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Research Paper

Neutrosophic Wilcoxon Signed-Rank Test with Application to Diabetes Data

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ABSTRACT
A well-known nonparametric alternative to a student t-test is the Wilcoxon signed-rank test from the library of classical statistic tests. The test is frequently used in decision-making situations when it is necessary to compare the means of two populations using two matched samples or test the mean of a population based on a sample of data. The interval-valued data frequently exhibit uncertainty and imprecision and frequently result from unclear and ambiguous circumstances. This research developed a neutrosophic Wilcoxon signed-rank test for analysing sample observations or groups of observations by modifying the classical Wilcoxon signed-rank test under uncertainty where the assumption of normality does not hold. The proposed test was applied to a set of data related to diabetes patients. The diabetic patients' pre- and post-treatment data were collected for both determinate and indeterminate parts for one month. The findings of the study revealed that interval-valued data circumstances would be better suited for the modified Wilcoxon signed rank test. Also, the neutrosophic Wilcoxon signed-rank test used on diabetes data set revealed that the proposed test yields more accurate and appropriate results for interval-valued data whereas the classical nonparametric Wilcoxon signed-rank test would have produced false results The proposed test revealed that, at a 5% level of significance, the diabetic patients' median differences between pre-treatment and post-treatment are equal to zero. Therefore, in the presence of indeterminacy, the proposed neutrosophic Wilcoxon signed-rank test is appropriate as a substitute for the classical form of the test.

Keywords: *Wilcoxon signed-rank test, Interval-valued data, Neutrosophic statistics, Diabetes patients*

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I. Introduction

Hypothesis testing is a systematic scientific procedure used to assess the validity or dismissal of a proposed statement or assertion. There are two approaches in statistics which are used to verify a hypothesis: the parametric approach and the non-parametric approach (Buckley, 2005). The assumptions underpinning the parametric technique pertain to the population distribution from which the sample was selected since no presumptions are made. The assumption of normality in the data is a vital component of the parametric method, and several tests also need the equality of population variances (Higgins 2004). Nonparametric or distribution-free tests are increasingly being used since it can be difficult to fulfil the distributional assumption for a parametric test in many situations. Nevertheless, it's important to note that all such nonparametric tests are typically employed when dealing with data that consists of definite observations (Chan 2003). As a rank-based substitute for the parametric t-test, the well-known non-parametric Wilcoxon signed-rank test was introduced by Frank Wilcoxon in 1945 for comparing two treatments employing paired and unpaired sample observations, respectively, two comparison techniques are utilised: the Wilcoxon signed rank test and the Wilcoxon rank sum test (Wilcoxon 1945). The Wilcoxon signed-rank test, in contrast to the t-test, assumes the symmetry of differences between pairs rather than the assumption of normality (Conover et al., 2010). This test is particularly useful when comparing two related samples, matching samples, or doing many measurements on a single sample to see whether the population mean ranks differ. A few assumptions must be met for the Wilcoxon signed-rank test to be valid. Each set of data should be selected separately and at random, and they should come from the same population. Furthermore, if possible, the data should be measured on an interval scale; nonetheless, pairs of comparisons on an ordinal scale are also appropriate. Different authors have made a lot of modifications to the Wilcoxon-signed rank test. Ayman & Baklizi (1999) introduced a modified version of the Wilcoxon signed rank test specifically designed for detecting a shift in location in which the Wilcoxon scores

are adjusted based on the estimated tail lengths of the distribution. Ebuh & Oyeka (2012) created an updated version of the Wilcoxon signed rank test that addressed the test's shortcomings. The suggested approach took into consideration the possibility of zero differences and tied absolute levels of differences, in contrast to the traditional Wilcoxon signed rank test. Abdullah et al. (2014) concentrated on assessing the modified Wilcoxon signed rank test's performance. The indicator function of positive, zero, and negative differences was added to the Wilcoxon signed rank test in their study to calculate the Wilcoxon statistic. Okeh & Onyeagu (2020) employed a modified Wilcoxon signed-rank test to compare two diagnostic test techniques. A common method for comparing the performance of two paired diagnostic test data sets is receiver operating characteristic (ROC) analysis, where the area under the curve (AUC) provides a summary of the overall activity between two ROC curves. Furthermore, several authors introduced different statistics tests using neutrosophic statistics, Arif et al. (2020) developed a diagnostic test for diabetes patients using Neutrosophic Statistics. The concept of Neutrosophic Statistics was used to develop a new approach for the determination of sensitivity and specificity of medical tests in the diagnosis of patients with a particular ailment. Under classical statistics, diagnosis tests (DT) were used with the presumption that every observation in the data was known. Aslam (2022) focused on creating a modified Z-test since the existing Z-test for uncertainty events does not indicate the level of uncertainty or indeterminacy associated with the test, which makes it difficult to account for the unpredictable nature of COVID-19 events. In his research, he introduced the Z-test for uncertainty events under neutrosophic statistics. Aslam (2020) investigated the use of Dixon's test in neutrosophic statistics to identify outliers in complex data In the classic Wilcoxon signed rank test sample problem, the data are simple and clear of any doubt or uncertainty. However, the observations are not always constant. In many recent scientific investigations, ambiguous portions numerically indicate the uncertainties in a sample (Smarandache, 2014). The data measured in the neutrosophic intervals cannot be investigated using the Wilcoxon signed rank test as it is currently implemented. A thorough assessment of the literature demonstrates the lack of a test that can serve as a nonparametric alternative in an uncertain environment. Therefore, in this paper, a neutrosophic version of the Wilcoxon signed-rank test is proposed to analyse samples or groups of observations in the presence of uncertainty. A real-life dataset of diabetes patients was applied to illustrate the application of the proposed neutrosophic Wilcoxon signed-rank test. The goal is to develop the neutrosophic Wilcoxon signed-rank test for the analysis of indeterminate data. Therefore, the goals of this article are to: (1) derive the neutrosophic Wilcoxon signed-rank test; (2) define the methodology of the neutrosophic Wilcoxon signed-rank test; and (3) use an application on the Diabetes data set under Neutrosophy to compare the performance of the proposed Wilcoxon signed-rank test with the classical Wilcoxon signed-rank test. The following is the article's schedule. The computational approach for using the neutrosophic Wilcoxon signed-rank test is presented in Section 2. In section 3, an engaging example from the Diabetes dataset is used to demonstrate the efficacy and competence of the modified Wilcoxon signed-rank test. It is expected that the modified nonparametric Wilcoxon signed-rank test will effectively analyze data in the face of uncertainty and ambiguity, outperforming the traditional Wilcoxon signed-rank test in classical statistics. Ultimately, the outcomes are deliberated upon and extended, accompanied by conclusive remarks.

1. Computational Method of the Wilcoxon Signed Rank Test under Neutrosophic Statistics

In classical statistics, nonparametric tests represent statistical analysis techniques that do not necessitate adherence to the assumptions required for analyzing a distribution. These tests are suitable for datasets that do not conform to a normal distribution, which is why they are occasionally labelled as distribution-free tests. The primary objective behind introducing the suggested Wilcoxon signed-rank test is to investigate whether all independent samples, comprising neutrosophic observations, are derived from neutrosophic populations. The proposed test is specifically designed for datasets containing neutrosophic values. For $I_N \in [I_L, I_U] = 0$ neutrosophic number where $a_N$addresses the determinate part and $b_N I_N$, $I_N \in [I_L, I_U]$ addresses the vague piece of the neutrosophic number. For $I_N \in [I_L, I_U] = 0$, the neutrosophic number lessens to a variable under traditional measurements. The neutrosophic variable X_N addresses the neutrosophic test acquired from the populace containing loose, unsure, and vague perceptions (Smarandache 2010)

2. The Proposed Neutrosophic Wilcoxon signed rank test

The classical Wilcoxon signed rank test cannot be used when dealing with indeterminate measurements. To address this limitation, the neutrosophic Wilcoxon signed rank test is proposed. This test examines the sign ranks of observed differences in neutrosophic observations, which include an indeterminate component. It serves as a straightforward alternative to the paired t-test when data does not meet the assumptions of normality or equal variances. The test is based on the signs (+/-) of the ranks assigned to the observed neutrosophic differences. The Neutrosophic Wilcoxon signed rank test aims to assess the neutrosophic null hypothesis that the median of the neutrosophic population differences between paired data is zero. It tests whether the neutrosophic population median, denoted as NM_N, has a specified value, such as zero. This

hypothesis assumes that each neutrosophic perception is similarly liable to be above or underneath the neutrosophic middle. On account of two neutrosophic tests, it suggests that the two populaces are indistinguishable. To apply the proposed Neutrosophic Wilcoxon signed rank test, the following assumptions should be met:

1. The dataset comprises values that are uncertain, imprecise, and indeterminate in nature.
2. Randomness must be ensured in selecting the two neutrosophic samples.
3. While the test is typically resilient to ties, in cases where ties are present in the dataset, they should be clustered in a specific section of the sample.

Suppose we have k_N independent neutrosophic samples of sizes $n_{1N}, n_{2N},\ldots, n_{kN}$, $(\sum n_{iN} = n_N)$. Let $x_{iN}(x_{i1N}, x_{i2N}, x_{i3N}, \ldots., x_{inN})$ and $y_{iN}(y_{i1N}, y_{i2N}, y_{i3N}, \ldots., y_{inN})$ represents the i^{th} pair of neutrosophic observations in the sample, which is symmetric for i = 1, 2, ..., n. The difference between the i^{th} pair of neutrosophic observations is denoted as $d_{iN} = y_{iN} - x_{iN}$. To direct the test under vulnerability, all n_N perceptions containing vulnerability in k_N samples are organized in rising request in light of their disparities and doled out positions. On account of ties, the positions are found the middle value of. The neutrosophic tests' perceptions are then supplanted with their relating positions. Let $R_N(|d_{iN}|)$ be the rank assigned to $|d_{iN}|$, ranked from the smallest to the largest value of d_{iN}. The perceptions of the neutrosophic tests will be supplanted with their comparing.

Let $Z_{iN}=\begin{cases}1, if\ d_{iN} > 0;\\ -1. if\ d_{iN} < 0.\end{cases}$ (1)

Thus, Z_{iN} will assume the value of 1 if $R_N(|d_{iN}|)$ is the rank assigned to a positive value of the difference $d_{iN} = y_{iN} - x_{iN}$ that is when y_{iN} is greater than x_{iN} and will assume the value -1 if d_{iN} is negative that is if y_{iN} is less than x_{iN}.

Let θ_{iN} = P (Z_{iN}=1) (2)

and define

$T_N^+ = \sum_{i=1}^{n} Z_{iN} R_N(|d_{iN}|)$ (3)

That is, T will be the sum of the ranks with positive differences.

Hence, the expected value and variance of T_N^+ respectively will be

$$E(T_N^+) = \frac{n_N(n_N+1)}{2}\theta_N \quad (4)$$

$$Var(T_N^+) = \frac{n_N(n_N+1)(2n_N+1)}{6}\theta_N(1-\theta_N) \quad (5)$$

The neutrosophic form of the proposed test $X_N \in [X_L, X_U]$ will be expressed as follows

$X_N = X_L + X_U I_{NH}; I_{NH} \in [I_{LH}, I_{UH}]$ (6)

where the first part X_L shows the determinate part, $X_U I_{NH}$ denotes the indeterminate part and $I_{NH} \in [I_{LH}, I_{UH}]$ will be the measure of indeterminacy. The neutrosophic test statistic X_N will follow a chi-square distribution with 1 degree of freedom.

Application of the proposed neutrosophic Wilcoxon signed-rank test

The proposed neutrosophic Wilcoxon signed-rank test was used to compare the pre-treatment and post-treatment data of 20 patients with Diabetes (high blood sugar levels) who were seen at the general hospital in Ondo Town, Ondo State, Nigeria, over one month in January 2023, The data clearly exhibits a neutrosophy, and we are interested in testing the hypothesis that, after one month of therapy for diabetic patients, there is no significant change in the median of the differences between the pre- and post-treatment. As a result, utilizing the Wilcoxon signed rank test for inferential analysis of data under simple data may yield false results. For such circumstances, it will be rather practical to apply the proposed neutrosophic Wilcoxon signed rank test, which is used to test the null hypothesis that the median of the differences between the pre-treatment and post-treatment is zero. The Pre-treatment and Post-treatment in January 2023 is presented in Table 1, the null and alternative hypothesis for the neutrosophic data given in Table 1 is: the median of the population of differences between the pre-treatment and post-treatment of Diabetes patients is zero against the alternative hypothesis that the median of the population of differences between the pre-treatment and the post-treatment is not zero. Signed ranks for the Pre-treatment and Post-treatment of Diabetes patients are shown in Table 2, Descriptive Statistics for the Pre-treatment and Post-treatment of Diabetes Patients are shown in Table 3, Ranks for the Pre-treatment and Post-treatment of Diabetes patients are shown in Table 4 and the test statistics for the Pre-treatment and Post-treatment of Diabetes patients are shown in Table 5.

Table 1 The Pre-treatment and Post-treatment of Diabetes patients in January 2023

PATIENT	PRE- TREATMENT	POST-TREATMENT
1	[9.7,10.8]	[6.4,7.3]
2	[13.8,15.0]	[10.2,11.4]
3	[7.2,8.5]	[5.5,6.4]
4	[21.5,22.4]	[9.6,11.0]
5	[8.2,9.0]	[8.1,9.2]
6	[10.2,11.4]	[10.6,12.0]
7	[7.0,8.2]	[11.4,12.4]
8	[32.3,33.8]	[13.3,15.0]
9	[6.0,7.2]	[6.1,7.5]
10	[5.9,6.9]	[6.1,7.4]
11	[10.3,11.5]	[10.1,10.9]
12	[16.2,17.2]	[7.1,8.5]
13	[8.5,9.3]	[9.9,11.1]
14	[4.6,6.4]	[6.4,7.2]
15	[5.9,6.9]	[4.6,5.5]
16	[12.6,14.0]	[5.8,6.5]
17	[7.4,8.2]	[6.0,7.2]
18	[9.5,10.5]	[3.8,5.0]
19	[5.5,6.4]	[4.5,6.1]
20	[23.1,24.4]	[9.8,11.2]

Table 2 Signed ranks for the Pre-treatment and Post-treatment of Diabetes patients

PATIENT	PRE- TREATMENT	POST-TREATMENT	DIFFERENCES	RANK	SIGNED RANK
1	[9.7,10.8]	[6.4,7.3]	[3.3,3.5]	[12,12]	[12,12]
2	[13.8,15.0]	[10.2,11.4]	[3.6,3.6]	[13,13]	[13,13]
3	[7.2,8.5]	[5.5,6.4]	[1.7,2.1]	[10,11]	[10,11]
4	[21.5,22.4]	[9.6,11.0]	[11.9,11.4]	[18,18]	[18,18]
5	[8.2,9.0]	[8.1,9.2]	[0.1,-0.2]	[1.5,1]	[1.5,-1]
6	[10.2,11.4]	[10.6,12.0]	[-0.4,-0.6]	[5,5.5]	[-5,-5.5]
7	[7.0,8.2]	[11.4,12.4]	[-4.4,-4.2]	[14,14]	[-14,-14]
8	[32.3,33.8]	[13.3,15.0]	[19,18.8]	[20,20]	[20,20]
9	[6.0,7.2]	[6.1,7.5]	[-0.1,-0.3]	[1.5,2.5]	[-1.5,-2.5]
10	[5.9,6.9]	[6.1,7.4]	[-0.2,-0.5]	[3.5,4]	[-3.5,-4]

11	[10.3,11.5]	[10.1,10.9]	[0.2,0.6]	[3.5,5.5]	[3.5,5.5]
12	[16.2,17.2]	[7.1,8.5]	9.1,8.7]	[17,17]	[17,17]
13	[8.5,9.3]	[9.9,11.1]	[-1.4,-1.8]	[8.5,10]	[-8.5,10]
14	[4.6,6.4]	[6.4,7.2]	[-1.8,-0.8]	[11,7]	[-11,-7]
15	[5.9,6.9]	[4.6,5.5]	[1.3,1.4]	[7,9]	[7,9]
16	[12.6,14.0]	[5.8,6.5]	[6.8,7.5]	[16,16]	[16,16]
17	[7.4,8.2]	[6.0,7.2]	[1.4,1]	[8.5,8]	[8.5,8]
18	[9.5,10.5]	[3.8,5.0]	[5.7,5.5]	[15,15]	[15,15]
19	[5.5,6.4]	[4.5,6.1]	[1.0,0.3]	[6,25]	[6,25]
20	[23.1,24.4]	[9.8,11.2]	[13.3,13.2]	[19,19]	[19,19]

Table 3 Descriptive Statistics for the Pre-treatment and Post-treatment of Diabetes Patients

	N	Mean	Std. Deviation	Minimum	Maximum
Post-treatment (determinate)	[20,20]	[7.7650,8.9400]	[2.65236,2.74579]	[3.80,5.00]	[13.30,15.00]
Pre-treatment (indeterminate)	[20,20]	[11.2700,12.4000]	[7.09752,7.15799]	[4.60,6.40]	[32.30,33.80]

Table 4 Ranks for the Pre-treatment and Post-treatment of Diabetes patients

		N	Mean Rank	Sum of Ranks
Pre-treatment-Post treatment (determinate)	Negative Ranks	6[a]	7.25	43.50
	Positive Ranks	14[b]	11.89	166.50
	Ties	0[c]		
	Total	20		
Pre-treatment-Post treatment (indeterminate)	Negative Ranks	7[d]	6.29	44.00
	Positive Ranks	13[e]	12.77	166.00
	Ties	0[f]		
	Total	20		

Table 5 Test statistics for the Pre-treatment and Post-treatment of Diabetes patients

	Pre-treatment-Post treatment (determinate)	Pre-treatment-Post treatment (indeterminate)
Z	-2.297[b]	-2.278[b]
Asymp. Sig. (2-tailed)	.022	.023

II. Discussion of Results

Table 2 shows the pre-treatment and the post-treatment of 20 diabetes patients for a period of one month. The first patient had a value of [9.7, 10.8] for the pre-treatment and [6.4, 7.3] for the post-treatment, the second patient had [13.8, 15.0] for pre-treatment and [10.2, 11.4] for post-treatment, the third patient having [7.2, 8.5] for pre-treatment and [5.5, 6.4] for the post-treatment, the eighteenth patient having [9.5,10.5] for pre-treatment and [3.8,5.0] for post-treatment, the nineteenth patient having [5.5,6.4] for pre-treatment and [4.5,6.1] for post-treatment and the last patient having [23.1,24.4] for pre-treatment and [9.8,11.2] as the post-treatment. We proceeded in subtracting the post-treatment from the pre-treatment in which the differences were obtained. The difference between the pre-treatment and post-treatment for the first patient was [3.3, 3.5], for the sixth patient, it was [-0.4,-0.6] and for the last patient, it was [13.3, 13.2]. after the differences were obtained, we

moved on to the next step which by arranging the differences from the lowest to the highest and assigning ranks to them given the first patient to have [12,12], the third patient to have [10,11] and the ninth patient to have [1.5,2.5] as their rank value. It was found that ties exist in the neutrosophic differences for both determinate and the indeterminate parts, by this, the rank of the tied differences was gotten by calculating their average and assigning ranks to them like patient 5 and patient 9 having 1.5 as their rank for the determinate part and patient 10 and patient 11 having 5.5 as their rank for the indeterminate part. We concluded by assigning the signs of the differences to the ranks which provided the Signed ranks of each patient like the fourteenth patient, the value for the difference is [-1.8,-0.8], the rank is [11,7] and the signed rank is [-11,-7]. Table 3 shows the descriptive statistics of the pre-treatment and the post-treatment having the neutrosophic mean value for the pre-treatment to be [7.7650, 11.2700] and [8.9400, 12.4000] for the post-treatment. The neutrosophic standard deviation value for the pre-treatment for both the determinate and indeterminate parts is [2.65236, 7.09752] and [2.74579, 7.15799] for the post-treatment. Table 4 shows the ranks of the differences. For the determinate part of the ranks, six patients have a negative rank, fourteen patients have positive ranks and there are no ties. For the indeterminate part, seven patients have negative ranks, thirteen patients have positive ranks and there are no ties. The mean rank values for the determinate negative ranks and the positive ranks are 7.25 and 11.89 respectively and for the indeterminate negative and positive ranks, the mean rank values are 6.29 and 12.77 respectively. The value for T_- is [43.5, 44.0] and the value for T_+ is [166.5, 166] for the determinate and indeterminate parts respectively. The test statistics in this table is T= min [T_-,T_+], which shows that the minimum is [43.5, 44.0], indicating the value for the determinate and indeterminate part of the result, respectively. Table 5 shows that the Z value for the test statistics is [-2.297, -2.278] and the p-value for the test statistics is [0.022, 0.023], the level of significance $\alpha = 0.05$. Given that the computed test statistics value based on neutrosophic observations falls within the critical region (p-value < α), the neutrosophic null hypothesis is rejected. This leads to the conclusion that the median of the differences between pre-treatment and post-treatment in diabetes patients is zero. The neutrosophic form, represented as $X_N = X_L + X_U I_{NH}$; $I_{NH} \in [I_{LH}, I_{UH}]$, comprises both determinate (existing test) and indeterminate parts. The specific expression for the real data in neutrosophic form of $X_N \in [X_L, X_U]$ is $X_N = 0.022 + 0.023 I_{NH}$; $I_{NH} \in [0, 0.001]$, where 0.022 reflects the results of the existing test when $I_{NH}=0$ and $0.023 I_{NH}$ represents the indeterminate part. The associated measure of indeterminacy for the test $X_N \in [X_L, X_U]$ is 0.001. This study demonstrates that the proposed test yields a result within the range of 0.022 to 0.023, offering a broader spectrum compared to the existing test, which provides only a determined/exact value. Moreover, the proposed test, $X_N \in [X_L, X_U]$ provides insights into the measure of uncertainty. Interpreting the results with a significance level $\alpha = 0.05$, the proposed test indicates a 0.05 chance of rejecting the true null hypothesis, a 0.95 probability of accepting the null hypothesis, and a 0.001 chance of uncertainty. Comparatively, the proposed test, $X_N \in [X_L, X_U]$ furnishes more comprehensive information about the test, highlighting its flexibility, adequacy, and effectiveness in handling uncertainty compared to the existing test.

III. Summary and Conclusion

This study introduces a modified version of the Wilcoxon signed-rank test designed for comparing paired samples in the presence of uncertainty or falseness measurements. The data presented in Table 1 indicates that when uncertain observations are absent, the uncertain data used for illustration converges to the determined part under classical statistics. For instance, in the case of patient one, the initial observation of 9.7 for pre-treatment corresponds to the determinate portion of the indeterminate interval, while the second value, 10.8, signifies the indeterminate segment of the interval. Notably, instead of producing precise determined values, the modified Wilcoxon signed-rank test produces findings within the indeterminacy interval. This implies that the suggested test functions as a useful gauge of uncertainty. Recent research also supports the notion that methods tailored for handling interval-valued data are more appropriate in indeterminate environments compared to traditional statistical techniques (Meyer & Seaman 2013). The motivation for this work stems from a thorough investigation into the applications of fuzzy logic and neutrosophic statistics in handling interval-valued datasets. The implementation of the suggested nonparametric test for comparing paired samples and evaluating the null hypothesis of a zero median difference yielded valuable insights. Employing the newly proposed neutrosophic Wilcoxon signed-rank test on the diabetic dataset provided more accurate and relevant outcomes within the neutrosophy framework. This comprehensive analysis accounted for both the determinate and indeterminate aspects in examining the pre-treatment and post-treatment of diabetes patients. In contrast, the utilization of classical statistics with the current nonparametric Wilcoxon signed-rank test resulted in erroneous conclusions. However, the proposed test conclusively demonstrated that, at a 5% level of significance, there is no statistically significant difference between the pre-treatment and post-treatment of diabetic patients. This conclusion underscores the effectiveness of the proposed neutrosophic test in generating dependable findings for this specific scenario. In conclusion, the study has contributed to knowledge by developing a new Wilcoxon signed-rank test under uncertainty/indeterminacy for data analysis as an alternative to the classical Wilcoxon signed-rank test. It is advised that the suggested test be applied in a number of sectors, such as engineering, the

biological sciences, and many other statistical domains. However, applying nonparametric tests to data that is unclear within the context of classical statistics may result in incorrect results. To sum up, the proposed neutrosophic nonparametric test provides data analysts with a useful instrument to analyse paired samples when uncertainty and ambiguity are present.

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