Author

First Name	Middle Name	Surname	Role	Email
Eloiza Maria	Cauduro Dias	Paiva	No	eloiza@ct.ufsm.br

Affiliation

Organization	Address	Country
Depto. Engenharia Sanitária e Ambiental, Universidade Federal de Santa Maria	Av. Roraima, 1000, Camobi, 97105-900, Santa Maria, RS	Brazil

Author

First Name	Middle Name	Surname	Role	Email
Conrad	D.	Heatwole	Yes	heatwole@vt.edu

Affiliation

Organization	Address	Country
Center for Watershed Studies, Biological Systems Engineering, Virginia Tech	301 Seitz Hall, Blacksburg, VA, 24061-0303	United States

Author

First Name	Middle Name	Surname	Role	Email
João Batista	Dias de	Paiva	No	paiva@ct.ufsm.br

Affiliation

Organization	Address	Country
Depto. Engenharia Sanitária e	Av. Roraima, 1000, Camobi,	Brazil

Ambiental, Universidade Federal de Santa Maria	97105-900, Santa Maria, RS	

Author

First Name	Middle Name	Surname	Role	Email
Rodrigo	C.D.	Paiva	No	rodrigocdpaiva@gmail.com

Affiliation

Organization	Address	Country
Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul	Av. Bento Gonçalves, 9500, 91501-970 Porto Alegre RS Caixa postal: 15029	Brazil

Author

First Name	Middle Name	Surname	Role	Email
Fábio	Alex	Beling	No	fabiobeling@gmail.com

Affiliation

Organization	Address	Country
Programa de Pós-Graduação em Engenharia Civil, Universidade Federal de Santa Maria	Av. Roraima, 1000, Camobi, 97105-900, Santa Maria, RS	Brazil

Publication Information

Pub ID	Pub Date
staff will complete	name of conference

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Conference Presentation

Paper Number: ASABE staff will complete

Trends in streamflow in the Ibicuí river basin - influence of rice crop irrigation

Eloiza Maria Cauduro Dias de Paiva

DESA-UFSM / CAPES (BEX 0695/11-4), Santa Maria, RS, Brazil, eloiza@ct.ufsm.br.

Conrad D. Heatwole

BSE, Virginia Tech, Blacksburg, VA, USA, heatwole@vt.edu.

João Batista Dias de Paiva

DESA-UFSM / CAPES (BEX 0700/11-8), Santa Maria, RS, Brazil.

Rodrigo C. D. Paiva

IPH-UFRGS, Porto Alegre, RS, Brazil.

Fábio A. Beling

PPGEC-UFSM, Santa Maria, RS, Brazil.

Watershed Technology Conference
ASABE
IRSA/CNR
Bari, Italy
May 27 – June 1, 2012

Abstract. *The Ibicuí basin, located in the south of Brazil, is close to 50,000 km^2 in drainage area. The basin has big problems with water deficits, attributed to the indiscriminate use of water to irrigate rice. The objective of this study is a statistical analysis of water flow data in the Ibicuí basin to verify if there are significant trends in water availability related to the withdrawal of water for rice crop irrigation. We used data from 11 fluviometric stations for 1970 to 2011, corresponding to the period of major growth in rice cultivation. Records of daily flow data were normalized, then for each month, the flow at durations between 50% to 99% were calculated. Trends in these series were evaluated using the Mann-Kendall test. The results showed that there are trends of increasing water flow for 8 of the 11 stations, and in 6 of those 8 stations the increasing trend was statistically significant. Just 3 stations had negative trends and these were in sub-basins with higher percentage area in rice. Analyzing the trends for several flow durations, it was observed that there was a reduction of the trends with duration. Also, in a river with sequential stations, the significance of trends as reflected by the Mann-Kendall Z_s decreased with irrigated area. We conclude that for the Ibicuí Basin analysis of trends in the flow data does not clearly reflect the effect of water withdrawals for irrigation of rice.*

Keywords. Statistical analysis, Mann-Kendall test, rice irrigation, flow duration, water withdrawal

Introduction

The expansion of agricultural land is widely recognized as one of the most significant human alterations to the global environment (Matson et al., 1997). According to Sacks et al. (2008), global patterns of irrigation alter the climate significantly in some large regions of the planet. About 2% of annual precipitation over land is used for irrigation.

Brazil has a large agricultural sector. It is the third largest exporter of agricultural products and it is the ninth largest producer of rice in the world. The State of Rio Grande do Sul accounts for 63% of the national production of rice. The Ibicuí river basin is among the largest rice producing areas of the world (RS-DRH, 2010). One of the important environmental problems in the state of Rio Grande do Sul is the significant water withdrawal for rice irrigation and the resulting conflicts with other water uses (FEPAM, 2011). Paiva et al. (2000) found that 89% of the total consumptive use of water in the Ibicuí river basin is for rice irrigation.

The influence of irrigation withdrawals on water availability for other uses is an obvious concern in a situation of a limited resource. The influence of irrigation on the ecosystem in a more indirect way and on a broader scale has also been shown. Kustu et al. (2010; 2011) and DeAngelis et al. (2010) analyzed precipitation, evapotranspiration, streamflow, soil moisture and water table depth and found evidence that higher rates of evapotranspiration associated with irrigation in the U.S. High Plains have likely caused increased downwind precipitation.

Assessing trends in hydrologic time series data is often of great interest, but it is challenging due to the variability in the data. The Mann-Kendall statistic is frequently used for trend analysis. It is a nonparametric statistic so avoids some assumptions about the data, and despite some weaknesses of the method, is widely used for preliminary analyses (Clarke, 2010).

The objective of this study is to determine if there are trends in flow data in the Ibicuí River Basin that would reflect a decline in water availability concurrent with the increasing withdrawals for rice irrigation over the past 4 decades. The approach is to analyze flow data from multiple gages in the basin which have different fractions of area in rice cultivation in the subbasins. In addition to the flow data, we also analyze rainfall data to identify any trends in this input.

The Ibicuí Basin

The Ibicuí basin is located in the southwest of the state of Rio Grande do Sul, and has a drainage area around 47,740 km^2 (Fig. 1). It is part of the Uruguay basin, and is characteristic of the Pampa biome. The Brazilian Pampa lies within the South Temperate Zone where grasslands scattered with shrubs and trees are the dominant vegetation. The soil, originating from sedimentary rocks, often has an extremely sandy texture that makes them highly prone to water and wind erosion (Roesch et al., 2009).

The land use of the basin shown in figure 2 was derived from 1999 Landsat imagery, and the percentage of area in different classes is given in Table 1. In this region, since 1950, there has been increasing area devoted to rice cultivation. Data from 1950 to 2010 (IRGA, 1988; 2012) shows this expansion for the municipalities that make up the basin (Fig. 3).

Eleven stage stations in the basin which have data from1970 to the present are shown in figure 3 along with the subbasin boundary. Table 2 presents the percentage of rice in 1999 for each sub-basin.

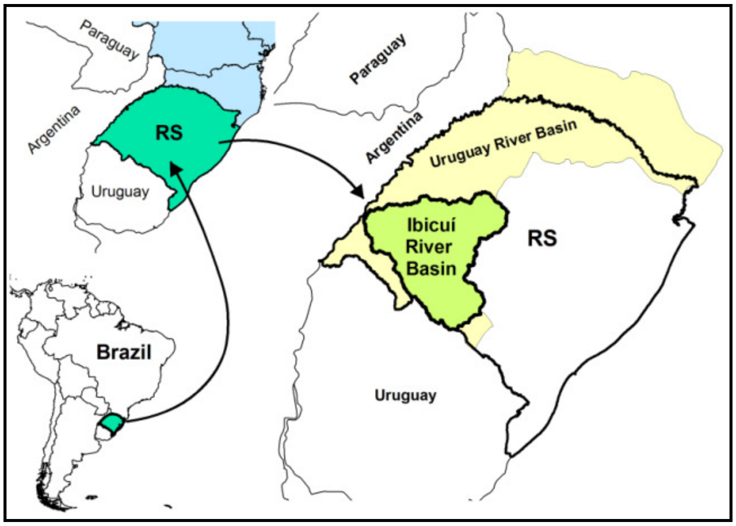

Figure 1. Location of the Ibicuí Basin.

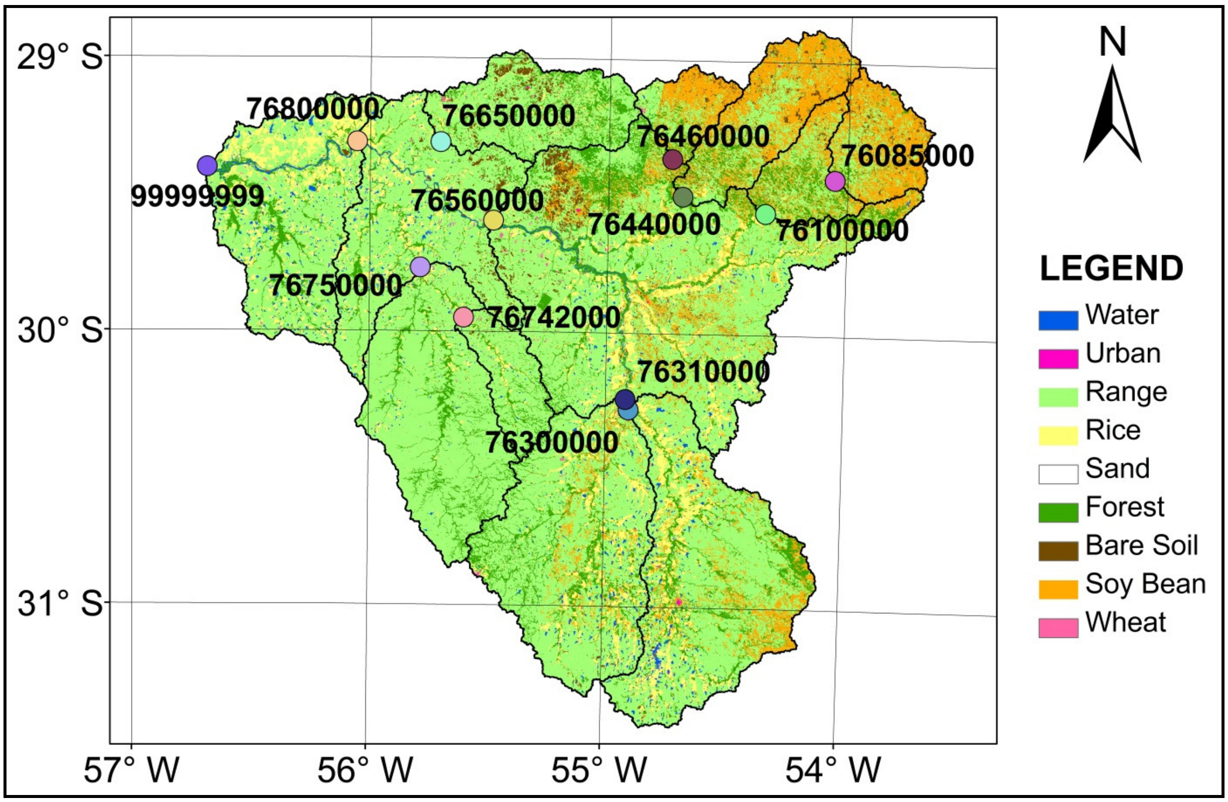

Figure 2. Ibicuí Basin land use, and location of stage stations and subbasins.

Table 1. Land use in the Ibicuí basin (classification of 1999 Landsat image).

Land cover	Percentage	Land cover	Percentage	Land cover	Percentage
Water	1.68	Sand	0.04	Bare soil	2.18
Urban	0.11	Forest	11.43	Soy bean	11.34
Range	62.27	Rice	10.76	Wheat	0.20

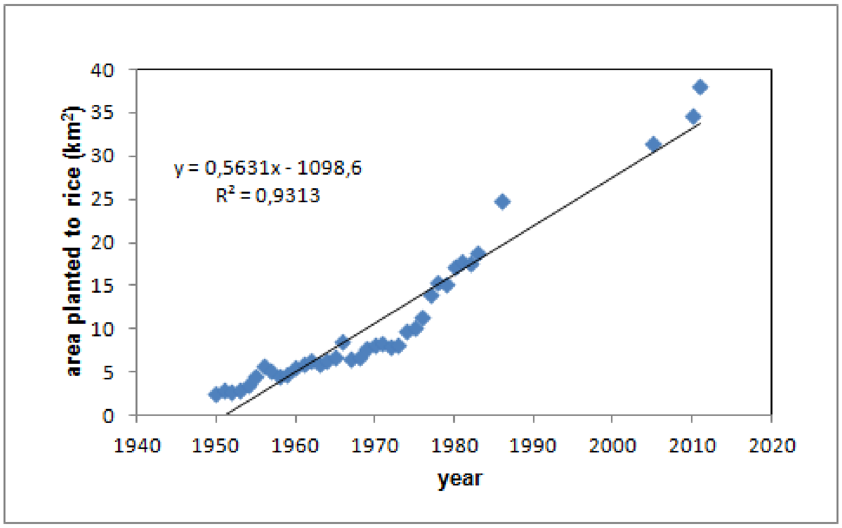

Figure 3. Expansion of rice culture in the Ibicuí basin.

Table 2. Stage stations and percentage of subbasin area in rice cultivation.

code	name	latitude	longitude	start	end	area (Km^2)	% rice in 1999
Toropi River							
76085000	Cachoeira 5 Veados	-29º25'44"	-54º03'15"	1976	2011	1541	0.04%
76100000	Vila Clara	-29º33'21"	-54º20'31"	1941	2011	2798	0.42%
Santa Maria River							
76300000	Ponte Ibicui Da Armada	-30º16'50"	-54º54'11"	1967	2011	6007	11.74%
76310000	Rosário Do Sul	-30º14'34"	-54º55'00"	1967	2011	12014	11.74%
Jaguari River							
76440000	Jaguari	-29º29'56"	-54º41'21"	1941	2011	2330	0.78%
76460000	Ernesto Alves	-29º21'45"	-54º44'07"	1958	2011	930	1.86%
Ibirapuitã River							
76742000	Passo Do Osório	-29º57'01"	-55º36'09"	1977	2011	1163	5.93%
76750000	Alegrete	-29º46'06"	-55º47'13"	1940	2011	5940	3.84%
Itú River							
76650000	Passo Da Cachoeira	-29º18'33"	-55º42'20"	1962	2011	2561	7.86%
Ibicuí River							
76560000	Manoel Viana	-29º35'39"	-55º28'53"	1967	2011	29393	9.83%
76800000	Passo Mariano Pinto	-29º18'33"	-56º03'16"	1955	2011	42574	9.32%
River Ibicuí Outlet						47119	10.76%

Methods

Eleven fluviometric stations that have data covering the period of increasing rice cultivation from 1970 to 2011 were identified in the basin (figure 2; table 2). Daily data for the observed period were retrieved from the ANA website (ANA, 2011). The daily flow values were normalized by reducing each daily flow by the average daily flow of the month and dividing by the standard deviation. Two different data series were analyzed, one with all months of the year, and the other having only the four months corresponding to the rice irrigation season (November -- February). The flow at durations between 50% to 99% were calculated for each month. The assumption of independence was tested according to Wilks (2006). From the series we analyzed for trends using the Mann-Kendall test and linear regression. The linear regression results are not presented because they are very similar to the Mann-Kendall test results which are presented here.

We identified 27 rain gages in the basin with records covering the period of flow data, and analyzed the data to determine if there were trends in rainfall over this same period. Monthly rainfall was normalized similar to the flow data and the presence of trends was evaluated using the Mann-Kendall test for the four months corresponding to the rice irrigation season (Nov-Feb).

The Mann-Kendall test can be applied to a sample of data ($x_1, x_2, \ldots, x_n$) of *n* independent and identically distributed random variables (Douglas et al., 2000; Kustu et al., 2010). The test first ranks the entire observations according to time, and then successively compares each data value to all data values following in time by evaluating the Mann–Kendall test statistic, Z_s, as:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}(x_j-x_i) \qquad (1)$$

Where x_i and x_j are the sequential data values, n is the number of observations, and sgn( ) = 1, if $x_j - x_i > 0$, sng( ) = 0, if $x_j - x_i = 0$ and sgn( ) = -1, if $x_j - x_i < 0$.

$$E(S) = 0 \qquad (2)$$

$$Var(S)=\frac{n.(n-1).(2.n+5)}{18}=\sigma^2 \qquad (3)$$

For n larger than 10, the test statistic Z_s:

$$\begin{aligned} Z_s &= (S-1)/\sigma && \text{for } S>0 \\ Z_s &= (S+1)/\sigma && \text{for } S<0 \qquad (4) \\ Z_s &= 0 && \text{for } S=0 \end{aligned}$$

Hence, H_0 should not be rejected in a two-sided trend test if $|Z| \leq z_{\alpha/2}$ where α is the significance level. A positive value of Z_s indicates an upward trend, whereas a negative value indicates a decreasing trend.

Results

Table 3 presents the results of Mann-Kendall trend analysis for 11 gaging stations in Ibicuí basin. At the 90% flow duration for the 4-month data series corresponding to the irrigation season, the results show that only 3 stations had negative trends (i.e. decreasing flow) and these trends were not statistical significant (at α= 5%). The other 8 stations had trends of increasing water flow with results statistically significant (at α= 5%) for 6 of these 8 stations. This conclusion is surprising, because there are important deficits of water due to withdrawals for rice irrigation during the developing period of this crop. River discharge is low in the period of irrigation, from November to February, and there are studies with physical models that have verified the problem (Collischonn et al., 2011). Although a distinct trend in flow reduction has not been confirmed in this analysis, it can be seen that the subbasins with negative trends were the ones that have a higher percentage area in rice, specifically, the Santa Maria and Ibirapuitã sub basins. Analyzing the trend statistic across flow duration, it can be seen that there tends to be a decrease in the trend statistic with the decreasing duration of water flow although this pattern is not consistent.

From the analysis of the rainfall data, the map of the basin showing the Mann-Kendall Z_s value at the location of the 27 rain gauges can be seen in figure 4. Eighteen of the gages had negative trends (6 statistically significant) and 9 had positive trends (three statistically significant). For the period of rice irrigation, November to February, these trends were close to zero, with only one negative statistically significant trend and two positive statistically significant trends. Thus, analysis of this data does not indicate any clear trends in rainfall patterns, particularly in the rice irrigation season that would bias or confound the analysis of the flow data.

Water withdrawals for irrigation of rice in the region are commonly considered to be a source of low flows and water conflicts, yet the results of this trend analysis of flows at individual stations did not reflect the assumed impact of irrigation over the 4 decades of increasing rice cultivation. An analysis of relative changes is possible in the Toropi subbasin where there are two stations and the majority of rice cultivation occurs below the upstream station. While there is less than 1% of the basin area in rice, the downstream flow is sometimes less than the upstream flow. The data series of the difference between downstream (76100000) and upstream (76085000) stations was analyzed for trends and results are shown in figure 5. While the trend at both stations is increasing, the difference shows a decreasing trend, thus verifying the influence of rice irrigation when it is concentrated in the area close to the outlet of the sub-basin.

Conclusion

For the Ibicuí basin, trend analysis did not clearly show an influence of water withdrawals for rice irrigation on decreasing river flows. This result was surprising and contrary to common belief, and we suggest two possible explanations. It is possible that the analysis failed due to inadequate number and/or poor location of fluviometric stations to characterize effects of rice withdrawals, or due to limitations of the technique. However, it is also possible that this result is valid showing the common perceptions to be in error. River flows are historically low Nov-Feb, and this analysis shows that, in fact, withdrawals are not a significant influence on flow in light of the historical variability in flow. Further analysis is needed to confirm this result.

Table 3. Mann-Kendall Z_s values by station at different durations for full and partial data series.

	flow duration									
	all months							November to February		
code station	50%	60%	70%	80%	90%	95%	99%	90%	95%	99%
76085000	4.48*	4.85*	4.73*	4.98*	5.09*	4.34*	4.35*	2.34*	2.29*	2.30*
76100000	7.02*	7.30*	7.54*	7.75*	7.82*	7.76*	7.51*	5.88*	5.85*	5.87*
76300000	-0.48	-0.48	-0.65	-0.92	-1.20	-1.37	-1.58	-1.13	-1.32	-1.42
76310000	-1.02	-0.90	-0.75	-0.71	-0.95	-1.10	-1.19	-0.64	-0.69	-0.58
76440000	7.47*	7.36*	7.08*	6.75*	6.37*	5.89*	5.19*	5.18*	4.96*	4.40*
76460000	3.82*	4.21*	4.40*	4.50*	4.19*	3.88*	3.62*	4.49*	4.13*	3.81*
76742000	-1.59	-1.53	-1.36	-1.10	-1.01	-1.07	-1.08	-1.65	-1.77	-1.72
76750000	2.58*	2.45*	1.96*	1.66	1.39	1.08	0.85	0.85	0.55	0.34
76650000	5.60*	6.48*	7.04*	7.78*	8.39*	8.40*	8.33*	6.53*	6.61*	6.64*
76560000	1.38	1.38	1.30	1.37	1.22	1.02	0.95	0.59	0.57	0.68
76800000	2.66*	2.67*	2.77*	2.82*	2.31*	2.25*	2.12*	2.45*	2.67*	2.68*

* statistically significant at α= 5%

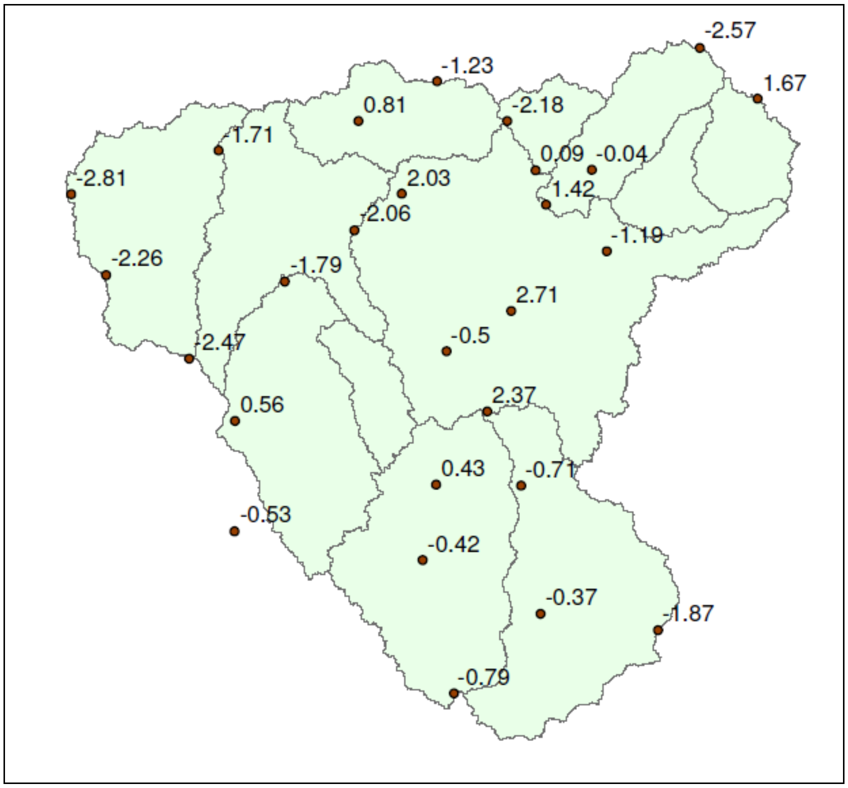

Figure 4. Location of rain gauge stations with Mann-Kendall Z_s for full year data.

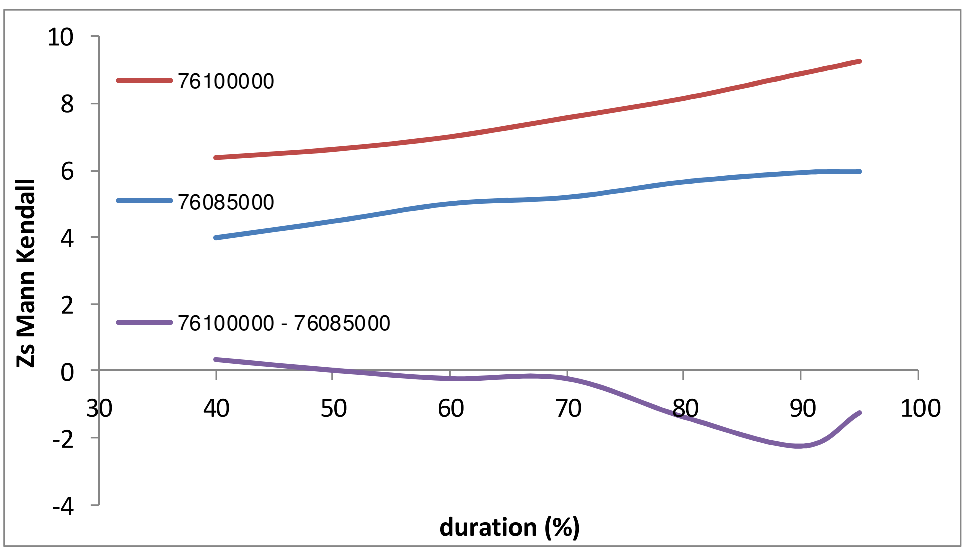

Figure 5. Mann-Kendall Z_s for Toropi sub-basin stations and the difference between them.

Acknowledgements

This research was supported by CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), UFSM (Universidade Federal de Santa Maria) and Virginia Agricultural Experiment Station (Hatch project S1042).

References

ANA. 2011. Agência Nacional de Águas - Dados hidrológicos - Séries históricas. Available at: http://hidroweb.ana.gov.br/HidroWeb.asp. Accessed Oct 15, 2011.

Clarke, R.T. 2010. On the (mis)use of statistical methods in hydro-climatological research. *Hydrological Sciences Journal* 55(2): 139-144.

Collischonn, B., R.C.D. Paiva, W. Collischonn, F.S.C. Meirelles, E.B.C. Schettini, and F.M. Fan. 2011. Modelagem Hidrológica de Uma Bacia com Uso Intensivo de Água: Caso do Rio Quaraí-RS. *Revista Brasileira de Recursos Hídricos.* 16(4): 119-134.

DeAngelis, A., F. Dominguez, Y. Fan, A. Robock, M.D. Kustu, and D. Robinson. 2010. Evidence of enhanced precipitation due to irrigation over the Great Plains of the United States. *Journal of Geophysical Research* 115, D15115, doi:10.1029/2010JD013892.

Douglas, E.M., R.M. Vogel, and C.N. Kroll. 2000. Trends in floods and low flows in the United States: impact of spatial correlation. *Journal of Hydrology* 240:90-105.

FEPAM. 2011. Fundação Estadual de Proteção Ambiental Henrique Luiz Roessler – RS. Available at: <http://www.fepam.rs.gov.br/qualidade/regiao_uruguai.asp>. Accessed 02 March 2011.

IRGA . 1988. Anuário Estatístico do Arroz. Porto Alegre: Instituto Rio Grandense do Arroz. *(19 bi-annual reports from 1952 to 1988).*

IRGA . 2012. Área, Produção e Produtividade – Relatório Final Municipal da Colheita do Arroz 2009/10 e 2010/11. Porto Alegre: Instituto Rio Grandense do Arroz. Available at http://www.irga.rs.gov.br/uploads/anexos/1329418135Area_Producao_e_Produtividade.pdf. Accessed January 2012.

Kustu, M.D., Y. Fan, and A. Robock. 2010. Large-scale water cycle perturbation due to irrigation pumping in the High Plains: A synthesis of observed streamflow changes. *Journal of Hydrology* 390:222-244.

Kustu, M.D., Y. Fan, and M. Rodell. 2011. Possible link between irrigation in the U.S. High Plains and increased summer streamflow in the Midwest. *Water Resources Research* 47:, W03522, doi:10.1029/2010WR010046.

Matson, P.A.; W.J. Parton; A.G. Power; and M.J. Swift. 1997. Agricultural intensification and ecosystem properties. *Science* 277:504-509.

Paiva, J.B.D., E.M.C.D. Paiva, M.C.C. Gastaldini, C.A.O. Irion, J.R. Dias, L.C.M. Costa, and L.A. Richter. 2000. Quantificação da demanda de água na bacia do Rio Ibicuí – RS. *Revista Brasileira de Recursos Hídricos* 5(3): 93-111.

Roesch, L.F.W., F.C.B. Vieira, V.A. Pereira, A.L. Schünemann, I.F. Teixeira, A.J.T. Senna, and V.M. Stefenon. 2009. The Brazilian Pampa: A Fragile Biome. *Diversity* 1: 182-198.

RS-DRH. 2010. Processo de Planejamento da Bacia Hidrográfica do Rio Ibicuí Fases A e B. RELATÓRIO TÉCNICO 01 - RT01. Estado Do Rio Grande Do Sul, Departamento DRH/SEMA. Available at: http://www.comiteibicui.com.br/planodabacia/ Accessed 20 February 2012.

Sacks, W.J., B.I. Cook; N. Buenning, S. Levis, and J. Helkowski. 2008. Effects of global irrigation on the near-surface climate. NASA Publications. Paper 5. Available at: http://digitalcommons.unl.edu/nasapub/5. Accessed 20 February 2012.

Wilks, D.S. 2006. *Statistical Methods in the Atmospheric Sciences*. 2nd ed. New York: Elsevier.