



A Spatial Study on the Ecological Signatures of Landscapes in Colombo

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Abstract. Urbanization is a governing demographic feature and a significant part of global land transformation. According to the United Nations, more than half of the world's population lives in urban areas. If not studied and managed properly, urbanization can affect negatively its residents, and in Sri Lanka this is about 20%–30% in commercial areas and residential areas. Yet, studies related to exploring functions and status quo of different landuses are rare and rather unfound in Sri Lanka. This study the variations of temperature, humidity, soil moisture, infiltration rate, shrub cover and tree richness with different landuses namely, cemeteries, parks, residential areas and institutes have been investigated to see whether the landuses actually are the landscapes people perceive. It was found that the humidity of land plots with Institutes is significantly higher than all the other landscape types. Interestingly, it was observed that parks and cemeteries possessed high humidity levels while Institutes and Residential areas possessed a comparatively lower humidity level. The soil moisture content and infiltration rates of institutal landscape significantly differed from those of other landscape types. Shrub cover variation between Residential areas and Institutes was insignificant, while shrub cover of all the other landscape types resulted in substantial differences with a significance level of 0.00. The analysis of variation of multiple ecological factors under landscape types depicted that for all the temperatures, the shrubs cover percentage of cemeteries lies higher than the rest of the landscapes. In cemeteries, initially, the shrub cover increased with the humidity and with increments of humidity level, the shrub cover decreased. Overall sense, the Institutional areas depicted relatively adverse liveable conditions, and Cemeteries depicted most favourable conditions, interestingly it was better than Parks. This study gave insights into how these landscapes be best managed and engineering interventions needed in that regard.

Keywords: Colombo · Ecology · Landscapes · Urban planning · Vegetation

1 Introduction

Colombo is the commercial capital of Sri Lanka. It was well known among the Greece, Roman, Persian, Chinese and Arabian traders even before 2000 because of the significant location of the city. Colombo is between latitudes $6^{\circ} 55'N$ to $6^{\circ} 59'N$ and longitudes $79^{\circ} 50'E$ to $79^{\circ} 53'E$. The Colombo area has a resident population of 637,865 and approximately 100,000 floating population. Because of the living conditions (i.e., facilities)

and higher job opportunities in urbanised areas in and around Colombo, the migration of people from rural areas to Colombo has increased during the past decades. With this rapid urbanization and growth of population, and it can be identified that a significant diminish in vegetation cover (and similar changes to the landscape) is taking place within the city due to unplanned developments. Reformation of land surfaces, which consists of vegetation cover into different types of land covers, including paved surfaces, bare sand surfaces, compacted soil surfaces and different constructions, leads to the formation of distinctive urban climates affecting the inhabitants of the area (Grimmond et al., 2010). If not managed and planned properly, urbanization can easily result in harsh conditions in the area. For proper planning and management, scientists, decision-makers and planners need to recognize how the ecological aspects of an urban area interrelate.

Colombo has several distinct landscapes (rather micro landuses). Interestingly, it has many parks including large cricket grounds, perhaps at a density more than any other city of the world. The main objective of this study was to evaluate whether the designated places and spaces in urban areas, such as parks, institutions, etc. perform their intended purposes in terms of ecology. For that, the variation of six environmental factors with landscape types were to identify. These factors were selected after reviewing several past works (Pauleit et al., 2005; Nagendra & Gopal, 2010). The study considered four types of landscape types (Cemeteries, Institutes, Residential areas and Parks including wetland parks and recreational areas). Through analysis of those factors some relationships were intended to distinguish. Firstly, to identify the variation of different environmental factors with landscape types. Secondly to identify the vegetation cover variation patters with identified environmental factors in relation to landscape types. The third objective is to propose best planning practices or engineering interventions. This study is one of the first to be conducted in Colombo and it is expected that this research will assist the intervention of guidelines regarding land use in Colombo. The rapid urbanization of the Colombo, if not properly managed it can lead to poor environmental conditions as well as substandard socioeconomic conditions in the area. Even though the findings are based on Colombo, one of well-known urban center in South Asia, the findings can be applicable elsewhere.

2 Methodology

2.1 Selection of Landscapes

The urbanized areas in Colombo are composed of different landscapes types namely commercial areas (~23%), residential areas (~34%), recreational areas (~3%), parks (~3%), marshy lands (~20%), institutes (~2%), cemeteries (~0.7%) and water bodies (~3%). Out of these heterogenic landscapes, some landscapes are intended to provide the dwellers with a comfortable environment while positively effecting the ecology of the area (e.g. Parks). From each of the four landscape types fifteen to 25 number of sites were considered for field observation. In this regard 18 sites from cemeteries, 18 sites from institutes, 14 sites for parks and 25 sites for residential areas were sampled. Also, within a site three to four number of plots were considered in order to get a better representation.

All sites (Fig. 1) were selected within the Colombo Municipality limit or within the close proximity such that those sites represent “the Colombo”, an average person perceives. As an example, a Cemetery from the Nugegoda area was selected but not from the Labugama area. Also, to get more reliable results, only large cemeteries with a considerable land area were selected. Fig. 1 shows the locations on the satellite image. The selection of institutes was done by considering the number of students accommodated. Only the institutes with more than 2500 students were selected for the study. In case of parks, the parks with a land area exceeding 120 perches were considered. Concern was also given to the selection of parks, which are extended all over the urbanized areas of Colombo. In case of residential landscapes, the residential areas only the land plots with a considerable area (> 25 perches) were selected.

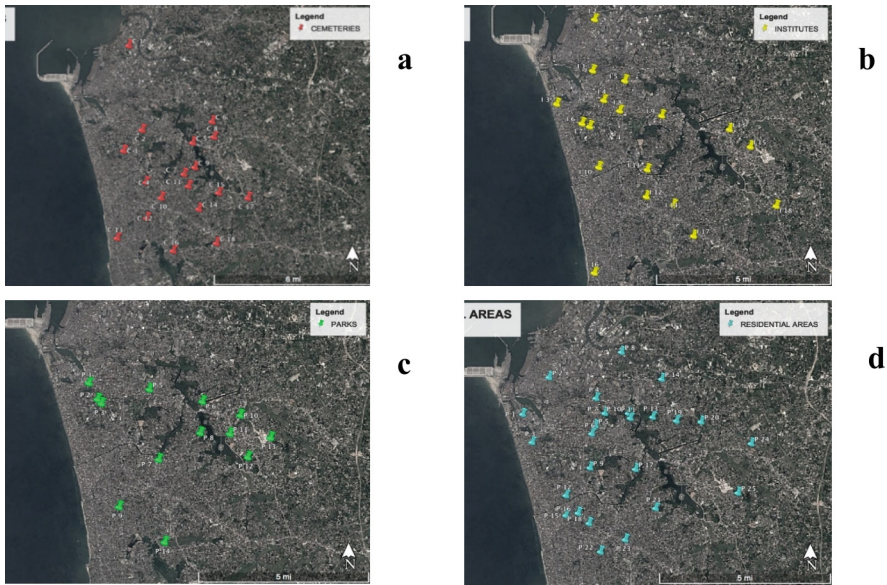


Fig. 1. Locations of (a) Cemeteries (e.g. Borella, Dehiwala) (b) Institutes (e.g. Maradana, Battaramulla) (c) Parks (e.g. Rajagiriya, Sri Jayawardenapura Kotte) (d) Residential Areas (e.g. Kollupitiya, Nawala).

2.2 Data Collection

Past works (Scott et al., 2011; Weiqi et al., 2011) have considered different variables to identify the ecological and/or livable quality of landscapes. Out of those, four prominent or widely used factors were selected in our study. They are temperature, as higher the heat, lower the comfort for the urban dwellers and lead to greater health risks (Poumadere et al., 2005), soil moisture, as it represents the runoff, the balance of precipitation and evapotranspiration of an area (Wang et al., 2012), percentage of shrubs cover, and tree richness as past researches proved that percent of woody vegetation is the most important

factor affecting the temperature rise in urban areas (Weiqi et al., 2011). In addition, the infiltration rate and relative humidity were also considered. As higher infiltration rates reduce surface runoff and loss of nutrients and soil (Scott et al., 2011), and the relative humidity represents the quality of air and it affects the heat and population mental health (Ning et al., 2016). The ecological factors were measured from four landscape types in urban areas of Colombo, Sri Lanka. The measurements were carried out during daytime from 1200 h to 1400 h on clear days in June and July 2018, when the temperature and humidity level were at their peak and considerably favourable climate for shrubs growth was prevailing. And also, again in 2020 (July) and 2023 (June). These months ensured exclusion of extreme weather conditions. However, this also indicate our study do not tackle the entire spectrum of climate conditions. The urban planning and design implications of these findings could contribute to the development of a more favourable environment for the inhabitants of urban areas in Colombo.

To collect air temperature a thermometer, VC330 VICTOR, manufactured in China, was used with an accuracy of ± 1 °C. The data were taken from 1200 h to 1400 h on clear days. When taking the reading the thermometer was kept 4–5 feet above the ground level to avoid the excess heat picked up from the ground and natural cooling aloft. The thermometer was placed in the shade while taking readings as direct radiation from the sun may result in erroneously higher temperatures than what it should be. When measuring humidity, a digital hygrometer of VC330 VICTOR, manufactured in China was used to collect relative humidity data with an accuracy level of $\pm 5\%$ RH. While collecting these data types, it was decided to get data from 3 to 4 plots per site to overcome random error. The average of those values was considered as the temperature and relative humidity of that particular site.

Soil moisture readings were taken by a soil moisture meter, LL1825 RAPITEST, made in the USA. The moisture at 50 mm depth of soil was considered. The measurements were taken between the same time period as above mentioned. When taking the readings, the surface of the ground was cleared so that there were no any leaves and other debris. The same method was practiced, by taking readings from different locations at the same site. When it came to measuring the percentage of shrubs covering the land, 3 to 4 25 m \times 25 m land plots were considered per site for cemeteries, parks and institutional areas. But for residential areas, the plot size was considered depending on the land area as each and every residential area was not processed with a 25 m \times 25 m land plot free of any structure. Then the land area coverage with shrubs was measured as a percentage of the total considered area. The same land plots were considered for calculating tree richness. The number of trees in each land plot was counted and then an average was taken for the site. To get the infiltration rate of the sites, again 3 to 4 locations were considered to perform the test per site. And an average rate was taken. The single ring infiltrometer test was followed to get infiltration rates, which provided the time taken to infiltrate 1 inch of water through the soil.

For the test, a six-inch diameter ring with a mark around the outside three inches from the bottom of the ring, plastic wrap, 500 mL plastic bottle or graduated cylinder, Water and a Stopwatch or timer were needed. Before conducting the test, an area of sq. foot was cleaned of all debris, weeds and vegetation. (Testing area should not be saturated). Then, the ring was driven up to a three-inch mark into the ground. After that, the soil and

inside of the ring were covered with plastic wrap completely and 444 mL, 1" of water, was poured into the ring lined with plastic wrap. Finally, the plastic wrap was removed gently, allowing the water to pour into the ring and the time taken to infiltrate through the soil until there is only a glistening sheen on the soil was recorded in minutes. The taken readings, which were in minutes per second (min/s), were then converted to SI units, mm per hour (mm/hr.). For one location, the infiltration test was conducted only once, as according to the study, only a comparison among the readings was necessary. A data recording sheet was used per site for the ease of collecting and recording data for each location. Once the data collection was completed, all the data were tabulated.

2.3 Data Analysis

All the collected data was tabulated according to the landscape type, site number and data type. Then all the data was imported to a data analyzing software, IBM SPSS Statistics Version 23.0.0.0. After that, using One-Way ANOVA, all the dependent variables, temperature, humidity, soil moisture, shrub cover percentage, tree richness and infiltration rates were subjected to a multiple comparison with the landscape type factors. The one-way analysis of variance was used to determine the significant difference between the means of two independent groups. For the analysis, equal variance was assumed as Tukey, and a significance level of 0.05 was considered. After that graphs were plotted for each ecological factor considered, with the landscape type. The significance level of each ecological factor between the landscape types was tabulated. The average values of considered ecological factors vs landscape type graphs were also plotted for the examination. Then, each pair of ecological factors was plotted against the landscape type to compare the relationships of different ecological factors with the interested landscape types using multiple line-defining tools. Finally, all the relationships obtained were thoroughly examined and determined.

3 Results and Discussion

3.1 Temperature and Humidity Variations with the Landscape Type

According to the analyzed data of average temperatures of each landscape type, as shown in Fig. 2(a), all of the landscape types show average temperatures ranging from 30.06 °C to 31.31 °C. This shows that there is no significant change in temperatures depending on the landscape types. Comparing the results with past studies, such as Weiqi (2011), reveals that the spatial configuration of land cover significantly influences land surface temperature. Specifically, the patterns of land cover, including the extent of building coverage and woody vegetation, have a direct impact on land surface temperatures in urban areas (Weiqi et al., 2011).

This does seem to depend on the location of the selected plots. The plot distribution is concentrated in a comparatively smaller area as the interested area is the Colombo district, which makes the plots have the same latitude and altitude because the amount of sunlight hitting the surface is more or less the same. Another limitation of the study areas is, as the urbanized areas of the Colombo district are located close to the sea

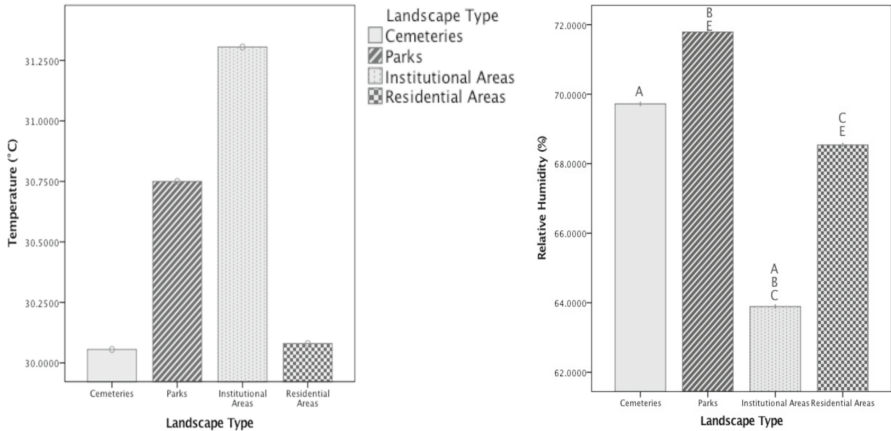


Fig. 2. (a) Mean Temperature variation with Landscape Type (b) Relative Humidity variation with Landscape Type.

between Longitudes E 79° 51' and E 80° 10', the effect of maritime influence on the temperature of the atmosphere along the longitudinal way across Colombo is the same due to proximity to the sea from each location does not vary much (Kelsey, 2013).

But the slight variation of temperature can be explained as the institutes show a comparatively higher temperature due to the high building coverage and paved surface coverage and because of that, the albedo effect on such environments may be high, resulting in high temperatures. The cemeteries with more vegetation cover resulted in lower temperatures due to the evapotranspiration process that is occurring in the environment.

The analysis depicts that the humidity of institutes is significantly different from all the other landscape types, with a significance level of 0.000 (One-Way ANOVA; $P < 0.05$). However, the cemetery and park comparison and the cemetery and residential areas comparison resulted in a significant difference values of 0.646 and 0.294, respectively, which means there is no considerable difference. (One-Way ANOVA; $P < 0.05$).

According to the results, another pair with a significant difference can be identified as parks and residential areas, as depicted in the notation E-E in Fig. 2(b). When the average humidity of the landscape types was considered, it was observed that parks and cemeteries processed high humidity levels. At the same time, institutes and residential areas possessed a comparatively lower humidity level with an average humidity of Cemeteries = 69.7 Parks = 71.8, Institutes = 63.9 and for Residential areas = 68.5. We speculate that this might be due to the location of the land plots. It was observed that the distance between water bodies and the sea is much less than that of plots with higher humidity levels.

3.2 Soil Moisture and the Infiltration Rate Variations with the Landscape Type

Soil moisture of an area represents the runoff, balance of precipitation and evapotranspiration of an area (Wang et al., 2012). According to the analyzed data, the soil moisture of institutes is significantly lower than that of all the other landscape types, with a soil moisture content of 1.63, as shown in Fig. 3(a). The notations of A-A, B-B, and C-C show the resulting pair-wise comparisons. Cemeteries and parks show comparatively higher moisture content of 2.03 and 2.36, respectively.

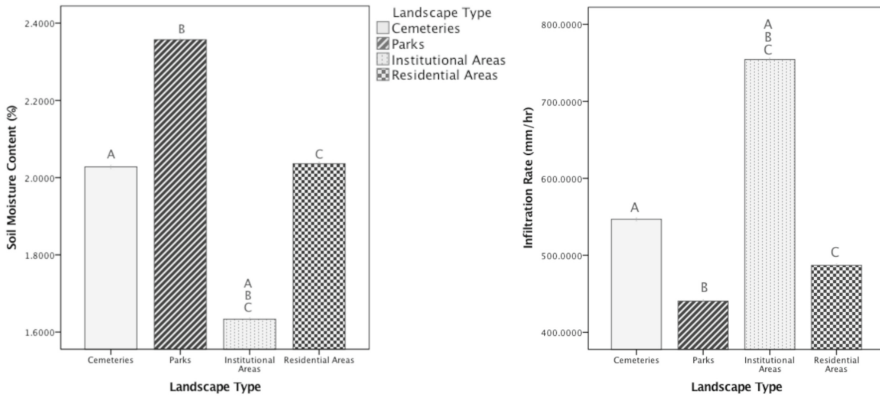


Fig. 3. (a) Soil Moisture variation with Landscape Type [A-A, B-B and C-C denotes the Landscape types with a significant difference in Soil Moisture Content, (One-Way ANOVA; $P < 0.05$)] (b) Infiltration Rate variation with Landscape Type [A-A, B-B and C-C denotes the Landscape types with a significant difference in Infiltration Rate, (One-Way ANOVA; $P < 0.05$)].

A possible explanation for this would be in cemeteries, residential areas and parks, it could be observed that the texture of the soil was finer and also soil consisted of a higher amount of organic matter, unlike in institutes, where most of the areas were paved and was consisted of compacted soil not allowing water retention in soil. Also, in Parks, ponding of water was spotted at some of the sites, which eventually resulted in higher soil moisture contents.

The downward entry of water into the soil is simply know an infiltration. The infiltration rate means the velocity at which water enters the soil. The infiltration rate of a ground surface is important as it indicates the soil’s ability to allow water movement into and through the soil surface. (Lowery et al., 1996).

When considering the results obtained through the single-ring infiltrometer method in the study, the values obtained deviated from the average values, as shown in Fig. 8. However as the comparison was among the results from this study, the deviation was not problematic.

According to the results obtained through One Way ANOVA, the infiltration rates of institutional areas showed a significant difference than those of cemeteries. The above Fig. 3(b) depicts it from the notation A-A. The main reason for that could be the inherent factors of the soils in cemeteries. In cemeteries it could observe that the soil was consisted with clayey particles. The movement of water through the small pores of clayey soil is

comparatively low. So the infiltration rates at cemeteries might have been influenced by this. Then as shown in the above Fig. 8, the infiltration rate of parks possesses the lowest resulting the maximum infiltration rate difference with that of institutional areas with a significance level at 0.001 (One-Way ANOVA; $P < 0.05$).

The main factor for that would be the in parks a considerable area was effected with ponding of water on the soil surface. Therefore, infiltration rates were comparatively lower than other landscape types. This situation in parks can lead to poor function and plant growth. Ponding and soil saturation decreases soil strength, and eventually makes soil more erodible due to detachment of soil particles. On the other hand, ponded water is subjected to evaporation which leads to decrease water available for plant growth (Lowery et al., 1996).

3.3 Shrubs Cover Percentage and the Tree Richness Variations with the Landscape Type

When the significance levels were considered it resulted in a way as shown in Fig. 4(a), which depicted that shrubs cover variation between residential and institutes was not significant while shrubs cover of all the other landscape types resulted to be significantly different. According to the data it is visible that, the shrubs cover percentage of cemeteries is much higher, even more than parks which is quite unusual.

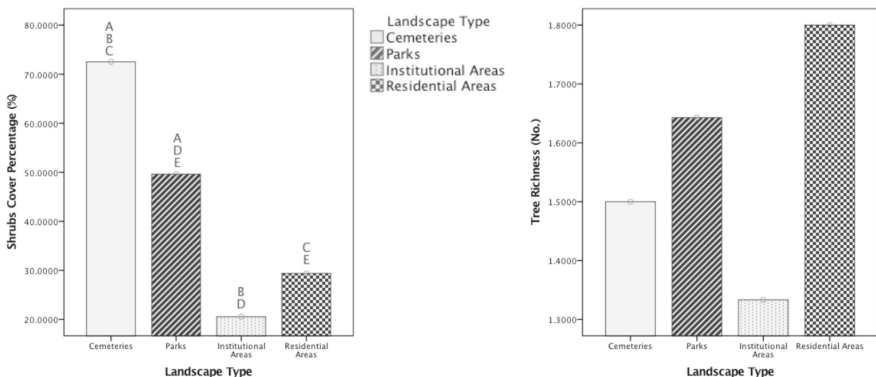


Fig. 4. (a) Shrubs Cover Percentage variation with Landscape Type [A-A, B-B, C-C, D-D and E-E denotes the Landscape types with a significant difference in Shrubs Cover Percentage, (One-Way ANOVA; $P < 0.05$)] (b) Tree Richness variation with Landscape Type.

The major factor affecting the shrub cover variation could be identified as the nature of the soil. Where the cemeteries were consisted mostly of compacted soil as well as paved areas which disrupts the plant growth. And also the human inhabitant is comparatively high in Residential, Parks and Institutional areas interrupting the plant growth where as the cemeteries are most of the time abandoned. Another factor which may have influenced this is the fine texture of soil in cemeteries with high organic content to have a shrub cover which is very much higher in cemeteries.

According to the obtained values as in Fig. 4(b), it is visible that the tree richness results were not up to the expected values. The main cause for this is consideration of a comparatively smaller land plots. According to the results obtained there is no significant variation of tree richness between landscape types.

3.4 Variation of Multiple Ecological Factors Under the Landscape Types

As shown in Fig. 5(a), it is clear that for of all the temperatures, the shrubs cover percentage of cemeteries lies higher than the rest of the landscapes with shrubs cover percentage of more than 60%. And also, for the temperatures above 30 °C, shrubs cover percentage of institutes is the lowest with shrubs cover of only 20%. That of residential areas and parks does not show a pattern in the variation according to the graph.

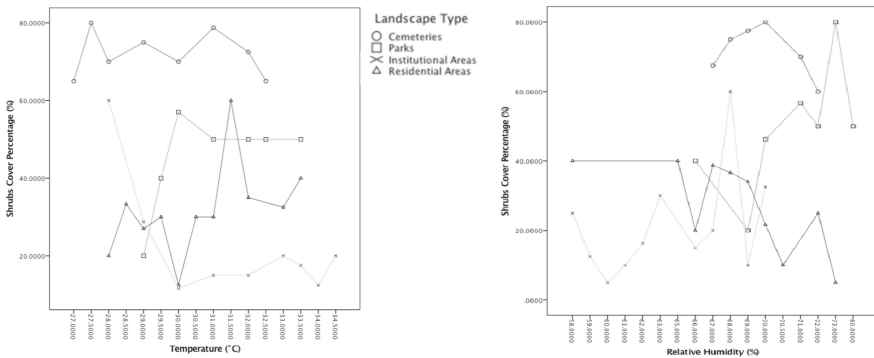


Fig. 5. (a) Shrubs Cover Percentage variation with the Temperature under the four landscape types (b) Shrubs Cover Percentage variation with the Humidity under the four landscape types

According to the graph obtained it can be seen that there is not much relationship between the shrubs cover percentage with humidity, see Fig. 5(b). However, it is visible that in cemeteries the shrubs cover increases with the humidity and on further increment of humidity level the shrubs cover tends to decrease.

As depicted in the graph in Fig. 6(a), there is no relationship between the variation of soil moisture on the shrubs cover for the measured values. But we can observe that for most all the soil moisture contents the shrubs cover of cemeteries possesses a higher value while residential areas and institutional areas possess comparatively lower values.

In the graph of infiltration Vs soil moisture in Fig. 6(b), it is obvious that with increasing soil moisture the infiltration rates gradually decrease for all the four landscape types. Therefore, it is evident that infiltration rate variation with soil moisture content was independent of the landscape type. Although there are some deviated points, those can be explained as some of the locations where infiltration tests were carried out was consisted of compacted soil, which decreases the infiltration rate. And some locations were consisted of different land cover types such as bare soil and grass cover which effects the infiltration rate. From the graph it can be seen that for soil moisture contents of 1.8 to 2.2 the infiltration rates for all the four landscape types is almost the same.

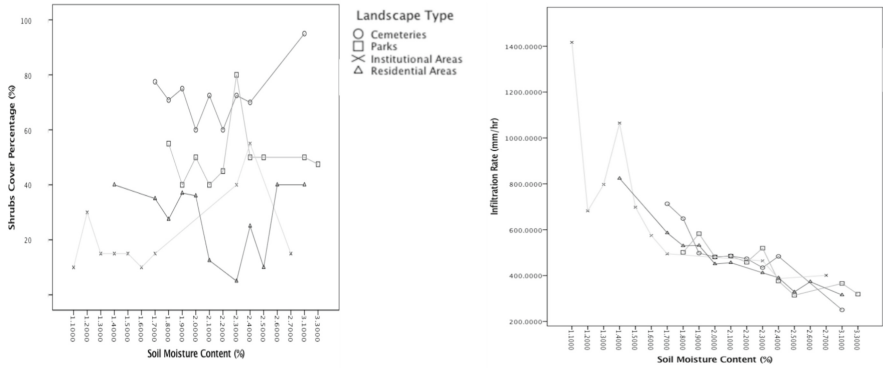


Fig. 6. (a) Shrubs Cover Percentage variation with the Soil Moisture Content under the four landscape types (b) Infiltration Rate variation with the Soil Moisture Content under the four landscape types.

It has been noticed that, a considerable limitation of this study was, when considering shrubs cover Vs soil moisture previous studies showed that with the shrubs cover type soil moisture content changes (Wang et al., 2012). But in this particular study all the shrub cover types were taken as a one category.

4 Conclusion and Recommendations

Institutions depicted an overall negative conditions with highest average temperature resulting uncomfortable experience to the occupants, lowest soil moisture content, very low shrubs cover percentage and lowest tree richness. Cemeteries depicted more favorable conditions with lower temperatures, higher shrubs cover percentages and higher infiltration rates than Parks, which were designed to possess a significant surface area of compacted and paved surfaces which caused ponding of water on ground surface.

Further studies are needed to develop planning strategies that could improve the ecology of urban areas by considering different landscape types. Those could include questionnaire surveys to explore the socioeconomic variation with ecological factors such as vegetation in urban areas. By conducting this study, we could come up with few recommendations that can be contemplated in future planning of some landscape types.

Though this study we recommend the following:

- The designing of parks in urban areas should be more ecological by minimizing the paved areas and by increasing vegetation cover in parks will provide a better experience for this users and a better condition for the ecology of environment of urban areas.
- The designing of institutes should be done in a way avoiding dense building populace and higher paved surfaces as it ultimately increased the air temperature of the surrounding and also with less soil compacted areas providing more space for vegetation growth facilitating students with a better surrounding.

Formualte guidelines that cover ecological variables, and perhaps represented by easy to measure surrogate variables such as vegetation abundance and diversity, percent impervious fracyion etc.

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