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近 40 年来窟野河流域土地利用类型变化及驱动因素

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摘要:为分析土地利用变化的内部特征及驱动机制,从土地利用整体格局、土地利用转移方向、转移程度和土地利用单一动态度方面出发,全面分析近 40 年以来窟野河流域土地利用的时空变化特征,并利用 SPSS 软件系统地阐述了其驱动机制。主要结果表明:目前,该流域各土地类型面积占比为草地>耕地>煤矿用地>林地>沙地>居住用地>水域>未利用土地,耕地主要分布在研究区中部和东南部,煤矿用地主要分布在河流沿岸;在研究时段内,煤矿用地作为动态度最高的土地利用类型,其面积大幅增加,主要流入源为草地和耕地,该流域煤炭的大规模开采已严重影响到该流域的植被覆盖情况以及农业生产活动;经济的高速发展,尤其是第二、第三产业的壮大是导致该流域煤矿用地和居住用地发生明显变化最主要的驱动因子,而耕地、林地、草地和水域的面积变化也与其息息相关,但变化幅度相对较小;此外,人口作为重要因素之一,也在土地利用的变化过程中起到了较为明显的推动作用。

关键词:窟野河流域;土地利用变化特征;煤矿用地;主成分分析;线性回归模型;人类活动;驱动机制

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土地利用的动态变化过程及其驱动机制已被认为是全球环境变化研究中的重要方面[1-3],土地系统作为人类-环境关系的纽带和桥梁[4],是人类活动与自然环境之间相互作用最直接且剧烈的场所[5-6]。通过探究土地利用演化过程及其变化方向来研究人为因素在土地利用变化中的驱动作用,有利于为该区以后的水土保持及经济建设提供指导性方针。

窟野河是黄河中游一条重要支流(见图 1),属于黄土高原侵蚀地区的典型河流,该流域植被覆盖稀少,受水蚀、风蚀等侵蚀严重,水土流失面积约占流域总面积的 95%,因此研究窟野河流域土地利用的变化及驱动因素对开展该地区的水土保持与经济建设具有重要意义。目前,针对窟野河流域土地利用变化分析的研究较多。陈利利[7]认为从 1989—2011 年的 22 年间窟野河流域植被覆盖度呈波动中上升趋势;代润润[8]认为 1986—2005 年建设用地和林地增幅较大,而耕地、未利用地和水域面积减少,其中未利用土地的减幅较大;吴喜军等[9]认为近年来窟野河流域煤炭的大规模开采造成地下水静储量大量流失。然而,针对于窟野河流域土地利用变化驱动因素的研究尚缺乏。鉴于此,基于遥感和 GIS 等途径,利用遥感图像解译、土地转移矩阵及单一土地类型动态度、主成分分析及多元线性回归模型,分析窟野河流域 1980—2018 年近 40 年土地利用格局变化过程及其驱动力因素。

1 数据来源

研究的数据来源有:研究区域的人口数(万人)、耕地面积(万 hm^2)、人均 GDP(元)、第二和第三产业增加值(亿元)以及农业产值(万元)等指标数据来源于中国经济社会大数据研究平台(http://data.

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cnki. net/NewHome/index)；1980、1990、1995、2000、2005、2010、2015和2018年内蒙古自治区、陕西省及山西省境内土地利用类型栅格数据来源于中国科学院资源环境科学数据中心(http://www.resdc.cn)，分辨率为 1 km×1 km。

图 1　窟野河流域地理位置

2　土地利用变化特征

2.1　土地利用结构分析

根据窟野河流域的地域特点，利用 GIS 将研究区的原始二级土地利用类型，按照土地分类系统的标准进行整合，最终得到以下 8 种一级类型。这 8 种类型分别为耕地、林地、草地、水域、居住用地、煤矿用地、沙地和未利用土地，具体分类系统见表 1。

表 1　土地利用类型分类系统

二级类型	一级类型	二级类型	一级类型
11 水田 12 旱地	耕地	41 河渠 42 湖泊 43 水库坑塘 46 滩地	水域
21 有林地 22 灌木林 23 疏林地 24 其他林地	林地	51 城镇用地 52 农村居民地	居住用地
31 高覆盖度草地 32 中覆盖度草地 33 低覆盖度草地	草地	53 其他建设用地	煤矿用地
		61 沙地	沙地
		63 盐碱地 65 裸土地	未利用土地

通过对原始栅格数据的镶嵌、提取以及重分类，得到窟野河流域 1980—2018 年各时期各类别的土地面积，见表 2。整体上来看，近 40 年间窟野河的耕地面积和草地面积略有波动，但始终是最具优势的两种土地利用类型，且煤矿用地为变化幅度最大的土地利用类型。

1980 年耕地面积占流域总面积的 18.29%，草地占 65.53%，林地、水域、居住用地、煤矿用地、沙地和未利用土地分别占流域总面积的 3.45%、2.46%、0.78%、0.03%、6.93%和 2.51%。这个时期窟野河流域以草地及耕地面积为主，人类活动对土地利用类型的改造还不太明显。

表 2　1980—2018 年窟野河流域土地利用类型面积　　单位：km^2

土地利用类型	1980 年	1990 年	1995 年	2000 年	2005 年	2010 年	2015 年	2018 年
耕地	1 588	1 588	1 618	1 619	1 519	1 506	1 473	1 281
林地	300	300	285	295	387	392	385	431
草地	5 691	5 693	6 026	5 920	5 870	5 867	5 580	5 543
水域	214	212	216	214	200	200	186	176
居住用地	68	70	68	72	88	90	107	261
煤矿用地	3	3	3	3	35	53	404	584
沙地	602	599	417	500	507	496	475	352
未利用土地	218	219	50	60	74	77	74	50

依据表 2 中各土地利用类型的面积数据在时间序列上的变化趋势，可以看出：1980—2000 年，耕地面积略有增加，共计增长约 31 km^2，耕地比例增加至 18.65%；但从 2000 年后，耕地面积开始持续减少，截至 2018 年耕地比例降至 14.76%。在 1980—1995 年，草地面积所占比例从 65.53%持续增加至 69.40%，而从 1995 年开始，草地面积持续减少，截至 2018 年时草地面积所占比例已减少至 63.87%。可见 1980—2018 年，耕地面积和草地面积均呈现先增加后减少的变化趋势，其可能与由经济发展变化引起的土地利用格局的转变有一定的关系。煤矿用地，作为近 40 年间变化幅度最

大的土地利用类型,其在1980—2000年几乎无明显变化,但在2001—2010年与2011—2018年两个时段内均呈增加态势,且在2011—2018年增长速率极快,达到了1 001.89%,增幅速度为同期最快,为居住用地增速的5.27倍。其余各类土地利用类型变化强度差别较大:林地呈先减少后增加的变化趋势,其中2000—2005年增长速率最快,这主要是缘于我国自2000年初左右开始实施的退耕还林政策。水域变化较小,2010—2018年略有减少,但整体呈平稳态势,比例从2.46%降低至2.03%。居住用地在1980—2000年呈稳定态势,在2001—2018年开始持续增长,且增长速率在2015—2018年达到峰值,为143.93%,这与经济增长和人口数量增加密切相关。沙地和未利用土地比例分别从6.93%和2.51%转变为4.06%和0.58%,均具有明显的降低趋势。由此可见该研究区在近40年间对于流域土地的利用程度整体上有明显增加的趋势。

从空间格局上来看:耕地主要分布在研究区地势较低的东南部,西北部较少;居住用地集中分布于北部偏西海拔相对较高的位置;煤矿用地大面积集中于研究区中部及北部,在东南部有零星分布,整体上分布于乌兰木伦河和悖牛川河两条支流附近;沙地和未利用土地则分布集中于中部和西北部地区。

2.2 土地利用转移方向分析

为了探究各土地利用类型之间的迁移转化,一般情况下常借助土地利用类型转移矩阵来进行土地利用类型内部转移特征的研究[10]。这种方法能直观地反映出土地利用类型变化的转化量、结构特征以及转移方向[11]。转移矩阵数学形式为

$$\boldsymbol{S}_{ij}=\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1j} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2j} & \cdots & S_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ S_{i1} & S_{i2} & \cdots & S_{ij} & \cdots & S_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nj} & \cdots & S_{nn} \end{bmatrix}$$

其中:S为土地面积;n为土地利用类型的数目;S_{ij}代表T时期第i种土地利用类型在$T+m$年时已转变为第j种土地利用类型的面积。

基于8个时期的栅格数据,采用Arcgis将1980—2018年重分类后的土地利用分布图像以"Type"字段各自融合,减小程序数据运算量。接着分别将1980—1995、1996—2005、2006—2015、2016—2018以及1980—2018年等5个时段的图像进行叠加,得到窟野河流域土地利用转移矩阵(由于篇幅所限,文中仅给出1980—2018年土地利用转移矩阵),见表3。

表3　1980—2018年窟野河流域土地利用动态转移矩阵　　单位:km²

分类	耕地	林地	草地	水域	居住用地	煤矿用地	沙地	未利用土地	总计
耕地	484	53	825	29	54	112	16	4	1 577
林地	22	81	141	7	13	23	11	2	300
草地	687	254	3 966	65	149	382	140	20	5 663
水域	29	8	82	55	9	14	7	7	211
居住用地	7	5	23	4	26	2	0	0	67
煤矿用地	1	0	2	0	0	0	0	0	3
沙地	42	20	307	10	4	42	170	2	597
未利用土地	2	9	172	6	3	5	6	14	217
总计	1 274	430	5 518	176	258	580	350	49	8 635

从表3可以看出,研究时段内窟野河流域不同土地利用动态。

(1)煤矿用地面积的增长幅度较大,转入源主要是耕地、林地、草地、水域和沙地,转化的面积均超过6%,且据计算此期间煤矿用地面积增长了近200倍。

(2)耕地在此期间主要向草地转化,转化率为52.31%,另有7.10%变为煤矿用地,3.42%变为居住用地,3.36%变为林地,同时又有12.13%的草地以及13.74%的水域转变为耕地。但整体上来看,这40年间,转出量约为转入量的1.4倍,耕地面积整体减少19.21%。

(3)未利用土地变化也较大,总面积净减少77.42%,其中绝大部分变为草地,转化面积约占未利用土地转化总量的84.73%。

(4)水域面积有较小幅度的减少,其中有6.64%退化为未利用土地及沙地,另有24.64%被开发用作耕地、居住用地以及煤矿用地,河渠、湖泊

及水库面积有所缩小。

(5)此外,居住用地以及林地面积增长迅速,增长幅度分别为 285.07%和 43.33%;沙地面积减少 41.37%,主要流向了草地,转化面积达 307 km^2。

通过对比分析发现,近 40 年来,该区耕地面积减少幅度较大,林地面积增加显著,同时沙地的 51%以及未利用土地的 79%均流向草地。这说明在该区推行的大面积造林植草、退耕还林等措施实施的效果良好,大量沙地与未利用土地被有效利用于生态建设,使得该区植被覆盖面积有所增加,整体生态环境得到改善,这一现象与王童等[12]在 2017 年的研究结果基本一致。但同时,煤矿的开采规模日趋扩大,年开采量已从 1980 年的 90 万 t 激增到 2017 年的22 500万 t,增长近 250 倍,同时矿区面积扩大十分明显,增长率甚至达到19 233%,该现象对环境的影响作用已不容忽视。

2.3　土地利用变化动态度分析

在分析土地利用类型动态转移规律时,常采用土地利用动态度模型。模型分为单一动态度 K[13] 和综合动态度 LC[14],可定性定量地描述土地利用的变化速度,对比较不同用地类型之间的变化差异有积极作用[15]。使用单一动态度来衡量某一具体用地类型在规定时间范围内的变化速度和幅度[16]。计算公式为

$$K=\frac{U_{bi}-U_{ai}}{U_{ai}}\times\frac{1}{T}\times100\% \tag{1}$$

式中:U_{ai}、U_{bi}分别是研究初期和研究末期土地利用类型 i 的面积;T 为研究时长。

依据式(1)绘制单一土地利用类型动态度表,见表 4。与其他用地类型相比,草地的动态度一直处于较低水平,变化速率相当缓慢,并处于低速缩减的趋势;煤矿用地在 1996—2015 年动态度开始激增并持续维持在高水平状态,呈现出异常明显的扩增趋势,尽管在 2016—2018 年增长速率开始变缓,但动态度依旧位居第二;耕地面积自 1995 年后一直处于缩减的趋势,动态度在 2016—2018 年达到峰值;居住用地在 1980—1995 年处于缓慢扩增的态势,从 1995 年以后,变化速率开始增长,并在 2016—2018 年突然激增达到峰值,动态度位居首位;林地的变化过程较为复杂,动态度一直处于正负交替的状态中,但正值的绝对值显著高于负值的绝对值,说明林地面积的扩增趋势要明显快于缩减趋势,所以在整个时段内,林地呈现增长的趋势。

表 4　单一土地利用类型动态度　　单位:%

土地利用类型	1980—1995 年	1996—2005 年	2006—2015 年	2016—2018 年	1980—2018 年
耕地	0.13	−0.60	−0.31	−4.29	−0.51
林地	−0.33	3.63	−0.05	3.90	1.14
草地	0.39	−0.25	−0.50	−0.19	−0.08
水域	0.06	−0.74	−0.65	−2.30	−0.44
居住用地	0.10	2.94	2.13	48.43	7.50
煤矿用地	0	106.67	107.94	14.84	506.14
沙地	−2.03	2.11	−0.61	−8.53	−1.09
未利用土地	−5.14	4.51	0	−10.81	−2.04

3　驱动因子选取与诊断

从土地利用转移矩阵与单一土地利用类型动态度的分析结果看,1980—2018 年耕地与煤矿用地的面积变化显著,这主要是自然因素与社会经济因素共同作用的结果。为了探究影响窟野河流域土地利用类型变化的动力因素,需要对各驱动力因子进行深入分析,准确把握其影响土地利用变化过程的内在规律性,以便对未来的变化趋势进行合理预测。

3.1　驱动因子的选取

土地利用变化系统中,驱动因子之间的相互作用以及其对外界的影响错综复杂,因此针对土地利用变化驱动力的研究通常要求在某一特定区域展开。土地覆盖变化的驱动力一般分为自然驱动力和人为驱动力,其中自然驱动力相对稳定,短尺度上影响不明显,有积累效应[17],因此人为驱动力一般为主导因子,针对驱动力的研究多集中于此方面[18]。

在对窟野河流域土地利用格局和动态转移进行详细分析的基础上,根据主成分分析的要求以及窟野河流域资料的选取,确定了 11 个指标(X_1 至 X_{11})作为分析的自变量,见表 5。

其中:最为重要的变量是代表产业发展状况的 X_5 至 X_8,意在通过人均 GDP 来衡量该流域经济的宏观发展状况;同时第一、第二及第三产业的 GDP 值及其变化可表征近 40 年窟野河流域产业结构的

变化方向及速率，最终以此数据为基础来为该流域土地利用类型转移的原因作出部分解释。农业GDP可与耕地面积变化建立联系；第二产业增加值则与煤矿用地面积变化息息相关；而第三产值增加值主要可用来代表商业、服务业活动的变化。这也会对该流域用地类型的结构造成一定影响。

表5　变量代码

人口变量	自然条件变量	产业发展变量	煤炭开采变量
城镇人口总数 X_1	降水总量 X_3	人均GDP X_5	神木煤炭涌水量 X_9
农村人口总数 X_2	气温(年均温) X_4	农业产值 X_6	煤炭开采量 X_{10}
		第二产业增加值 X_7	煤炭采空区面积 X_{11}
		第三产业增加值 X_8	

煤炭开采变量同样是本研究中所参考的重要变量：涌水量是衡量煤矿区含水层出水能力的重要指标，其值越大，代表该矿区井的产水能力越高；采空区则是指由于开采活动而造成的地下“空洞”。一般来说，在开采初期，涌水量会随着开采面积及开采量的增加而增加，但当达到一定开采深度时，矿井的涌水量则会最终维持在一个较稳定的常数。所以 X_9 至 X_{11} 是衡量窟野河流域近40年煤炭开采强度变化的关键指标。

3.2　数据标准化

由于各指标原始数据在量纲及数量级上存在明显差异，因此为了避免计算结果因受不同量纲影响而出现误差，在进行分析前应对原始数据进行统一的标准化，采用标准差标准化法对原始数据进行描述统计。

3.3　主成分分析

因选取的驱动力因子数量较多、数据量较大以及因子之间具有一定相关性等问题，直接操作将会导致分析的局限性，因此拟选用主成分分析法来解决这一问题。主成分分析就是将影响因子通过降维，简化为少量的几个彼此之间相互独立的分量，用以抓住复杂问题中的主导因子，力求以最少的指标反映绝大部分信息量。

3.3.1　因子特征值和贡献率

选取11个影响因子(表5)进行主成分分析，并根据特征值的大小和累积方差贡献率的大小确定主成分个数。表6罗列出所有驱动因子的特征值、累积贡献率和方差贡献率。可以看出第一、第二主成分的累计贡献率达到了92.45%，相当于已经涵盖了原始数据量的92.45%，说明两个主成分已能充分代表原始驱动因子来反映窟野河流域土地利用的具体情况。

3.3.2　因子载荷矩阵计算

在主成分确定后，根据主成分载荷公式

$$l_{ij}=p(z_i\,x_j)=\sqrt{\gamma_{ij}\,e_{ij}}\quad(i,j=1,2,\cdots,p)\qquad(2)$$

表6　特征值与主成分贡献率

成分	初始特征值			提取载荷平方和		
	总计	方差/%	累积/%	总计	方差/%	累积/%
1	9.012	81.927	81.927	9.012	81.927	81.927
2	1.207	10.975	92.902	1.207	10.975	92.902
3	0.499	4.538	97.440			
4	0.217	1.975	99.415			
5	0.030	0.272	99.687			
6	0.020	0.184	99.871			
7	0.005	0.049	99.920			
8	0.005	0.043	99.963			
9	0.002	0.023	99.985			
10	0.001	0.011	99.996			
11	0	0.004	100.000			

计算初始因子在各主成分上的载荷(因子的载荷系数代表的是原始变量与主成分之间的相关程度，数值越大说明两者的相关性越强)，形成初始载荷矩阵。由于初始载荷矩阵具有非唯一性的特点，只能表征变量的部分信息。为了更加清楚、全面地表示变量信息，对初始载荷矩阵运用凯撒正态化最大方差法进行旋转，使得矩阵结构相对简单，用以对主成分进行充分的解释与分析，主成分旋转后的载荷系数分布见图2。

表6中各变量所对应的载荷系数的绝对值大小体现了其在相应主成分中具有的重要性程度。从图2可以看出：第一主成分中载荷系数超过0.800的驱动因子有第三产业增加值、第二产业增加值、人均GDP、神木煤炭涌水量、煤炭开采量、煤炭采空区面积和农业产值，可见第一主成分可以用来大致表明研究区经济发展以及工业发展情况；而第二主成分中载荷系数较大的因子有城镇人口总数、农村人口总数和气温，因此第二主成分可用来代表人口与自然环境变化。

3.3.3　计算因子得分

确定了分析中采用的主成分因子后，还需计算

原始指标在第一、第二主成分因子上的具体数值,即计算因子得分,具体方式有回归法、巴特利特法等,本文选用回归法计算各因子得分。根据表 7 以及式(3)可得到各年份主成分得分系数 F_1、F_2 和驱动力综合得分 F,见表 8。其中 F 是以提取载荷平方和中各主成分方差所占总方差的百分比为权重,对得分系数进行加权汇总的结果。

$$F=\frac{F_1\times A_1+F_2\times A_2}{A_1+A_2} \tag{3}$$

式中:A_1、A_2 为两个主成分的方差。

从表 8 可以看出,在 1980—2018 年,影响窟野河研究区土地利用变化的驱动力综合得分虽略有波动,但整体上呈现较为明显的上升趋势,说明影响窟野河土地利用类型变化的驱动力正在逐渐加强。

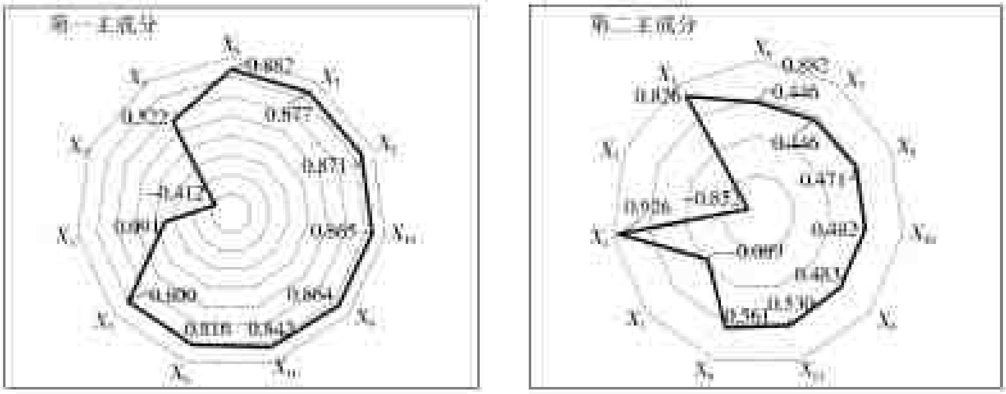

图 2　载荷系数分布

表 7　因子得分矩阵

变量	第一主成分	第二主成分	变量	第一主成分	第二主成分
Zscore(X_1)	−0.093	0.297	Zscore(X_7)	0.166	−0.043
Zscore(X_2)	0.142	−0.350	Zscore(X_8)	0.168	−0.045
Zscore(X_3)	0.321	−0.326	Zscore(X_9)	0.149	−0.018
Zscore(X_4)	−0.284	0.502	Zscore(X_{10})	0.149	−0.019
Zscore(X_5)	0.155	−0.027	Zscore(X_{11})	0.125	0.017
Zscore(X_6)	0.104	0.044			

表 8　各年份主成分因子得分系数

年份	F_1	F_2	F	年份	F_1	F_2	F
1980	−0.50	−0.97	−0.56	2000	−1.22	0.93	−0.96
1981	−0.41	−1.02	−0.48	2001	−1.06	0.97	−0.82
1982	−0.36	−1.05	−0.44	2002	−0.50	0.35	−0.40
1983	−0.08	−1.48	−0.24	2003	−0.36	0.40	−0.27
1984	−0.01	−1.57	−0.19	2004	−1.13	1.37	−0.83
1985	−0.03	−1.53	−0.20	2005	−0.90	1.29	−0.64
1986	−0.46	−0.87	−0.51	2006	−0.81	1.53	−0.54
1987	0.18	−1.54	−0.02	2007	0.27	0.40	0.28
1988	0.03	−1.35	−0.13	2008	0.06	0.92	0.16
1989	−0.49	−0.65	−0.51	2009	0.06	0.98	0.17
1990	−0.67	−0.42	−0.64	2010	0.41	0.96	0.48
1991	−0.23	−1.01	−0.32	2011	1.09	0.56	1.03
1992	−0.09	−1.20	−0.22	2012	1.61	0.25	1.45
1993	−0.47	−0.66	−0.49	2013	1.58	0.57	1.46
1994	−0.32	−0.70	−0.37	2014	1.55	0.72	1.45
1995	−0.08	−1.06	−0.20	2015	1.08	1.27	1.10
1996	−0.44	−0.28	−0.42	2016	2.53	−0.13	2.22
1997	−0.93	0.33	−0.78	2017	1.82	0.81	1.70
1998	−1.59	1.47	−1.23	2018	2.24	0.46	2.03
1999	−1.39	0.95	−1.12				

4　驱动力分析

4.1　线性回归分析

以煤矿用地为例,运用多元回归分析法,计算该土地利用类型变化与提取出的两个主成分之间的函数关系。以各年份主成分得分系数 F_1、F_2 作为自变量构建回归矩阵,进而建立起一个多元线性回归模型式(4),其中 a_0,a_1,a_2 代表相关性系数

$$Y=a_0+a_1F_1+a_2F_2 \tag{4}$$

借助 SPSS 软件,对已经过标准化的数据进行多元线性回归计算,由于煤矿用地面积和各年的得分系数都是标准化之后的数值,因此 a_0 的值为 0。在计算时,将 Y 设为因变量;F_1、F_2 设为自变量;同时选用 F 检验和拟合度检验确定分析结果的准确性。回归分析结果与回归分析的参数估计及假设检验结果见表 9、10。

从表10可以看出：$R^2=0.909$，方差分析 $P=0$，说明方程(5)的拟合程度较好；且 F_1、F_2 的显著性 P 均为0，表明提取的两个主成分对因变量 Y：土地利用类型数量的变化具有显著作用。将 a_1、a_2 代入回归模型式(4)中，可得到回归方程(5)。

$$Y=0.850\times F_1+0.321\times F_2 \tag{5}$$

采取相同方式，分别建立窟野河流域其他土地利用类型的线性回归方程，具体分析结果见表11。从表中可以看出，除草地外，各类土地利用类型线性回归方程的拟合度及显著性水平都较高，说明回归分析的结果可信度较高。

表9　回归分析结果

模型	R	R^2	F
1	0.953[a]	0.909	85.286

表10　回归分析的参数估计及检验结果

模型	标准化系数 Beta	标准误差
(常量)	0	0.069
F_1	0.850	0.070
F_2	0.321	0.070

表11　回归分析结果

土地利用类型	回归方程	显著性水平
耕地	$Y=-0.813F_1-0.403F_2$	$R^2=0.907$，$F=83.272$
林地	$Y=0.672F_1+0.624F_2$	$R^2=0.917$，$F=95.576$
草地	$Y=-0.659F_1+0.272F_2$	$R^2=0.713$，$F=18.587$
水域	$Y=-0.817F_1-0.513F_2$	$R^2=0.965$，$F=242.939$
居住用地	$Y=0.825F_1+0.367F_2$	$R^2=0.903$，$F=79.160$
煤矿用地	$Y=0.850F_1+0.321F_2$	$R^2=0.909$，$F=85.286$
沙地	$Y=-0.526F_1-0.676F_2$	$R^2=0.857$，$F=49.774$
未利用土地	$Y=-0.212F_1-0.852F_2$	$R^2=0.878$，$F=60.562$

4.2　回归方程结果分析

通过回归方程及模型可以看出不同土地类型分析结果。

(1)煤矿用地。窟野河流域的煤矿用地面积与代表经济发展的主成分 F_1 有着极为显著的正相关关系($R=0.850$)。煤矿作为主体能源和钢铁等行业最主要的工业原料，是经济快速发展的基础性要素。所以随着窟野河流域经济发展的增速，其对于煤炭资源的需求也逐年递增。资料显示：1980—2018年，窟野河流域煤炭开采量从90万t激增到23 000万t、神木煤炭涌水量翻了近230倍、煤炭采空区面积更是净增长了577 km²。可见近40年经济的高速发展促使煤炭面积大规模扩增。

(2)耕地。耕地变化与 F_1、F_2 均呈负相关，且与 F_1 的相关系数较高($R=-0.813$)，与 F_2 的相关系数较低($R=-0.403$)。根据主成分因子所代表的含义可知，经济发展尤其是以煤矿开采为代表的重工业发展是近年来耕地面积减少的主要原因。煤炭开采过程中不仅会因扰动地表而破坏土壤结构，增加耕地受侵蚀和旱化的可能性[19]，还会直接侵占农田。据统计，从1980—2018年窟野河流域煤矿用地面积净增长的19.41%均来自于耕地面积。此外代表与人口变化有关的 F_2 对耕地的影响同样为负相关，这主要与研究期窟野河流域内人口结构发生较大转变有直接关系。从1988—2018年，窟野河流域农村人口数从31.29万人不断减少至12.74万人，城镇人口占流域总人口的比例则由21%高速攀升至78%。研究区人口结构的变化直接导致农村劳动力不断减少，城镇人口数的不断增加也促使城市化进程加快，城市边缘不断向农村扩张，大量土地用于城市化及工业化的建设。

(3)林地。从回归方程可以看出，林地面积与 F_1、F_2 均呈正相关，且与 F_1 的相关系数略高($R=0.672$)，所以影响林地面积变化的主要原因之一是城镇化水平的增加与经济的快速发展。经济发展水平越高，生态环境保护的意识也会越强烈；同时综合国力的提升也为退耕还林提供了充足的物质支撑。此外，代表自然环境变化的 F_2 也是影响窟野河流域林地面积变化的重要因素之一，近年来该流域年降水总量始终维持在较高水平，且气温有较为明显上升趋势，这都促使了窟野河流域林地面积的增长。

(4)居住用地。表11显示，第一、第二主成分与居住用地面积均呈正相关($R_1=0.825$、$R_2=0.367$)关系，但第一主成分 F_1 仍是其中最主要的因素，这说明经济发展是现如今窟野河流域居住用地面积不断扩张最主要的驱动力因素。同时，近40年窟野河流域人口数量的持续增长(图3)也导致该流域对居住用地的需求与日俱增，而现有居住用地又不足以满足不断增长的人口压力，因而近40年间，沙地、未利用土地、草地和耕地均有少部分流向居住用地，其最终促使居住用地面积不断扩张。

(5)草地。与草地面积相关性最高的因子仍是代表经济发展的 F_1，且为负相关($R=-0.659$)。工业发展进程的加快，尤其是煤矿开采规模的进一步扩张是致使草地覆盖被破坏的主要因素之一。窟野河流域具有丰富的煤炭、石英砂等矿产资源，且绝大部分位于山区，煤炭开采严重影响了地表覆盖植被

的质量。据统计，1980—2018 年窟野河流域煤矿用地面积净增长的 66.20%均来自草地，但由于国家对于退耕还林还草政策的大力支持，窟野河流域近 40 年来草地面积净减少量较少。

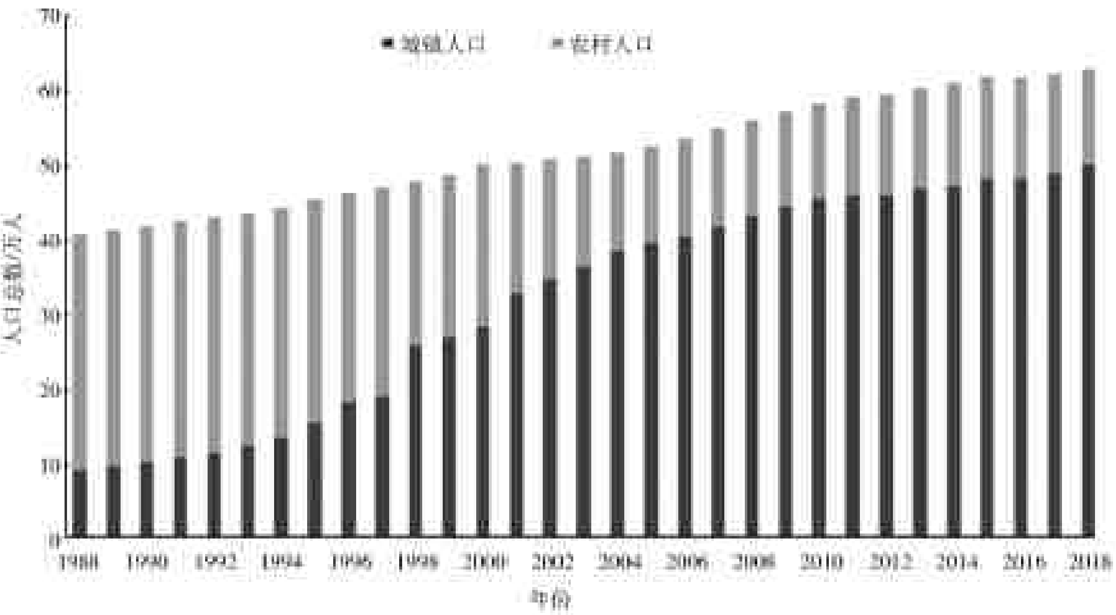

图 3　窟野河流域人口总数

(6)水域。与 F_1、F_2 均呈负相关，且与 F_1 的相关性较高($R=-0.817$)，与 F_2 的相关系数较低($R=-0.513$)，说明在研究期内，经济的发展在一定程度上促使了窟野河流域水域面积的缩小。这主要与当地大规模、高强度的煤炭开采活动有关，不断扩大规模的煤炭开采促使工业用水量激增，直接导致煤矿区地下水位大幅下降，同时致使周围地区河水断流、泉水干涸，这与杨琳洁[20]在 2014 年关于窟野河流域径流量变化的研究结果基本相符。

(7)沙地。与主成分 F_1、F_2 均呈负相关，且相关程度都较低($R_1=-0.526$、$R_2=-0.676$)，说明窟野河流域近 40 年来，无论是经济的快速发展、人口数量的持续增加还是自然环境的改变，都对沙地面积的缩小起了一定的推动作用，但影响程度都较低，与研究区实际情况相符。

(8)未利用土地。未利用土地面积与 F_1、F_2 均呈负相关，且与 F_1 相关系数较低($R=-0.212$)，与 F_2 相关系数较高($R=-0.852$)，这说明影响窟野河流域未利用土地面积的主要因素是代表人口变化和自然环境变化的 F_2。表 7 显示，在 1980—2018 年，约有 79%的未利用土地转化为草地，这与窟野河流域充沛的年降水量和适宜的温度条件有一定的关系，同时还与国家推行的造林植草政策息息相关。此外人口数量的不断增长极大地增加了该流域的用地压力，因此未利用土地不断被开发用于缓解用地紧张的现象；同时，人口结构的变化也会通过促使消费结构转型而加深对土地的利用程度。

5　结　论

(1)现阶段窟野河流域各土地利用类型面积占比：草地>耕地>煤矿用地>林地>沙地>居住用地>水域>未利用土地。耕地主要分布在研究区中部和东南部地势较低的地区，煤矿用地主要分布在河流主干流沿岸，居住用地及未利用土地主要分布在该流域的西北部。

(2)单一土地利用类型动态度：煤矿用地>居住用地>未利用土地>林地>沙地>耕地>水域>草地。在研究时间尺度内，煤矿用地面积增长的速率最快，未利用土地面积减少的速率最快，草地的变化过程与其他用地类型相比较为平缓。这表明流域整体的植被覆盖结构有所改善，退耕还林、造林政策效果显著，土地退化现象有所缓解。同时，裸地与沙地面积大幅度缩减，说明土地开发利用综合水平明显提高。

(3)本文采用多元线性回归分析法，对各驱动力因素进行定性定量分析的结果表明：①经济发展，尤其第二、第三产业的日益壮大是该流域土地利用变化最主要的原因，且这种影响的力度正在逐年增大。在所有土地利用类型中，煤矿用地受第二、第三产业变化的影响最大，在研究期内呈现出快速变化的特点；同时，该流域第二、第三产业增加值在近 40 年不

断攀升，人均GDP涨幅近70倍，经济呈现较为全面且高速的发展，也促使了其他土地利用类型发生一定转变。②人口数量的快速增长与人口结构的转变，极大地影响了该流域耕地、居住用地以及未利用土地等用地类型的面积、转变方向与速度，也成为近40年来驱动窟野河流域土地利用类型发生变化的重要因素。

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·译文(Translation)·

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Changes and driving factors of land use types in Kuye River basin in recent 40 years

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Abstract: In order to analyze the internal characteristics and driving mechanism of land use change, the spatial and temporal changes of land use have been comprehensively examined based on the overall pattern of land use, the direction of land use transfer, the degree of transfer, and the single dynamic degree of land use in the Kuye River basin in the past 40 years. SPSS software is used to systematically explain its driving mechanism. The results showed that: The proportions of different land types throughout the basin are grassland>farmland>coal mine land>forest land>sand land>residential land>water area>unused land, respectively; Farmland is largely gathered in the middle and southeast of the basin while coal mine land is mainly distributed along the river bank; In the research period, as the most dynamic type of land use, coal mine land had greatly increased its area, and its main inflow sources are grassland and farmland, and The large-scale exploitation of coal in this basin has seriously affected the vegetation cover and agricultural production activities in this basin; The rapid economic development, especially the growth of the secondary and tertiary industries are the most important driving factor leading to obvious changes in the coal mine land and residential land in the basin, However the changes in farmland, forest land, grassland, and water area are also closely related to them, but the changes are relatively small; Besides, the population also plays a more obvious role in the process of land use change.

Key words: Kuye River basin; characteristics of land use change; coal mine land; principle component analysis; l inear regression model; human activity; driving mechanism

The dynamic changing process of land use and its driving mechanisms have been considered as important in the study of global environmental change[1-3]. The land system, as a link and bridge between human and environment[4], is the most direct and intense site for the interaction between human activities and natural environment[5-6]. This paper proposes to study the driving role of human factors in the land use change by exploring the evolution process and the changing direction of land use, which will provide guidelines for water and soil conservation and economic construction in the study area.

As an important tributary of middle reaches of the Yellow River, the Kuye River (whose location is shown in Fig. 1) is a typical river in the eroded areas of the Loess Plateau. The basin is covered with sparse vegetation and severely eroded by water and wind, with soil erosion accounting for about 95% of the total basin area. Therefore, it is important to identify land use changes and their driving factors in the Kuye River basin for soil and

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water conservation and economic development in the region. Currently, there are many studies analyzing the land use changes of the Kuye River basin. Chen[7] concluded that the vegetation coverage of the Kuye River basin showed a fluctuating upward trend over the 22 years from 1989 to 2011; Dai[8] believed that from 1986 to 2005 there were large increases in construction land and forest land, while the areas of cultivated land, unused land, and water area reduced, especially the area of unused land; Wu et al.[9] pointed out that the large-scale coal mining in the Kuye River basin led to a significant loss of static reserves of underground water. However, there is no research on driving factors of land use changes in the Kuye River basin. In view of this, based on remote sensing and GIS, this paper analyzes the changing process of land use patterns and its driving factors in the Kuye River basin over the past 40 years from 1980 to 2018 using remote sensing image interpretation, land transfer matrix, single dynamic degree of land use, principal component analysis, and multiple linear regression model.

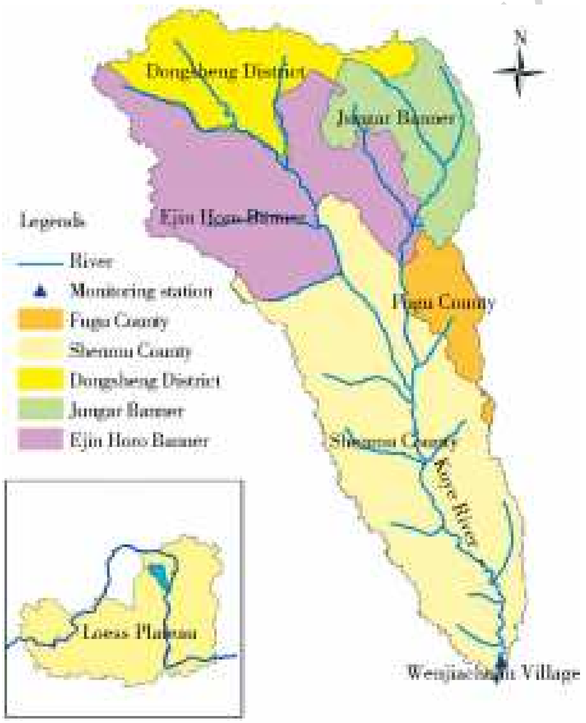

Fig. 1　Geographical location map of the Kuye River basin

1　Data source

The population in the study area ($\times 10^4$ people), the farmland area ($\times 10^4$ hm^2), GDP per capita (CNY), the added value of secondary and tertiary industries ($\times 10^8$ CNY), and the output value of agriculture ($\times 10^4$ CNY) come from China's Economic and Social Big Data Research Platform (http://data.cnki.net/NewHome/index); the raster data of land use types in the Inner Mongolia Autonomous region, Shaanxi Province, and Shanxi Province in 1980, 1990, 1995, 2000, 2005, 2010, 2015, and 2018 come from Resource and Environment Data Cloud Platform, Chinese Academy of Sciences (http://www.resdc.cn), with the resolution of 1 km×1 km.

2　Changing characteristics of land use

2.1　Structure analysis of land use

Considering the geographic characteristics of the Kuye River basin, we used GIS to integrate the original secondary land use types in the study area according to the criteria of the land classification system, obtaining the following eight primary types, which are farmland, forest land, grassland, water area, residential land, coal mine land, sand land, and unused land. The specific classification system is shown in Tab 1.

The land area of each type in the Kuye River basin from 1980 to 2018 is obtained with mosaic, extraction, and reclassification of the original raster data (as shown in Tab. 2). Overall, the areas of farmland and grassland of the Kuye River basin fluctuated slightly over the past 40 years, but these two land use types were always the most dominant types. In addition, the coal mine land was the most variable one.

In 1980, farmland accounted for 18.29% of the total basin area; grassland accounted for 65.53%; forest land, water area, residential land, coal mine land, sand land, and unused land made up 3.45%, 2.46%, 0.78%, 0.03%, 6.93%, and 2.51%, respectively. During this period, the Kuye River basin was dominated by grassland and farmland, and the modification of land use types by human activities was not yet apparent.

Based on the changing trend of the area of each land use type in time series shown in Tab. 2, it can be seen that from 1980 to 2000 the area of farmland increased slightly by about 31 km^2, and the proportion of farmland increased to 18.65%. However, after 2000, the area of farmland began to decrease continuously, and the proportion of farmland decreased to 14.76% by 2018. The share of the grassland area increased from 65.53% to 69.40% from 1980 to 1995. But the grassland area continuously reduced since 1995, and its proportion decreased to 63.87% by 2018. It can be seen that during the period from 1980 to 2018, the areas of farmland and grassland showed a trend of first increasing and then decreasing. It might be related to the variation in land use pattern caused by changes in economic development. As the most variable land use type in the last 40 years, the coal mine land did not have obvious change from 1980 to 2000, but it increased in the periods from 2001 to 2010 and from 2011 to 2018. Moreover, it had an extreme fast growth rate of 1 001.89% from 2011 to 2018. This growth rate was the biggest among those in the same period, which was 5.27 times higher than that of residential land. The other land use types differed much in the variation intensity. The forest land showed a trend of decreasing first and then increasing, and it had the highest growth rate from 2000 and 2005. This was mainly caused by the policy of returning the grain plots to forestry which has been implemented in China since the beginning of 2000. The water area changed little. It reduced slightly from 2010 to 2018, but it presented a stable trend in overall with the proportion decreasing from 2.46% to 2.03%. The residential land showed a stable trend from 1980 to 2000. It began to grow continuously from 2000 to 2018, and the growth rate reached the maximum of 143.93% between 2015 and 2018. It was closely related to economic growth and population increase. The proportions of sand land and unused land changed from 6.93% to 4.06% and from 2.51% to 0.58%, respectively, which both had evident reducing trends. It can be seen that the overall land use degree in the study area increased significantly over the last 40 years.

Tab. 1 Land use classification system

Secondary type	Primary type	Secondary type	Primary type
11 Paddy field 12 Dry land	Farmland	41 River and canal 42 Lake 43 Reservoir, puddle, and pond 46 Bottomland	Water area
21 Woodland 22 Shrubs 23 Open forest land 24 Other forest lands	Forest land	51 Urban and town land 52 Rural residential land	Residential land
31 High-coverage grassland 32 Moderate-coverage grassland 33 Low-coverage grassland	Grassland	53 Other construction lands	Coal mine land
		61 Sand land	Sand land
		63 Saline-alkali land 65 Bare land	Unused land

Tab. 2 The area of land use types from 1980 to 2018 in Kuye River basin Unit: km^2

Land use type	1980	1990	1995	2000	2005	2010	2015	2018
Farmland	1 588	1 588	1 618	1 619	1 519	1 506	1 473	1 281
Forest land	300	300	285	295	387	392	385	431
Grassland	5 691	5 693	6 026	5 920	5 870	5 867	5 580	5 543
Water area	214	212	216	214	200	200	186	176
Residential land	68	70	68	72	88	90	107	261
Coal mine land	3	3	3	3	35	53	404	584
Sand land	602	599	417	500	507	496	475	352
Unused land	218	219	50	60	74	77	74	50

From the perspective of spatial pattern: The farmland was mainly distributed in the low-lying southeast and less in the northwest of the study area; The residential land concentrated in the west-north at a high elevation; The coal mine land was mainly distributed in the central and northern parts of the study area and had sparse distribution in the southeast, and it was overall distributed near two tributaries of the Ulan Moron River and the Beiniuchuan River; The sand land and unused land concentrated in the central and northwestern regions.

2.2 Analysis of changing direction of land use

To explore the conversion among different land use types, we generally use the transfer matrix of land use type to study the internal converting characteristics of land use types[10]. This approach visually reflects conversion amount, structural characteristics, and converting direction in the variations of land use types[11]. The transfer matrix is shown below

$$\boldsymbol{S}_{ij}=\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1j} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2j} & \cdots & S_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ S_{i1} & S_{i2} & \cdots & S_{ij} & \cdots & S_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nj} & \cdots & S_{nn} \end{bmatrix}$$

where S is the land area, n is the number of land use types, S_{ij} indicates the area of the i-th land use type in period T converting to the j-th land use type in period $T+m$ years.

Based on the raster data in eight periods, Arcgis is used to integrate the reclassified land use distribution images from 1980 to 2018 with the field of "Type", so the computation amount of program can be reduced. The images in the five periods from 1980 to 1995, from 1996 to 2005, from 2006 to 2015, from 2016 to 2018, and from 1980 to 2018 are superimposed to obtain the transfer matrix of land use in the Kuye River basin (only the transfer matrix of land use from 1980 to 2018 is provided due to the limitation of space), as shown in Tab. 3.

The followings during the study period can be seen from Tab. 3.

(1) The area of coal mine land increased significantly, which was mainly converted from farmland, forest land, grassland, water area, and sand land, and their conversion areas all exceeded 6%. It has been calculated that the area of coal mine land increased nearly 200 times during this period.

Tab. 3　Dynamic transfer matrix of land use during 1980-2018 in Kuye River basin　　Unit: km^2

Categories	Farmland	Forest land	Grassland	Water area	Residential land	Coal mine land	Sand land	Unused land	Sum
Farmland	484	53	825	29	54	112	16	4	1 577
Forest land	22	81	141	7	13	23	11	2	300
Grassland	687	254	3 966	65	149	382	140	20	5 663
Water area	29	8	82	55	9	14	7	7	211
Residential land	7	5	23	4	26	2	0	0	67
Coal mine land	1	0	2	0	0	0	0	0	3
Sand land	42	20	307	10	4	42	170	2	597
Unused land	2	9	172	6	3	5	6	14	217
Sum	1 274	430	5 518	176	258	580	350	49	8 635

(2) Farmland mainly converted to grassland during this period with a conversion rate of 52.31%. In addition, 7.10% of farmland converted to coal mine land, 3.42% to residential land, and 3.36% to forest land. Meanwhile, 12.13% of grassland and 13.74% of water area converted to farmland. Overall, the area of farmland changing into other types of land was about 1.4 times that of other types of land converting into farmland in the past 40 years, and the total area of farmland reduced by 19.21%.

(3) The change in unused land was also significant. The total area reduced by 77.42%. Most of the unused land converted to grassland, which accounted for about 84.73% of the total conversion area of unused land.

(4) The water area reduced slightly. Specifically, 6.64% of it degraded to unused land and sand land, and 24.64% of it was developed as farmland, residential land, and coal mine land. The areas of

rivers and canals, lakes, and reservoirs accordingly reduced.

(5) Besides, the areas of residential land and forest land increased rapidly by 285.07% and 43.33%, respectively. The area of sand land reduced by 41.37%. The sand land mainly converted to grassland, with the conversion area reaching to 307 km^2.

Through comparison, it can be found that over the last 40 years, the area of farmland in this area declined considerably, and the area of forest land increased significantly. Meanwhile, 51% of sand land and 79% of unused land converted to grassland. It shows that the measures such as large-scale afforestation and grass planting as well as returning the grain plots to forestry promoted in this area achieved good results. Plenty of sand land and unused land were used for ecological construction, which resulted in an increase in the vegetation coverage and improvement of the overall ecological environment in this area. This phenomenon was basically consistent with the research result of Wang et al.[12] in 2017. But at the same time, the coal mining was expanding. The annual exploitation quantity increased from 900 000 tons in 1980 to 225 million tons in 2017 with an increase of nearly 250 times. Meanwhile, the mine area evidently expanded, the growth rate of which even reached to 192 33%. The effect of this situation on the environment could not be ignored.

2.3 Dynamic degree analysis of land use change

The dynamic degree models of land use are generally used to analyze the rules of dynamic conversion of land use types. The models include the single dynamic degree K[13] and the comprehensive dynamic degree LC[14], both of which can qualitatively and quantitatively describe the changing speed of land use. They can effectively compare the variation differences of different land use types[15]. This paper mainly uses the single dynamic degree to measure the changing rate and amplitude of a specific land use type in a fixed period[16]. The formula is shown in Equation (1)

$$K=\frac{U_{bi}-U_{ai}}{U_{ai}}\times\frac{1}{T}\times100\% \quad (1)$$

where U_{ai} and U_{bi} are areas of land use type i at the beginning and end of the study, respectively; T is the studying period.

The single dynamic degree of a land use type is obtained through the above formula, as shown in Tab. 4. Compared with other land use types, grassland had a dynamic degree always at a low level, whose rate of change was very low. Grassland was in a reducing trend with a slow speed. The dynamic degree of coal mine land began to surge from 1996 to 2015 and maintained at a high level, which showed a very apparent expanding trend. Although its growth began to slow down from 2016 to 2018, its dynamic degree still ranked second. The farmland area has decreased since 1995, and its dynamic degree reached to peak between 2016 and 2018. The residential land showed a trend of slowly expanding in the period from 1980 to 1995. However, its change rate began to increase since 1995, and increased sharply to the maximum frem 2016 to 2018. Its dynamic degree ranked first. The process of the change in forest land was complicated, and the dynamic degree fluctuated between positive and negative values. But the absolute values of the positive values were significantly bigger than those of the negative values, indicating that the expanding trend of the area of forest land was obviously faster than the reducing trend, so the forest land showed a growing trend over the entire period.

3 Selection of driving factors and analysis

Form the analysis results of the land use transfer matrix and the single dynamic degree of land use type, it can be seen that the areas of farmland and coal mine land changed apparently from 1980 to 2018, which was mainly caused by the combination of natural and social-economic factors. In order to explore the driving factors influencing changes in land use types in the Kuye River basin, we should deeply analyze the driving factors and obtain their rules influencing the change process of land use, so as to reasonably predict the changing trends in future.

Tab. 4　The single dynamic index of land use in distinct parts of Kuye River basin　Unit: %

Land use type	1980—1995	1996—2005	2006—2015	2016—2018	1980—2018
Farmland	0.13	−0.60	−0.31	−4.29	−0.51
Forest land	−0.33	3.63	−0.05	3.90	1.14
Grassland	0.39	−0.25	−0.50	−0.19	−0.08
Water area	0.06	−0.74	−0.65	−2.30	−0.44
Residential land	0.10	2.94	2.13	48.43	7.50
Coal mine land	0	106.67	107.94	14.84	506.14
Sand land	−2.03	2.11	−0.61	−8.53	−1.09
Unused land	−5.14	4.51	0	−10.81	−2.04

3.1　Selection of driving factors

In a land use change system, the interactions among driving factors and their effects on the outside are so complex that the study on driving forces of land use change is generally required to be carried out in a specific region. The driving forces of land coverage change are generally divided into natural driving forces and human driving forces. The natural driving forces are relatively stable, whose effects are not obvious at short scales and can be accumulated[17]. Thus, the human driving forces are often dominant, and the research on driving forces mostly focuses on them[18].

Based on the detailed analysis of land use pattern and dynamic conversion in the Kuye River basin, this paper confirms 11 indexes (X_1—X_{11}) as independent variables (as shown in Tab. 5) for analysis according to requirements of principal component analysis and data selection of the Kuye River basin.

Tab. 5　The codes of variables

Population variable	Natural condition variable	Industrial development variable	Coal mining variable
Total urban population X_1	Total precipitation X_3	GDP per capita X_5	Water yield of coal mine in Shenmu County X_9
Total rural population X_2	Temperature (annual average) X_4	Output value of agriculture X_6	Coal mining amount X_{10}
		Added value of secondary industry X_7	Goaf area of coal mine X_{11}
		Added value of tertiary industry X_8	

The most important variables were X_5—X_8 which represented development states of industries. These indexes aimed to measure the macroscopic economic development in this basin through GDP per capita. The GDP values of the first, secondary, and tertiary industries and their variations could represent the changing direction and rate of industrial structure in the Kuye River basin over the nearly 40 years. The conversion between land use types in this basin is partially explained based on the data. The agriculture GDP could be related to the change in the farmland area. The added value of secondary industry was closely linked with the area change of coal mine land. The added value of tertiary industry could represent the change in commercial and service activities, which also had effects on the structure of land use types in this basin.

The coal mining variable was also an important variable in this study. The water yield was an important index measuring the capacity of the aquifer in the coal mining area to produce water. Higher water yield indicated that the mine had a larger capacity to produce water. The goaf meant the underground "cavity" created by mining activities. Generally, the water yield increased with the enhancement of mining area and volume in the early stage of mining. But the water yield of a mine remained at a stable constant when a certain mining depth was reached. Thus, X_9—X_{11} were critical indexes to measure the change in mining intensity in the Kuye River basin over the nearly 40 years.

3.2　Standardization of data

As the original data vary much in dimension and order of magnitude, the original data should be standardized uniformly before analysis in order to avoid errors in the calculation results caused by influences of different dimensions. This paper adopts the normalization method based on standard deviation for the descriptive statistics of original data.

3.3 Principal component analysis

Due to the large number of selected driving factors, the large amount of data and the correlations among the factors, direct operation will make the analysis limited, so the principal component analysis method is chosen to solve this issue. Principal component analysis simplifies the influencing factors to a few independent components through dimension reduction, so as to concentrate on dominant factors in a complex problem and try to reflect most of information with minimum indexes.

3.3.1 Eigenvalues and contribution rates of factors

In this paper, 11 influencing factors (Tab. 5) are selected for principal component analysis and the number of principal components is determined according to eigenvalues and contribution rates of cumulative variances. Tab. 6 lists the eigenvalues, cumulative contribution rates, and variance contribution rates of all driving factors. It can be seen that the first and the second principal components had a cumulative contribution rate of 92.45%, namely that 92.45% of the original data were covered. This indicated that the two principal components could fully represent the original driving factors to reflect the specific situations of land use in the Kuye River basin.

Tab. 6 The eigenvalue and the principal components contribution rate

Componen	Initial eigenvector			Quadratic sum of extracted loading		
	Sum	Variance/%	Cumulative/%	Sum	Variance/%	Cumulative/%
1	9.012	81.927	81.927	9.012	81.927	81.927
2	1.207	10.975	92.902	1.207	10.975	92.902
3	0.499	4.538	97.440			
4	0.217	1.975	99.415			
5	0.030	0.272	99.687			
6	0.020	0.184	99.871			
7	0.005	0.049	99.920			
8	0.005	0.043	99.963			
9	0.002	0.023	99.985			
10	0.001	0.011	99.996			
11	0	0.004	100.000			

3.3.2 Calculation of factor loading matrix

After the principal components are confirmed, according to the following loading formula of principal components

$$l_{ij}=p(z_i x_j)=\sqrt{\gamma_{ij} e_{ij}} \quad (i,j=1,2,\cdots,p) \qquad (2)$$

the loadings of initial factors at each principal component are calculated (the loading coefficient of factor represents the degree of correlation between the original variable and the principal component, and a larger value indicates stronger correlation between the two) to form the initial loading matrix. The initial loading matrix can only represent partial information of variables as it is not unique. For a clearer and more comprehensive representation of variable information, the initial loading matrix is rotated with Caesar normalized maximum variance method, which makes the matrix structure simple, so the principal components can be fully interpreted and analyzed. The distribution of loading coefficients after the principal components are rotated is shown in Fig. 2.

The absolute value of the loading coefficient corresponding to each variable in the table reflects the important degree of this variable in the corresponding principal component. Fig. 2 shows that the driving factors whose loading coefficients were bigger than 0.800 on the first principal component include the added value of tertiary industry, the added value of secondary industry, GDP per capita, the water yield of coal mine in Shenmu County, the coal mining amount, the goaf area of coal mine, and the output value of agriculture. This suggested that the first principal component could be used to approximately indicate the economic and industrial development in the study area. The factors with higher loading coefficients on the second principal component included the total urban population, the total rural population, and the temperature. Thus, the second principal component could be used to represent the changes in population and environment.

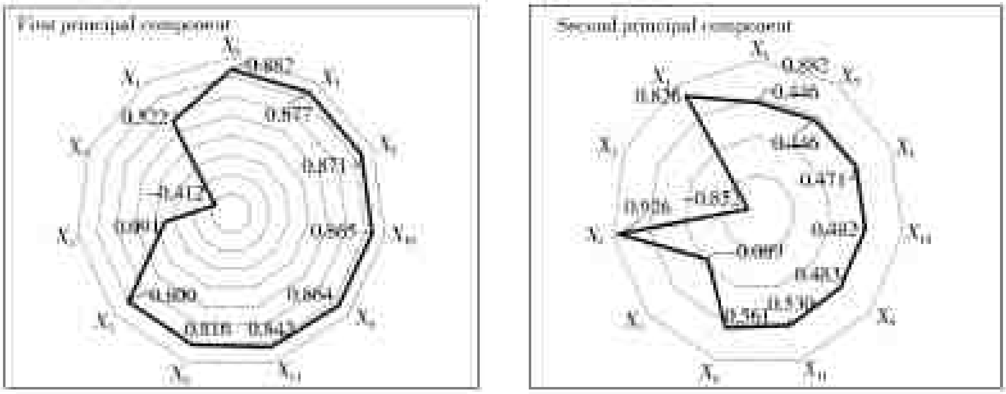

Fig. 2 The distribution of load coefficient

3.3.3 Calculation of component scores

After the principal components used in the analysis are confirmed, it is necessary to calculate the values of original indexes on the first and second principal components, namely the scores of components, with the methods such as regression method and Bartlett method. This paper uses the regression method to calculate the scores of components (Tab. 7). Based on Tab. 7 and Equation (3), the score coefficients F_1 and F_2 of principal components and the comprehensive score F of driving forces in each year can be obtained (Tab. 8), where F is the weighted result of score coefficients with the percentage of the variance of each principal component in the total variance in the quadratic sum of extracted loadings as the weight.

Tab. 7 Component score coefficient matrix

Variable	First principal component	Second principal component	Variable	First principal component	Second principal component
Zscore(X_1)	−0.093	0.297	Zscore(X_7)	0.166	−0.043
Zscore(X_2)	0.142	−0.350	Zscore(X_8)	0.168	−0.045
Zscore(X_3)	0.321	−0.326	Zscore(X_9)	0.149	−0.018
Zscore(X_4)	−0.284	0.502	Zscore(X_{10})	0.149	−0.019
Zscore(X_5)	0.155	−0.027	Zscore(X_{11})	0.125	0.017
Zscore(X_6)	0.104	0.044			

$$F=\frac{F_1\times A_1+F_2\times A_2}{A_1+A_2} \quad (3)$$

where A_1、A_2 is variance of two principal components.

It can be seen from Tab. 8 that although the comprehensive scores of driving factors influencing the land use change in the Kuye River basin fluctuated slightly from 1980 to 2018, an obvious rising trend was exhibited overall. This indicated the driving factors influencing the land use change in the Kuye River basin were gradually strengthening.

4 Analysis of driving factors

4.1 Linear regression analysis

With coal mine land as the example, the multiple linear regression is used to calculate the function between the land use change and two extracted principal components. The regression matrix is established with score coefficients F_1 and F_2 of the principal components in each year (Tab. 8) as independent variables, so a multiple linear regression model can be further established, as shown in Equation (4), where a_0, a_1, and a_2 represent the correlation coefficients.

The standardized data is processed with the multiple linear regression method through SPSS software. As the area of coal mine land and the score coefficients in each year are standardized values, a_0 is 0. During calculation, Y is the set as the dependent variable; F_1 and F_2 are set as independent variables; F-test and goodness-of-fit test are adopted to evaluate the accuracy of analysis results. The regression analysis results are shown in Tab. 9 and the parameter estimation and hypothesis testing results of regression analysis in Tab. 10.

Tab. 8 Principal component score coefficient for each year

Year	F_1	F_2	F	Year	F_1	F_2	F
1980	−0.50	−0.97	−0.56	2000	−1.22	0.93	−0.96
1981	−0.41	−1.02	−0.48	2001	−1.06	0.97	−0.82
1982	−0.36	−1.05	−0.44	2002	−0.50	0.35	−0.40
1983	−0.08	−1.48	−0.24	2003	−0.36	0.40	−0.27
1984	−0.01	−1.57	−0.19	2004	−1.13	1.37	−0.83
1985	−0.03	−1.53	−0.20	2005	−0.90	1.29	−0.64
1986	−0.46	−0.87	−0.51	2006	−0.81	1.53	−0.54
1987	0.18	−1.54	−0.02	2007	0.27	0.40	0.28
1988	0.03	−1.35	−0.13	2008	0.06	0.92	0.16
1989	−0.49	−0.65	−0.51	2009	0.06	0.98	0.17
1990	−0.67	−0.42	−0.64	2010	0.41	0.96	0.48
1991	−0.23	−1.01	−0.32	2011	1.09	0.56	1.03
1992	−0.09	−1.20	−0.22	2012	1.61	0.25	1.45
1993	−0.47	−0.66	−0.49	2013	1.58	0.57	1.46
1994	−0.32	−0.70	−0.37	2014	1.55	0.72	1.45
1995	−0.08	−1.06	−0.20	2015	1.08	1.27	1.10
1996	−0.44	−0.28	−0.42	2016	2.53	−0.13	2.22
1997	−0.93	0.33	−0.78	2017	1.82	0.81	1.70
1998	−1.59	1.47	−1.23	2018	2.24	0.46	2.03
1999	−1.39	0.95	−1.12				

Tab. 9 Regression analysis results

Model	R	R^2	F
1	0.953[a]	0.909	85.286

Tab. 10 Parameter estimation and test results of regression analysis

Model	Standardized Beta	Standard error
(Constsnt)	0	0.069
F_1	0.850	0.070
F_2	0.321	0.070

Tab. 10 shows: $R^2=0.909$, variance analysis $P=0$, indicating that Equation (5) has a good fitting degree; Moreover, the P values indicating significance of F_1 and F_2 are both 0, suggesting that the two extracted principal components have significant effect on the change in dependent variable Y (i. e., the number of land use types). Substitution of a_1 and a_2 into the regression model, Equation (4), gives the following regression Equation (5).

$$Y=0.850\times F_1+0.321\times F_2 \tag{5}$$

The linear regression equations of other land use types in the Kuye River basin are established with the same method, and the analysis results are shown in Tab. 11. It can be seen from the table that the fitting degrees and significance levels of linear regression equations are high for all land use types except grassland, indicating that the results of regression analysis are reliable.

Tab. 11 Regression analysis results

Land use type	Regression equation	Significance level
Farmland	$Y=-0.813F_1-0.403F_2$	$R^2=0.907, F=83.272$
Forest land	$Y=0.672F_1+0.624F_2$	$R^2=0.917, F=95.576$
Grassland	$Y=-0.659F_1+0.272F_2$	$R^2=0.713, F=18.587$
Water area	$Y=-0.817F_1-0.513F_2$	$R^2=0.965, F=242.939$
Residential land	$Y=0.825F_1+0.367F_2$	$R^2=0.903, F=79.160$
Coal mine land	$Y=0.850F_1+0.321F_2$	$R^2=0.909, F=85.286$
Sand land	$Y=-0.526F_1-0.676F_2$	$R^2=0.857, F=49.774$
Unused land	$Y=-0.212F_1-0.852F_2$	$R^2=0.878, F=60.562$

4.2 Result analysis of regression equations

According to the regression equations and models, the followings can be obtained.

(1) Coal mine land. The area of coal mine land in the Kuye River basin has a highly significant positive correlation with principal component F_1 ($R=0.850$), which represents economic development. As the most important industrial raw material for energy and steel industries, coal is a fundamental element for rapid economic development. Therefore, as the economic development in the Kuye River basin grew, the demand for coal resources also increased year by year. Data show that from 1980 to 2018, the coal mining amount in the Kuye River basin surged from 0.90 million tons to 230 million tons, the water yield of coal mine in Shenmu County increased by nearly 230 times, and the net increase in goaf area of coal mine reached

577 km^2. It can be seen that the rapid economic development in the last 40 years led to a massive expansion of coal area.

(2) Farmland. The changes in farmland are negatively correlated with F_1 and F_2. The correlation coefficient with F_1 is high ($R=-0.813$) and the correlation coefficient with F_2 is low ($R=-0.403$). According to the meanings represented by the principal components, it can be known that economic development, especially the development of heavy industries represented by coal mining, is the main reason for the decrease in the farmland area in recent years. The coal mining not only destroys the soil structure and increases the possibility of erosion and drought on farmland as a result of disturbing the surface[19], but also directly encroaches on farmland. Data suggests that 19.41% of the net increase in the area of coal mine land in the Kuye River basin from 1980 to 2018 was from farmland. Moreover, F_2 which was related to population changes also has a negative correlation with the change in farmland, which was directly related to big changes in population structure in the Kuye River basin in the study period. From 1988 to 2018, the number of rural people in the Kuye River basin decreased from 312 900 to 127 400, and the proportion of urban population in the total population of the basin rapidly rose from 21% to 78%. The changes in the population structure in the study area directly resulted in the decrease in rural labor force. The increase in the urban population also promoted the urbanization process. The city continuously expanded to the countryside, and many lands were used for urbanization and industrialization.

(3) Forest land. It can be seen from the regression equation that the area of forest land is positively correlated with F_1 and F_2, and the correlation coefficient with F_1 is slightly large ($R=0.672$). Therefore, one of the major reasons influencing the change in the area of forest land is the increasing urbanization and the rapid economic development. As the economic development grows, people are more aware of eco-environmental protection. Meanwhile, the improvement of comprehensive national power also provides sufficient material support for returning the grain plots to forestry. In addition, F_2 which represents changes in natural environment was also one of important factors influencing changes in the area of forest land in the Kuye River basin. The total annual precipitation of this basin remained high in recent years and the temperature had an apparent upward trend, which both promoted the increase in the area of forest land in the Kuye River basin.

(4) Residential land. Tab. 11 shows that: The first and second principal components are positively correlated with the area of residential land ($R_1=0.825$, $R_2=0.367$); However, the first principal component F_1 remains the dominant factor, which indicates that economic development was the most important driving factor resulting in the expansion of residential area in the Kuye River basin. Meanwhile, the continuous growth of population in the Kuye River basin over the last 40 years (Fig. 3) also led to an increasing demand for the residential land in this basin. As the existing residential land could not satisfy the continuous growing population, small parts of sand land, unused land, grassland, and farmland converted to residential land in the past 40 years, so the area of residential land increased.

(5) Grassland. F_1, which represents economic development, remains as the factor with the highest correlation with the grassland area, and the correlation coefficient is negative ($R=-0.659$). The acceleration of industrial development, especially the further expansion of coal mining, was one of the main factors contributing to the destruction of grassland coverage. The Kuye River basin is rich in mineral resources such as coal and quartz sand, and most of them are located in mountainous areas. Coal mining severely influenced the quality of vegetation coverage. Data suggests that 66.20% of the net increase in the area of coal mine land in the Kuye River basin from 1980 to 2018 came from grassland, but the grassland in the Kuye River basin over the past 40 years had a small net decrease due to the strong support of China for the policy of returning the grain plots to forestry and grassland.

(6) Water area. It is negatively correlated with

F_1 and F_2 and has a high correlation with F_1 ($R = -0.817$) and a low correlation with F_2 ($R = -0.513$). This indicates that economic development contributed to the decrease in the water area of Kuye River basin to some extent during the study period. It was mainly associated with large-scale and high-intensity coal mining activities in the basin. The increasing scale of coal mining led to a sharp increase in consumption of industrial water, which directly resulted in significant decrease in the underground water level in the coal mining areas and caused cutoff of rivers and drying up of spring water in the surrounding areas. This is basically consistent with Yang′s research results[20] concerning the changes in runoff of the Kuye River basin in 2014.

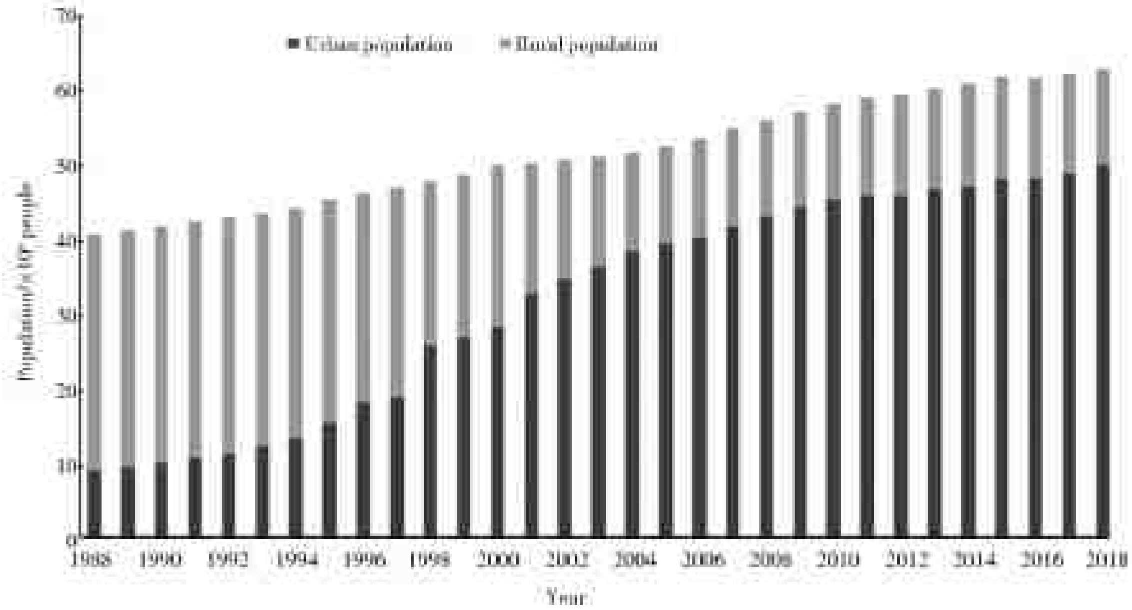

Fig. 3 The population in the Kuye River basin

(7) Sand land. It is negatively correlated with principal components F_1 and F_2 with low correlation degrees ($R_1 = -0.526$, $R_2 = -0.676$). It shows that rapid economic development, continuous increase in population, and changes in natural environment all contributed to the reduction in the area of sand land but with small influencing degrees. This is consistent with the actual situation in the study area.

(8) Unused land. The area of unused land is negatively correlated with F_1 and F_2 and has a low correlation coefficient with F_1 ($R = -0.212$) and a high correlation coefficient with F_2 ($R = -0.852$). This indicates that the major factor influencing the area of unused land in the Kuye River basin was F_2, which represents the changes in population and natural environment. Tab. 7 shows that nearly 79% of unused land converted to grassland from 1980 to 2018. This was related to abundant annual precipitation and suitable temperature in the Kuye River basin, as well as to the afforestation and grass planting policy implemented in China. Moreover, the continuous growth of population increased the land use pressure in the basin, so unused land was continuously developed to alleviate this pressure. Meanwhile, the changes in population structure could deepen the land use degree by promoting the transformation of consumption structure.

5 Conclusions

(1) The proportions of areas of land use types in the Kuye River basin currently were in the order of grassland > farmland > coal mine land > forest land > sand land > residential land > water area > unused land. Farmland as mainly distributed in central and low-lying southeastern areas in the basin; coal mine land was mainly distributed along the mainstream of the river; residential land and unused land were mainly distributed in the northwestern part of the basin.

(2) The sequence of single dynamic degrees of

land use types was coal mine land＞residential land＞unused land＞forest land＞sand land＞farmland＞water area＞grassland. During the study period, the area of coal mine land increased at the highest rate; the area of unused land decreased at the highest rate; the changes in grassland were smooth compared with those in other land use types. This indicates the overall vegetation structure of the basin improved. The policies of returning grain plots to forestry and afforestation achieved significant results. The land degradation was reduced. The areas of bare land and sand land reduced greatly. This shows that the comprehensive development and utilization of land improved significantly.

(3) This paper adopted multiple linear regression to qualitatively and quantitatively analyze the driving factors. The results show the followings: ① Economic development, especially the growing secondary and tertiary industries, was the major cause of land use change in this basin, and the influencing intensity was increasing year by year. In all the land use types, coal mine land was influenced the most by the changes in the secondary and tertiary industries, which showed a rapid change in the study period. Meanwhile, the added values of the secondary and tertiary industries in the basin rose in the past 40 years, with GDP per capita increasing by nearly 70 times. The economy was developed comprehensively and rapidly, which also led to the conversion of other land use types. ② Rapid growth of population and transformation of population structure also extremely influenced the areas, converting direction, and converting speed of farmland, residential land, and unused land in the basin, which were also important factors driving the changes in land use types in the Kuye River basin over the past 40 years.

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