On the Suitability of Non-Parametric Tests for Detection of Trends in Brazilian Rivers

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Abstract

The non-parametric test of Mann-Kendall is used to determine whether there is, or not, an statistically significant trend in the series and as an indication of the general direction of the change. The Mann-Kendall statistic demands statistical independence of the series. Since the year-to-year correlation of streamflow in a given year with the same streamflow of the previous or subsequent year is usually quite low, the test has been widely applied in climatic and hydrologic data. However, it has been found that for regions with large basin-memory such as the Amazon basin or Pantanal, or under intense use of water for irrigation or electricity generation such as the São Francisco River basin, this test may be misleading due to a large serial autocorrelation of river data.

1 Introduction

In this paper, we used streamflow records of the main basins of Brazil: the Amazon, Tocantins, São Francisco, Paraná, Uruguay and the South Atlantic to explore the long-term variability of the hydrology since the beginning of the century. To assess the direction and the significance of the trends, the statistical test of Mann-Kendall (MK) was applied to the time series.

Lettenmaier et al. (1994) studied streamflow trends in rivers in the United States, and found larger positive trends in the period November-April especially in north and central parts. Many of these trends were not entirely consistent with the changes in climatic variables and may be due to a combination of climatic and water management effects. Marengo (1995) has demonstrated that most of the rivers in the Northern coast of Peru, as well as the São Francisco in eastern Brazil exhibit significant trends towards drier conditions, while rivers and rainfall records from nearby regions such Northeast Brazil or western Amazonia did not show any significant unidirectional trend. It is not clear whether the negative trends in river streamflow in the above mentioned regions are associated with drier conditions due to a regional climate change, or with anthropogenic effects that artificially may affect the hydrological series.

Complementary to river data analysis, rainfall in Amazonia has been the subject of several investigations (Marengo and Uvo 1996; Dias de Paiva and Clarke 1995; Chu et al. 1994; Marengo 1992; Gentry and López-Parodi 1980). Gentry and López-Parodi and Chu have investigated rainfall, river records and convection and have found periods (1962-78 and 1971-92) that have been characterized by high Amazon River levels at Iquitos and increased convection and rainfall in Northwest Amazonia. However, these are short periods that in the context of a long range time scales would look like part of a low-frequency variation, meaning the upward or downward tendencies part of the natural climate variability, rather than effect of climate change.

2 Objectives

It is proposed in this research an assessment of the suitability of the test of MK for trend analysis in the using river and rainfall data from the beginning of the century. Based on our preliminary results, we want to be sure if: (1) the trends detected in these regions by the MK test are real or not; (2) be able to identify regions where the river records show a large serial correlation in time, violating the theoretical assumptions of the test.

3 River data and Processing

Seasonal discharges used in this study were extracted from the archives of ELETROBRAS, ELETRONORTE, and the Departamento Nacional de Águas e Energia Elétrica (DNAEE). Rainfall data were extracted from the archives of CPTEC. To examine the long-term mean trends in the hydrometeorological data, annual seasonal discharge and rainfall have been calculated for all the times series. The seasons are defined as the 3-months peak rainfall or streamflow. Once the tendencies or trends have been identified, the direction and magnitude of the trends have been analyzed using the non-parametric test of MK (Press et al. 1989). This test has been widely applied in the detection of trends and in the assessment of its significance in river data and rainfall (Marengo 1995, Chu et al. 1994, Lettenmaier et al. 1994, Chiew and MacMahon 1993).

The MK test introduces a rank statistics, τ, that involves ranking and counting of each individual number, relative to others in a raw unranked series (Chu et al., 1994). A negative estimate of τ implies a decrease of a variable with time. In principle, this method is non-linear and based on ranks, so that results are more robust to the start and end of data than the regression analysis (Press et al. 1989). Discussions of this method and its advantages compared to other variations of the same method can be found in Marengo (1995) and Leternamier et al. (1994).

4 Trends in River Data in Brazil

According to the MK test, and the test of significance for the regression line, the time series of the Rio Negro at Manaus, the Paraná River at Posadas (Fig. 1a,1c)., Guaira and Corrientes, the Tocantins River at Tucurui, the Xingu River at Belo Monte, and the São Francisco at Sobradinho do not show any significant trend towards drier or wetter. This agrees with the analysis of rainfall in the middle and upper basins of those rivers. Therefore, it seems not to be signs of any systematic change of the components of the hydrological cycle, particularly in Amazonia where deforestation was thought as a possible cause for a potential regional climate change.

Other rivers, such as the Paraiba do Sul at Resende, Guaratinguetá and Campos, the Parnaiba at Boa Esperança (Fig. 1e,1f); the Paraguay at Asunción as well as the São Francisco at Juazeiro, show trends towards drier or wetter conditions. However these results do not seem to be supported by rainfall analysis at the upper and middle basins. Therefore, the possibility that they are due to climate change are very remote, and are more likely to be a consequence of water management.

5 Discussions of Trends, Are They Real?

The MK test has been applied for detecting trends in river/rainfall data as an indication of a possible climatic change. Our results indicate that for some basins in Brazil this test seems to have no problems (where no trend is noticed), but when a trend is detected, there is a reason for concern if that trend is real. The MK test assumes that the correlation between annual subsequent discharges is very low. However, there may be other factors that can make this assumption not realistic and make the serial correlation a real problem, at least for some basins.

In very large drainage basin, such as the Amazon, large serial correlation may affect the MK test. The serial correlation arises because of the enormous storage capacity within the basin, so that streamflow and water level records have a long memory (basin-memory effect). Another hypotheses raised up by Hodnett et al. (1996) is based in the ABRACOS soil storage observation in Marabá. The record showed that an extended dry year could affect the soil water replenishment in the subsequent dry season. Since the river streamflow in tropical areas is dominated by baseflow, a prolonged dry season might affect the groundwater discharge to the river in the next year. In Manaus, where the dry season is mild, this effect may be negligible.

It is important to notice that an increasing or decreasing trend in mean wet-season streamflow can be explained by man-made influences. Increase storage or increased water-loss for irrigation can explain observed trends, and a possible large serial correlation in those cases may also affect the MK test. On the other hand, for rainfall, deviations about mean values generally show very little serial correlation, not affecting the MK test. Thus, the MK was applied to rainfall data to confirm or not conclusions from the MK test applied to river series.

In this regard, coefficients of autocorrelation have been calculated for 4 river basins: the Negro River at Manaus, the Paraná River at Posadas, the Parnaiba River at Boa Esperança, and the Paraiba do Sul River at Guaratinguetá (Fig 1b,1d,1f,1h). It is shown that both the Manaus and Posadas series do not shown trend, and even though they have very large collecting basins, the correlation between streamflow/levels of two consecutive years is very low, making the MK test suitable for trend analysis in this basins. The Parnaiba shows a positive trend significant at 95% level, however, the autocorrelogram shows that the year-to-year correlation is very large, making the MK test not suitable for this basin. The same test was applied to rainfall in the upper basin of the Parnaiba, and shows no trends in the rainfall regime. For the Paraiba do Sul, the presence of negative trends, significant at 99% level, is not supported by the similar trends in the rainfall regime either, and there is a very large correlation between streamflow of consecutive years. Similar behavior was observed at other gauging sites along the same river.

6 Summary and Discussions

From the analysis of trends using the MK test, for both streamflow/level and for rainfall in the upper basin on several rivers in Brazil, it has been shown that this test may be not suitable for regions under intensive use of water and/or water managment or with large basin-memory. At least, it should not be applied to river data alone in a basin. If the null hypothesis in the MK test is rejected there are two possible interpretations: (1) there is a trend, (2) there is a failure in the null hypothesis, such as the assumption of no serial correlation. In cases where there is a substantial serial correlation, it seems incorrect to conclude that (1) is the explanation. For those basins, what we may need is a different test than MK. One way to solve this problem, we think, is that we can apply the MK test to rainfall records in the upper and middle basins to confirm the trends shown by the river data. At the end, it still will be difficult to explain a trend in rain and streamflow as due to a regional climate change.

7 References

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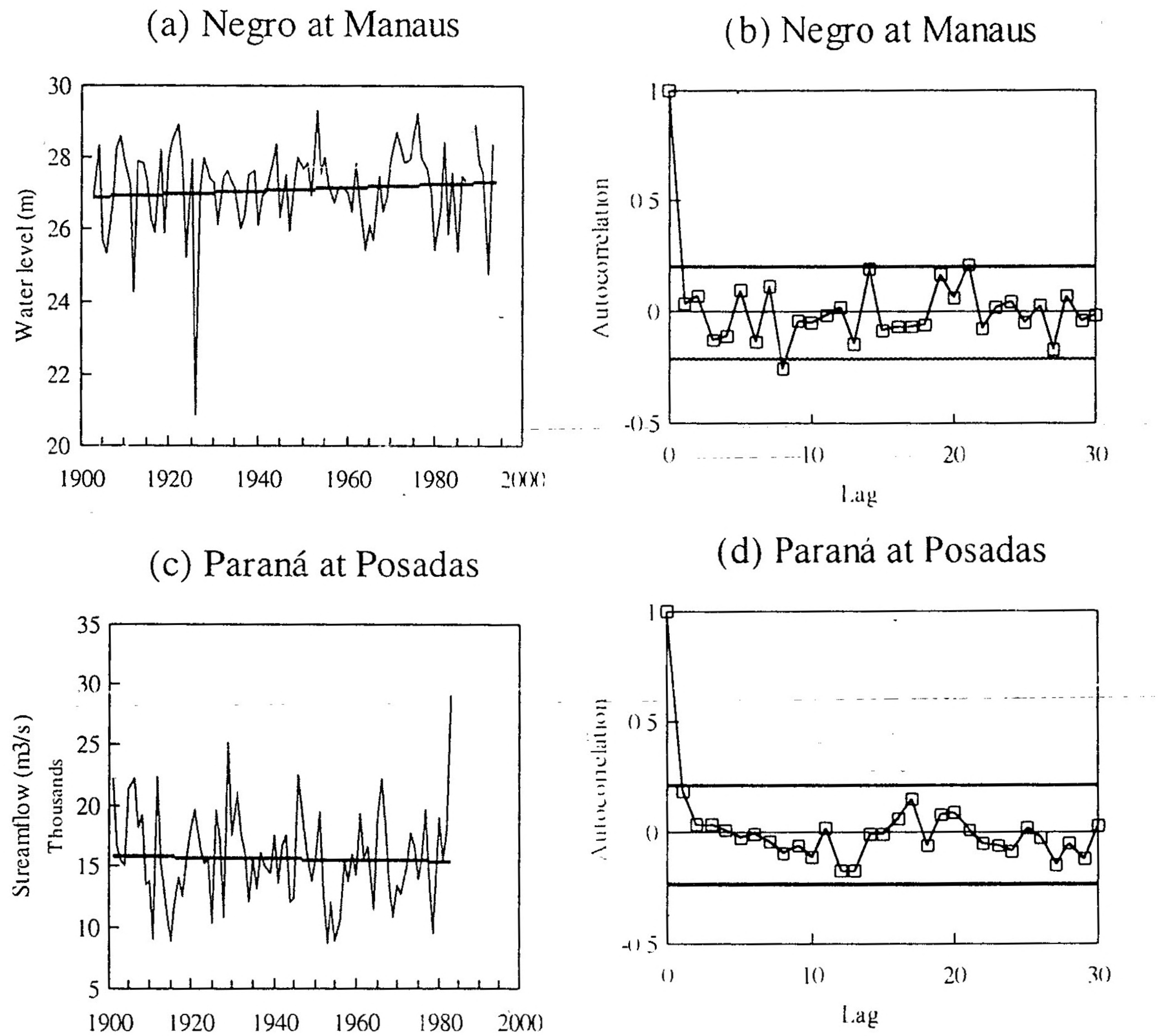

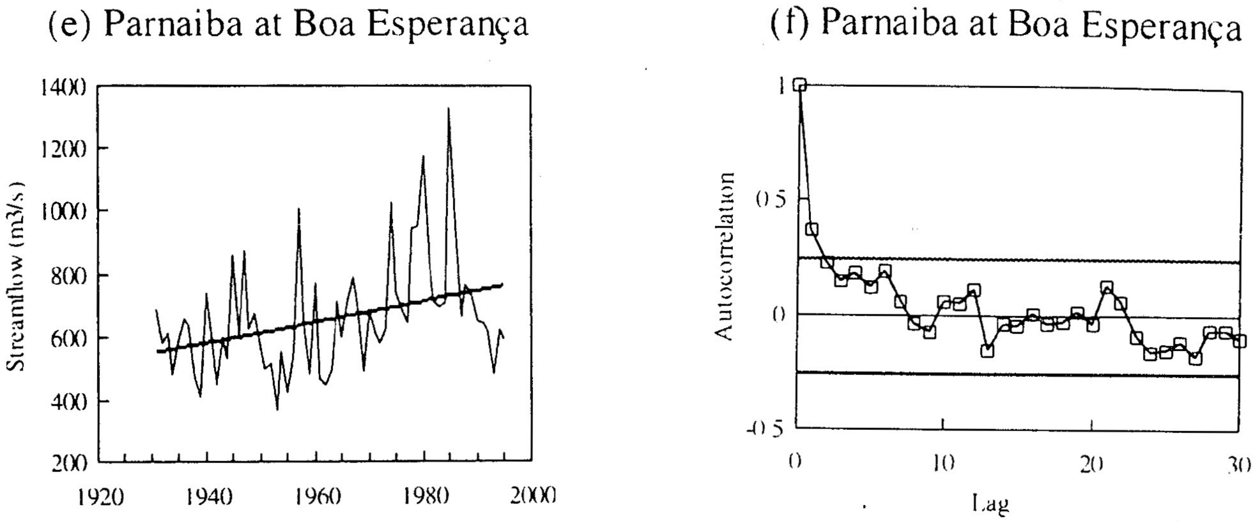

Figura 1: Trends and autocorrelations in different Brazilian basins

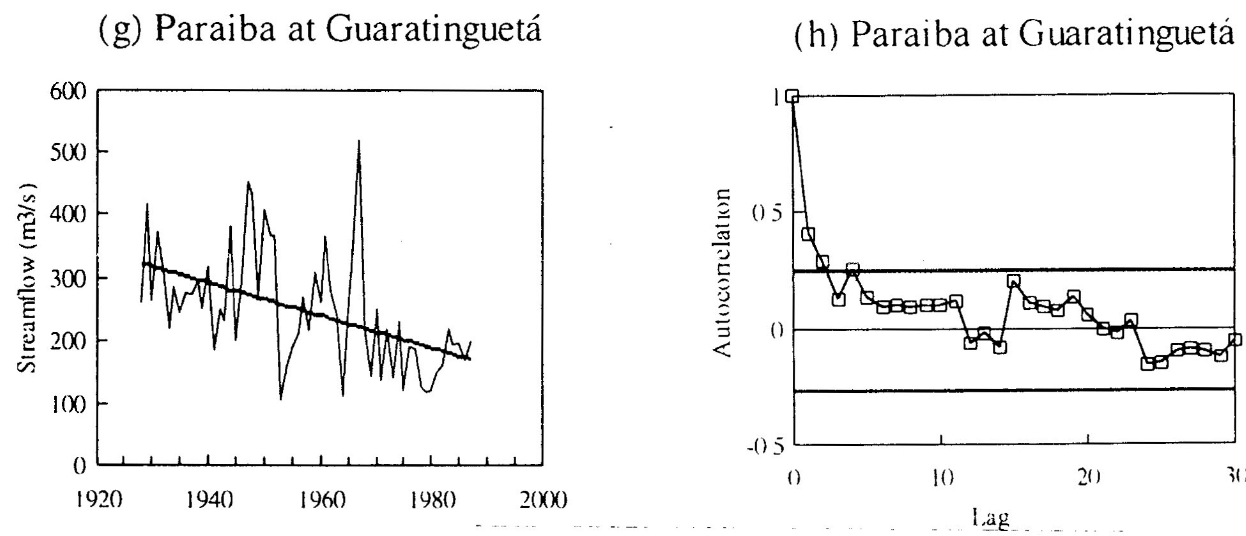

Figure 1 (cont): trends and autocorrelation in different Brazilian basins.