Research on Concentration and Matching Degree of water resources in Sri Lanka Based on Remote Sensing and GIS Technology

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Abstract: Sri Lanka is an important node country in the "One Belt and One Road" strategy, and the solution of water resources is the main demand to promote the sustainable development of the local country. Articles in several times, on the basis of field investigation, combined with the local review and summarize the existing research, calculation and analysis of the concentration of water source of rainfall in Sri Lanka and concentration, and with the local water resources per capita and GDP per capita of compatibility as a measure for the analysis of water resources utilization in Sri Lanka, highlight the area rainfall concentrated period of unstable situation, It is also found that the utilization of water resources in this area has a good development trend. Therefore, it is of great significance for the smooth implementation and promotion of "One Belt and One Road" strategy to improve the scientific utilization of water resources in Sri Lanka according to the current situation.

1. Introduction

"One Belt and One Road" is an international and regional cooperation initiative proposed by China in the new era. It is a new trans-regional cooperation model proposed to promote the common development of economic globalization, achieve win-win cooperation, and improve China's international influence and voice [1-2]. "Area" strategic lines long, wide cover countries, geographical difference is big, it will lead to the implementation of the "area" face a global problem, water problems, especially along the country basically is given priority to with developing countries, especially water resources, to the implementation of the "area" and the overall layout brings uncertainty influence [3]. In addition, Sri Lanka suffers from serious water pollution and severe water-borne diseases, namely chronic kidney disease of unknown cause (CKDu) [4]. Since the 1990s, the number of patients has been as high as 40,000, and the standardized prevalence is about 15%. Up to now, more than 20,000 people have died from this disease [5].

Sri Lanka, located at the "crossroads" of east-west transportation in the Indian Ocean, is an important partner country in China's construction of the "21st Century Maritime Silk Road". Solving the problem of water resources is a major demand for promoting sustainable development in Sri Lanka. Sri Lanka has a tropical monsoon climate, which is characterized by high temperatures throughout the year and divided into distinct dry and rainy seasons. The flat terrain and the long dry season lead to the difficulty in effective storage and utilization of rainy season rainfall. The temporal and spatial distribution of water resources in the island is unbalanced, the seasonal water shortage is serious, and the surface water area changes and fluctuates greatly, which further aggravates the shortage of local fresh water resources. Many scholars have done research on water resources in Sri Lanka. Ye Huping et al adopted the water spectral maximum value classification method [5] to analyze the changes of bio-optical characteristics of Sri Lanka's offshore water, so as to monitor and analyze the changes of the coastal Marine ecological environment of Sri Lanka. K.G. Vilhos et al. [6] reflected the challenges of groundwater resource management in Sri Lanka through the analysis of groundwater volume, water quality, tsunami impact and groundwater management system in Sri Lanka. Wang Yawei et al. [7] explored the main pathogenic factors and influencing factors of unknown nephropathy (CKDu) from the perspective of physical geography, toxic substances, behavior and genetics, water sources and other factors.

Many studies on the current situation of water resources in Sri Lanka show that the utilization of water resources in Sri Lanka is not optimistic and lacks reasonable planning and management. Most of the previous studies have explored the water resources and utilization in Sri Lanka, but few have quantitatively analyzed the water resources utilization of Sri Lanka's rainfall and the matching degree between Sri Lanka's economic development and per capita water resources. In this study, rainfall characteristics in Sri Lanka were analyzed by the calculation method of concentration degree and concentration period [8] and the matching degree calculation method [9] was used to analyze the matching degree between per capita GDP and per capita water resources in Sri Lanka, so as to better guide local decision makers to plan and manage water resources.

2. The Study Area

Sri Lanka is a tropical island near the southeastern tip of India, with a land area of 65 610 km^2 (Figure 1). Among them, three quarters of the land is composed of vast first level plains, with an average elevation of 75 m; The second level plain rises to 500 m, mainly distributed in the southern region. The third-level plain rose sharply, forming a mountain with an elevation of 2 500 m. Sri Lanka is divided into nine provinces: Central, East, North, North Central, North West, Sabalagamuwa, South, Uva and West. In 2010, Sri Lanka had a total population of more than 21 million, of whom about 86% lived in rural areas. The average population density is 315 people /km^2. The population is mainly concentrated in the humid areas (the southwest coastal areas and the central areas).

In northern Sri Lanka is a tropical grassland climate, the southern tropical rainforest climate, hot all the year round, annual average temperature 28 ℃. The highest average temperature was in April and May, with a monthly average temperature of 29 ℃. The lowest average temperature was in December, with a monthly average temperature of 24 ℃. The highest temperature in the range of historical statistics is 36 ℃, and the lowest temperature is 16 ℃. The temperature decreases with increasing altitude, about 2 ℃ for every 300 m elevation.

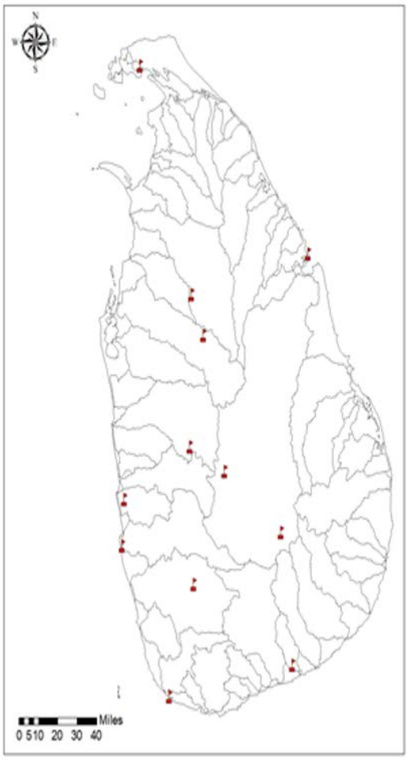

Figure 1 The study area

3. Methodology

The calculation method of runoff concentration degree and concentration period[8] is to regard the monthly rainfall in a year as a vector. The magnitude of the vector is the rainfall, and the direction of the vector is the ordinal number of the month in a year minus 1 and then multiply by 30°. The azimuth Angle of every month from January to December is from 0°, 30°, 60°,etc , to 330 °. 12 months bisect the circumference of the circle, and the direction of vertical 90° upward is north, then the direction of southeast, northwest and northwest is 0°, 270°, 180° and 90° respectively. Starting from due east, the angular extension increases counterclockwise.

Summing the rainfall vectors of each month in a year, the ratio of the combined vector model to the annual rainfall is PCD_{year}, The combined vector direction is the annual rainfall concentration period PCP_{year}:

$$PCD_{year} = \sqrt{P_x^{\ 2} + P_y^{\ 2}} \ / \ P_{\text{year}} \tag{1}$$

$$PCP_{year} = \tan^{-1}(P_x / P_y) \tag{2}$$

$$\begin{cases} P_x = \sum_{i=1}^{12} p_i \cos\theta_i \\ P_y = \sum_{i=1}^{12} p_i \cos\theta_i \end{cases} \tag{3}$$

$$\theta_i = (i-1) \times 30° \tag{4}$$

In the above formula: P_{year} Is annual rainfall; P_x and P_y are respectively the horizontal and vertical components constituted by the sum of the monthly rainfall components; i is the ordinal number of the month（i =1,2,3, …, 12）; θ_i is the vector Angle of rainfall in the i^{th} month.

Calculation method of matching degree. Matching degree[9]refers to the matching degree of analysis variables X and Y. Assume that the lengths of X and Y are K, and the values of variables X and Y are (x_1, y_1), (x_2, y_2), $\cdots$, (x_k, y_k). The K corresponding values of X ,(x_1, x_2 $\cdots$, x_k) are sorted from the smallest to the largest, and the corresponding Ordinal Numbers are n_1, n_2, $\cdots$, n_k and (the minimum value is 1, the maximum value is K). The same sorting process is applied to the K values of variables Y. The corresponding ordinal number is m_1, m_2, $\cdots$, m_k (the minimum value is 1, the maximum value is K).

If the greater the value of X is, and also the greater the value of Y is, and the more matched the two variables are, then the formula for calculating the matching degree is

$$\alpha_i = 1 - \frac{|n_i - m_i|}{K-1} \tag{5}$$

$$(i = 1,\ 2,\ \ldots,\ K)$$

The degree of difference between serial numbers can also be used to measure the degree of match. When $n_i = m_i$, they have a perfect match, and the matching degree α_i is equal to 1; The larger the difference between the serial numbers of n_i and m_i is, the worse the matching degree is, and the closer the matching degree is to 0.

If the greater the value of X is, but the samller the value of Y is, and the more matched the two variables are, then the formula for calculating the matching degree is

$$\alpha_i = 1 - \frac{|n_i + m_i - K - 1|}{K - 1} \tag{6}$$

$(i = 1, 2, \ldots, K)$

In this case, the larger the difference between the serial numbers of n_i and m_i is, the closer the matching degree is to 1. The smaller the difference between the serial numbers of n_i and m_i, the closer the matching degree is to 0.

If the specific research area needs to be analyzed and calculated according to the matching degree between different variables in different time periods, the research object can be divided into T periods, and the values of variables in different time periods are respectively (x_1, y_1), (x_2, y_2), $\cdots$, (x_T, y_T). Also, sort these indices, the serial numbers are $n_1, n_2, \cdots, n_T$; $m_1, m_2, \cdots, m_T$. Then, the formula for calculating the matching degree between time-divided variables can be changed into

$$\alpha_j = 1 - \frac{|n_j - m_j|}{T - 1} \tag{7}$$

$(j = 1, 2, \cdots, T)$

$$\alpha_j = 1 - \frac{|n_j - m_j - T - 1|}{T - 1} \tag{8}$$

$(j = 1, 2, \cdots, T)$

The matching degree can also be calculated according to the proportion of the specific value of the variable in the total value of the variable in the study period. The calculation formula is

$$\alpha_j = 1 - \frac{|r_j - s_j|}{\max(r_k, s_k) - \min(r_k - s_k)} \tag{9}$$

$$\alpha_j = 1 - \frac{|r_j + s_j - \max(r_k, s_k) - \min(r_k, s_k)|}{\max(r_k, s_k) - \min(r_k, s_k)} \tag{10}$$

$$r_k = \frac{x_k}{\sum_{j=1}^{T} x_j} \qquad s_k = \frac{y_k}{\sum_{j=1}^{T} y_j} \tag{11}$$

$(k = 1, 2, \cdots, T)$

Sri Lanka's annual average precipitation is obtained by TRMM satellite. Hambantota rainfall data is the meteorological data of Hambantota City meteorological station in Sri Lanka for 15 years, including rainfall, temperature, pressure, etc., data are recorded 8 times a day, once every 3 hours. GDP Per capita and the amount of water resource data by the world bank database (https://data.worldbank.org.cn/indicator).

4. Results and Disscion

In this study, data from 1998 to 2019 were used to analyze the process of inter-annual rainfall changes in Sri Lanka, and the inter-annual rainfall changes were diagramed (2002 data was not included in the diagram because of the anomaly).

Do the above to get Figure 2. Figure 2 shows the inter-annual rainfall change in Sri Lanka over the past 20 years. The average annual rainfall in Sri Lanka generally showed an upward trend, with a general fluctuation range of 1 500-2 000mm. In 2003, it was the lowest value in the past 20 years (1

482.63 mm), and in 2015, the highest average annual rainfall was 2 168.08 mm. The annual rainfall variation of Sri Lanka is relatively large, mainly because it belongs to the tropical monsoon climate, with abundant precipitation, and under the control of the equatorial Marine air mass in summer, there is more convective rain, and the transit of the tropical cyclone brings a lot of precipitation, so it causes more summer rainfall than the dry and wet tropical climate. On some windward coasts, the summer rainfall is even higher than that of equatorial rainy climates due to topographic effects.

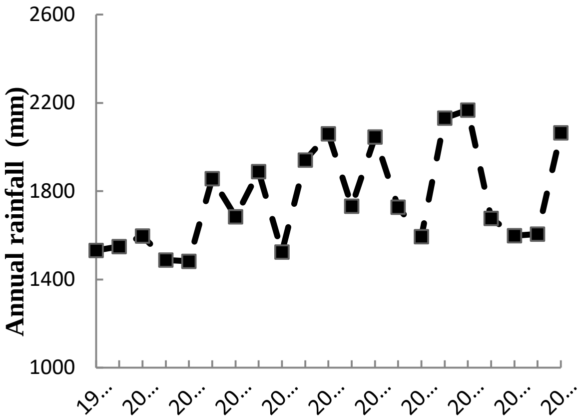

Figure 2 Annual Rainfall Changes in Sri Lanka

Meanwhile, spatial rainfall distribution in Sri Lanka is uneven. The average annual rainfall in Galle was the highest, which was 5 302.32mm. The average annual rainfall in Kanti and Hambantot is relatively low. The average annual rainfall in Kanti and Hambantot is 2 032.46mm and 2 444.94mm respectively. It can be seen that although Sri Lanka has a small land area and little difference in longitude and latitude among its cities, in fact, there are significant differences in rainfall among different regions. Annual rainfall ranges from 2 540 mm to 5 080 mm in the south-west and less than 1 250 mm in the north-west and south-east.

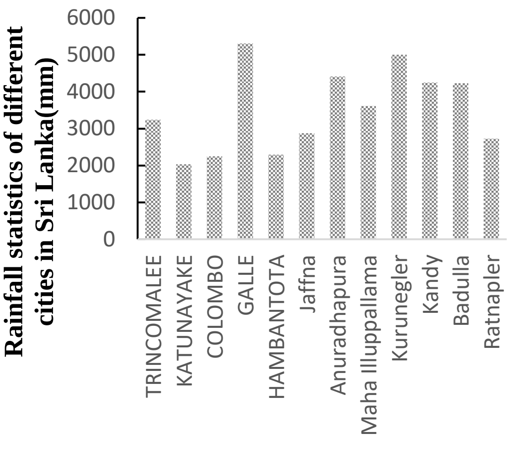

Figure 3 Statistical Characteristics of Rainfall at Various Stations in Sri Lanka

Based on the above analysis, in order to explore the spatial distribution characteristics of rainfall in Sri Lanka, the monthly average rainfall data of Hambantota, the central city of Sri Lanka, from 2016 to 2020 were selected for calculation and analysis, and the concentration degree and concentration period of annual rainfall in each year were calculated respectively. The results are shown in Table 1. The following results are obtained. According to the results in the table, the concentration of rainfall in Hambantota in recent five and a half years is unstable and the difference is large, the lowest is 13.02%, the highest is 59.52%; The same is true of the concentration period. From 2016 to 2020, the concentration period of Hambantota rainfall occurred in January, December, April, September and August, respectively. The concentration of 2020 sets in August, 2019 sets in September, 2018 sets in April, 2017 sets in December, 2016 sets in January. Therefore, the rainfall in this area does not have an obvious centralized rule, nor does it have a strict inter-annual variation. The main reason may be that the region belongs to the tropical monsoon climate, which is significantly affected by the monsoon and has a large climate change, so the rainfall is not concentrated. In addition, the tropical monsoon climate is a rainy climate, with the rainy season for about half a year. The rainy season in Sri Lanka starts from April, generally from May to August and from November to February of the next year. The rainy season is longer, so the unification of the concentrated period is not high, which is more in line with the actual situation.

Table1 Statistical Characteristics of Rainfall in Hambantota

Year	***Concentration/%***	**Concentration period**	
		Direction of composite vector / (°)	***Time***
2020	29.74	226.7316	8/17
2019	59.52	269.9252	9/30
2018	21.15	92.25818	4/2
2017	37.44	334.4638	12//4
2016	13.02	16.98716	1/17

According to the results in the table, the concentration of rainfall in Hambantota in recent five years is unstable and the difference is large, the lowest is 13.02%, the highest is 59.52%; The same is true for the focus period, the middle of 2020 is in August, 2019 is in September, 2018 is in April, 2017 is in December, 2016 is in January. Therefore, there is no obvious pattern of concentration of rainfall, and there is no strict annual change. The main reason may be that the region belongs to the tropical monsoon climate, which is significantly affected by the monsoon and has a large climate change, so the rainfall is not concentrated. In addition, the tropical monsoon climate is a rainy climate, with the rainy season for about half a year. The rainy season in Sri Lanka starts from April, generally from May to August and from November to February of the next year. The rainy season is longer, so the unification of the concentrated period is not high, which is more in line with the actual situation.

This study divides the period from 2002 to 2014 into seven periods. With the growth of the period, the per capita GDP ratio also increased from \$867.49 to \$3819.25, but the per capita water ratio decreased from 0.1496 to 0.1373. According to formula (10), the matching degree is calculated. According to the analysis results, the matching degree increases at any time, from 0.45 to 0.84. Although the per capita water use in this region decreases over time, the per capita GDP keeps increasing, indicating that the economic development of this region is good. Under the circumstance that the amount of water resources is not synchronized with the economic growth, the GDP of this region can still achieve positive growth, which can reflect the continuous improvement and improvement of the utilization efficiency of local water resources. On another level, the decline in per capita water use may be a reflection of growing awareness of water conservation among local residents. However, the matching degree increases with the increase of per capita GDP, which indicates that local economic development is dependent on water resources, or that water resources are an important factor limiting local social and economic development.

From 2002 to 2014, Sri Lanka experienced rapid economic and social development, and per capita GDP continued to grow, while per capita water consumption began to stabilize after a period of relative growth. The matching between the two peaked in 2008 and has declined steadily since.The main reasons are as follows:Before 2008, with the rapid economic and social development, the amount of water resources could meet the development needs, and the two increased synchronously, and the matching degree gradually increased;From 2009 to 2011, due to the limitation of water resources shortage, the water resources could not bear the demand of further economic and social development. Therefore, the development demand could only be met by improving the efficiency of water resources utilization.

After 2012, the utilization of water resources tends to be stable, while the economy and society continue to grow, and the matching degree is further reduced, which indicates that the utilization efficiency of water resources has a bottleneck in the technical promotion and financial support, and also indicates that water resources have become a restrictive factor for the further development of the economy and society.

Table2 Sri Lanka's per Capita GDP and per Capita Water Resources Matching

Year	*GDP per capita /dollar*	*Per capita water /m³*	*Proportion of GDP*	*Proportion of water used per capita*	*Match degree*
2002	867.49	2769.84	0.0564	0.1496	0.45
2004	1065.78	2708.4	0.0693	0.1463	0.47
2006	1435.82	2661.02	0.0934	0.1437	0.52
2008	2037.32	2632.11	0.1325	0.1422	0.60
2010	2799.65	2615.55	0.1821	0.1413	0.70
2012	3350.52	2585.07	0.2179	0.1396	0.78
2014	3819.25	2541.15	0.2484	0.1373	0.84

5. Conclusions

Sri Lanka is an important node country in China's "One Belt and One Road" strategy. It has abundant water resources. Due to its special island topography and tropical climate and other natural geographical factors, its water resources are characterized by unstable inter-annual variation and uneven rainfall periods. Meanwhile, in recent years, the matching degree between per capita GDP and per capita water resources in Sri Lanka has been increasing year by year while per capita water resources have been decreasing year by year, but in fact, the management and utilization of water resources in Sri Lanka is not fully scientific. On the whole, China and south Asian and Southeast Asian countries along the "Belt and Road" are facing many challenges in the field of water resources, but they also have broad space for cooperation. Sri Lanka can pay more attention to the collection and saving of natural precipitation, and China can also provide some water purification technology to improve the available water. In general, it is suggested to comprehensively consider various water resource utilization areas, exploitation planning, water supply routes and other factors, so as to formulate corresponding water resource utilization methods, provide scientific basis for Resolving key livelihood issues in Sri Lanka, and effectively support the smooth implementation and promotion of "One Belt and One Road" strategy.

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