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PRECIPITATION, RUNOFF, AND EVAPORATION TRENDS IN NORTHWEST CHINA OVER THE PAST 40 YEARS

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ABSTRACT

Understanding of the trends of water resources in the arid region of northwest China (NWC) is essential for effective flood control, scientific management of water resources, protection of the ecological environment, reasonable irrigation, and navigation in China. Herein hydrological trends in NWC were analyzed based on total precipitation, evaporation, and runoff using climate trend rate method. Then Mann-Kendall sequential test was employed to carry out the detection of trend significance, and the future trend was calculated employing R/S analysis method (Rescaling range analysis). The results indicated that a significant change was observed in 2004 for precipitation, evaporation, and runoff so that an increasing trend was more pronounced after 2004 in comparison with the results obtained between 1979 to 2004. Additionally, most water resources concentrated in a small part of the southwestern border of NWC. Since runoff represented good correlation with precipitation and evaporation, regression analysis can be used to establish a runoff prediction model to forecast future runoff.

Keywords: Precipitation; Evaporation; Runoff; Northwest China; Spatial Distribution; Temporal Tendency

1 INTRODUCTION

Water resources play an essential role in economic development and ecological environment of arid areas (Boehmer et al., 2000; Chen et al., 2007; Wang et al., 2013). During the hydrological cycle, precipitation, runoff, and evaporation are important components. Northwestern China (NWC) accounts for over 20% area of China, located in central Asia, far from the sea. Due to scarce precipitation and high evaporation, the area is lack of water resources. More precipitation occurs in the mountainous area and water is consumed in the downstream regions of rivers in NWC. For the fragile ecological environment and arid climate in NWC, water resources affect the balance of the whole regional system (Zhang et al., 2000; Wang et al., 2017). Thus, the trend detection of water resources in NWC is vital for future water management and social development.

The air temperature, precipitation, evaporation, and runoff in NWC have been affected by both human activities and climate change. The trends of these variables have been studied by researchers in the whole region of NWC or part of it. Mean annual air temperature experienced an increasing trend in NWC during 1961-2010 (Shi et al., 2007; Sun et al., 2013). Seasonal and spatial distribution was observed in the trend of temperature. The temperature in winter increased most significantly, and the slowest rate of increase was found in spring. The climate has become warmer and wetter in the arid region of NWC (Chen et al., 2014). Annual precipitation showed a positive trend followed by the most significant trend in winter (Wang et al., 2013). Glaciers melting is an important source of water for rivers in southern areas in NWC. Thus, the impact of climate change on runoff appears to be complicated in the area.

Additionally, the trends of runoff showed a spatial distribution in NWC (Qin et al., 2016). The runoff experienced a decreasing trend in the eastern headwaters of NWC while there was an opposite trend in the western area (Wang et al., 2013; Qin et al., 2016). Correlations between these variables have also been investigated. Wang et al. (2013) found that precipitation and runoff showed a strong correlation with the temperature. Most studies mainly focused on the impacts of climate change and human activities on runoff in rivers. Therefore, the relationships among precipitation, evaporation, and runoff need to be addressed.

In this paper, the trends of total precipitation, evaporation, and runoff in NWC are analyzed during 1979-2018. Moreover, the spatial distribution of given variables is compared and the correlation between them is assessed. The data were provided by ERA-Interim dataset of European Centre for Medium-Range Weather Forecasts (ECMWF). The nonlinear regression model was adopted to assess the trend rate. Then Mann-Kendall-Sneyers sequential test was employed to carry out significance detection of the trends, followed by future trend calculated by R/S analysis method.

2 MATERIALS AND METHODS

2.1 Study area

As shown in Figure 1, the arid region of northwest China, (34° ~ 50° N, 73° ~ 108° E), includes Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region, Gansu Province, and Xinjiang Uygur Autonomous Region. The endorheic drainage basins in this region cover the area of 2.53×10^6 km^2, and they are composed of Qaidam Basin, Tarim Basin, Heihe Basin, etc. (Liu et al., 2010). Since the studied area is under control of arid conditions of inner-continent and has a long distance to the surrounding oceans, this region has a typical arid inner-continental climate, characterized by a wide temperature range, low humidity, and low precipitation.

Daily total precipitation, evaporation, and runoff data covering the study area were provided by ERA-Interim dataset of European Centre for Medium-Range Weather Forecasts (ECMWF). ERA-Interim is a global atmospheric reanalysis on a $0.75^\circ \times 0.75^\circ$ grid from 1979, continuously updated in real time. This paper adopted the data from 1981-2016. Such a long-term data is sufficient enough to obtain relatively reliable analysis results from a statistical point of view.

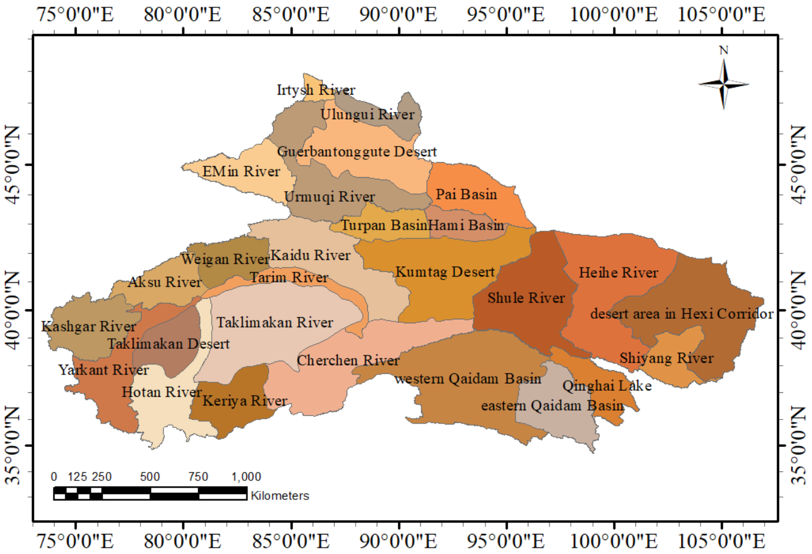


Figure 1. The location of northwestern China.

2.2 Methods

2.2.1 Nonlinear Regression Model

The nonlinear regression model was used to calculate the climate trend rate and to determine the climate change trend. To employ given model, the data as a time series X_1, X_2, X_3, X_4,⋯⋯, X_n was used. These data can be expressed by a polynomial as follows:

$$x_t = a_0 + a_1 t + a_2 t^2 + \ldots + a_p t^p \qquad [1]$$

where t (year) is time. a_0, a_1, a_2, a_3, a_4,⋯⋯, a_p are determined by least squares method or orthogonal polynomial, and a_1 is the linear tendency rate.

2.2.2 Mann Kendall test

The Mann-Kendall test (Mann, 1945; Kendall,1975) has been widely used in hydrological and climatological data analysis to detect the monotonic trend as well as the step (shift) change points. The strength of this method is its good application for biased variables by ignoring the influences of the outliers. Following the method of Gerstengarbe and Werner (1999), for a sample X_i, the null hypothesis is that the sample under studying shows no beginning of developing trend, and a rank series S_K of the progressive and retrograde rows of this sample is constructed as:

$$S_K = \sum_{i=1}^{k} r_i, k = 2,3,...,n \tag{2}$$

where

$$r_i = \begin{cases} 1, X_i > X_j \\ 0, X_i \le X_j \end{cases}, 1 \le j \le i \tag{3}$$

Then the statistic is defined as

$$UF_k = \frac{S_k - E(S_k)}{\sqrt{\mathrm{var}(S_k)}}, k = 1,2,...,n \tag{4}$$

where UF_1=0, E (S_k) and var (S_k) are the mean and variance of the rank series S_k, respectively, which can be calculated by:

$$E(S_k) = \frac{k(k-1)}{4} \tag{5}$$

$$\mathrm{var}(S_k) = \frac{k(k-1)(2k+5)}{72} \tag{6}$$

then repeat the calculation above with the sample X_i in reserve time order and make:

$$\begin{aligned} &UB_i = -UF_i (i = n, n-1, ..., 1) \\ &UB_1 = 0 \end{aligned} \tag{7}$$

In this paper, the significant level is given as 0.05, thus the thresholds of *UF* and *UB* are ± 1.96. If *UF*>0, the sequence X_i shows an upward trend and the sequence illustrates a downward trend when *UF*<0.The trend is significant when absolute value of *UF* exceeds 1.96. If the sequence of *UF* and *UB* have intersections within the significance level interval, the time order of the intersections are the points of step change.

2.2.3 R/S Analysis Method

R/S analysis is a method proposed by Hurst based on a large number of empirical studies (Feng et al., 2008; Peng J et al., 2012). It can distinguish a random sequence from a non-random sequence and can explore the long-term memory process of nonlinear systems. The Hurst index in R/S analysis was used to reveal the trend component in the time series, and to judge the persistence of the trend component or the magnitude of the anti-persistence intensity. Table 1 presents the classification of the Hurst index. Persistence and anti-persistence strength are divided into five levels from weak to strong in which the persistence strength is expressed in the order of 1 to 5, and the anti-persistence strength is expressed in the order of -1 to -5.

Table 1. Classification of Hurst index

Grade	Hurst index scale	Persistence strength	Grade	Hurst index scale	Anti-persistence strength
1	0.5<H<0.55	Very weak	-1	0.45<H<0.55	Very weak
2	0.55<H<0.65	Relatively weak	-2	0.35<H<0.45	Relatively weak
3	0.65<H<0.75	Relatively strong	-3	0.25<H<0.35	Relatively strong
4	0.75<H<0.80	Strong	-4	0.20<H<0.25	Strong
5	0.80<H<1.00	Very strong	-5	0.00<H<0.20	Very strong

3 ANALYSIS AND RESULTS

3.1 Step change detection and trend analysis of variables

Figure 2 illustrates the annual time series of total precipitation, evaporation, and runoff in NWC from 1979 to 2018. The linear trends are also given to show the monotonous changes of the parameters. For all of these time series of the total precipitation, evaporation, and runoff in NWC, the abrupt change was identified in 2004 at the significance level 0.05. Accordingly, the increasing trend for investigated variables was more pronounced after 2004 compared with that of before 2004. During 1979-2004, the rising rate of total precipitation, evaporation, and runoff were $4.7(\mathrm{mm \cdot a^{-1}})/10a$, $1.8(\mathrm{mm \cdot a^{-1}})/10a$, and $1.7(\mathrm{mm \cdot a^{-1}})/10a$, resprctively. During 2004-2018, total precipitation, evaporation, and runoff increased at the rate of 36 $(\mathrm{mm \cdot a^{-1}})/10a$, $24(\mathrm{mm \cdot a^{-1}})/10a$ and $8(\mathrm{mm \cdot a^{-1}})/10a$, resprctively.

Table 2 displays the average value and Hurst index of precipitation, evaporation, and runoff in NWC after the step change in 2004. It can be found that precipitation, evaporation, and runoff in NWC are likely to keep the positive tendency in the future since all the Hurst indexes of these elements are larger than 0.5.

Table 2. Average value and Hurst index of precipitation, evaporation, and runoff in NWC (2004~2018).

	Precipitation	Evaporation	Runoff
Multi-year average	172.3 mm/a	167.8mm/a	39.3mm/a
Hurst index	0.92	0.94	0.98
Persistence strength	Quite Strong	Quite Strong	Quite Strong

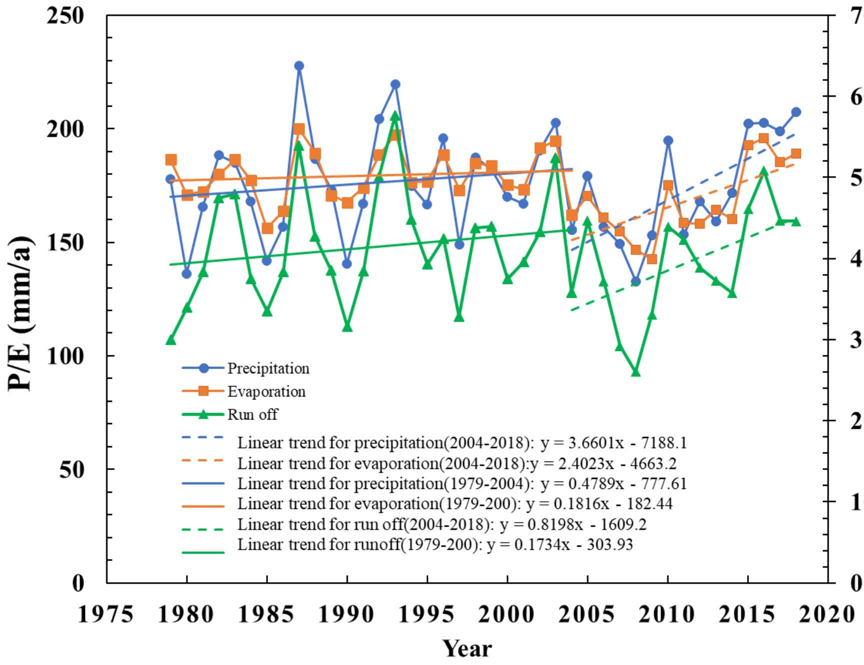


Figure 2. The inter-annual changes of precipitation, evaporation, and runoff in NWC (1979~2018).

3.2 Spatial distribution of the variables

Figure 3 exhibits the spatial distribution of the multi-year average of precipitation, evaporation, and runoff in NWC from 1979 to 2018. As seen, all of the three variables are unevenly distributed in the study area. More precipitation was found in the area near the south and west boundaries of Xinjiang, especially at Qinghai and Gansu province. Similar spatial distributions were observed for the evaporation and runoff. However, in the north of Xinjiang, the west of Inner Mongolia and nearly the whole Gansu province, the precipitation, evaporation, and runoff are less than that of the other areas. The range of the precipitation, evaporation and run off are 100-800 mm/a, 100-500 mm/a and 50-300 mm/a, respectively.

3.3 Correlation between precipitation, evaporation, and runoff

Figure 3 shows the correlation between precipitation, evaporation, and runoff. Surprisingly, both of the correlation coefficients of runoff and precipitation and the correlation coefficients of runoff and evaporation are 0.876. With the annual increase of precipitation or evaporation, the runoff will have a positive tendency. Since the runoff represents a good correlation with precipitation and evaporation, regression analysis can be used to establish a runoff prediction model to predict future runoff.

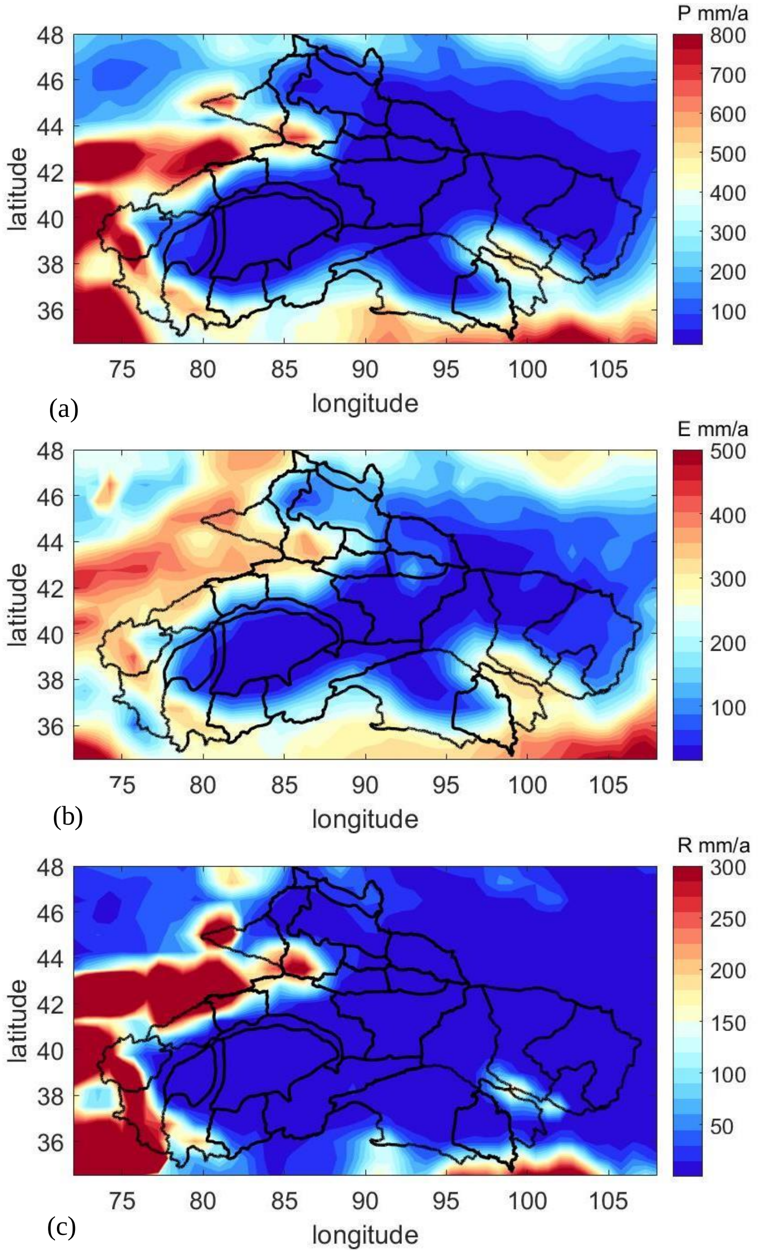
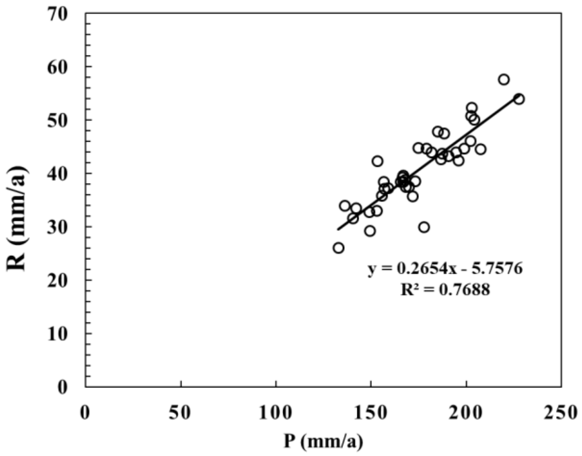
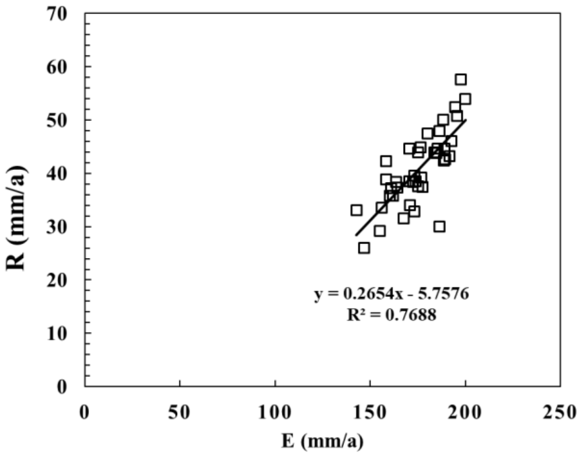


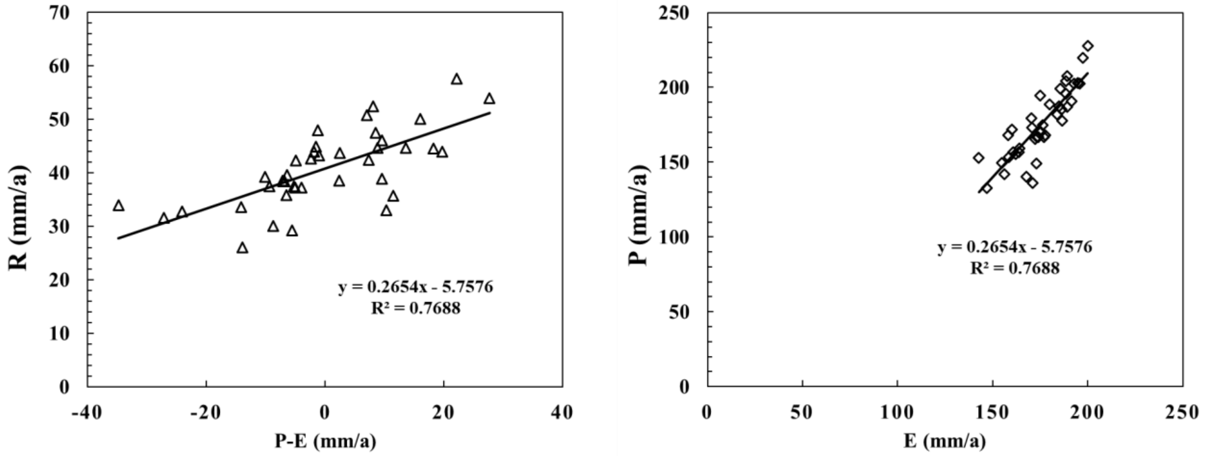
Figure 3. The distribution of multi-year average of (a) precipitation, (b) evaporation, and (c) runoff in NWC during 1979 to 2018



a. Runoff & Precipitation



b. Runoff & Evaporation



c. Runoff & Precipitation-Evaporation **d.** Precipitation & Evaporation

Figure 4. Correlation between (a) runoff and precipitation, (b) runoff and evaporation, (c) runoff and precipitation-evaporation, and (d) precipitation and evaporation in NWC during 1979 to 2018

4 CONCLUSIONS

This paper studied the change of water sources of NWC between 1979 to 2018. The trends of precipitation, evaporation, and runoff were analyzed using the averaged observed data. The distribution of the given parameters was further discussed. In the following, the correlation between precipitation, evaporation, and runoff was investigated. The results of the present study are as follows.

(1) A noticeable change was observed for precipitation, evaporation, and runoff in 2004. The results indicated that after 2004 the increasing trends for the investigated parameters were much higher than before 2004.

(2) There was more precipitation at the south and west boundaries of Xinjiang, which was quite similar to the spatial behavior of precipitation and evaporation.

(3) The runoff represented a good correlation with precipitation and evaporation so regression analysis can be used to establish a runoff prediction model to predict future runoff.

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REFERENCES

Boehmer K, Memon A, Mitchell B. (2000). Towards sustainable water management in Southeast Asia experiences from Indonesia and Malaysia. Water International, 25(3): 356–377.

Chen Y N, Li W H, Xu C C et al. (2007). Effects of climate change on water resources in Tarim River Basin, Northwest China. Journal of Environmental Sciences-China, 19(4): 488–493.

Chen, Y. (2014). Water resources research in northwest china.

Feng X. L., Luo L.C., Qiu L. L., Liu P., & Feng Z.L. (2008). Fractal analysis of climate change and hurst index experiment in tibetan plateau in future. Arid Land Geography, 31(2), 175-181.

Gerstengarbe, F., Werner, P. (1999). Estimation of the beginning and end of recurrent events within a climate regime. Climate Research. 11, 97–107.

Kendall M G.(1975). Rank-Correlation Measures. London:Charles Griffin, 202.

Liu C, Chen Y, Xu Z. (2010). Eco-hydrology and sustainable development in the arid regions of China Preface. Hydrological Processes, 24(2): 127–128.

Mann H B(1945). Non-parametric tests against trend. Econometrica,13(3): 245–259.

Peng, J. , Liu, Z. , Liu, Y. , Wu, J. , & Han, Y. . (2012). Trend analysis of vegetation dynamics in qinghai–tibet plateau using hurst exponent. Ecological Indicators, 14(1), 0-39.

Qin, J., Liu, Y. , Chang, Y. , Liu, S. , Pu, H. , & Zhou, J. . (2016). Regional runoff variation and its response to climate change and human activities in northwest china. Environmental Earth Sciences, 75(20), 1366.

Shi Y, Shen Y, Kang E, Li D, Ding Y, & Zhang G, et al. (2007). Recent and future climate change in northwest china. Climatic Change, 80(3-4), 379-393.

Sun L D, Zhang G J, Zhao H Y, & Lin J J, et al. (2013). Features of climate change in northwest china during 1961–2010. Advances in Climate Change Research, 4(1), 12-19.

Wang, H., Chen, Y., Li, W., & Deng, H. (2013). Runoff responses to climate change in arid region of northwestern china during 1960-2010. Chinese Geographical Science, 23(3).

Wang Yu-Jie[1, 2., & Da-He[3], Q. . (2017). Influence of climate change and human activity on water resources in arid region of northwest china: an overview.

Zhang, Q., Hu, Y.Q., Cao, X.Y., et al., (2000). On some problems of arid climate system of Northwest China. J. Desert Res. 20 (4), 13-18.