Assessing climate change on classic gully: A case study from Western Iowa

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ABSTRACT

The purpose of this study is to assess the temporal distribution of climate and hydrologic attributes measured in a field-scale watershed in Treynor, IA. ARIMA models have been applied in 36 years of measured data and from final models long term change were identified at runoff and gully sediment time series. During wet-season (summer) temperature and precipitation slightly increased at this site from 1965-1999, whereas sediment yield decreased 0.48 ton per decade in summer and 0.26 ton in spring season.

Keywords: Soil erosion, Time series analysis, Serial correlation.

1. INTRODUCTION

Classic gullies are an extreme form of soil erosion that degrades diverse environments through the siltation of streams and water bodies. The permanent or classic type of gully is described as a small, steep-sided channel and cannot be crossed by ordinary farm machinery (Soil Science Society, 2012). Indirectly, gully erosion compromises crop productivity working as a link to watercourses. It allows movement of detached topsoil particles from agricultural fields during heavy storm events. This complex process involves multiple factors such as surface temperature and precipitation patterns and it demands to be studied consistently in order to examine its landscape evolution during runoff process.

Generally, soil erosion models, such as WEPP and AGNPS, calculate projected soil loss in ephemeral gully erosion which can be erased and filled by tillage operations. Nonetheless, little attention is given to classic gully soil erosion models because its causes and process are well not understood (Poesen et al., 2003). Previous studies in classic gully erosion are based mostly in on channel erodibility and flow shear stress. Furthermore, there is little information that support the hypothesis of climate change fostering gully erosion (Li et al.,2004).

There are areas susceptible to increase of water erosion as consequence of increase of precipitation intensity. For instance, Li et al. (2004) reported that areas in Western Australia with known reduction of annual rainfall have presented no significant decline

L. G. Vendrusculo, A. Kaleita. "Assessing climate change on classic gully: A case study from Western Iowa". EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013.

in high-intensity rain event. Thus, precipitation amount and intensity are critical control factors of climate change which also affects water erosion.

Precipitation is considered the driving mechanism controlling runoff which is associated with water erosion. Despite of uncertainty of different global change models (GCM's), the only agreement of the models employed by Milly et al. (2005) is the increasing of 10 % to 40% of runoff in the high latitudes of North America and Eurasia. Long-term climate and hydrological observations can be useful to understand and simulate future events. In gullied areas, the modeling of erosion processes is essential to implementation of conservation management practices

The goal of this study is modeling of long-term monthly rainfall and temperature in a classic gully in Western Iowa. Fluctuations on monthly runoff characteristics and soil erosion are investigated under the time domain analysis.

The paper is organized as follows. In section 2 we describe briefly the time series concepts, characteristics of study area and data analysis performed including classical and time series analysis. Section 3 shows the main findings. The paper concludes with discussion in section 4.

2. MATERIAL AND METHODS

2.1 Time Series Background

A time series is defined as a sequence of *n* observations of uncorrelated variables taken in a regular interval, $t_1, t_2, \ldots, t_n$. Generally, a suitable model is selected to explain the observed data allowing simulate future events. In order to analyze time series with classical statistics techniques is assumed that time series is stationary. The assumption of a time series x to be stationary is when the (μ) mean is the same for each interval of time and variance (σ_x^2). Even though stationarity is required to employ time series analysis, the trend study is important to understand broad topic.

The ARIMA time series model simulate each variable using auto-regression of order p, AR(p) and moving average of order q, MA(q).

In order to select the optimum model some information criteria are commonly employed in time series (Sumway & Stoffer, 2011). The first one is the Akaike`s Information Criterion (AIC), which helps to selecting predictors for regression process and determining the order of ARIMA models. AIC can be obtained as

$AIC = -2\log(\mathrm{L}) + \dfrac{n+2k}{n}$, where L is the likelihood of dataset, n is the number of observations, and k is number of parameters in the model.

For ARIMA models, the corrected AIC can be found as

$AIC_c = AIC + \frac{n+k}{n-k-2}$, The minimum value of AIC_c is the optimum value.

Ultimately, the Bayesian Information Criterion can be obtained as

$BIC = AIC + \frac{k \log n}{n}$, Also the minimum value of BIC is selected as the final model.

2.2 Site description

The data from one area that encompasses 26 ha (68.2 ac) field-scale watershed (41° 9' 44.54"N, 95° 38' 19.94" W) near Treynor in southern Pottawattamie County, IA was analyzed. Entitled as Watershed #1, this field is one of four study areas established by the U.S. Department of Agriculture Research Service (USDA-ARS).. It was chosen due to its position in the western loess hills (Fig.1) and also well documented research in erosion and runoff under conventional tillage (Kramer et al, 1999). The predominant soil was Monona silt loam (fine silty, mixed, superactive, mesic Typic Hapludolls). The watershed was instrumented in 1965 to provide measurements of runoff, base flow and sediment concentration. These measurements were quantified using broad-crested V-notch weirs located at the base of each watershed where the gullies channels are located. Precipitation was measured by rain gauges placed in the watershed perimeter. This watershed was managed in continuous corn and conventional tillage from 1963 through 1995. In 1996, a no-tillage with rotation of corn and soybean was started. The causes and processes of the long-term growth of this valley-bottom gully are described by Thomas et al. (2004).

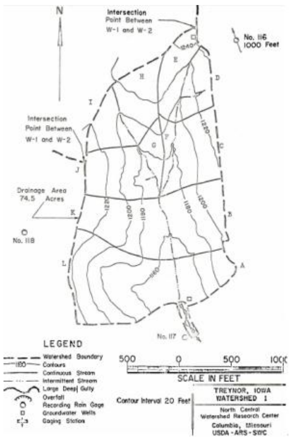

Figure 1 . Classic topography at watershed #1 in Treynor, Western Iowa (Onstad et al., 1976).

2.3 Site-specific data analysis

From USDA experiment raw data, monthly mean temperatures in a classic gully located in watershed #1 were obtained averaging daily minimum and maximum temperatures. The time series presented a few outliers (> 95% quantile or <5% quantile) and one extreme event (6/20/67). However, we decided include the outliers in the time series analysis because the variance and mean values regarding the whole time series were not significantly affected by them. The baseline period studied herein goes from January, 1965 to December, 1999.

The statistic and time series analyses were conducted using R Statistical environmental, mostly performing functions available at forecast package. Annual and seasonal estimates were summarized quantitatively and graphically trough Box-and-whisker diagrams.

In order to assess whether climate observations in this site are likely to carry trend and seasonality we have decomposed the time series in three distinct signals: trend, seasonality and remainders (noise). To investigate those components, monthly data from meteorological station at watershed #1 was plotted over time and smoothed by local weighted regression (LOWESS).

Another critical aspect in time series analysis is its classification in stationary or no-stationary. The trend and seasonality components of one time series might confound the modeling process because it will give different values for those time series values. Thus, we applied the Mann-Kendall test, in order to investigate possible trend trough time, measure the direction and significance of observed trends in time series. This non-parametric test assumes as null hypothesis the nonstationarity condition.

Auto correlation (ACF) and partial autocorrelation function (PACF) plots were produced and analyzed in order to help to construct the suitable ARIMA time series model. From the analysis of those plots, the appropriate orders of AR(p) or MA(q) model was constructed. Fitting ARIMA models is a combination of statistical techniques and underlying process, but still find out optimal model is a research problem.

In this study, aside the ACF and PACF analyses, the function auto.arima from *forecast* package was performed for model selection purpose. Auto.arima function was implemented from Hyndman & Khandakar (2008) algorithm which integrates unit root tests, minimization of the AICc and maximum likelihood estimator (MLE).

3. RESULTS AND DISCUSSION

The highest temperatures and rainfall were recorded in the summer season, according Table I, which also correspond to high losses in the sediment yields. The highest data spread is from temperature (s.d.= 11) and the lowest data spread comes from runoff (s.d.=0.3).

Table I - Annual and periodic mean values.

Variables	Annual Mean	Winter Mean	Spring Mean	Summer Mean	Fall Mean
Mean temperature (^{o}C)	11.25 ±11	-4.3	10.2	23.2	11
Precipitation (mm)	2.3 ±2	0.62	2.75	3.6	2.2
Runoff (mm/day)	0.61 ±0.3	0.43	0.7	0.9	0.4
Gully sediments (Ton)	0.82 ±3.6	0.12	1.07	1.8	0.27

Figure 1 shows the LOWESS filter applied in each time series and reference line (red line) corresponds to the mean curve. It was noted that climate variables (e.g., precipitation and temperature) did not present statistical significant of trend. However, monthly temperature and precipitation series showed strong yearly cycles. For example, it can be noted season's cycle at monthly temperature. An upward trend, which represents a long term change in mean and/or variance, can be graphically noted in runoff attribute (Fig 1c). Conversely, precipitation observations only using visual inspection it seems that remains with mean and variance without change. A strong periodic (seasonal) component in almost all of the series, suggest that winter-summer alterations play an important role in the water erosion process. Furthermore, every time series values oscillate around curve line with the only exception is sediment losses. In that time series mostly the values are less than mean sediment losses time series (2.3 ton) suggesting influence of extreme events (outliers).

The monthly runoff of figure 1c shows strong seasonality within each year, as well as some strong cyclic behavior with period about 6–10 years. Conversely, in the monthly gully soil yield panel (bottom right) in figure 1 there is no apparent trend over this period, seasonality or cyclic long-term evolution. There were random fluctuations (spikes) which are unpredictable and have no consistent patterns.

The mann-Kendall trend test results have identified trend at runoff and gully sediment time series ($p < 0.05$). Those results were quite consistent with visual analysis.

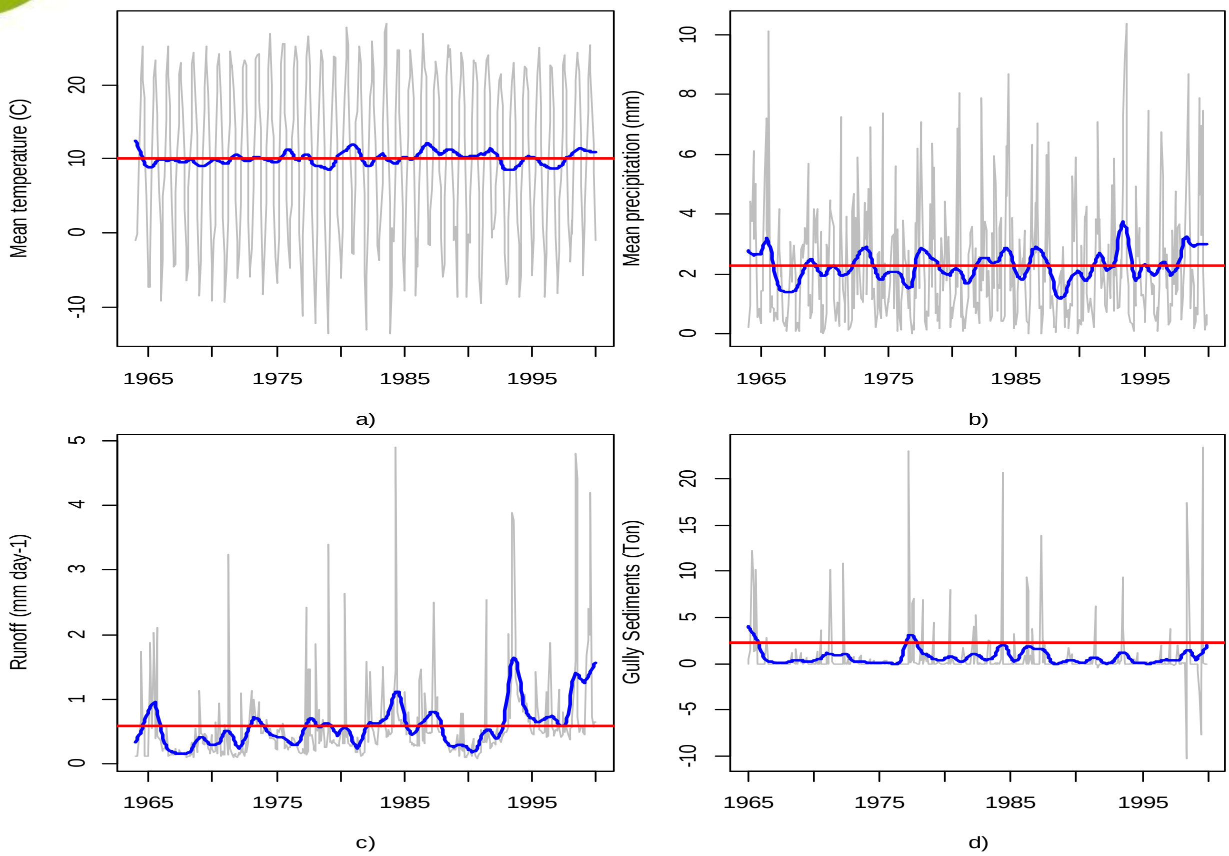

Figure 1 – Monthly series of temperature, precipitation, runoff and gully sediments (grey curve) fitted by polynomial regression curves (LOWESS smoother filter in blue curve) and mean curve (red line) at Treynor site relative to the period 1965 to 1999.

Analyzing the seasonal plots, in Fig 2, it can be noted that the interannual variability in temperature is largest in spring, even though the largest seasonal departure from normal occurs in the summer (23.4 ^{o}C). Linear trends of seasonal mean precipitation are all positive.

Also, decadal analysis showed that temperature in the summer has cumulative decreased, according the regression line, about 0.36 ^{o}C and increased 1 ^{o}C in spring period. Despite of small increasing changes in runoff in the summer and spring, the sediment delivery decreased over the studied period. Regression analysis under decadal-scale has shown that watershed #1 delivered, cumulatively, 0.48 Ton of sediment during summer period and 0.26 ton in spring season.

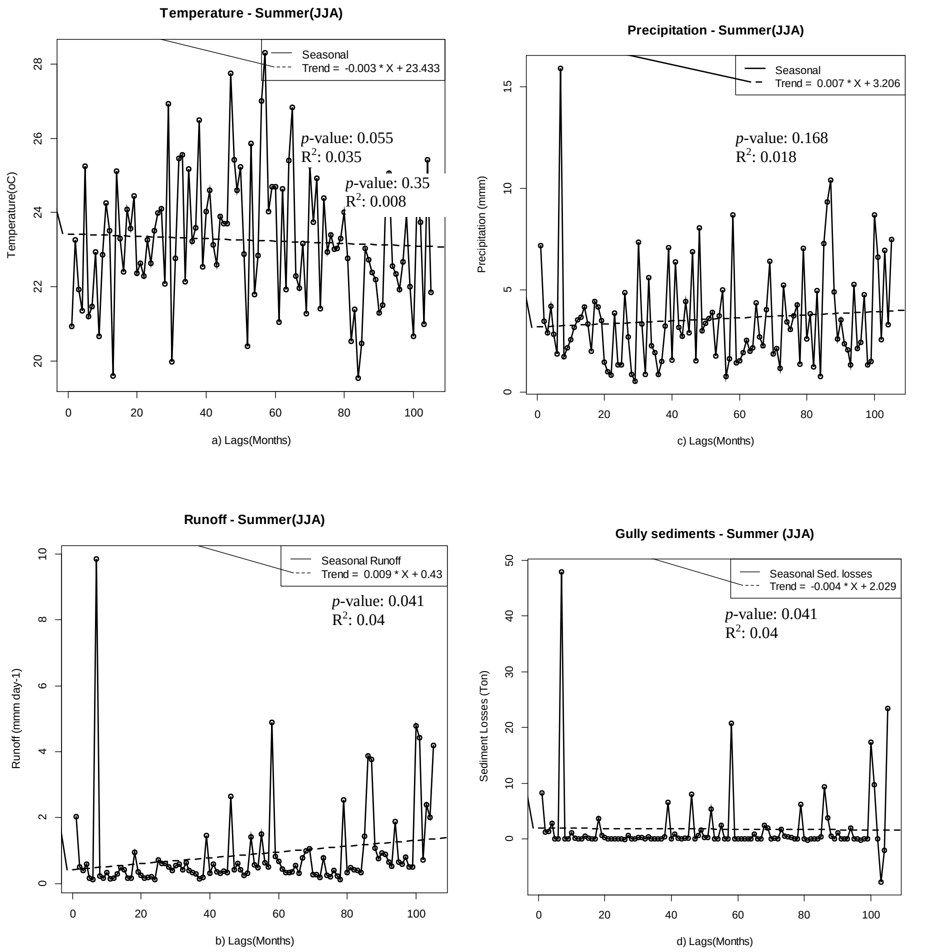

Figure 2 - Seasonal mean time series (spring and Summer) and linear trends of surface air temperature, precipitation, runoff and gully sediments for 1965-1999.

Using the optimal values of AIC, AICc, and BIC, orders suggested by ACF and PACF function plots, and auto.arima function configuration, the models candidates were selected as depicted in Table II. The first set of ARIMA terms, considered the whole time series (e.g. temperature ARIMA**(2,0,1)(**2,0,0)) and the second set of terms is applied only in the seasonal term (e.g. temperature ARIMA(2,0,1)**(2,0,0)**).

Table II- Final ARIMA models

Variable	Model	AIC	AICc	BIC
Temperature	ARIMA(2,0,1)(2,0,0)[12] with non-zero mean	2081	2081.3	2109.3
Precipitation	ARIMA(0,0,2)(2,0,2)[12] with non-zero mean	1679	1679.3	1711.3
Runoff	ARIMA(3,1,3)(1,0,2)[12]	931.4	931.9	971.8

4. CONCLUSIONS

A long-term climate and hydrologic time series was modeled with ARIMA model which is an efficient tool to quantify and make inference using past values. As result, the ability to predict soil losses in a long-term, for example, is critical for decision makers and strategies to avoid degradation of water and soil resources.

ARIMA models were able to detect a small upward trend in runoff and downward trend in gully sediment detachment. As future research, we are planning to investigate and quantify the correlation of runoff and precipitation, through multiple linear regression, in order to predict sediment losses to scenarios where soil erosion measurements are not available. Also, compare our findings with regional global climate models (RCMs).

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