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Proceeding Paper

Spatio-Temporal Assessment of Land Use Land Cover Changes and Population Dynamics Using Geoinformatics: A Case Study of Mardan, Khyber Pakhtunkhwa, Pakistan †

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Abstract: Over the last three decades, Tehsil Mardan has gone through an incredible expansion of the built-up layer. This study explored the land use land cover changes of Tehsil Mardan from 1990 to 2021 along with population dynamics by applying geographic information systems and remote sensing techniques. Landsat satellite images for the years 1990, 1995, 2000, 2010, 2015, and 2021 were used for land use land cover classification. Maximum likelihood Supervised algorithm and confusion matrix were applied for classification and accuracy assessment respectively. Classification results outlined that there is a substantial increase in the built-up layer from 37 km^2 to 188 km^2 and a significant decrease in bare land class from 437 km^2 to 252 km^2 from 1990 to 2021. The classification process's overall accuracy was 87.42% to 98.30%, and Kappa Coefficient was from 0.82 to 0.97. Population dynamics were also studied in the present study and found that the total population of tehsil Mardan was 502,435, 864,017, 1,403,002 in 1981, 1998, and 2017 respectively, which was further forecasted based on historical trends till 2027. Statistical analysis found a strong positive correlation (0.98) between built-up and population and a significant negative correlation (−0.91) between population and bare land. Based on the findings of this study, policymakers should be able to better plan future land use and associated possibilities while keeping environmental threats and opportunities in mind.

Keywords: LULC classification; GIS and RS; change detection; mardan

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1. Introduction

Global land use has changed by one-third over the last decades once or multiple times [1]. The dynamic conditions of land use land cover changes (LULC) have given birth to various socio and environmental issues like degradation of the ecosystem, food security, water, and climatic variation [2–4]. According to [5] in 1950 only 30% of the global population was residing in urban areas which increased to 55% in 2018 and is projected to be 68% by 2050. About 90% of the projected increase will be happening in developing countries. Urban growth is attributed to population flare-ups and rural-urban migration. A developing country like Pakistan is urbanizing with an annual growth rate of 3%, which is the highest in South Asia [6]. This growing population will require natural resources for survival such as energy and water [7]. Urbanization has become a widely known reality [8] and poses serious threats to environmental resources such as water quality and quantity, vegetation (deforestation), and agriculture [9]. Urbanization creates negative impacts on socioeconomic conditions and biophysical factors[10], such as a high rate of urbanization will result in a larger impervious cover layer and eventually will reduce infiltration capacity [11]. It was recently revealed that uncontrolled urban sprawl will limit water availability in its intensity, duration, and frequency [12]. The speedy conversion of permeable earth surface to impervious cover due to land use and land cover changes have triggered regional as well as local environmental impacts [13,14]. According to the Pakistan Bureau Statistics, and World Bank 2017 reports, Pakistan ranked 6th in the list of most populous countries in the world. Since its inception urbanization is a key factor in land use and land cover changes [15,16]. Globally these changes have modified the earth's surface by two third over in the last thousand years [17,18]. The expertise of LULC changes would improve the current land use policies and practices based on scientific data for sustainable environmental development [19]. Land use of an area represents its natural and anthropogenic environmental characteristics [20–22]. Increasing built-up trigger, the impervious cover which ultimately results in a high amount of runoff and decline of groundwater recharge [23–25]. Remote Sensing (RS) and Geographic Information System (GIS) are largely applied and recognized as a leading procedure to assess and examine land use dynamics. Satellite imagery data was successfully used for the assessment of LULC change analysis for the last 30 years [26–28]. Population increase along with no policy for land use resulted in an alarming situation [29], as the built-up layer has been increased at the cost of cultivable land [30] in tehsil Mardan. Therefore, assessment and quantification of the current and historic land use land cover changes over spatio-temporal scales along with population dynamics are necessary for all types of policy making to comprehend the associated environmental issues on both regional and local scales.

2. Study Area

Tehsil Mardan was chosen based on its rapid urban and population growth over the last three decades (Figure 1). Mardan is the 2nd larger city after the provincial capital Peshawar of Khyber Pakhtunkhwa and 23rd on the list of the biggest cities of the country. The climatic conditions of Mardan range from hot to semi-arid. The average annual temperature remained 22 °C with June being the hottest month and total annual rainfall was 560 mm, with August having the highest rainfall of 122 mm. Since 1990 Mardan witnessed a shift in population growth and spatial change [31], and was recognized as a business circle for the adjoining districts of Khyber Pakhtunkhwa.

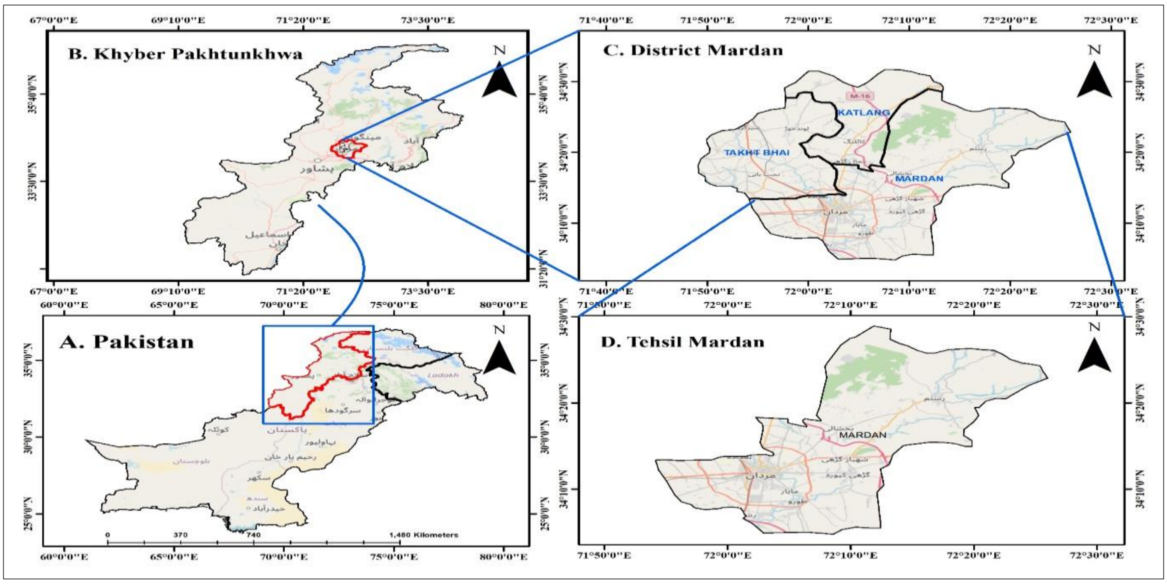

Figure 1. Location map of the study area ((**A**)-Country, (**B**)-Province, (**C**)-District, (**D**)-Tehsil Mardan).

3. Methodology and Dataset

3.1. Land Use Land Cover Classification and Change Detection

Both primary and secondary data sets (literature and published reports) were accessed and analyzed during the current study. To know the extent and space of urbanization, Landsat satellite imageries were downloaded from the USGS website (https://earthexplorer.usgs.gov/). A detailed methodological approach applied for the assessment of LULC changes and change detection is displayed in Figure 2. Methodological flow chart Landsat imageries were used in various studies for the assessment of land use land cover (LULC) changes on a spatiotemporal scale [32–34]. The temporal interval was 5 years; however, 2005 imageries were not included in the list due to the non-availability of the imageries data from 2003 to 2007 over the study area. Imageries for the years 1990, 1995, 2005, 2010, 2015, and 2021 were downloaded as per the given details in (Table 1). The downloaded imageries were passed through the radiometric and geometric correction process [35]. Radiometric calibration and atmospheric correction techniques are required for spatial change assessment [36,37]. Four land use land cover classes were selected based on the intended objective and maximum representation of the study area (Table 2). ENVI 5.3 software was used for land use land cover assessment and change detection analysis. Sufficient and accurate training samples of each class were collected [38] for classification process by using various band combinations, Google Earth historical preview, local knowledge, and ground truth points [38]. Supervised classification technique based on maximum likelihood algorithm was used [39,40] for classification of LULC of tehsil Mardan from 1990 to 2021. The accuracy assessment technique is used for the calculation of classification accuracy quantitively [37,41–43], while the change detection technique is employed for quantification and assessment [43] of land cover changes during the study period over time [44,45]

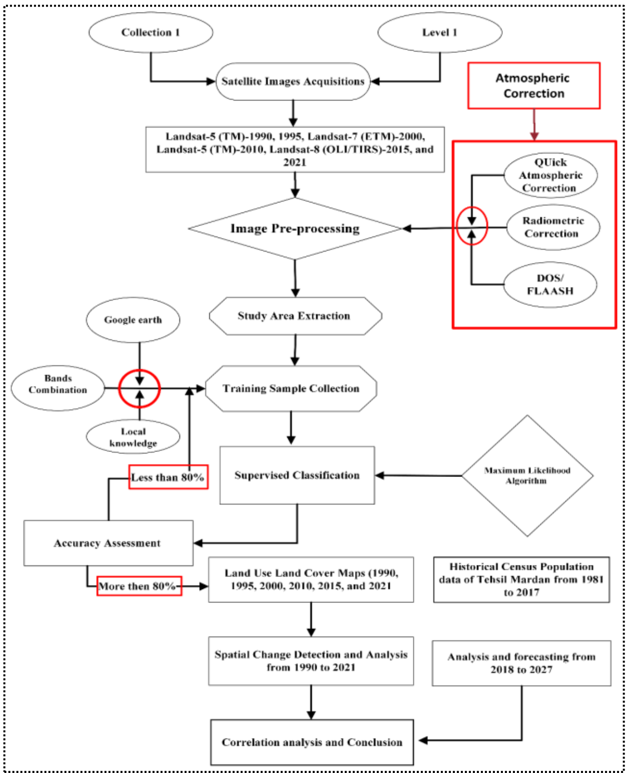

Figure 2. Methodological flow chart.

Table 1. Landsat Satellite Imageries Data for Detection LULC.

S.No.	Year	Satellite	Sensor	Acquisition date	Cloud Cover (%)	Remarks
1	1990	Landsat 5	TM	14th March 1990	2	-Targeted Months -Minimum Cloud Coverage -Clear Study Area -Free from Scan-Line Error -Resolution =30x30 meters
2	1995	Landsat 5	TM	13th April 1995	1	
3	2000	Landsat 7	ETM+	18th April 2000	3	
4	2010	Landsat 5	TM	6th April 2010	1	
5	2015	Landsat 8	OLI/TIRS	19th March 2015	1.7	
6	2021	Landsat 8	OLI/TIRS	19th March 2021	2.4	

Table 2. Land use classes description.

S.No.	LULC Type	Description
1	Built-up	This class includes buildings, roads, concrete, and asphalt structures that are covered with impervious surfaces and anthropogenic.
2	Vegetation	This class includes forest, grasslands, green belts, and cropland
3	Water bodies	This class includes lakes, reservoirs and streams, and inundated area
4	Bare land	This class includes areas where no permanent built-up, vegetation, or water bodies exist.

3.2. Population Data

Population data was obtained from the Pakistan Bureau of Statistics for population census for 1981, 1998, and 2017. Using the inter-census annual growth rate (ICGR) formula, the inter-census annual population was calculated by Equation (1). The Exponential Smoothing Forecast function in Microsoft Excel was used to project/forecast population statistics from 2017 to 2021 and onward till 2027. Using time series historical population data, this technique might forecast future population Equation (2) [46].

$$ICGR = X + XR \quad (1)$$

whereas X is the population of the previous year and R is the census reported growth rate factor.

$$\text{Forecast} = \text{FORECAST.ETS (target year, values, timeline, [seasonality], [data completion], [aggregation])} \quad (2)$$

4. Results and Discussion

4.1. Land Use Land Cover Dynamics and Accuracy Assessment

The overall results of the LULC assessment showed that the built-up class remains on a continuous increase from 1990 to 2021 [47], however, the bare land class was showing a decreasing pattern of change (**Error! Reference source not found.** and **Error! Reference source not found.**). LULC assessment results of tehsil Mardan for the years 1990, 1995, 2000, 2010, 2015, and 2021 are displayed in **Error! Reference source not found.** LULC for 1990 showed the built-up class was 37 km^2 (4%), vegetation was recorded 441 km^2 (47%), surface water bodies covered 21 km^2 (2%), and Bare land spread over 437 km^2 (47%). Bare land and vegetation land cover were equal in 1990 [47]. In 1995 the LULC of tehsil Mardan was comprised of 61 km^2 as built-up, 527 km^2 as vegetation class, 12 km^2 as surface water bodies, and 399 km^2 as bare land. After 10 years in 2000, the land cover pattern results showed an increase in built-up (83 km^2) and vegetation (527 km^2), however, water bodies were found 18 km^2, and bare land decreased to 308 km^2. In 2010 the LULC composition showed expansion in the built-up layer (101 km^2) and a slight decrease in vegetation class (516 km^2) as compared to 2000 LULC results. In 2021 the LULC was composed of 52% Vegetation and 20% built-up, and 27% bare land. The net change in LULC from 1990 to

2021 in tehsil Mardan was observed 408% increase in built-up class, 10% increase in vegetation sector, while the bare land and water bodies decreased by 52% and 42% respectively. Overall classification accuracy for the years under study was more than 90 % except for 2010. Kappa Coefficient was also recorded above 0.80 for all the imageries (**Error! Reference source not found.**).

Table 3. Accuracy Assessment.

Year/Parameter	1990	1995	2000	2010	2015	2021
Overall Accuracy (%)	97.25	96.69	94.15	87.42	94.71	98.30
Kappa Coefficient	0.95	0.95	0.91	0.82	0.88	0.97

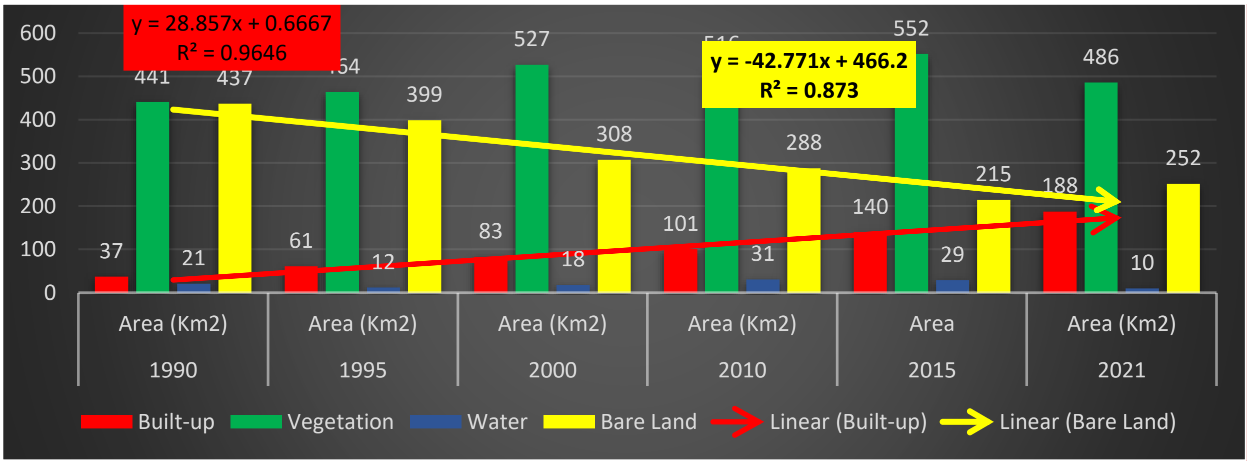

Figure 3. LULC of Tehsil Mardan from 1990 to 2021.

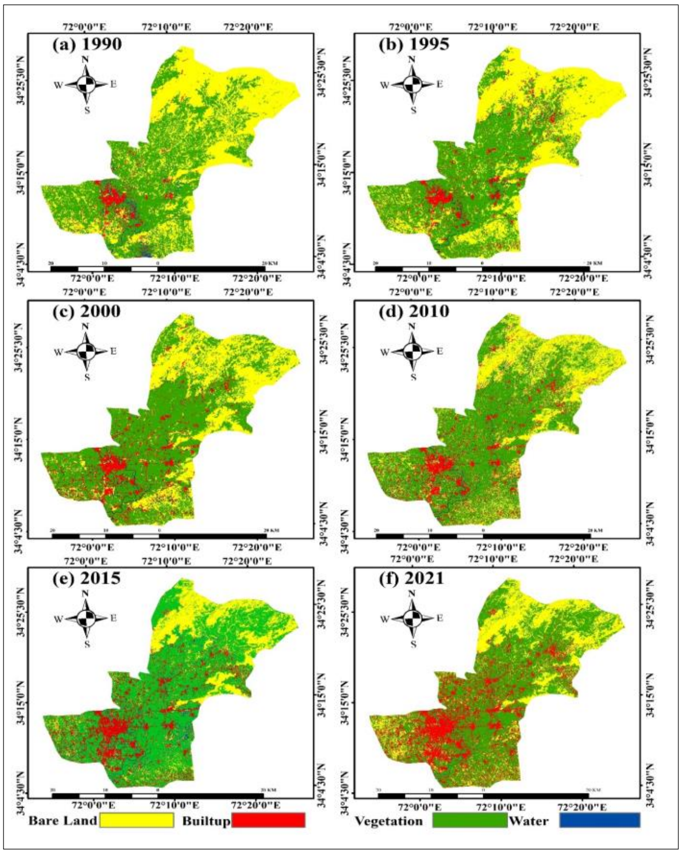

Figure 4. Land use land cover maps of tehsil Mardan.

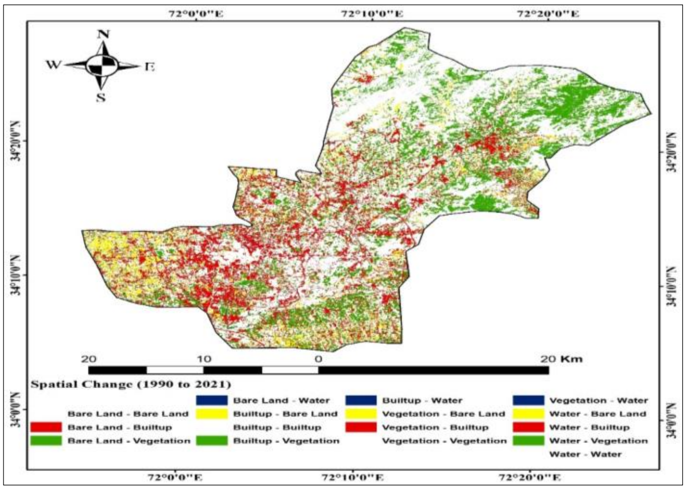

Figure 5. Spatial Change Detection from 1990 to 2021.

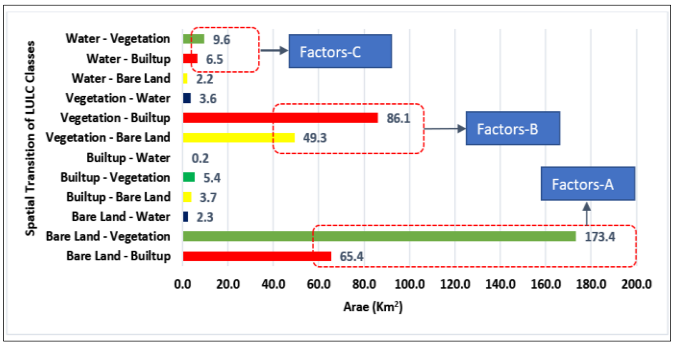

Figure 6. Change Detection from 1990 to 2021.

4.2. Spatio-temporal Change Detection from 1990 to 2021

Change detection technique was applied to evaluate and measure various transitions from one land use class to another. The present study focused on the already set temporal range from 1990 as the base map (LULC) and 2021 as the final land use land cover map. The transition between these targeted years was visualized and quantified in Arc Map (**Error! Reference source not found.** and **Error! Reference source not found.**). Significant transitions were observed among the land use classes, wherein bare land changed to vegetation class (173.4 Km^2), the vegetation changed to built-up layer (86.1 km^2), bare land changed to built-up (65.4 km^2), and vegetation changed to bare land (49.3) during the last three decades. The major contributors to the spatial change are divided into three Factors (**Error! Reference source not found.**). Contributing factors-A, where bare land changed to vegetation and built-up by 238.8 km^2. Factors-B, where vegetation class has changed to built-up and bare land by 135.4 km^2. Factors-C, where water class has been changed to built-up and vegetation by 16.1 km^2. Spatially the vegetation improved in north-eastern and south-eastern parts of tehsil Mardan due to the billion tree afforestation project [48,49], implementation of Khyber Pakhtunkhwa Forest Ordinance 2002, enactment of The Khyber Pakhtunkhwa wildlife and Biodiversity (Protection, preservation, conservation and management act, 2015, and Forestry Sector Master Plan (FSMP). Conversion of vegetation to bare land found in the southwestern parts of the study area near the vicinity of the city. It is anticipated that this bare land will be transformed into built-up in the near future.

4.3. Population Change Dynamics of Tehsil Mardan

According to the 6th population census 2017, the total population of tehsil Mardan was 1,403,002, in which the urban population share was 359,024 and the rural population numbered 1043978. Similarly, in 1998, the total population was 864,017 and the urban population was 245,926. For 1981 the population data of the district Mardan was proportionally divided based on the current boundaries of tehsils. The forecasted population of tehsil Mardan for the years 2021 and 2027 was recorded as 1,580,539 and 1,759,485 respectively (**Error! Reference source not found.**).

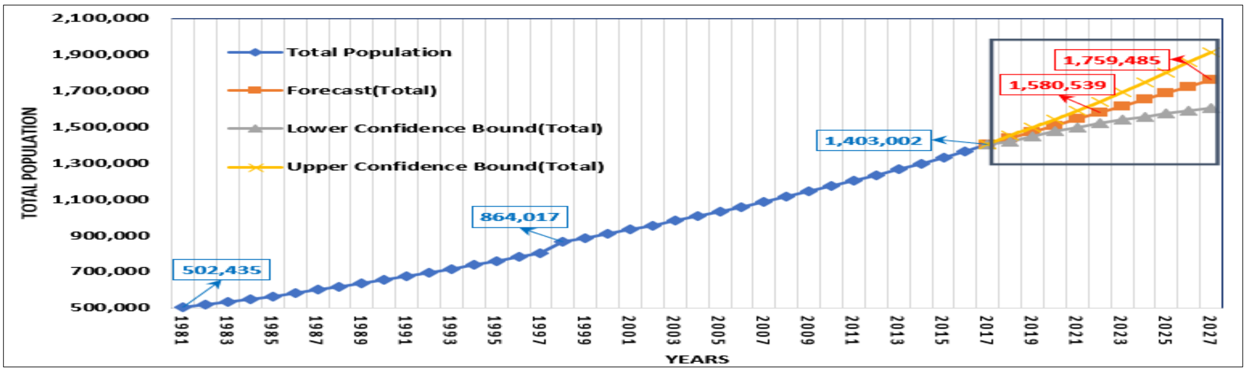

Figure 7. Population dynamics of tehsil Mardan.

4.4. Correlation Analysis

Correlation analysis was performed to assess the correlation between the land use classes and total population data. The total population showed a strong positive correlation (0.98) with built-up and a strong negative correlation with bare land (−0.90). Built-up showed a significant negative correlation with bare land (−0.86). Correlation results are depicted in the table.

Table 5. Correlation Matrix of LULC classes and population.

	Total Population	*Built-up*	*Vegetation*	*Water*	*Bare Land*
Total Population	1				
Built-up	0.982	1			
Vegetation	0.554	0.486	1		
Water	0.077	-0.096	0.537	1	
Bare Land	-0.907	-0.868	-0.851	-0.300	1

5. Conclusions and Recommendations

The current study demonstrated the LULC change dynamics by exploiting RS and GIS. The study showed that the built-up layer increased from 3.96% to 20% from 1990 to 2021. The built-up layer is increasing at the cost of bare land and vegetation cover. The main driver behind the increase in the built-up layer is population growth, infrastructure development, and provision of basic amities of life in the city. Bare land decreased from 46.7% to 27%. The population of tehsil Mardan increased from 502,435 in 1981 to 1,544,750 in 2021.

It is recommended that further research should be carried out on the impact assessment of LULC changes on environmental parameters such as water quality and quantity, and climatic parameters like temperature and precipitation.

Government should formulate an approved and sustainable land use plan for current and future generations of the tehsil Mardan. An awareness campaign should be launched to raise awareness among all stakeholders regarding the negative implication of the built-up layer and consequent ecosystem degradation.

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