Research of Equilibration on Water Resources utilization in Yunnan plateau by Gini Coefficient

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Abstract: Based on the investigated data from 2000 to 2015 that related to water resources utilization in 103 units about Water Resources Fourth Sub-Region divided by Drainage Basin overlying Prefecture (abbr. WRFSRDBP) in Yunnan Province that belongs to Yunnan – Guizhou plateau, Gini coefficient, Theil coefficient and Variation coefficient were adopt to evaluated equilibration on water resources utilization of the whole province. The results shows that the Gini coefficients about water resources utilization in the province was 0.105~0.763, the average value was 0.544. Water supply quantity of reservoirs and ponds increased $3.033 \times 10^9$ m$^3$ in recent 15 years, resulted in the Gini coefficient decreased from 0.327 to 0.256, namely the equilibration changed better; While the Gini coefficient of water supply quantity of projects by gravity channel, pump and trans-valley increased from 0.209 to 0.266, as new reservoir was built across river upstream, thus water supply amount was transferred to water supply amount of reservoir; Water supply by wells, rain collection and wastewater reused projects in different units changed various, the Gini coefficient of water supply by wells were 0.584~0.614, and rain collection and wastewater reused projects were 0.611~0.641 in the last 15 years, respectively. Non-cigarette industry developed rapidly, due to the restriction policy of state’s tobacco cultivate and cigarette plant, which promoted industrial structure changed from 2000. Those was the reason that the Gini coefficient of industrial water usages decreased from 0.542 to 0.329; Synchronously, the Gini coefficient of municipal water usage also decreased from 0.463 to 0.321, and the equilibration changed better too; On the other hand, the extent of water utilization different about livelihood and livestock in countryside was broaden, the Gini coefficient increased from 0.100 to 0.321; In recent 15 years, provincial irrigated rate of Yunnan was raised from 21.8% to 29.1%, the gap among sub-regions on agriculture irrigation development was reduced gradually, the Gini coefficient of irrigated water consumption decreased from 0.294 to 0.153 consequently. Ulteriorly, local entropy spatial distribution in the sub-regions revealed degree of importance of its water supply and water usage in the province. Besides, research by Theil coefficient and Variation coefficient also proved the same results.

1. Introduction
The impact of global climate change on the natural and social environment has become more and more obvious. Meteorological disasters such as significant changes in climate humidity and high
temperature and drought have occurred more frequently, and the impact on water resources and agricultural production has become more significant \cite{1}. Affected by the natural environment and human activities such as topographic and geological conditions, temporal and spatial changes in precipitation, and socio-economic patterns, the spatial balance of sustainable use of water resources is a global problem. Geospatial analysis tools such as GIS and Geoda are generally used to reveal geography and the spatial distribution of hydrology \cite{3}, or Gini coefficient, Theil coefficient, Moran coefficient, coefficient of variation and other mathematical models to analyze the spatial variability and equilibrium of a factor \cite{4,5}. At present, the latter research is mainly divided into three aspects: revealing the fairness and imbalance of water resources utilization in provinces or river basins by analyzing the matching Gini coefficients of water resources and cultivated land resources, regional GDP, population, etc. \cite{6-10}, analyzing the balance of urban scale, land use, industrial and agricultural water, water pollution and other indicators among the members of each component using Gini coefficient \cite{11-15}, and researching the problem of unbalanced space factors using Theil coefficient and coefficient of variation \cite{16}.

Yunnan Province both belongs to low latitude plateau and longitudinal range-gorge region (abbr. LRGR) which features a monsoon climate, so the spatial and temporal distribution of water resources is uneven. It is the region which suffers the most severe winter and spring drought in the country. The shortage of water resources, the deterioration of water environment and the fragility of water ecology are prominent. Over the past decade, there was a series of comprehensive utilization and rational allocation planning research on water resources, including the construction of the Central Yunnan Water Diversion Project, the Niulanjiang-Dianchi Water Replenishment Project, the Qingshuihai Water Resources Environmental Management Project, and Chemabi, Agang reservoirs etc. These key water source projects gradually solved the engineering problems of the province and the resource shortage of the economic zone in the central Yunnan \cite{39}. However, it is rare to reveal the spatial balance and change rules of water resources development and utilization by the spatial scale of fourth sub-region divided by drainage basin overlying prefecture, and to study the changes in water resources. Technological innovations such as these are of great significance for refined water resource allocation, water conservation and water connection projects in plateau mountainous area.

2. Materials and methods

2.1 Data used
Annual Report on Social and Economic Statistics of 16 prefectures and 129 Counties (Cities, Districts) in Yunnan Province from 2000 to 2015 was used; the data on the socio-economic, water resources, water supply, and water consumption of the 103 WRFSRDBP units in the province are obtained from comprehensive planning of water resources in Yunnan province, middle and long period water supply and demand planning in Yunnan province, and the third water resources survey and evaluation in Yunnan province.

2.2 Research methods
The Lorenz curve and its location entropy, Gini coefficient, Theil coefficient and coefficient of variation are used to analyze and reveal spatial equilibrium of the main indicators related to water resources development and utilization in the time dimension (four typical years 2000, 2004, 2008 and 2015 was chose) and in spatial dimensions as WSFSRDP in Yunnan Province, the specific calculation method can be found in the related literature \cite{16,18-22}.

3 Results analysis

3.1 Relationship between Gini coefficient and r-index of water resources development indicators
The degree of unbalanced distribution of water resources in the geographical space is described by Lorenz curve and Gini coefficient, which has good consistency. For the Lorenz curve with no scale
distribution, when the study object distribution obeys Zipf's law, that is, the Zipf index \( r \) value is ideally equal to 1, the Lorenz function based on Euler's formula can be used to quickly estimate the Gini coefficient.\(^{[15]}\) Yunnan Province belongs to the low-latitude plateau mountainous areas. The light and water resources are incompatible with the industrial and agricultural economic layout. The distribution of water resources and related social and economic indicators in the geographical space is not balanced. The mathematical law of its connotation is very similar to income. As shown in Figure 1(a), among the selected indicators such as irrigation quota, surface water resources, groundwater resources, total population, irrigated area, cultivated land area, water supply modulus, total water consumption, and water consumption per 10,000 yuan RMB of GDP, etc., the Gini coefficient increases linearly when the \( r \) value varies from 0.198 to 1.500. However, the Gini

![Figure 1](image1.png)

Figure 1 Rapid estimation of the \( r \)-index variation of the Gini coefficient based on the Euler formula (a. \( r \)-Gini coefficient, b. \( r \)-LN (extreme value ratio), c. Centralization index I-Gini coefficient)

![Figure 2](image2.png)

Figure 2 Zipf's law test (a. amount of surface water resources, b. total water use, c. groundwater resources) coefficient fluctuates slightly between 0.65 and 0.75 when the \( r \) value is greater than 1.750, and does not increase with the increase of the \( r \) value. Since there is no scale at one end and the other end is very large, the frequency obeys the Pareto distribution (theoretically equivalent to Zipf's law). The relationship between the natural logarithm of the ratio of the maximum value to the minimum value and the corresponding Zipf index \( r \) value is shown in Fig. 1(b). The relationship between the Gini coefficient and the centralized index \( K \) is as shown in Fig. 1(c), and they correspond highly in the trend. As can be seen from the three figures, the Zipf index \( r \) and the Gini coefficient or the natural logarithm of the ratio of the maximum value to the minimum value fit a linear line when \( r \in [0.25, 1.75] \). It is reasonable to use the Lorenz function of Euler's formula to estimate the Gini coefficient quickly in this extent. The corresponding ratio of the maximum value to the minimum value are 30–3000, and the ratio of the horizontal section in Figure 1(a) is greater than 50000. The Zipf law is
selected for the amount of surface water resources, groundwater resources and total water. After normalization, the R² of the curve fitting is above 0.97, and the r values are 1.285, 1.371, 1.385, respectively, and the corresponding Gini coefficient is 0.554, 0.563 and 0.581 are as shown in Figure 2 above.

3.2 Changes in water supply structure

The water supply capacity of various water supply facilities (divided into four categories: water storage project, water diversion project, groundwater project, rain harvest and wastewater reuse project) in the units of WRFSRDBP were obtained from the "Yunnan Water Resources Comprehensive Planning", "Yunnan Water middle and long period Supply and Demand Planning", "Yunnan Province third Water Resources Survey and Evaluation" and other projects in four typical years of 2000, 2004, 2010, 2015, etc.. The Lorenz curve of water supply capacity of various water supply facilities and the total water supply is shown in Figure 3.

![Figure 3 Lorenz curve during water supply structure changing in Yunnan Province from 2000 to 2015](image)

(a. water storage works, b. water diversion projects, c. groundwater, d. rain harvest and wastewater reuse)

The Gini coefficient of the water supply capacity of the water storage project gradually decreased from 0.327 to 0.256 during the period from 2000 to 2015. This is the embodiment of the construction of various reservoir projects and the change of water supply structure in the province. As the reservoir capacity is increased, the proportion of the water supply structure has gradually increased from 37.0% in 2000 to 48.9% in 2015. The construction speed of the key water source project has been accelerated because of the expansion of domestic demand in 2008 affected by the adjustment of national water conservancy construction policies and the drought in the five southwestern provinces of China from 2009 to 2010. In the past 15 years, the water supply capacity of the water storage project has increased by 3.033 billion m³, of which the increase since 2010 is 2.506 billion m³, and these water storage projects are mainly small and medium-sized reservoirs, which are scattered in various river basins in
the province, there is a significant change in Figure 3(a); the water supply in the water diversion project in each typical year in Figure 3(b) is continuously and slowly reduced, and the proportion in the water supply structure is reduced from 60.6% to 48.7%. The main water supply projects of the province have gradually changed from “water diversion projects” to “water storage projects”. The Gini coefficient increased from 0.209 to 0.266, because the supply amount of some original water diversion projects transfer to the water storage projects, water balance in space of supply amount of the rest water diversion projects have gradually deteriorated. In contrast, the water supply of groundwater, rain connection and wastewater reuse projects has not significant spatial changes in the past 15 years. The groundwater supply is mainly concentrated in the central Yunnan Plateau Basin and the lakeside area. The wastewater reuse is also concentrated in the provincial capital Kunming and other cities. The water supply amount of the rain harvest projects is small and the projects distributed across the province, the spatial distributions of water supply, such as groundwater, rain harvest and wastewater reuse, was very different. The Gini coefficients respectively are 0.584 ～0.614, 0.611~0.641 in the period from 2000 to 2015. The variation trend of the Gini coefficient of water supply for various types of water source projects is shown in Fig. 5(a).

Taking the survey results at the year of 2015 as an example, the location entropy of water supply in various types of water source projects in the units about WRFSRDBP is shown in Figures 4(a) to (d). In the four graphs, the high value of the local entropy is indicated by reddish color, and the low value of the local entropy (abbr. LQ) is indicated by the green color. It can be seen from the figures that the local entropy reflects the proportion of water supply of a certain type of projects to total water supply in the partition unit, and the total water supply of this unit to the whole province. Taking Figure 4(a) as an example, the units are with high local entropy in the water storage project such as Kunming Dianchi Basin, Zhaotong Wujiang and Hengjiang Shang, Dali Yupao River, Yuxi Lvzhi River, Honghe Dianxi River, Pu'er Weiyuan River, Baoshan Mengboluo River, the water supply of the water storage project in these units accounts for 67.9%~92.1% of the total water supply, and the adjustment ability of the abundance is good. The low value area of the local entropy is concentrated in the Jinsha River in Diqing and Lijiang in the northwestern Yunnan. In the upper section of the Nujiang River in Nujiang and Dali, the upper section of the Lancang River in Diqing and Nujiang, the LRGR valley in Dulong River and the southwestern border of Yunnan, the water supply of the water storage project accounts for less than 10% of the total water supply. The seasonal shortage of water supply is outstanding.
Figure 4 Schematic diagram of spatial distribution of local entropy of various types of water supply in Yunnan Province in 2015 (a. water storage works, b. diversion water projects, c. groundwater, d. rain harvest and waste water reuse)

Figure 5 Gini coefficient during water resources developing from 2000 to 2015 (a. water supply structure, b. water use structure, c. water resources usage)

Similarly in Figure 4(b), the local entropy is in the high value area in the northwestern Yunnan and southwestern Yunnan areas where the water diversion accounts for a large proportion of water supply, and the local entropy is lower in the central Yunnan and northeastern regions, and Figure 4 (a ) Just the opposite. Figure 4 (c), (d) shows that the water supply of groundwater, rain harvest and waste water reuse is very small, but the main water supply projects of each unit in the province is very different. The area with a large proportion of groundwater supply is in Longchuan River, YuPao River, Qujiang River, Lujiang River, and Beipan River, and the proportion of rainwater harvesting and wastewater reuse in the province's WRFSRDBP, is about almost 1%.

3.3 Changes in water use structure

Similarly, in 2000, 2004, 2010, 2015 of four typical years, The Lorenz curve of the four major categories of water consumption (divided into urban life, rural life and livestock, industry, agriculture) and total water consumption of the province is shown in the units about WRFSRDBP in Yunnan Province in Figure 6. The variation trend of the Gini coefficient of water consumption of various types of water users is shown in Figure 5(b). The proportion of industrial water consumption in Yunnan Province decreased from 9.91% in 2000 to 9.27% in 2015. Although the industrial added value continued to increase, it was affected by the industrial economic downturn (2000~2010), the elimination of backward industry, the adjustment of industrial park layout and the compulsive demand of water saving (after 2012). The non-tobacco industry in various places has grown rapidly after the restriction policy of state’s tobacco cultivate and cigarette plant. The industrial added value has blossomed everywhere in the province. The gap of the secondary and tertiary industries has narrowed
between different areas as shown in Figure 5(c). Therefore, although the industrial water consumption has increased slightly between 1.300 and 1.496 billion m³, the Gini coefficient has decreased from 0.542 to 0.329, and the spatial imbalance has gradually reduced. The trend is shown in Figure 6(a). With the improvement of urbanization process and living environment, the urban and rural living water consumption of the province has gradually increased during the year of 2000 and 2015. The annual water consumption of urban life has increased from 719 million m³ to 2.326 billion m³, and the Gini coefficient has been reduced from 0.463 to 0.321, the distribution tends to be balanced; although the annual water consumption of rural life and livestock has increased from 892 million m³ to 1.075 billion m³, the spatial imbalance has increased because a part of water consumption of rural life transferred to water consumption of urban life, and the spatial imbalance of urban domestic water consumption is reduced. The Gini coefficient of rural domestic water use increases from 0.100 to 0.321, as shown in Figures 6(b) and (c). The Gini coefficient of agricultural irrigation water consumption decreased from 0.294 in 2000 to 0.153 in 2015, which has been in an absolute average state. In fact, Yunnan Province has been paying more attention to the development of irrigated area since the “State Ninth Five-Year Plan”. Although the total amount of irrigation water is strictly controlled, it only slightly increased from 10.009 billion m³ to 10.410 billion m³, but the irrigated area increased from 1.34 million hectares in 2000 to 1.76 million hectares in 2015, and the effective irrigation rate of farmland increased from 21.8% to 29.1%. The agricultural production has gotten more profit because of farmland water conservancy, and the distance of agricultural irrigation development of each unit has gradually narrowed.

Taking the survey results at the year of 2015 as an example, the water resource location entropy of various types of water users in the units about WRFSRDBP is shown in Figure 7 (a) ~ (d). In the four figures, the local entropy is also indicated by a reddish color when the value is high, and the green entropy when the value is low. The figure shows that the local entropy (abbr. LQ) reflects the...
proportion of water consumption of a certain type of projects to total water consumption in the partition unit, and the total water consumption of this unit to the whole province. Taking Figure 7(a) as an example, the units are with high local entropy in the water consumption such as Kunming Dianchi lake basin, the downstream of Jinsha River in Zhaotong, Yanggong River and upstream of Jinsha River in Dali, Nanpan River in Qujing and Qujiang River and Lvzhi River in Yuxi, Lu River and the downstream of Nanpan River in Honghe and Shuodu River in Diqing. Water consumption of urban life accounts for 19.5% to 36.3% of the total water consumption, while the units are with low local entropy in the water consumption are concentrated in southwestern Yunnan and southeastern Yunnan, the proportion of urban domestic water consumption in total water consumption is below 8.0%. Similarly in Figure 7(b) above, in the areas where the industrial water consumption accounts for a large proportion of total water consumption, such as Central Yunnan, Southwestern Yunnan, WuJiang River and Chishui River in northeastern Yunnan, and Shuodu River in northwestern Yunnan, the proportion of industrial water consumption in total unit to total water consumption are 12.1. %~39.8%, the local entropy is in the high value area; The location entropy is lower in most of the southwestern Yunnan and northwestern Yunnan, the proportion is mostly below 6.0%, which is also opposite contrasting Fig. 7(a). Figure 7(c) shows that the proportion of water consumption of rural domestic life in a part of units in northeast, southeast and northwest is more, and the proportion of the other units is very small. In Figure 7(d), the proportion of water consumption of agricultural irrigation in most units is generally 60.0%~91.7%, there is little difference between each units, but in the Dianchi basin of Kunming, Wujiang and Chishui River in Zhaotong, and Shuodu River in Diqing, the proportion of agricultural irrigation water consumption is only 9.9%~40.0%.
3.4 Characteristic of water resources development and utilization in spatial and temporal scale

Theil coefficient and the coefficient of variation of each indicator are analyzed and calculated including 16 indicators of per capita water resources amount, per hectare cultivated land water resources, effective irrigation rate, urbanization rate, per capita cultivated land, per capita GDP, per capita industrial added value, per capita water consumption, agricultural water use proportion, runoff controlled proportion, water resources development rate, water supply modulus, water consumption per 10,000 yuan RMB of GDP, water quotas of industrial added value, water quotas of urban life, water quotas of rural life and water quotas of agricultural irrigation using the data of the water resources development and utilization survey and evaluation results of every unit in the four typical years 2000, 2004, 2010, 2015, as shown in Figure 8.

It can be seen from Fig. 8 that the Theil coefficient of the runoff controlled proportion (the water supply of the water storage projects and the outer basin water diversion projects accounts for the proportion of the total water resources of the unit) and the per capita industrial added value are the largest, which is between 0.579~0.997, 0.282~0.372 respectively, the coefficient of variation is also the largest, which is between 1.804~2.032, 0.982~2.043 respectively; In general, the runoff controlled proportion increases with water supply capacity of the water storage projects, and the spatial imbalance is gradually reduced. But in 2010, there was an abnormal situation. The reason was that the province suffered from a drought that had not happened in a hundred years. The water supply
of various water storage projects dropped sharply. A number of drought-resistant emergency projects with water diversion, water pumping and groundwater wells were built and alleviate to supply for urban and rural life and agricultural irrigation.

The gap between the units that having lots of water storage projects and the units that having no water storage projects was narrowed, so the Theil coefficient was only 0.579, and the Theil coefficient in 2000, 2004 and 2015 were at the section of 0.826 to 0.997. The Theil coefficient and coefficient of variation of the other 14 indicators vary between 0.012–0.272 and 0.206–1.300 respectively. Generally speaking, with the progress of society developing and the strengthening of national economic strength, the investment in water conservancy construction is gradually increasing, especially after the “State Eleventh Five-Year Plan”. Since the whole country emphasized the importance of people’s livelihood and water conservancy, the focus of water conservancy and poverty relief projects is for the alpine mountainous area, so the water supply security gap between the economically developed areas such as the Central Plateau and the poor and backward valley basin areas, and the imbalance is gradually reduced, the Theil coefficient and the coefficient of variation are decreasing. However, the value of various indicators is much different, inspite of its change tendency are similar in the period of 2000 t0 2015.

4. Conclusion

Based on the survey data of various indicators related to water resources development and utilization in four typical years of 103 WRFSRDBP units in Yunnan Province, the Gini coefficient, Theil coefficient, and coefficient of variation is used to analyze the spatial equilibrium of water resources development and utilization in the province, and the Gini coefficient estimation without scale distribution is verified. The results show that the Gini coefficient of water resources development and utilization indicators varies from 0.105 to 0.763 with an average of 0.544. The water supply capacity of the water storage project in the water supply structures increased 3.033 billion m$^3$ during the period from 2000 to 2015, and the Gini coefficient gradually decreased from 0.327 to 0.256. As new reservoir was built across river upstream, the water supply amount was transferred to water supply amount of reservoir, and then Gini coefficient of the water diversion project increased from 0.209 to 0.266; The spatial distribution of groundwater supply, rain harvest and wastewater reuse was very different, the Gini coefficient was between 0.584–0.614 and 0.611–0.641 during 2000–2015. As the non-tobacco industry in various cities is rapidly growing, the Gini coefficient of industrial water consumption is reduced from 0.542 to 0.329, and the spatial imbalance is gradually reduced; The Gini coefficient of urban domestic water consumption is reduced from 0.463 to 0.321, and the spatial distribution is also towards balanced; The spatial imbalance of rural domestic water consumption is expanding, and the Gini coefficient has increased from 0.100 to 0.321; In the past 15 years, the effective irrigation rate of farmland in the province has increased from 21.8% to 29.1%, and the difference in agricultural irrigation development among the units has gradually narrowed, so the Gini coefficient of agricultural irrigation water consumption also decreased from 0.294 in 2000 to 0.153 in 2015, which is in an absolute average state.

The spatial distribution of location entropy of water supply and water use is a good reflection of the amount proportion of the unit to the whole province the amount proportion of a type of projects to all of the projects. When the $r$ value of the selected indicators for water resources development and utilization varies from 0.198 to 1.500, and the linear relationship between the Zipf index $r$ and the Gini coefficient, the index $r$ and the natural logarithm of the ratio of the maximum value to the minimum value is $r \in [0.25, 1.75]$, the results of using the Lorenz function of the Euler formula to quickly estimate the Gini coefficient are reasonable, and the centralization index is closely related to the change of the Gini coefficient.

The evaluation results of Theil coefficient and coefficient of variation also revealed the same conclusion. After the “State 11th Five-Year Plan”, the whole country emphasized the importance of people’s livelihood and water conservancy. The focus of water conservancy and poverty relief projects is for the alpine mountainous area, so the water supply security gap between the economically
developed areas means the central Yunnan plateau and the poor and backward valley basin areas which include Wumeng revolutionary mountainous, Southeast Yunnan rocky desertification region, West Yunnan border mountainous, Zang minority settlement region, etc., and the imbalance is gradually reduced, the Theil coefficient and the coefficient of variation are decreasing.

**Acknowledgements**

Foundation of Yunnan Provincial Nature Science Research Key Program (2017FA022); Major Projects of National High Resolution Earth Observation System Special Fund (89-040-G19-9001-18/20-03); Scientific Research and Technical Innovation Team Construction of Yunnan Province (2018HC024).

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