactylon*, followed by *Cannabis sativa* in second place and *Melilotus indica* in third place. DCA divided the study area vegetation into three main plant groups, which were populated by species similar to those found in the TWINSPLAN communities. CCA was then used to develop a relationship between the study area sites’ vegetation and the soil’s physical and chemical parameters (known as explanatory predictors or environmental variables). The graph predicted that available potassium was the environmental gradient among EC, pH, moisture and available phosphorus that strongly affected the study area sites’ vegetation, specifically, *Bambusa arundinacea*, *Diclyptera roxburghiana* and *Sonchus asper*. Potassium has many effects on a plant species: it stimulates early growth, increases protein production, improves the efficiency of water use (which is vital to stand persistence, longevity, and the winter hardiness of alfalfa), and improves resistance to diseases and insects. These roles or functions are general; however, all of them are important to profitable crop production (Rehm and Schmitt, 2002). Therefore, it can be said that plant species occupied by specific climatic and edaphic factors experience variability in their composition. It is generally assumed that soil saturation and OM matter are affected by the climate and that other parameters are dependent upon edaphic factors. OM is the soil parameter that determines both living organisms and the presence of their decomposed material in the soil. Thus, OM indirectly reveals the soil’s fertility. A separate graph was drawn for the heavy metals present in soil, including manganese, iron and zinc. Manganese strongly affected the presence and absence of species and showed an association with specific species, including *Vicia faba*, *Anagalis arvensis* and *Malvastrum coromendelianum*. The T-value biplot not only developed the relationship between plant species and environmental gradients but also predicted species’ response in terms of significant and non-significant association with those gradients. The T-value biplots drawn for the environmental variables
showed that most of the species found in the study area sites had a strong relationship with the variables, especially Potassium. NMS scree plots showed that the results were significant. This study highlighted the conservation and importance of native flora in the study area. This baseline data can be used to formulate a comprehensive species classification for the entire area.

5. Conclusion and Recommendations

Ordination techniques are widely used by ecologists for various purposes, including both population and community ecology. In this study, these statistical methods have been extensively used to develop the linkage between soil’s physical and chemical parameters and herbaceous vegetation. These environmental variables strongly affected the presence or absence of species, ultimately determining species frequency, dominance and abundance. The study area contained a large amount of herbaceous vegetation species and diverse ecosystems; the most dominant species was *Cynodon dactylon*. Moreover, an NMS scree plot declared that the results of this research project as significant, with \( p \leq 0.050 \). Therefore, by using these ordination methods, vegetation patterns and the arrangement of plant communities were determined by quantifying the vegetation along Rawal Dam and its tributaries. This study also provided information for future conservation and provided baseline data for this ecologically important area.

Because the study area consisted of both picnic points and residential areas, along with degraded soil and poor or no management, the following recommendations are proposed to better protect areas with ecologically important vegetative species.

1. The filtration plants installed near the Rawalpindi and Islamabad residential areas should be properly and regularly tested.

The agricultural practices in surrounding area or villages should be correctly managed on a small scale e.g. the discharge of farm manure and inorganic fertilizer waste into the lake water should be minimized.

References


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