ABSTRACT

Analysis of Vegetation Indices in Urban Areas from TM-Landsat and HRV-SPOT Orbital Data

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The spatial organization of the brazilian cities in several areas of the country reflects the impact of the accelerated and disorganized urbanization that has occurred during the last years. This urbanization without an adequate planning has caused a process of degradation of the natural urban environment. An imbalance between built up areas and green areas has occurred where the presence of the vegetation element has grown less. A quantitative and qualitative survey of urban green areas establishes basic information to elaborate adequate planning in order to improve the quality of the urban environment. Through the transformation of orbital data into numerical models, called Vegetation Indices (VI), it is possible to obtain a qualitative and quantitative indicator of the vegetation cover relative to built up areas. The main objective of this study is to analyse the Normalized Difference Vegetation Index (NDVI) in the urban environment obtained from orbital data. The study area is located in the city of Taubaté in São Paulo state. The NDVI is calculated from orbital data from TM-Landsat (TM3,TM4,TM5) and HRV-SPOT (XS2,XS3) corresponding to spectral bands in the red, near-infrared and middle-infrared ranges. The data was taken on 8 August, 1988 and 19 July, 1988, respectively. It is calculated by the formulae:

$$VI = gain \times \frac{NIR - R}{NIR + R} + offset \quad \text{and} \quad VI = gain \times \frac{MIR - R}{MIR + R} + offset.$$

The influence of spectral and spatial characteristics from TM-Landsat and HRV-SPOT data was taken into account in analyzing the performance of classification for the VI calculated from those sensor systems. Ground information and the percent vegetation cover were determined from panchromatic aerial photographs (in scale 1:10 000) and planimetric maps (in scales of 1:25 000 and 1:50 000). The different classes of urban land use were discriminated and classified on the basis of VI. In the results, it was found that the NDVI calculated by TM-Landsat and HRV-SPOT data allowed a distinct classification associating urban land use and vegetal cover to be obtained. It is concluded that the VI is a good estimator to compare green areas with built up areas and it permits a global view of the spatial distribution and density of vegetal cover.

KEY WORDS: Urban Environment, Vegetation Index, TM-Landsat, HRV-Spot.

1. INTRODUCTION

In the most brazilian cities occupation of the urban land has occurred without an adequate planning. It shows the great urbanization impact through the last years , when the urbanization got the percentage of 65.57 around the country (Censo,1980).

The change in the urban spaces has taken place rapidly, becoming extense build up areas occupied with reduced vegetation.

Through knowledge of cities green cover, urban planners and urbanists can take some directions in the urban planning such as determining deficient and preservation areas and the establishment of suitable areas to be used as green spaces in the urban area.

Using information from remote sensing in orbital level it gives data that makes the analysis less costly, timely information and makes the work fatigueless when compared to traditional methods.

Also the orbital data is important because of when one works in urban areas there is the need of periodic survey to update the information since the urbanization process has been very dinamic. In addition, these data permit to acquire information about the targets on the ground in different wavelenghts of eletromagnetic spectrum.

The vegetation index is one of these information that through spectral data permits to obtain qualitative and quantitative indicators of the distribution and density of vegetation inside the urban area, and its proportion compared to build up area.

The main objective of this study is to analyse the Normalized Difference Vegetation Index (NDVI) obtained from TM-Landsat and HRV-SPOT orbital data, and the use of it as a tool in the vegetation survey in the urban environment.

2.STUDY AREA

The work was developed in the city of Taubaté in Sao Paulo state.

The study area includes the urban continuous agglomeration of the city, which occupies an area of approximately 51.50 Km². It is situated between the coordinates south latitude 22°59' 09" to 23°04' 51" and west longitude 49°31' 08" to 45°36' 43".

The municipality of Taubaté is located in Parayba Middle Valley in Taubate Basin extending over an area of 655 Km² at an average altitude of 554 m.

Actually its population is estimated in 239,945 hab, with 97.82 % concentrated in the urban area (Macrozoneamento da Regiao do Vale do Paraíba e Litoral Norte do Estado de Sao Paulo-in press). The urbanization problem is conditioned with the circulation issue due to its location in Sao Paulo-Rio de Janeiro axis where the urban expansion is related with the industrialization of the Parayba Valley Region.

3. MATERIAL AND METHODS

3.1 Material

For this study were utilized orbital data from CCT's TM-Landsat (218/76 orbit in 8 August,1989) and HRV-SPOT (coordinates 780 K/396 J in 19 July,1988) corresponding to red, near infrared and middle infrared spectral bands.

The selection of the spectral bands of the orbital data used in the vegetation index calculation is based in studies already developed in Pearson and Miller (1972); Carnegie and De Gloria (1974); Tucker (1979); Thibault (1986) and others. The red, near infrared and middle infrared spectral regions related to their basic properties with respect to green vegetation. The relationship between the red range and green vegetation results from the absorption of incident radiation by the chlorophyll. The near infrared range is resulted from high degree of intra and interleaf scattering in the canopy of the plant and the middle infrared its relationship with the hidric contents of the canopy plant Tucker(1979), Thibault (1986).

In addition were used panchromatic aerial photographs in scale 1:10 000 and planimetric maps in scale 1:25 000 and 1:50 000.

The automatic process of orbital data were realized through SITIM system developed by INPE / ENGESPAÇO.

3.2 Methods

3.2.1 Photointerpretation In this step was realized the photointerpretation of the 45 aerial photographs in scale 1:10 000. Through that was determined the land use classes obtained in the first and the second level of the classification system (Anderson et al, 1979). This classification had the support of planimetric maps in scale 1:50 000 and 1:25 000 and field verification. Table I lists the 8 land use classes representative of the study area.

The photointerpretation of these photographs was also utilized in the determination of the cover vegetation classes (adaptation from Sadowski et al, 1987) which was obtained seven classes described in table I.

This classification was useful in the determination and explanation of the vegetation index classes obtained from TM-Landsat and HRV-SPOT orbital data.

3.2.2 Selection of samples area From the photointerpretation of 45 aerial photographs that covered the study area was selected seven sample areas, in such way that was possible to find the maximum variability of urban land use classes showed in the study area.

The sample areas incorporated about 30 percent of the study area measuring approximately 1625 x 1300 meters on the ground. It included one area of 54 x 43 and 85 x 65 pixels, corresponding to spatial resolution from TM-Landsat and HRV-SPOT respectively.

All these sample areas were located in planimetric maps in scale 1: 10 000, where the photointerpretation information overlays were transposed.

3.2.3 Measureament of vegetation cover percentage In development of these phase was utilized the photointerpretation overlays of the seven selected sample areas. The information of these overlays was overlaped over a millimeter grid with 0.09 centimeter-square relative to TM-Landsat spatial resolution.

The vegetation cover percentage existence was quantify through minimum area of one pixel. It was defined five classes of vegetation cover percentage that intervals occurred among 0-10 class I, 11-25 class II, 26-50 class III, 51-75 class IV and 76-100 class V.

This measurement consisted to verify the number of the square there were in the land use classes. Utilizing the classes mean values above described, it was multiply for the number of square.It was possible to determinate the vegetation cover average total area in meters-square of the land use class as well of each sample area.

3.2.4 Automatic analysis of orbital data It was developed through SITIM system (INPE/ENGESPAÇO) where it followed the steps described below:

a. geometric correction of TM-Landsat and HRV-SPOT images In this procedure a program called "Registro" was utilized to permit that the location of the sample areas from planimetric maps to TM-Landsat and HRV-SPOT images were executed with maximum possible precision (Thibault,1986).

b. calculation of vegetation index (NDVI) from TM-Landsat and HRV-SPOT data The calculation of vegetation index was realized by means of transformations of orbital data into numerical models using the combinations of the spectral bands TM3/TM4, TM3/TM5-Landsat and XS2/XS3 HRV-

SPOT (Lenco et al, 1982; Delavigne and Thibault, 1984; Thibault, 1986; Foresti, 1986; Foresti and Pereira, 1987; Santos, 1988 and others). The vegetation index was obtained from the formulae:

$$NDVI = gain \times \frac{NRI - R}{NRI + R} + offset \quad (1)$$

$$NDVI = gain \times \frac{MIR - R}{MRI + R} + offset \quad (2)$$

The NDVI calculated from TM3/TM5-Landsat spectral bands combination was denominated Wetness Index due to the TM5 spectral band to be sensitive to liquid water within plant leaves permitting to describe better the canopy hydric contents (Jackson et al, 1983).

As a result of the calculation index three index images were obtained, where the areas covered with densely vegetation appeared in light tones while the areas with rare vegetation cover in darker.

c. extraction of spectral values from vegetation indices In determination of vegetation indices classes intervals we utilized selected samples from each different land use classes determinated in the study area which was possible to find great variation in relation to the vegetation cover.

26 samples included in the 7 tests sites selected previously were extracted. The 26 samples were considered as the most representative of land use classes of the study area. Each sample included one area between 3.2 to 7.2 Km^2 on the ground.

Digital values from each sample were extracted and analysed to determine the intervals of vegetation index classes.

d. automatic classification of the vegetation indice images Supervised classification (Slicing) was performed in the vegetation indice images obtained from TM-Landsat and HRV-SPOT orbital data (Foresti, 1986; Thibault, 1986; Foresti et al, 1987). This classification permitted to elaborate the histogram of the training areas vegetation index determining its means, minimum and maximum values and dividing those values in zones associated to different colours in the monitoring screen. Each zone was representative of one vegetation index class.

The study area was mapped in different colours by automatic classification where the vegetation index classes were associated with the urban land use classes.

4. RESULTS AND DISCUSSION

4.1 Results

4.1.1 Analysis of NDVI elaborated with TM-Landsat: The table II shows the spectral values expressed in digital numbers of vegetation index obtained from TM-Landsat orbital data to 26 selected samples.

Fig. 1 shows the NDVI values from TM3/TM4-Landsat plotted where one can analyze their behaviour through the different urban land use classes.

These samples had VI values in a range of spectral values between 26.47 to 40.20 when were used TM3/TM4-Landsat orbital data (fig.1).

The minimum mean VI value was associated to commercial/service class and the overlap among the VI values was reduced when compared with other samples of the urban land use classes.

The residential and industrial classes showed high approximation among VI values permitting to be grouped in the same class of VI. The samples representative of vacant sites, agriculture/pasture, institutional and development areas, even with near values, it was possible to establish more number of classes of VI. It happened because of the density and quantity variation of vegetation cover found in the samples representative of these classes.

Examining the standard deviation (fig.1) the results provided a great variation in the VI of the samples. The highest standard deviation was observed for the samples representative of institutional, development areas, agriculture/pasture classes. It was observed that these areas had more heterogenity of targets with spectral signature distinguished, for example: great variation due to density and proportion of vegetation cover types.

The lowest standard deviation was identifed in commercial/service and residential classes, where the vegetation cover was more homogeneous. Variations of VI standard deviation showed to be connected with the composition and structure of the samples of urban land use classes.

Using the TM5 spectral band in calculation of VI, here called Wetness Index (WI) we found that the means values of VI resulted closer from each other. These values also exihibited a little variation in digital values and a great overlap between the values of the samples. These two factors did not permit the differentiation and separability of the samples in WI classes.

The Wetness Index (WI) (Jackson et al, 1983) or Normalized Difference Vegetation Index (NDVI) suggested by Thibault (1980) utilizing the TM3 and TM5-Landsat did not show satisfactory results in this study. Thus it was ruled out. So the subsequent analysis of the indices calculated from TM-Landsat orbital data were based only in the indices calculated from TM3 and TM4 bands combination.

Determinig the intervals of VI classes, the index image was classified (see fig.2).

It was suitable to establish 7 classes of VI where are described quantitatively associated with the land use classes (see table III).

4.1.2 Analysis of NDVI elaborated with HRV-SPOT orbital data: Table II contains the spectral values of VI acquired from XS2 and XS3 HRV-SPOT orbital data.

Figure 3 displays these values plotted.

The variation of mean values VI occurred between 31.68 to 43.08 digital values, being the minimum and maximum values defined for sample number 1 and 22 representative of commercial/service and vacant sites respectively. These data demonstrated the separability in two groups, which are correlated to variability of density and type of vegetation cover.

The mean values appeared close to each other among the samples representative of commercial/service, industrial and residential and among institutional, vacant sites, development areas and agriculture/pasture land use classes.

Even through the residential samples land use class were close, this fact permitted to establish two VI classes.

For standard deviation (see fig.3) the higher values were related to institutional and agriculture/pasture classes, where it showed targets heterogeneous of vegetation cover which the VI displayed more sensible. The lower values corresponded to commercial/service class.

Evaluating the performance of these data and utilizing the same process to establish the VI classes from TM-Landsat, it was possible to determine four VI classes (Table IV).

The spatial distribuition of VI classes is showed in fig.4, where there are the index image classified.

4.1.3 Comparison between NDVI calculated from TM-Landsat and HRV-SPOT: A comparison of the NDVI performance obtained from TM-Landsat and HRV-SPOT was analised through VI mean values and standard deviation obtained from selected sample sets.

Through descriptive analysis, we found that TM-Landsat mean values show more disperse along of the linear configuration relative to HRV-SPOT mean values. The HRV-SPOT VI mean values were closer from each other, building up area two distinct region This TM-Landsat and HRV-SPOT VI's behaviour could be associated to the different location of the sensor spectral bands, where the TM-Landsat has narrower intervals in the red band TM3 (0.63-0.69μm) than XS2 (0.61-0.69μm) HRV-SPOT. The TM-Landsat obtained higher separability among the samples which were composed of a large amount of vegetation cover. It was found in institutional, development areas, vacant sites and agriculture/pasture classes showed closer from each other.

The HRV-SPOT data did not exhibit very sensible to the difference of the vegetation cover amount. It was found in the institutional, vacant sites and development areas classes, like as occurred with TM-Landsat data.

The HRV-SPOT VIs mean values appeared closer than TM-Landsat to these land use classes. The TM-Landsat VIs mean values showed to be much better to separate classes with great vegetation cover amount (institutional, development area, vacant sites, agriculture/pasture) while HRV-SPOT VIs mean values to residential classes.

In the standard deviation values, the VI from TM-Landsat and HRV-SPOT exhibited different behaviour. The VI standard deviation values from HRV-SPOT were lower than TM-Landsat, exception to 1,2,9,16,26 samples. The structure and composition of these samples displayed greater homogeneity what could be one reason for VIs standard deviation values from HRV-SPOT these samples showed higher than TM-Landsat values. Also the standard deviation values from VI TM-Landsat showed more variability when compared to HRV-SPOT values. It is expressed due higher spectral sensibility of TM-Landsat to identify the characteristic targets of the study area.

The relationship of the NDVI and vegetation cover mean percentage of the selected samples was analized through the regression analysis.

The NDVI from HRV-SPOT displayed the greatest regression in the relationship with vegetation cover mean percentage. Where 81.4% of the variation found in the dependent variable Y (NDVI) was explained through independent variable x (vegetation cover mean percentage), so that it showed more significative. This results can explain due the greatest spatial resolution from HRV-SPOT (20m) that it permitted identify small details relative to area covered with vegetation.

The variables from HRV-SPOT orbital data showed better relationship with the variable obtained from aerial photographs vegetation cover percentage.

5. CONCLUSIONS

Analyzing these indices calculated from TM-Landsat orbital data we found that: the TM3/TM5 band combination, correspondent to red and middle infrared respectively, did not perform satisfactory results in this study.
The TM3/TM4 band combination showed better results than the preceding index.

In comparative analysis between NDVI calculated from TM-Landsat and HRV-SPOT we found that:

- the mean values VIs permitted to obtain results distinct relative to definition of the VI classes, although the mean values VI behaviour had showed very close;
- the TM-Landsat VIs provided to establish a greater number of classes than HRV-SPOT;
- the mean values VIs from HRV-SPOT data showed lower confusion among the samples of the residential class;
- the establishment of the VI class from HRV-SPOT exihibited larger approximation relative to the defined land use classes.

The results suggest that HRV-SPOT data provided to be more useful to study the vegetation cover in the city of Taubaté, because it had permitted better separability among the VIs classes in residential area than TM-Landsat data.

The VI showed to be a good tool to study the vegetation cover in the urban area. It permitted to analyze the spatial distribution and density of vegetation in the urban area.

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Note: This paper is part of a M.Sc. thesis in Remote Sensing/INPE.

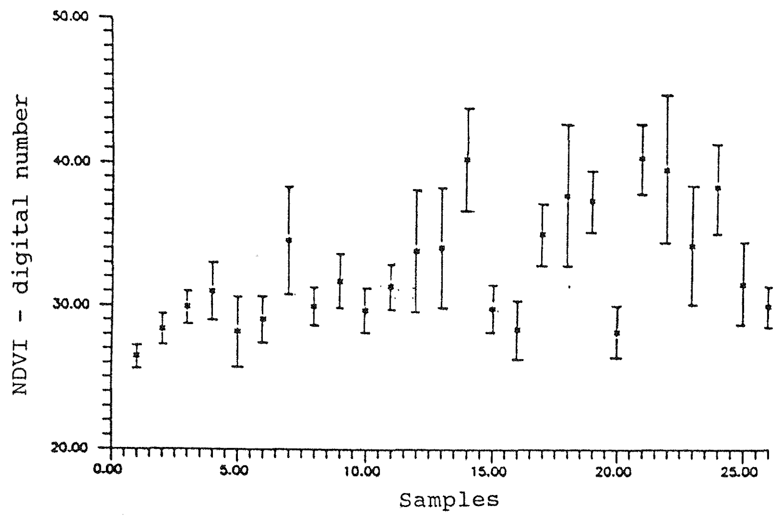

Fig.1 Mean values and standard deviation for NDVI obtained from TM3 and TM4-Landsat.

Fig.2 Index image classified obtained from TM3 and TM4-Landsat bands combination.

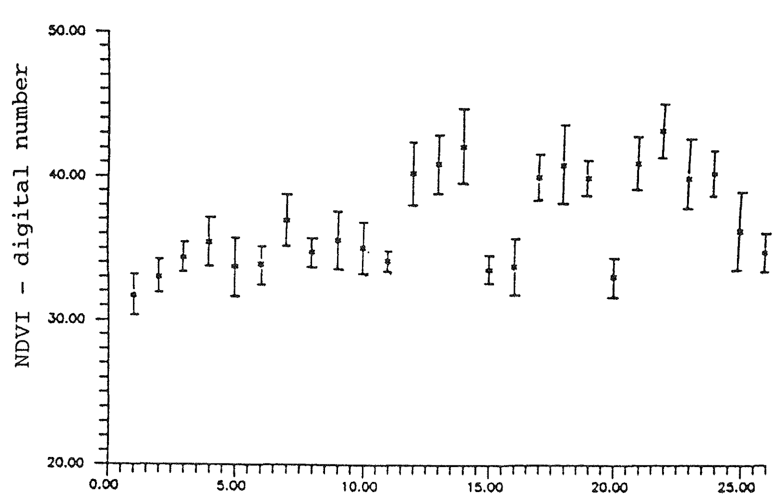

Fig.3 Mean values and standard deviation for NDVI obtained from XS2 and XS3 HRV-SPOT.

Table I - Vegetation Cover Classes

I. Areas covered with shrub and trees (>10%)	I.1 dense (60-100%) I.2 intermidiate (31-60%) I.3 diffuse (11-30%)
II. Herbaceous Vegetation (>50% herbaceous <10% trees and shrub)	II.1 rich in herbaceous II.2 intermidiate II.3 poor in herbaceous
III. Scarce vegetation area (<10% trees and shrub <50% herbaceous)	III.1 predominance of natural features with uncovered vegetation (bare soil, rock and water) III.2 predominance of cultural features with uncovered vegetation (roofs and paved areas)

Table II - Spectral values for NDVI obtained from TM3/TM4, TM3/TM5-Landsat, XS2/XS3 HRV-SPOT and vegetation cover percentage

Samples	TM3/TM4		TM3/TM5		XS2/XS3		Vegetation cover mean values (%)	Land use and vegetation cover classes
	Mean values	Standard deviation	Mean values	Standard deviation	Mean values	Standard deviation		
1	26.47	0.94	28.20	2.48	31.68	1.36	5.1	Commercial/Service III2
2	28.35	1.13	29.18	0.80	33.00	1.18	5.7	High Density Single Family Residential II2
3	29.90	1.48	29.67	1.13	34.34	1.03	35.7	Medium Density Single Family Residential II3
4	30.96	2.03	29.76	1.43	35.42	1.78	38.5	Medium Density Single Family Residential II3
5	28.19	2.54	27.94	2.30	33.71	2.10	30.4	Industrial II3
6	29.04	1.79	29.88	1.22	33.88	1.46	32.2	Low Density Single Family Residential II3
7	34.54	3.92	30.29	2.32	36.91	1.89	83.0	Low Density Single Family Residential II3
8	29.92	1.29	29.06	0.93	34.74	1.18	25.1	Low Density Single Family Residential II3
9	31.67	1.81	29.80	1.08	35.55	1.92	77.8	Development Area II3
10	29.65	1.62	28.06	1.25	35.03	1.33	42.4	Medium Density Single Family Residential II3
11	31.32	1.22	30.57	0.90	34.08	0.70	72.6	Vacant Sites II3
12	33.78	4.13	30.12	1.63	40.18	2.76	90.2	Agriculture/Pasture II2
13	34.00	4.14	29.94	2.82	40.84	2.30	97.8	Institutional II
14	40.14	3.65	32.53	1.10	42.02	2.49	91.7	Agriculture/Pasture II1
15	29.76	1.50	29.36	1.19	33.47	1.14	9.1	High Density Single Family Residential II3
16	28.33	1.36	28.49	0.92	33.70	1.82	15.7	High Density Single Family Residential I3
17	34.94	2.02	32.06	1.25	39.91	1.64	85.0	Development Area I3
18	37.63	4.93	32.04	1.74	40.73	2.87	90.4	Institutional I2
19	37.29	2.30	32.63	1.17	39.83	1.52	83.7	Agriculture/Pasture I2
20	28.14	2.02	27.55	1.77	33.00	1.56	15.0	High Density Single Family Residential I2
21	40.20	2.21	32.59	1.59	40.85	1.77	92.7	Vacant Sites I2
22	39.41	5.15	32.15	1.79	43.08	1.70	90.5	Vacant Sites I1
23	34.12	3.22	28.12	1.31	39.79	2.34	88.6	Agriculture/Pasture I2
24	38.20	2.94	32.29	1.27	40.16	1.47	89.9	Agriculture/Pasture I1
25	31.43	2.43	30.48	1.39	36.15	2.42	28.6	Medium Density Single Family Residential I1
26	29.92	1.35	28.82	0.93	34.70	1.38	18.1	Medium Density Single Family Residential I2

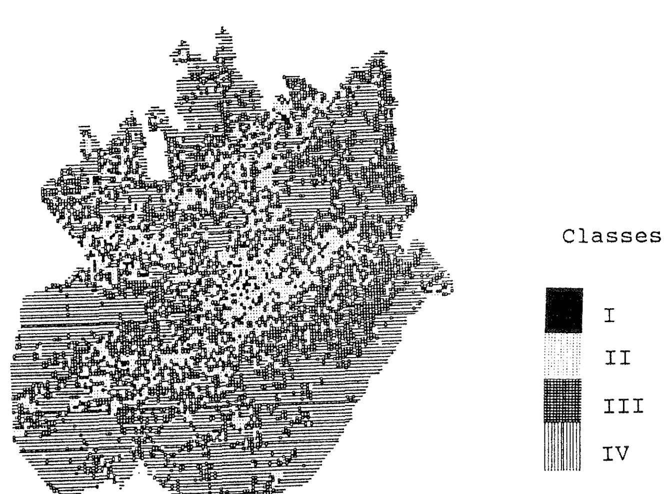

Fig.4 Index image classified obtained from XS2 and XS3 HRV-SPOT bands combination.

Table III - Quantitative description of VI obtained from TM3/TM4-Landsat orbital data

Classes of VI	Intervals of digital number	Number of pixels	Area (Km^2)	Urban land use classes
I	1-24	278	0.25	-
II	25-27	4489	4.04	Commercial/Service
III	28-30	16278	14.65	Residential Industrial
IV	31-36	26534	23.88	Vacant sites Development Areas Institutional Agriculture/Pasture
V	37-43	8356	7.52	Institutional Agriculture/Pasture
VI	44-47	964	0.87	Institutional Agriculture/Pasture
VII	48-56	322	0.29	Institutional Agriculture/Pasture

Table IV - Quantitative description of VI obtained from XS2/XS3 HRV-SPOT

Classes of VI	Intervals of digital number	Number of pixels	Area (Km^2)	Urban land use classes
I	1-30	1729	0.57	-
II	31-33	2714	9.45	Commercial/Service High Density Single Family Residential Industrial
III	34-36	42318	14.57	Medium and Low Density Single Family Residential Development Areas Vacant Sites
IV	37-49	71777	24.80	Vacant sites Development Areas Institutional Agriculture/Pasture