Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
Received 15 April 2021; Accepted 05 May 2021.

Dynamics of Land Use Change Using Markov Chains

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ABSTRACT

The change in land use in the central metropolitan area of the city of Huancayo (ACMH) in the last three decades has increased as a result of the migration of the rural population to the city, generating a dispersed and scattered urban fabric with a decrease in population density and the loss of agricultural land, as well as water surfaces. Markov chains (MC) is a mathematical tool that allows to quantify the change in land use in the period between 1995 - 2035. The classification for land uses is: commercial residential zone, industrial, agricultural, and equipment. The results of the model indicate that, if urban growth is not controlled, the annual change rates for the year 2035 would have the following values: residential area decreases by 0.40%, commercial predominance increases by 0.90%, industrial zone increases by 10.30%, forestry area decreases by 2.80%, equipment increases by 1.40%, reserve area decreases by 2.30 and urban roads increase by 1.90%.

Key words: urban impact, urban planning, economic and social development.

INTRODUCTION

The central metropolitan area of Huancayo (ACMH) is located in the Quechua zone at an altitude of 3500 m.a.s.l. and represents a highly favorable area for agriculture (Pulgar Vidal, 1996). In the last three decades, this area has increased its growth due to the demographic increase and, as a consequence, agricultural land has been reduced (Haller, A. 2017). These changes in land use are also affected by the urban Legislation that allows various types of soils to be developed (Gallardo, 2018). According to Arana, (2018) the appearance of new informal buildings in the surroundings of the city, have been modifying the urban morphology in an expansive and uncontrolled way. Damaging agricultural areas, natural wetland areas, continuously modifying land uses.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
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This causes a discontinuous and dispersed urban fabric, affecting the provision of public services for the population to meet basic needs.

The change in land use is affected by urban growth causing the increase of the artificialized area outside the city center and, resulting in the generation of peri-urban areas (Arana, A. 2018), which directly affects the agricultural area, forests and water surfaces. In the city of Huancayo there are no specific studies on land use change, except for some collateral studies such as "Diagnostico Urbano, del Plan de Desarrollo Urbano de Huancayo, 2015 - 2025 (MVCS y MPH, 2015) another study Environmental vulnerability in the Mantaro Valley due to urban activities (Martínez, 2006); "Urban indicators and their influence on the sustainable development of Huancayo Metropolitano - Peru" (Martínez, 2019); which also do not investigate land use change due to urban growth effects.

The metropolitan area of Huancayo presents the problem of land use changes that obey the structural order and that the occupation is spontaneous or in many cases by forced occupation, after analyzing and reviewing the studies of the researchers, it has been possible to show that there are no works related to how land use changes occur and what factors influence it so that the changes occur.

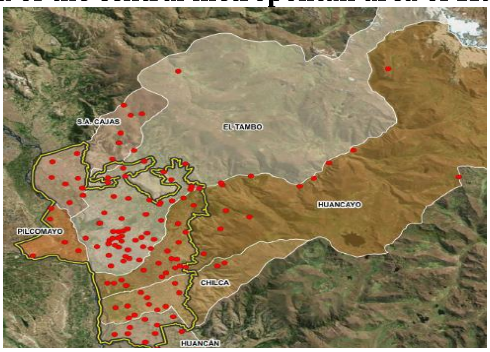
For the analysis of the research, Markov chains have been used as a methodology to forecast land use changes between 1995 - 2035 and the use of Landsat 5 TM satellite images (Buzai, 2005).

MATERIAL AND METHODS

Area of study

The study area is the central metropolitan area of Huancayo, which includes the districts of Huancayo, El Tambo, Chilca, Pilcomayo, San Agustin de Cajas, Huancan, as shown in Figure 2.

Figure 1: Study area of the central metropolitan area of Huancayo ACMH



Note: the study area is the central metropolitan area of Huancayo and is delimited by the yellow lines and the red dots are the population centers.

Data collection

The data are collected from Landsat 5 TM satellite images of the city of Huancayo, from the years 1995 and 2015 and digitized using the free software Qgis V 3.2. See figure 2.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
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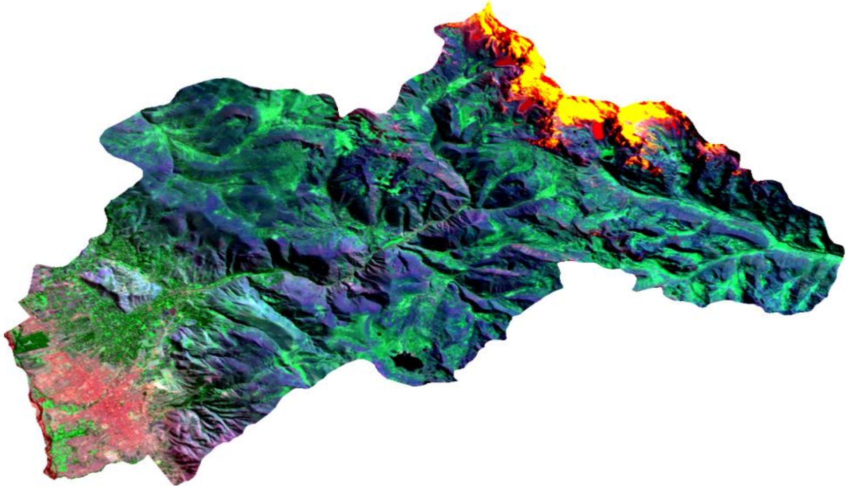
Figure 2: Landsat 5 TM satellite map of the year 1995.



Note: Map of the metropolitan area of Huancayo downloaded from the Landsat 5 TM satellite of the U.S. Geological Survey https://earthexplorer.usgs.gov/.

Image processing and validation

The maps downloaded from the Landsat 5 TN satellite were digitized using Qgis V. 3.2 software as a tool and orthorectification as a method to eliminate geometric distortions and inherent scales due to sensor imperfections and the curvature of the earth. Then the method of photointerpretation of the maps was used, identifying the following zones: residential predominance, commercial predominance, industrial, agricultural - forestry, existing equipment, area reserved for equipment and urban roads.

Markov Analysis

Land use modeling using Markov chains allows us to know land use changes using transition matrices in a finite number of possible states (Garrocho and Jimenez, 2018).

The Markov method is the most useful for modeling stochastic and probabilistic evolutionary processes when only the present state is known. Land use changes in the city of Huancayo, are modeled by stochastic process i.e. as any collection of random variables {X(t)} that depends on time t (Garrocho and Jimenez, 2018).

A stochastic process (X) has the Markovian property if the conditional on any future event t_i is independent of the past, it only depends on the current state of the process. In this case the process has no memory. If for all integers n≥0 and all states $i_o, i_1, \ldots, i_{n-1}$, i,j, then the equation (1) is applied.

$$P(X_{n+1} = J | X_n = i, X_{n-1} = i_{n-1}, \ldots, X_o = i_o) = P(X_{n+1} = J | X_n = i) \qquad \text{EC (1)}$$

It is mentioned that the process is in state i at time n. Be $\{X_n\}_{n \geq 0}$ a discrete stochastic process with state space $E = \{i.j.k, \ldots\}$

Therefore, for every state (i) and time (n) the equation (2) must be satisfied. Called Markov properties for all the variables i, j (Yin and Zhang, 2010).

$$\sum_{j\varepsilon E} P_{i,j} = 1, P_{i,j} \geq 0 \qquad \text{EC. (2)}$$

Where P_{ij} is the transition matrix, in this case the matrix of state changes (i.e. change from empty space to occupied space), where i is the classification of land uses for the year 1995 and j the classification in 2035.

The exposed methodology indicates the probabilistic situation of temporal change, but not spatial, therefore, the image at time t is used to apply the random diffusion rule of the pixels that have a higher probability of land use change in each use or category (Jiménez-López, E. 2019). In this way, the methodology of spatial Markov Chains is generated, which is supported in time and space.

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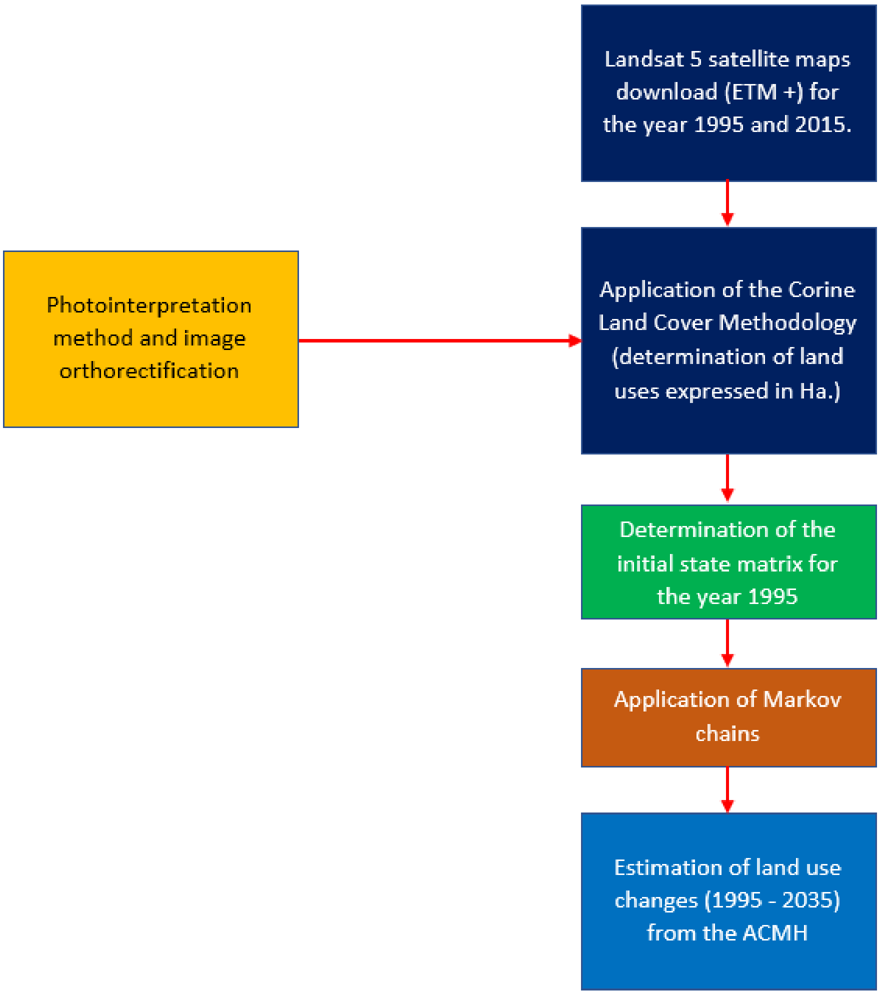

Figure 3: Determination of land use changes with Markov chains.

METHODOLOGY

First, the photo-interpretation methodology was used using the 1995 map, which identifies the land uses of the metropolitan area of Huancayo expressed in hectares. The identified themes of the changes in land use are: (P1) residential area, (P2) commercial predominance, (P3) Industrial, (P4) Agricultural - forestry, (P5) existing equipment, (P6) area reserved for equipment and (P7) urban roads.

Second, The Kappa index greater than or equal to 0.80 was considered in the analysis of land use changes. This index considers: elevation, slope, distance from the city center to the nearest town, with which it compares the data obtained with the Markov chains and the real map, its maximum value that can be reached is 1.0.
Third, the initial transition matrix is defined, corresponding to the year 1995, and then predicted by means of Markov chains up to the year 2035.
Fourth The validation of the model was performed by comparing the results obtained from the changes in land use with Markov chains and those obtained using Qgis V. 3.2 software with the zoning map of 2015, prepared jointly by the Provincial Municipality of Huancayo and the Ministry of Housing and Environmental Sanitation of 2015 (MPH, 2015), finding a Kappa index value of 0.80, for the comparison of land use with those estimated in the PDU of the Provincial Municipality of Huancayo.

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RESULTS

The results of the identification of land use changes in 1995 using the photointerpretation method and the Qgis V. 3.2 software tool are shown below. See Table 1.

Table 1: Land use in the metropolis of Huancayo 1995.

N°	Land use classes	Area (Ha)	Percentage
P1	Residential Predominium	2005.15	22.9%
P2	Commercial Predominium	254.39	2.9%
P3	Industrial	12.89	0.1%
P4	Agricultural - Forestry	4078.24	46.6%
P5	Existing Equipment	455.25	5.2%
P6	Area reserved for Equipment	348.15	4.0%
P7	Urban Roads	1597.77	18.3%
Total		**8751.84**	**100%**

Note: Thematic land use in the central metropolitan area of Huancayo (ACMH).

The transition matrix is obtained with the land use data in Table 1, placing the data in each column.

Table 2: Transition matrix of the initial state corresponding to the year 1995.

Transition Matrix									
Land use class		**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
P1	Residential Predominium	0.2291	0.0100	0.2000	0.2000	0.2000	0.0200	0.1409	1.000
P2	Commercial Predominium	0.0291	0.0300	0.4000	0.3000	0.1000	0.0200	0.1209	1.000
P3	Industrial	0.0015	0.0010	0.3000	0.4000	0.2500	0.0010	0.0465	1.000
P4	Agricultural - Forestry	0.4660	0.2000	0.0000	0.2000	0.0000	0.0000	0.1340	1.000
P5	Existing Equipment	0.0520	0.0100	0.2000	0.3000	0.2000	0.1200	0.1180	1.000
P6	Area reserved for Equipment	0.0398	0.4000	0.3000	0.0000	0.2000	0.0100	0.0500	1.000
P7	Urban Roads	0.1826	0.0000	0.0000	0.0000	0.0000	0.0000	0.8174	1.000

Note: Data obtained from the 1995 ACMH photo interpretation.

Table 2 shows the initial transition matrix for 1995, where the main diagonal is the probability of unchanging land use.

The probability of the initial land use status is shown below. See Table 3.

Table 3: Probability of initial state

Initial state							
P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
0.2291	0.0100	0.2000	0.2000	0.2000	0.0200	0.1409	1.000

Note: 22.9% is predominantly residential, 1% is predominantly commercial, 20% is industrial, 20% is agricultural and forestry, 2% is reserved for equipment, and 14.09% represents roads.

The data in Table 3 shows that the most predominant area is residential (P1) with an occupancy rate of 22.91%, followed by industrial (P3), agricultural (P4) and finally roads (P7).

For the year 2000 analysis, the transition matrix of land use changes from 1995 - 2000 for the ACMH is shown below. See Table 5.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
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Table 4: Matrix of land use transition from 1995 to 2000.

Transition Matrix											
Land use classes			Year 2000								
			P1	P2	P3	P4	P5	P6	P7	Suma
P1	Residential Predominium	Year 1995	0.1832	0.0528	0.1558	0.2288	0.1408	0.0292	0.2094	1.000
P2	Commercial Predominium		0.1760	0.0706	0.1638	0.2648	0.1328	0.0138	0.1782	1.000
P3	Industrial		0.2087	0.0832	0.1410	0.2756	0.1256	0.0304	0.1355	1.000
P4	Agricultural - Forestry		0.2302	0.0507	0.1732	0.1932	0.1132	0.0133	0.2262	1.000
P5	Existing Equipment		0.1890	0.1110	0.1504	0.2134	0.1254	0.0266	0.1841	1.000
P6	Area reserved for Equipment		0.0411	0.0187	0.3010	0.3080	0.1650	0.0332	0.1329	1.000
P7	Urban Roads		0.1911	0.0018	0.0365	0.0365	0.0365	0.0037	0.6939	1.000

Note: It shows the land use change from 1995 to 2000 by applying the Markov chains formula.

The probability of land use status from 1995 to 2000 is shown below. See Table 5.

Table 5: Land use status for the year 2000.

Del año 1995 al 2000							
P1	P2	P3	P4	P5	P6	P7	Total
0.1971	0.0624	0.1414	0.2028	0.1149	0.0221	0.2593	1.000

Note: Percentage of land uses between 1995 - 2000 of the MHCA.

The residential area decreased to 19.71%, i.e. there was a decrease of 16.26%, while the area of urban roads has increased to 25.93%, i.e. there is a growth of 84.06%, the equipment area has decreased from 20.00% to 11.49%, i.e. there was a reduction of 74.10%, the industrial area has decreased from 20.00% to 14.14%, i.e. it has decreased by 41.42% (Table 6).

For the analysis of 2005, the transition matrix of land use changes from 2000 to 2005 of the ACMH is shown below. See Table 6.

Table 6: Land use transition matrix from 2000 to 2005.

Transition Matrix											
Land use classes			Year 2005								
			P1	P2	P3	P4	P5	P6	P7	Total
P1	Residential Predominium	Year 2000	0.1959	0.0545	0.1364	0.1897	0.1084	0.0193	0.2957	1.000
P2	Commercial Predominium		0.1995	0.0567	0.1386	0.1944	0.1101	0.0193	0.2814	1.000
P3	Industrial		0.1966	0.0574	0.1467	0.2030	0.1151	0.0200	0.2611	1.000
P4	Agricultural - Forestry		0.1969	0.0532	0.1313	0.1877	0.1074	0.0195	0.3040	1.000
P5	Existing Equipment		0.1947	0.0559	0.1394	0.1970	0.1113	0.0194	0.2824	1.000
P6	Area reserved for Equipment		0.2025	0.0633	0.1449	0.2071	0.1119	0.0207	0.2494	1.000
P7	Urban Roads		0.1910	0.0205	0.0735	0.0956	0.0664	0.0108	0.5423	1.000

Note: It shows land use changes from 2000 to 2005 by applying the Markov chains formula.

The probability of land use status from 2000 to 2005 is shown below. See Table 7.

Table 7: Land use status for 2005**.**

From the year 2000 to 2005							
P1	P2	P3	P4	P5	P6	P7	Total
0.1955	0.0505	0.1294	0.1806	0.1043	0.0183	0.3214	1.0000

Note: Percentage of land uses for the years 2000 to 2005 of the ACMH.

The data in the table above show that the agricultural-forest area has decreased to 18.06%, i.e., there was a decrease in area by 12.33%, the industrial area has decreased to 12.94% which corresponds to 9.30% while the area reserved for equipment has increased to 32.14%, i.e. there is a growth of 23.96%.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
Received 15 April 2021; Accepted 05 May 2021.

For the 2010 analysis, the transition matrix of land use changes from 2005 to 2010 of the ACMH is shown below. See Table 8.

Table 8: Land use transition matrix from 2005 to 2010**.**

Transition Matrix											
Land use classes			**Year 2010**								
			P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
P1	Residential Predominium	**Year 2005**	0.1949	0.0450	0.1189	0.1647	0.0972	0.0170	0.3623	1.000
P2	Commercial Predominium		0.1950	0.0455	0.1198	0.1661	0.0978	0.0171	0.3587	1.000
P3	Industrial		0.1951	0.0462	0.1211	0.1681	0.0987	0.0173	0.3534	1.000
P4	Agricultural - Forestry		0.1949	0.0447	0.1183	0.1638	0.0968	0.0169	0.3646	1.000
P5	Existing Equipment		0.1950	0.0455	0.1197	0.1660	0.0978	0.0171	0.3589	1.000
P6	Area reserved for Equipment		0.1952	0.0466	0.1218	0.1692	0.0992	0.0174	0.3505	1.000
P7	Urban Roads		0.1934	0.0364	0.1029	0.1402	0.0863	0.0148	0.4260	1.000

Note: It shows the land use changes from 2005 to 2010 by applying the Markov chains formula, taken from the initial data of the Corine Land Cover Methodology 1995.

The probability of land use status from 2005 to 2010 is shown below. See Table 9.

Table 9: Land use status for the year 2010.

From the year 2005 to 2010							
P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
0.1948	0.0441	0.1172	0.1621	0.0960	0.0167	0.3690	1.000

Note: Percentage of land use for the years 2005 to 2010 of ACMH.

Table 9 shows that the agricultural-forestry area has decreased by 16.21%, i.e., there has been a decrease of 11.37%, followed by the area of commercial predominance which has decreased by 4.41%, i.e., it has decreased by 14.46%, while the area of urban roads has increased by 36.90%, i.e., there has been a growth of 14.80%.

For the 2015 analysis, the transition matrix of land use changes from 2010 to 2015 for the ACMH is shown below. See Table 10.

Table 10: Land use transition matrix from 2010 to 2015.

Transition Matrix											
Land use classes			**Year 2015**								
			P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
P1	Residential Predominium	**Year 2010**	0.1944	0.0421	0.1134	0.1563	0.0935	0.0162	0.3840	1.00
P2	Commercial Predominium		0.1944	0.0421	0.1135	0.1564	0.0935	0.0162	0.3838	1.00
P3	Industrial		0.1944	0.0422	0.1136	0.1566	0.0936	0.0163	0.3834	1.00
P4	Agricultural - Forestry		0.1944	0.0421	0.1134	0.1563	0.0934	0.0162	0.3841	1.00
P5	Existing Equipment		0.1944	0.0421	0.1135	0.1564	0.0935	0.0162	0.3838	1.00
P6	Area reserved for Equipment		0.1944	0.0422	0.1136	0.1566	0.0936	0.0163	0.3831	1.00
P7	Urban Roads		0.1943	0.0415	0.1124	0.1547	0.0927	0.0161	0.3882	1.00

Note: It shows the changes in land use from 2010 to 2015 by applying the Markov chains formula.

The probability of land use status from 2010 to 2015 is shown below. See Table 11.

Table 11: Land use status for the year 2015.

From the year 2010 to 2015							
P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
0.1944	0.0420	0.1133	0.1562	0.0934	0.0162	0.3844	1.000

Note: Percentage of land uses from 2010 - 2015 of the ACMH. The data on changes in use were validated with the zoning areas of the 2015 Huancayo Diagnostic Plan.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
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The data in Table 11 shows that the agricultural-forestry area has decreased to 15.62% i.e., there was a decrease in area by 3.81%, followed by the industrial area which has decreased to 11.33%, i.e., there was a decrease in area to 3.42% while the area of urban roads has increased to 38.44% i.e., there is a growth of 4.18%.

For the 2020 analysis, the transition matrix of land use changes from 2015 to 2020 of the ACMH. See Table 12.

Table 12: Land Use Transition Matrix 2015 to 2020.

Transition Matrix											
Land use classes			**Year 2020**								
			P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
P1	Residential Predominium	**Year 2015**	0.1944	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P2	Commercial Predominium		0.1944	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P3	Industrial		0.1944	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P4	Agricultural - Forestry		0.1944	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P5	Existing Equipment		0.1944	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P6	Area reserved for Equipment		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00
P7	Urban Roads		0.1944	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00

Note: It shows the change in land use from 2015 - 2020 by applying the Markov chains formula.

The probability of land use status from 2015 to 2020 is shown below. See Table 13.

Table 13: Land use status for the year 2020.

From the year 2015 to 2020							
P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Suma**
0.1944	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.000

Note: Percentage of land uses between 2015 - 2020 of the MCLH.

Table 13 shows that the agricultural-forestry area has decreased to 15.57%, i.e., there was a decrease in area by 0.28%, followed by the predominantly commercial area which has decreased to 4.19%, i.e., there was a decrease in area by 0.36% while the area of urban roads has increased to 38.55%, i.e., there is a growth of 0.28%.

For the analysis of the year 2025, the transition matrix of land use changes from 2020 to 2025 for the ACMH is shown below. See Table 14.

Table 14: Land use transition matrix from 2020 to 2025.

Transition Matrix											
Land use classes			**Year 2025**								
			P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
P1	Residential Predominium	**Year 2020**	0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P2	Commercial Predominium		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P3	Industrial		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P4	Agricultural - Forestry		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P5	Existing Equipment		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00
P6	Area reserved for Equipment		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00
P7	Urban Roads		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.00

Note: It shows the projected land use change from 2020 to 2025 by applying the Markov chains formula.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
Received 15 April 2021; Accepted 05 May 2021.

The probability of land use status from 2020 to 2025 is shown below. See Table 15.

Table 15: Land use status for the year 2025.

From the year 2020 to 2025							
P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3855	1.000

Note: Percentage of projected land uses between 2020 - 2025 of the MCHRA.

The data calculated for Table 16 show that the area of urban roads has decreased to 38.55%, i.e., there was a decrease in the area by 0.01%, while there is no increase in the other areas.

For the analysis of the year 2030, the transition matrix of changes in land use from 2025 to 2030 of the ACMH is shown below. See Table 16.

Table 16: Land use transition matrix for 2025 to 2030.

Transition Matrix										
Land use classes			**Year 2030**							
			P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
P1	Residential Predominium	**Year 2025**	0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00
P2	Commercial Predominium		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00
P3	Industrial		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00
P4	Agricultural - Forestry		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00
P5	Existing Equipment		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00
P6	Area reserved for Equipment		0.1943	0.0418	0.1130	0.1557	0.0931	0.0162	0.3853	1.00
P7	Urban Roads		0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.00

Note: It shows the projected land use change from 2025 to 2030 by applying the Markov chains formula, taken from the initial data of the 1995 Corine Land Cover methodology.

The probability of land use status from the year 2025 to 2030 is shown below. See Table 17.

Table 17: Land use status for the year 2030.

From the year 2025 to 2030							
P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.000

Note: Percentage of land uses between 2025 - 2030 of the MCHRA.

Table 17 shows that the area of urban roads has decreased to 38.54%, i.e., there was a decrease in the area by 0.02%, while there is no increase in the other areas.

For the analysis of the year 2035, the transition matrix of changes in land use from 2030 to 2035 of the ACMH is shown below. See Table 18.

Table 18: Land use transition matrix from 2030 to 2035.

Transition Matrix										
Land use classes			**Year 2035**							
			P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
P1	Residential Predominium	**Year 2030**	0.1942	0.0418	0.1129	0.1556	0.0931	0.0162	0.3852	1.00
P2	Commercial Predominium		0.1942	0.0418	0.1129	0.1556	0.0931	0.0162	0.3852	1.00
P3	Industrial		0.1942	0.0418	0.1129	0.1556	0.0931	0.0162	0.3852	1.00
P4	Agricultural - Forestry		0.1942	0.0418	0.1129	0.1556	0.0931	0.0162	0.3852	1.00
P5	Existing Equipment		0.1942	0.0418	0.1129	0.1556	0.0931	0.0162	0.3852	1.00
P6	Area reserved for Equipment		0.1942	0.0418	0.1129	0.1556	0.0931	0.0162	0.3851	1.00
P7	Urban Roads		0.1942	0.0418	0.1129	0.1556	0.0931	0.0162	0.3852	1.00

Note: t shows the changes in land use from 2030 to 2035, applying the Markov chain formula.

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The probability of land use status from the year 2030 to 2035 is shown below. See Table 19.

Table 19: Land use status for the year 2035.

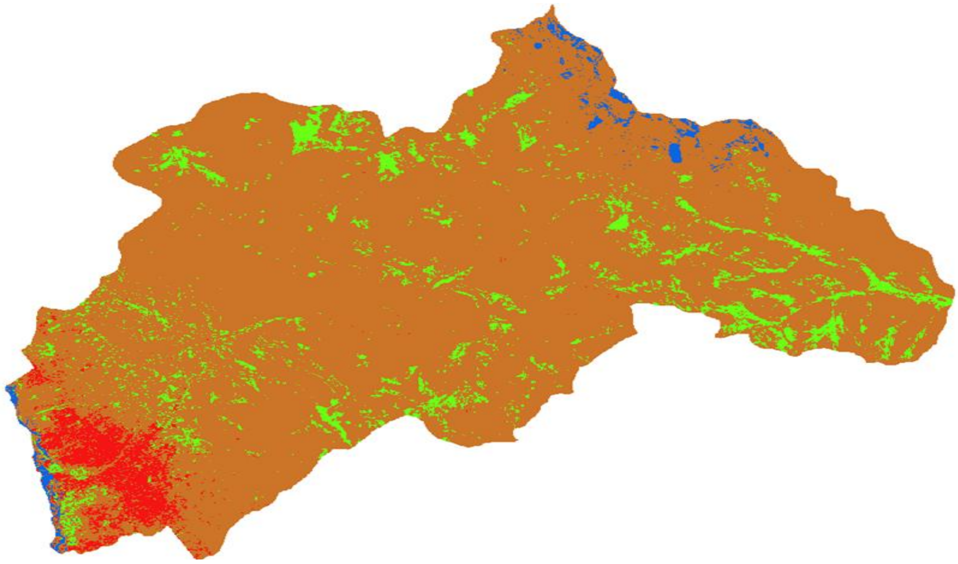
From the year 2030 to 2035							
P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total**
0.1943	0.0419	0.1130	0.1557	0.0932	0.0162	0.3854	1.000

Note: Percentage of projected land uses from the years 2030 to 2035 of the MCHRA.

The data calculated for Table 19 show that the area of urban roads has decreased to 38.54% with no decrease in area with respect to Table 18.

The initial map for the year 1995 of the ACMH area with the themes of land use, residential, forest agricultural zone, water and rocky soil is shown in Figure.

Figure 4: Initial land use map of the central metropolitan area of Huancayo using Markov chains for 1995.



Note: Results using Markov chains with Idrisi selva for the year 1995.

Figure 4 shows the initial state for the analysis of Markov chains using Idrisi selva v.3 .2, which has been georeferenced for the area of Huancayo, located at 10º45'55" and 12º43'10.5" South latitude and between 73º26'300" and 76º30'40.5" West longitude of the Greenwich meridian (Huancayo Urban Development Plan 2006 - 2011). Likewise, the red pixels represent artificialized areas, the green pixels indicate agricultural zones and forests, the light blue pixels are bodies of water and the brown pixels are rocky areas.

Validation of the land use change map 2035.

The results of the validation of the map generated with the Markov chains and the Landsat 5 TM satellite map was with Idrisi's VALIDATE algorithm, showed a high similarity between the satellite map and the map obtained with the Markov chains projected for the year 2015. The statistical analysis with Kappa index is above 80% for the selected criteria (Kstandar= 81.2 %, Kdistance = 85.01 %, and Klocalization = 85.2 %), so they are considered acceptable (Viera and Garrett, 2005).

The results of land use for the year 2035 (see Figure 4) show that there is saturation in the artificalized areas; agricultural areas are smaller than in 1995. Changes in land use have many factors such as: political, socio-demographic, social and

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
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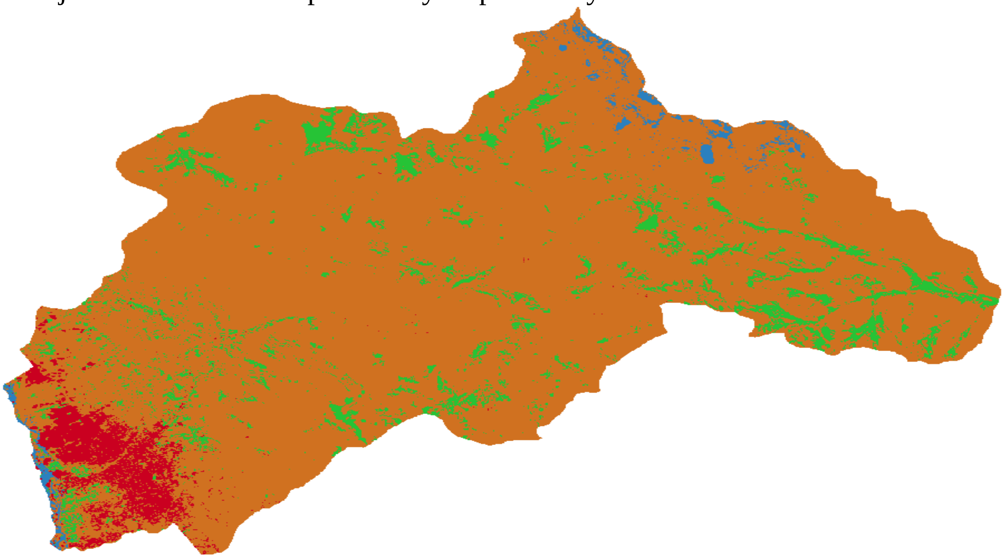
economic. However, the Markov model is linear and does not consider the effects of these factors on land use change (Pontius 2000), but is based solely on the analysis of the internal dynamics of the system (Paegelow et al. 2003). See Figure 5.

Figure 5: Projected Markov chain probability map for the year 2035.



Note: Projected map obtained using Markov chains for the year 2035, showing that land use changes in the artificialized areas, in the agricultural zone and in the forests, will be more than the changes in the land use in the urban and rural areas.

For the analysis of Figure 5, using the photointerpretation method, the pixels corresponding to the land uses have been located following the Corine Land Cover methodology within the ACMH area, the changes that can be seen with respect to 1995 are due to physical and socioeconomic factors such as population growth, migration to urban areas, population density, infrastructure. In this analysis the design corresponds to a non-experimental, longitudinal and panel design, where it is not possible to control the independent variable, the facts happen in time and only information of what happened is obtained.

Table 21: Dynamics of land use recorded in 1995 and projected to 2035 with Markov chains in the MHCA.

Land use classes		Registered Area 1995	%	Projected area 2035 (Ha)	%	Exchange rate 1995 - 2035 (%)
P1	Residential Predominium	2005.15	22.91%	1700.47	19.43%	-0.40%
P2	Commercial Predominium	254.39	2.91%	367.29	4.20%	0.90%
P3	Industrial	12.89	0.15%	989.76	11.31%	10.30%
P4	Agricultural - Forestry	4078.24	46.60%	1363.59	15.58%	-2.80%
P5	Existing Equipment	455.25	5.20%	816.28	9.33%	1.40%
P6	Area reserved for Equipment	348.15	3.98%	141.58	1.62%	-2.30%
P7	Urban Roads	1597.77	18.26%	3372.87	38.54%	1.90%
	TOTAL AREA	**8751.84**	**100.00%**	**8751.84**	**100.00%**	

Note: Two moments in time are shown in the analysis of land use data recorded in early 1995 that were obtained from the Landsat 5 (ETM+) satellites of the U.S. Geological Survey https://earthexplorer.usgs.gov/ quantified with the photo interpretation methodology and the land use data projected with Markov chains to the year 2035, there is a rate of change between the two, with some increasing and others decreasing.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
Received 15 April 2021; Accepted 05 May 2021.

DISCUSSION

The results found of the land use changes of the ACMH is done in period of 40 years from 1995 to 2035, in the case of Arana, V.F. (2018) in his PhD thesis makes an analysis between 1965 and 2015 of 50 years and for Sepulveda, V.A. (2019) in his scientific article on land cover and land use change makes an analysis between 1994 - 2007 i.e. in a period of 13 years, Aguilera, B.F. (2006) in his scientific article analyzes between 1984 and 1999, i.e., 15 years.

In this study, the photo interpretation method was used, the same one used by Arana, V.F. (2018) and Sepulveda, V.A et al. (2019) uses the methodology a mapping analysis and Kappa index and the use of the change matrix, while Aguilera (2006) uses the logistic regression model and the cellular automata.

In data analysis, in this case Markov chains are used, in the case of Arana (2018) uses statistical analysis to determine the percentages of land use changes, Sepulveda, V.A. (2019) analyzes with the change matrix, which is a double-entry table, where the columns represent the loss and the row are the gains.

The results according to the Markov chains model used in this research use Kappa index greater than 80% of coincidence, in the case of Arana, V.F. (2018) does not use the Kappa index, Aguilera (2006) uses the Kappa index with a value of 0.84, i.e., there is a very good correlation between the predicted map and the actual map.

The changes in land use with Markov chains indicate that the highest growth according to the model was between 2010 - 2015, while Haller (2017), uses and validates his own instrument with which he considers that the highest growth was between 2008 and 2010, which causes the decrease of agricultural area.

All the studies and articles reviewed consider the need to know the land uses of the city in order to be able to make decisions with greater certainty, for a more sustainable design.

The results of the Agricultural-Forestry area in the year 1995 represented 20% and by the year 2035 with the use of the Markov model it is estimated that it will reach 15.57% decrease which is consistent with what was raised by Diaz (2015) who also found changes in urban land uses that constitute adaptive transformations to development and also will become one of the great challenges for urban development planners in the city of Huancayo as warned by Haller (2017).

CONCLUSIONS

- The application of the photo interpretation method has allowed the initial quantification of land use changes for the year 1995, and orthorectification has been used to correct the errors due to the sensor and the curvature of the land.
- The residential zone growth decreases by 0.40%, the commercial predominance increases from 1% to 4.19%, the industrial dimension decreases from 20% to 11.30%, the agricultural zone decreases from 20% to 15.57%, the existing equipment decreases from 20% to 9.32%, the areas reserved for equipment decrease from 20% to 1.62% and the urban roads increase from 14.09% to 38.54%, these values are the comparison in two time periods 1995 and projected to 2035.
- This change in agricultural use is one of the most affected, i.e., it has an annual decrease rate of 2.80%, which impacts the farmers who have to migrate from the Quechua zone to the Suni, because the cost of renting land increases in this area. As a result, it can be inferred that the change in land use generates social inequality in

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 2482 - 2495
Received 15 April 2021; Accepted 05 May 2021.

the population, i.e., people with greater purchasing power will be located as close to the business zone as possible. Likewise, the city's surrounding areas are conurbations, which are places with low population density and have a high degree of horizontal construction.

- The use of the Kappa index helps to determine the correlation between the maps obtained with the use of Markov chains and the real maps, whose value is over 80%, which compared to other authors is above this average, which indicates that this Markov method is quite good for forecasting land use.

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