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Are COVID-19 Data Reliable? A Quantitative Analysis of Pandemic Data from 182 Countries

Noah Farhadi [1,*] and Hooshang Lahooti [2]

[1] School of Business and Management, IU International University of Applied Sciences, 10247 Berlin, Germany
[2] Sydney Medical School, Nepean Clinical School, University of Sydney, Sydney, NSW 2747, Australia; hooshang.lahooti@sydney.edu.au
* Correspondence: noah.farhadi@iu.org

Abstract: When it comes to COVID-19, access to reliable data is vital. It is crucial for the scientific community to use data reported by independent territories worldwide. This study evaluates the reliability of the pandemic data disclosed by 182 countries worldwide. We collected and assessed conformity of COVID-19 daily infections, deaths, tests, and vaccinations with Benford's law since the beginning of the coronavirus pandemic. It is commonly accepted that the frequency of leading digits of the pandemic data shall conform to Benford's law. Our analysis of Benfordness elicits that most countries partially distributed reliable data over the past eighteen months. Notably, the UK, Australia, Spain, Israel, and Germany, followed by 22 different nations, provided the most reliable COVID-19 data within the same period. In contrast, twenty-six nations, including Tajikistan, Belarus, Bangladesh, and Myanmar, published less reliable data on the coronavirus spread. In this context, over 31% of countries worldwide seem to have improved reliability. Our measurement of Benfordness moderately correlates with Johns Hopkin's Global Health Security Index, suggesting that the quality of data may depend on national healthcare policies and systems. We conclude that economically or politically distressed societies have declined in conformity to the law over time. Our results are particularly relevant for policymakers worldwide.

Keywords: COVID-19; data analytics; forensic; Benford's law; organizational learning

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1. Introduction

The World Health Organization's (WHO) announcement on 10 January 2020 [1] confirmed first cases of the novel coronavirus—also known as COVID-19 or SARS-CoV-2—in Wuhan City, China, on 31 December 2019. After eighteen months, the world now faces millions of incidents, and a tidal wave of data on COVID-19 spread has emerged. Since the beginning of the pandemic, all countries affected by the virus unanimously reported two metrics, "New Cases"—individuals testing positive for the virus, and "New Deaths"—the number of death incidents due to infection with the virus [2]. After introducing COVID-19 tests, countries commenced reporting "New Tests"—the number of daily tests conducted. The emergence of the COVID-19 vaccines by pharmaceutical companies enabled national vaccination programs. As such, "New Vaccinations"—the number of people vaccinated daily—were reported by countries that adapted their preventive measures against the deadly virus. Today, we know that the pandemic's growth follows the logistic law [3].

There is no doubt that access to reliable data is vital for the fight against the pandemic. Scientists typically develop new insights based on publicly available data. Restricting interventions colloquially known as lockdowns, travel bans, and flying restrictions have been implemented by many governments in numerous countries around the world. It is for this reason that public confidence in data is vital for the effective implementation of these interventions and policies. Public doubts about the credibility of COVID-19 data can cause a sluggish response to the pandemic in the beginning or, in the worst-case, civil disobedience [2].

Several researchers conducted forensic studies on COVID-19 data. Koch and Okamura [4] confirmed the reliability of the official data coming from COVID-19 flashpoints, the United States, China, and Italy. Idrovo and Manrique–Hernández likewise proved China's conformity to the law [5]. Jackson and Sambridge [6] assessed data from 51 countries from 16 January 2020 to 9 April 2020, providing some evidence for the overall reliability of COVID-19 data worldwide. Wei and Vellwock studied the pandemic data from over twenty hot spots. They confirmed the Benfordness of few countries, such as the US, Spain, the UK, France, China, Belgium, Pakistan, and Italy. Russia and Iran were identified as clear violators of the law [7]. Lee et al. discovered that Japan did not provide reliable data [8]. According to Isea, China, Germany, Brazil, Venezuela, Norway, South Africa, Singapore, Ecuador, Egypt, Ireland, France, Australia, Colombia, India, Russia, and Croatia comply with the law. However, Italy, Portugal, Netherlands, the UK, Denmark, Belgium, and Chile did not pass three tests carried out [9]. In the most extensive study of COVID-19 data, Farhadi investigated over 100,000 integers from 154 countries and applied three goodness-of-fit measures [2]. Approximately 28% of countries adhered well to the anticipated distribution frequency, while six countries disclosed fully undependable data. Farhadi recommended replicating the very same study by applying additional tests based on larger sets of observations at a later point in time. Clearly, extending the timeframe and improving the statistical measurement shall add value to the body of knowledge. Table 1 summarizes the main characteristics of the prior research into the COVID-19 data reliability.

Table 1. Prior research into COVID-19 data reliability measured by Benford's law.

Researcher	Variables	Deadline	Number of Countries
Idrovo and Manrique-Hernández	Confirmed cases, suspected cases, and deaths, cumulated confirmed cases and deaths	21 January 2020–15 March 2020	1
Koch and Okamura	Confirmed cases, deaths, and recoveries	20 January 2020–10 April 2020	3
Lee, Han, and Jeong	Number of deaths	22 January 2020–6 April 2020	10
Jackson and Sambridge	Cumulated confirmed cases and deaths	16 January 2020–9 April 2020	51
Isea	Daily cases and deaths	29 December 2019–30 April 2020	23
Wei and Vellwock	Total confirmed cases, daily cases and deaths	not stated–1 September 2020	20
Farhadi	Daily cases, deaths, tests	31 December 2019–24 September 2020	154

To this point, the previous studies on COVID-19 data faced two major challenges: (a) inconsistent data typically limited to a small sample size and (b) inconsistent application of various statistical techniques to evaluate the reliability of the data [2–9]. Our primary rationale is to overcome the prior limitations and provide a comprehensive assessment of the most recent data. Hence, we aim to assess Benfordness by extending the number of statistical tests and maximizing the timeframe of the analysis to over eighteen months since the beginning of the COVID-19 pandemic.

2. Method

2.1. *Benford's Law and Goodness-of-Fit Tests*

Benford's law (BL), also known as "the law of the first digits," is a widely known technique for the detection of data manipulation and fraud. Its core idea relates to the frequency of leading digits in naturally generated datasets. The idea relies on Newcomb's findings of 1881, which addressed the probabilities of first-digit numbers by the Equation (1) [10]:

$$P(d) = log_{10}\left(1 + \frac{1}{d}\right),\ d \in \{1,\ 2,\ 3, \ldots,\ 9\} \quad (1)$$

According to BL, the leading digits of numbers follow a particular logarithmic pattern: 30.1% for one, 17.6% for two, 12.5% for three, 9.7% for four, 7.9% for five, 6.7% for six, 5.8% for seven, 5.1% for eight, and 4.6% for nine [10,11]. See Table 2.

Table 2. Benford's Law Distribution of First Digit.

First Digit	1	2	3	4	5	6	7	8	9
Benford's frequency	0.301	0.176	0.125	0.097	0.079	0.067	0.058	0.051	0.046

In an artificially generated dataset, the frequencies diverge from the BL distribution. Benfordness can only be applied to data with a geometrical tendency and characterized by the non-existence of minima and maxima. BL is common practice in social sciences and has been applied in various disciplines, such as finance and accounting [12–14], politics [15,16], and pandemics [2–9]. The body of knowledge is built on different goodness-of-fit tests to assess the divergence of the observed and expected frequencies. The techniques commonly used are Kolmogorov-Smirnov statistic, Chi-square, Euclidean distance, Mean Absolute Deviation, z-values, and Sum of Squared Difference.

The Kolmogorov–Smirnov statistic (K-S) is a non-parametric test for discrete data and quantifies the empirical distance between the observed and expected frequencies [17,18]. The K-S statistic was frequently applied to detect potential anomalies and incompliance of data in prior research [2,5]. Manipulation is evident if the K-S statistic is greater than the square root of the total number of the leading digits observed in a probability sample (cut-off). Once the K-S statistic is identified, the null hypothesis can be accepted, if: $\sqrt{N}D_n > K_n$. The D_n is calculated as $D_n = Max_x\,|F_n(x) - F(x)|$, where F_n is the cumulative observed distribution, and F is Benford's cumulative distribution. Considering the critical value at a 5% significance, K is set to 1.36; for a 1%, K is set to 1.63 [2,17]. The non-parametric K-S test is distribution-free and more powerful when the sample size is small [2,17]. This technical characteristic is of particular importance in the case of small samples of epidemics. The K-S statistic is one of the most precise techniques to assess BL reliability in the context of COVID-19 data [17].

Another prevalent technique is the Pearson's chi-square (χ^2) goodness-of-fit test with a confirmatory null hypothesis [7,9,19]. It is common knowledge that the χ^2 test is sensitive to the sample size and cannot make reliable inferences when the dataset consists of 5000 observations or more [2,19]. Principally, if the sample size is too big, the null hypothesis will likely be rejected (even if there is no significant difference between the actual and expected subsets). For a small sample size, χ^2 encounters difficulties in measurement as well. The test is computed as follows, cf. Equation (2):

$$\chi^2 = \sum_{i=1}^{9} \frac{\left(\widetilde{p}_i - p_{i)}\right)^2}{p_i} \quad (2)$$

As a less sensitive technique to the sample size, researchers apply the d-factor (d^*), which is calculated by the Equation (3):

$$d^* = \frac{\sqrt{\sum_{i=1}^{9}(\widetilde{p}_i - p_{i)}^2}}{1.03606} \quad (3)$$

where $\widetilde{p}_i$ and p_i are the observed and expected frequencies [2,7,19]. The d^* ultimately measures the Euclidian distance between the measured and expected frequencies of leading digits. The d^* quantifies the distance between the sample and the cumulative distribution function of the reference dataset after normalization by 1.03606, the maximum possible distance [19]. A *d-factor* (d^*) equal to 0.0 suggests full conformity to BL, while the highest Euclidian distance, d^* = 1.0, signifies full non-conformity. A d^* above 0.2 indicates non-conformity with the law [2,7,19].

In this study, we further apply additional tests, i.e., Mean Absolute Deviation (MAD) and Sum of Squared Difference (SSD), which are less dependent on the sample size [20–22]. The Equation (4) shows the MAD calculation as the average absolute deviation of observed and expected frequencies:

$$\text{MAD} = \frac{1}{k} \times \sum_{i=1}^{k} |O_i - E_i| \tag{4}$$

SSD takes the sum of the squares of the deviation of each digit's frequency from the expected frequency of BL [22]. SSD is calculated by the Equation (5):

$$\text{SSD} = \sum_{i=1}^{k} (O_i - E_i)^2 \times 10^4 \tag{5}$$

For both the MAD and SSD statistics, k is the number of leading digit bins, O_i and E_i are the observed and expected Benford's frequencies. A $MAD > 0.015$ and an SSD > 100 indicate non-conformity with the law [21,22].

In order to be consistent with prior research, we postulate the following null hypothesis for all countries in scope—mainly, H_0: COVID-19 data from J_i adhere to BL, where J_i stands for individual jurisdiction in the scope. We operationalize the statistical measures and goodness-of-fit tests based on a 0.05 significance level.

2.2. COVID-19 Data Sampling

Consistent with the extant body of knowledge, we desire a sample size of 1000 observations or larger for each country (also referred to jurisdiction or territory), although the minimum threshold for the analysis of the BL compliance is not specified in the body of knowledge. The measurement of Benfordness makes only sense if the COVID-19 samples are not too small. Small datasets cannot detect nonconformities to BL. The quality of the assessment rises if the sample size and range of the underpinning dataset grow.

This study employs the theory based on the largest dataset available from over 182 countries worldwide. We collected a sample from the COVID-19 database by the *Centre for Systems Science and Engineering* at *Johns Hopkins University* and *Our World in Data* [23]. repository; our dataset includes daily observations, such as New Cases, New Deaths, New Tests, and New Vaccinations. By adding new variables to the COVID-19 observed samples, i.e., "New Tests" and "New Vaccinations," (which were technically not available) our study incorporates the most comprehensive dataset on SARS-CoV-2 globally. We collected 216,378 integers, which were reported by 182 countries from 21 January 2020 to 6 June 2021. We use "New Vaccinations" as additional measure, which was technically not reported and available in prior research [6]. We also documented leading digits of 86,917 new cases, 77,137 new deaths, 42,322 new tests, and 10,092 new vaccinations worldwide. Small samples of seven jurisdictions ($n < 100$), including the Vatican and Tanzania, were removed from our analysis. Small samples cannot detect non-conformity to the law. Our final dataset consists of 176 countries with about 873 COVID-19 related observations on average.

3. Results

For each country, we evaluated the consistency of the pandemic data's leading digits with BL. We operationalized the goodness-of-fit tests, K-S, χ^2, d^*, MAD, and SSD at a significant level. 32% of countries worldwide showed evident improvements in Benfordness, while 68% demonstrated non-conformity with BL. The results are coded as a global map (see Figure 1). As emphasized in Figure 2, twenty-seven countries (or 15.3%) disclosed data that fully comply with the law (green countries in Figure 1). For these countries, we accept the null hypothesis based on all tests. Twenty-six countries (or 14.8%) did not meet the requirements of BL tests based on all measures (see Figure 3). These jurisdictions failed to pass all goodness-of-fit tests. We rejected the null hypothesis for these jurisdictions, which are highlighted red on our global map. Notably, 123 countries or 69.9% demonstrated partial compliance with BL as they could pass at least one of the goodness-of-fit tests, flagged yellow (see Figure 4). Grey areas were excluded in our analysis as they do not offer a sufficient sample size. Figure 5 summarizes the global distribution of COVID-19 Benfordness.

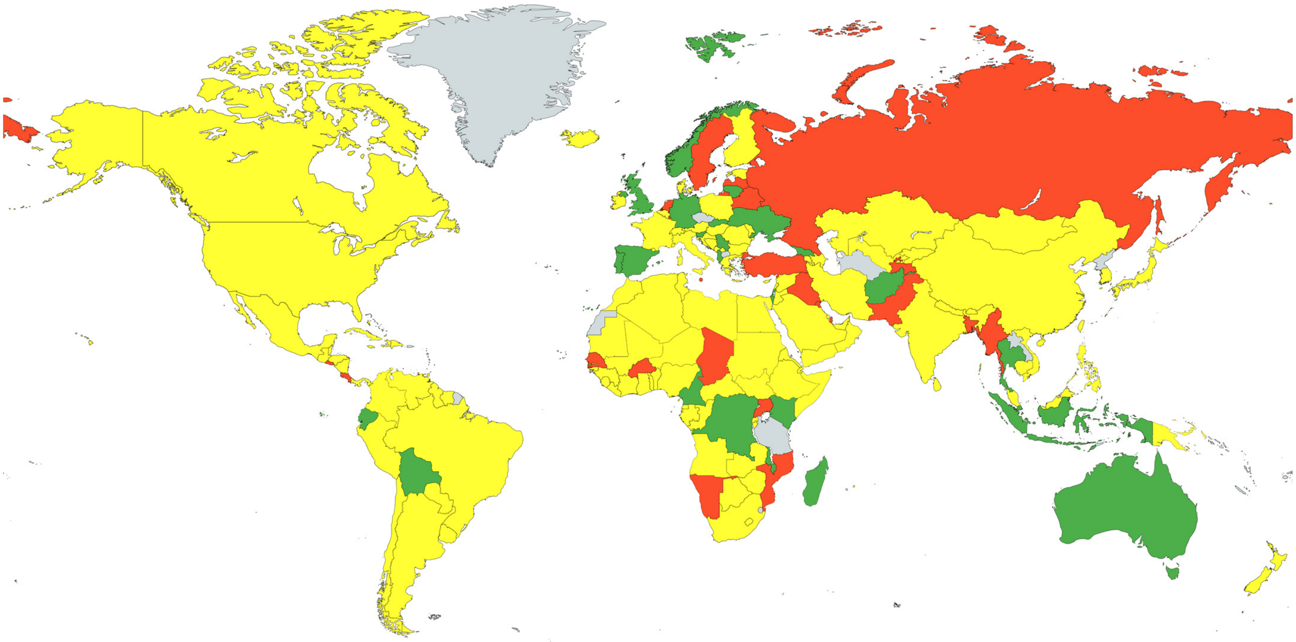

Figure 1. Reliability of COVID-19 data worldwide.

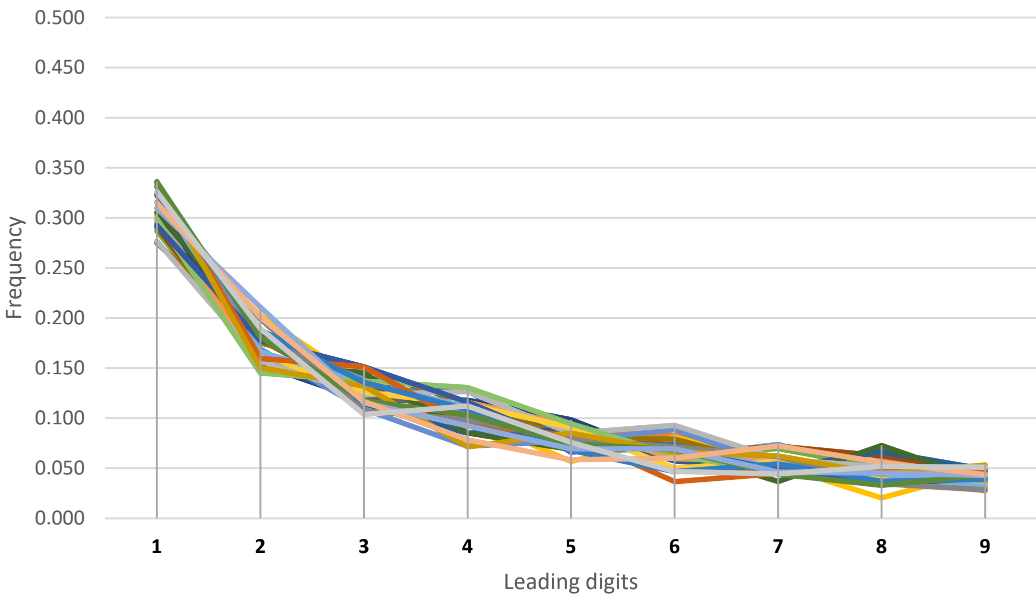

Figure 2. Twenty-seven countries with the highest level of conformity with BL.

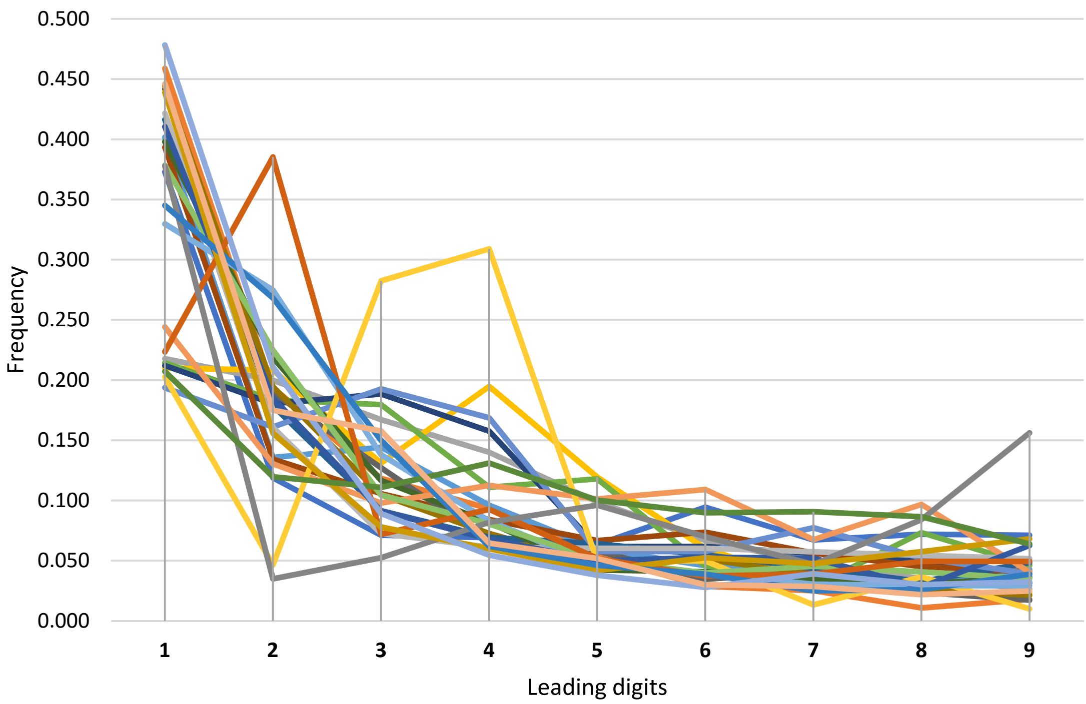

Figure 3. Twenty-six countries with the lowest level of conformity with BL.

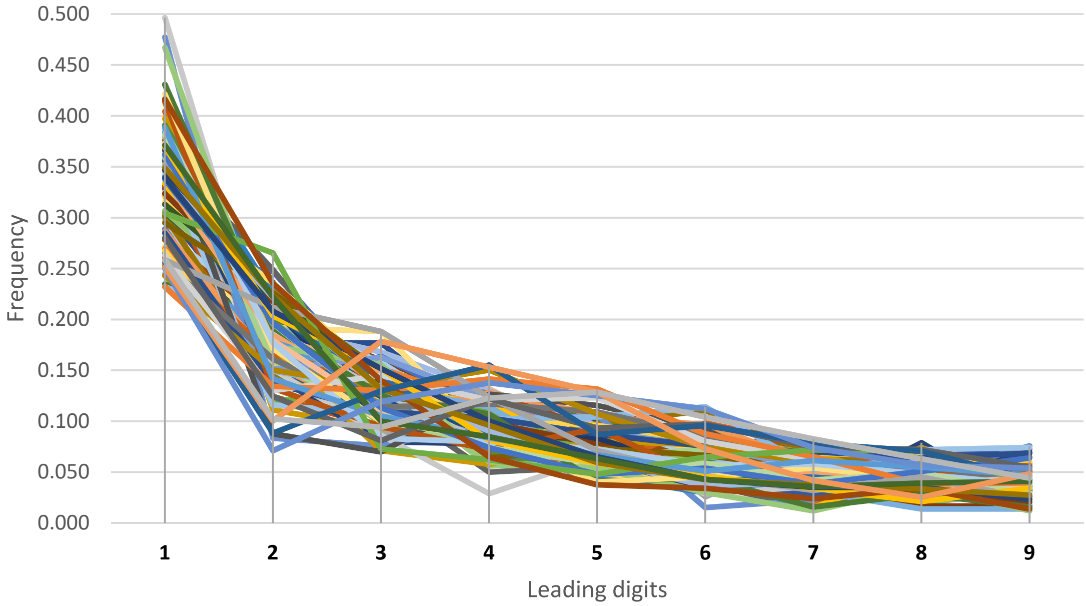

Figure 4. 123 countries with a moderate level of conformity with BL.

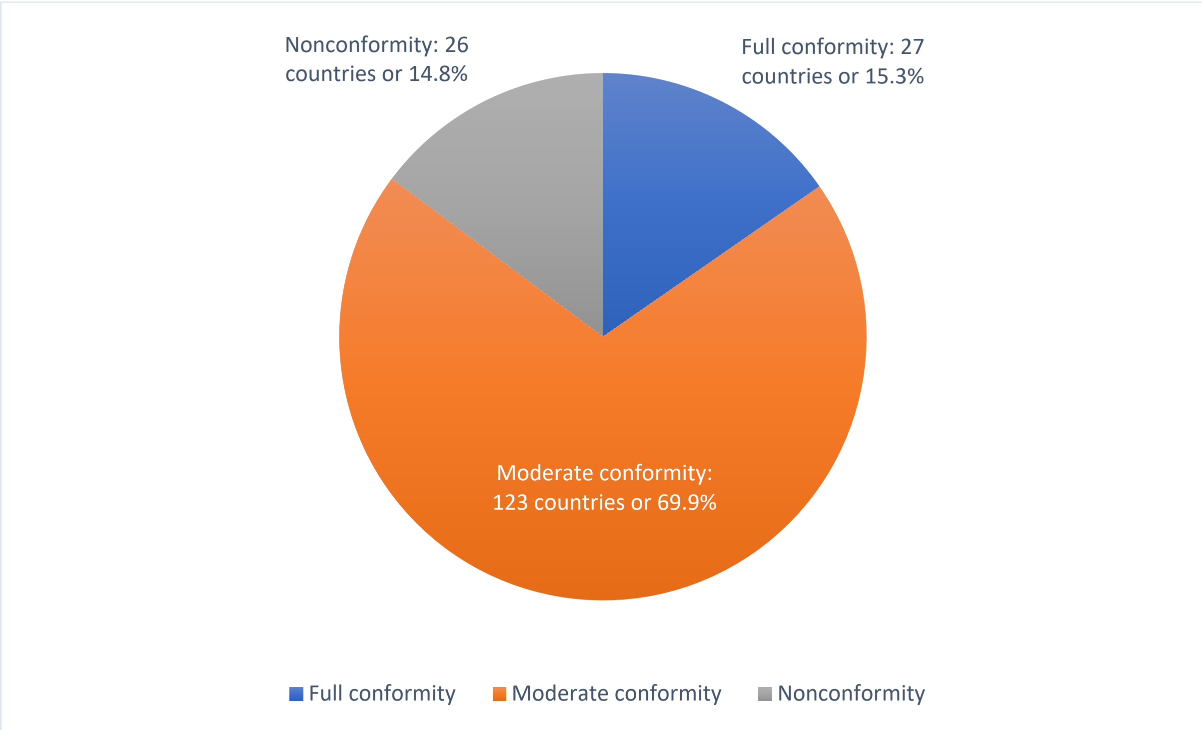

Figure 5. Distribution of conformity to BL.

Table 3 summarizes the results of the statistical analyses for all countries. The K-S, MAD, and χ^2 statistics reveal similar patterns, while Euclidean distance does not always flag non-conformity to BL. According to the K-S statistics, the most substantial evidence for abnormalities regarding BL was found with Bangladesh with D_n: 0.037 and KS: 0.177 at a 5% confidence level, followed by Myanmar and Kuwait. Based on the χ^2 test, we specifically recognized Bangladesh with the most notable non-conformity (n: 1332; χ^2: 177.155; $p < 0.000$). See Table 4 for the list of abbreviations.

In line with prior research [7,16,23], a Euclidean distance above 0.2 can be considered an indicator of BL non-conformity. In this context, Tajikistan showed by far the largest distance from Benford's proportions according to the Euclidean statistic (d^*: 0.306) , followed by El Salvador (d^*: 0.226) , Nicaragua and Timor (d^*: 0.211). Similarly, the very same countries, Tajikistan, Belarus, Nicaragua, and El Salvador, elicited large MAD and SSD statistics. Corresponding to the previous measures with a MAD: 0.082 and an SSD: 1007.9, Tajikistan was ranked one for non-conformity to the law in our assessment. Tajikistan, Belarus, and El Salvador failed to confirm the null hypothesis based on all goodness-of-fit tests (see Table 3). It is noteworthy to emphasize that the null hypothesis can be confirmed for the UK, Spain, Australia, Israel, and Germany, as well as twenty-two nations. According to the K-S statistics, the UK (n: 1358, *cut-off*: 0.037, *K-S*: 0.015) and Australia (n: 878, *cut-off*: 0.046, *K-S*: 0.021) disclosed the most reliable data worldwide.

Table 3. Results of the leading digit distribution analysis.

Location	Improve	Flag	N	GHSI Score	GHSI Rank	d*	Chi Square	*p*-Value	K-S	Cut-Off	SSD	MAD	1	2	3	4	5	6	7	8	9
Comoros	+	G	243	27	160	0.041	0.671	0.715	0.029	0.087	17.693	0.012	0.292	0.181	0.128	0.128	0.066	0.074	0.045	0.058	0.029
United Kingdom	+	G	1358	78	2	0.022	0.269	0.874	0.015	0.037	5.308	0.006	0.295	0.178	0.122	0.094	0.088	0.082	0.059	0.039	0.043
Australia	+	G	878	76	4	0.025	0.143	0.931	0.021	0.046	6.566	0.006	0.302	0.154	0.129	0.101	0.088	0.069	0.055	0.057	0.046
Cameroon	+	G	247	34	115	0.048	0.580	0.748	0.042	0.087	24.721	0.013	0.304	0.202	0.134	0.101	0.057	0.081	0.053	0.020	0.049
Cape Verde	+	G	883	75	5	0.035	1.062	0.588	0.024	0.046	12.976	0.011	0.294	0.159	0.143	0.106	0.086	0.061	0.074	0.044	0.033
Spain	+	G	690	66	15	0.026	0.676	0.713	0.028	0.052	7.074	0.007	0.287	0.162	0.130	0.101	0.090	0.062	0.070	0.051	0.046
Slovenia	+	G	1231	67	12	0.040	4.459	0.108	0.025	0.039	17.484	0.012	0.315	0.154	0.118	0.118	0.098	0.058	0.055	0.041	0.042
Israel	+	G	1335	47	54	0.028	3.830	0.147	0.026	0.037	8.642	0.008	0.291	0.160	0.137	0.092	0.076	0.064	0.072	0.062	0.046
Ecuador	-	G	1284	50	45	0.032	4.380	0.112	0.027	0.038	11.222	0.008	0.275	0.179	0.121	0.113	0.087	0.072	0.055	0.046	0.052
Portugal	+	G	1343	60	20	0.042	8.880	0.012	0.027	0.037	19.040	0.012	0.276	0.175	0.149	0.114	0.080	0.079	0.051	0.042	0.035
Lithuania	+	G	1190	55	33	0.042	5.817	0.055	0.030	0.039	19.319	0.013	0.331	0.160	0.114	0.085	0.088	0.057	0.050	0.066	0.049
Albania	+	G	1281	53	39	0.040	0.495	0.781	0.030	0.038	16.956	0.012	0.305	0.183	0.144	0.085	0.069	0.068	0.037	0.073	0.037
Bolivia	-	G	1267	36	102	0.048	12.762	0.002	0.031	0.038	24.243	0.012	0.332	0.169	0.109	0.072	0.077	0.088	0.052	0.054	0.047
Thailand	+	G	1028	73	6	0.043	9.379	0.009	0.035	0.042	20.066	0.013	0.296	0.159	0.151	0.116	0.092	0.059	0.057	0.043	0.027
Madagascar	-	G	625	40	86	0.051	1.762	0.414	0.045	0.054	28.185	0.014	0.277	0.157	0.123	0.126	0.085	0.093	0.059	0.051	0.029
Malawi	-	G	739	28	154	0.041	7.871	0.020	0.042	0.050	17.702	0.012	0.326	0.164	0.126	0.114	0.091	0.050	0.057	0.039	0.034
Kenya	-	G	999	47	55	0.036	4.676	0.097	0.037	0.043	13.686	0.011	0.323	0.166	0.135	0.111	0.068	0.071	0.050	0.044	0.031
Indonesia	-	G	1242	57	30	0.050	6.403	0.041	0.033	0.039	27.089	0.013	0.299	0.145	0.137	0.130	0.094	0.063	0.046	0.049	0.037
Democratic Rep. of Congo	-	G	992	52	42	0.039	8.025	0.018	0.038	0.043	16.050	0.011	0.292	0.177	0.151	0.116	0.073	0.069	0.048	0.033	0.040
Georgia	-	G	740	52	42	0.055	9.347	0.009	0.044	0.050	32.725	0.014	0.335	0.159	0.151	0.093	0.082	0.036	0.045	0.050	0.047
Afghanistan	-	G	814	32	130	0.042	3.843	0.146	0.044	0.048	19.157	0.012	0.322	0.199	0.107	0.098	0.079	0.071	0.061	0.034	0.028
Serbia	+	G	1318	52	41	0.051	9.552	0.008	0.035	0.037	27.600	0.013	0.336	0.150	0.132	0.071	0.085	0.066	0.062	0.044	0.053
Singapore	-	G	516	59	24	0.040	6.294	0.043	0.057	0.060	17.148	0.013	0.324	0.188	0.136	0.109	0.068	0.047	0.054	0.037	0.039
Norway	+	G	1066	65	16	0.042	9.673	0.008	0.040	0.042	18.949	0.011	0.336	0.181	0.117	0.103	0.074	0.068	0.044	0.033	0.043
Germany	-	G	911	66	14	0.040	1.897	0.387	0.043	0.045	16.883	0.010	0.310	0.211	0.115	0.092	0.069	0.069	0.046	0.045	0.043
Slovakia	+	G	1150	48	52	0.043	2.459	0.292	0.039	0.040	19.395	0.013	0.315	0.201	0.117	0.078	0.058	0.060	0.072	0.056	0.043
Ukraine	+	G	1178	38	94	0.045	6.767	0.034	0.038	0.040	21.283	0.013	0.326	0.189	0.104	0.112	0.076	0.047	0.044	0.052	0.051
Luxembourg	-	R	1027	44	67	0.115	100.876	0.000	0.083	0.042	142.875	0.034	0.373	0.119	0.071	0.069	0.063	0.094	0.067	0.072	0.071
Sao Tome and Principe	-	R	279	31	139	0.170	47.748	0.000	0.175	0.081	308.597	0.039	0.459	0.194	0.118	0.093	0.054	0.029	0.025	0.011	0.018
Pakistan	-	R	1286	36	105	0.107	86.303	0.000	0.083	0.038	122.535	0.029	0.218	0.200	0.167	0.140	0.099	0.067	0.048	0.035	0.026
Qatar	+	R	1114	41	82	0.145	140.096	0.000	0.091	0.041	226.746	0.039	0.210	0.208	0.131	0.195	0.119	0.060	0.031	0.022	0.023
Maldives	-	R	936	34	121	0.112	49.834	0.000	0.101	0.044	135.825	0.027	0.402	0.136	0.144	0.096	0.060	0.046	0.041	0.033	0.043
Russia	-	R	1297	44	63	0.115	73.142	0.000	0.087	0.038	140.934	0.031	0.214	0.184	0.180	0.111	0.118	0.045	0.029	0.073	0.046
Iraq	-	R	1231	26	167	0.123	66.979	0.000	0.089	0.039	161.702	0.029	0.212	0.180	0.188	0.158	0.062	0.062	0.056	0.050	0.032
Latvia	+	R	1154	63	17	0.102	50.915	0.000	0.092	0.040	110.782	0.022	0.393	0.134	0.106	0.084	0.067	0.074	0.056	0.045	0.041
Burkina Faso	-	R	464	30	145	0.150	55.086	0.000	0.157	0.063	242.833	0.035	0.442	0.190	0.127	0.067	0.058	0.034	0.041	0.024	0.017
Chad	-	R	468	29	150	0.152	50.635	0.000	0.162	0.063	248.236	0.036	0.444	0.194	0.105	0.073	0.047	0.051	0.038	0.026	0.021
Namibia	-	R	951	36	104	0.123	60.390	0.000	0.118	0.044	161.190	0.027	0.416	0.179	0.091	0.069	0.064	0.055	0.044	0.033	0.048
Liechtenstein	-	R	686	44	71	0.117	41.237	0.000	0.140	0.052	145.983	0.031	0.398	0.219	0.117	0.082	0.042	0.041	0.035	0.031	0.036
Sweden	-	R	919	72	7	0.144	55.668	0.000	0.122	0.045	224.055	0.036	0.194	0.161	0.193	0.169	0.058	0.058	0.077	0.052	0.039

Table 3. *Cont.*

Location	Improve	Flag	N	GHSI Score	GHSI Rank	d*	Chi Square	*p*-Value	K-S	Cut-Off	SSD	MAD	1	2	3	4	5	6	7	8	9
Netherlands	-	R	889	76	3	0.100	45.611	0.000	0.130	0.046	107.664	0.030	0.244	0.130	0.098	0.112	0.101	0.109	0.067	0.097	0.040
Mozambique	-	R	1046	28	153	0.134	83.369	0.000	0.121	0.042	192.475	0.029	0.422	0.161	0.073	0.061	0.060	0.060	0.057	0.054	0.052
Tajikistan	-	R	301	32	130	0.306	54.806	0.000	0.228	0.078	1007.938	0.082	0.203	0.047	0.282	0.309	0.050	0.050	0.013	0.037	0.010
Uganda	-	R	819	44	63	0.115	41.974	0.000	0.140	0.048	142.794	0.031	0.330	0.275	0.138	0.083	0.046	0.039	0.031	0.029	0.029
Costa Rica	-	R	1081	45	62	0.101	40.234	0.000	0.126	0.041	109.721	0.028	0.378	0.225	0.105	0.080	0.051	0.040	0.045	0.041	0.035
Turkey	-	R	1325	52	40	0.122	76.199	0.000	0.118	0.037	159.610	0.030	0.411	0.185	0.091	0.068	0.050	0.053	0.052	0.028	0.063
El Salvador	-	R	1155	44	65	0.226	72.338	0.000	0.132	0.040	546.613	0.047	0.223	0.385	0.072	0.093	0.052	0.037	0.039	0.049	0.049
Belarus	-	R	916	35	108	0.205	179.177	0.000	0.152	0.045	449.259	0.053	0.378	0.035	0.052	0.082	0.096	0.070	0.047	0.084	0.156
Senegal	-	R	1219	38	95	0.153	128.220	0.000	0.138	0.039	252.393	0.037	0.439	0.156	0.078	0.060	0.042	0.053	0.048	0.057	0.068
Malta	-	R	1081	37	98	0.122	54.984	0.000	0.161	0.041	159.349	0.036	0.345	0.268	0.150	0.062	0.046	0.039	0.025	0.026	0.039
Kuwait	-	R	1236	46	59	0.126	102.810	0.000	0.164	0.039	169.644	0.037	0.207	0.120	0.111	0.131	0.100	0.090	0.091	0.087	0.064
Myanmar	-	R	897	43	72	0.193	141.797	0.000	0.212	0.045	399.077	0.047	0.478	0.211	0.089	0.055	0.038	0.028	0.039	0.030	0.032
Bangladesh	-	R	1332	35	113	0.160	177.155	0.000	0.177	0.037	274.090	0.039	0.446	0.175	0.158	0.065	0.052	0.030	0.029	0.022	0.025
Burundi	+	Y	255	23	177	0.084	5.900	0.052	0.042	0.085	75.552	0.020	0.259	0.247	0.129	0.102	0.075	0.075	0.039	0.039	0.035
Tunisia	+	Y	741	34	122	0.049	1.681	0.432	0.028	0.050	25.807	0.016	0.321	0.150	0.108	0.101	0.097	0.084	0.070	0.040	0.028
Equatorial Guinea	+	Y	155	16	195	0.081	5.403	0.067	0.074	0.109	71.277	0.023	0.355	0.161	0.129	0.097	0.110	0.026	0.071	0.019	0.032
Benin	-	Y	168	29	150	0.061	3.663	0.160	0.075	0.105	39.345	0.019	0.321	0.190	0.149	0.113	0.065	0.077	0.018	0.042	0.024
Ghana	-	Y	793	36	105	0.055	10.155	0.006	0.035	0.048	32.314	0.015	0.266	0.208	0.142	0.116	0.067	0.055	0.055	0.048	0.042
Somalia	-	Y	331	17	194	0.062	3.019	0.221	0.055	0.075	40.701	0.018	0.341	0.190	0.097	0.073	0.076	0.054	0.054	0.076	0.039
Lesotho	-	Y	241	30	144	0.088	5.570	0.062	0.066	0.088	83.903	0.026	0.365	0.158	0.145	0.071	0.083	0.058	0.025	0.079	0.017
Malaysia	+	Y	1195	62	18	0.052	8.787	0.012	0.030	0.039	29.398	0.015	0.328	0.142	0.107	0.091	0.094	0.081	0.057	0.064	0.035
Botswana	+	Y	180	31	139	0.080	3.316	0.191	0.079	0.101	68.924	0.019	0.361	0.194	0.122	0.050	0.056	0.067	0.061	0.039	0.050
Oman	-	Y	695	43	73	0.063	8.769	0.012	0.044	0.052	43.012	0.018	0.345	0.153	0.135	0.065	0.072	0.059	0.047	0.059	0.065
Papua New Guinea	-	Y	212	28	155	0.093	7.982	0.018	0.081	0.093	92.590	0.024	0.382	0.156	0.118	0.085	0.094	0.033	0.038	0.061	0.033
Kosovo	+	Y	613	19	189	0.073	15.973	0.000	0.048	0.055	57.386	0.020	0.349	0.148	0.085	0.075	0.088	0.070	0.069	0.070	0.046
Greece	+	Y	1233	54	37	0.059	18.225	0.000	0.036	0.039	37.519	0.016	0.265	0.211	0.142	0.084	0.101	0.066	0.058	0.042	0.032
Belize	+	Y	395	32	135	0.065	6.175	0.046	0.064	0.068	45.385	0.016	0.354	0.182	0.129	0.068	0.078	0.056	0.068	0.035	0.028
Central African Republic	-	Y	211	27	159	0.104	7.976	0.019	0.088	0.094	117.203	0.027	0.389	0.152	0.085	0.128	0.066	0.071	0.047	0.033	0.028
Nigeria	+	Y	922	38	96	0.056	10.820	0.004	0.045	0.045	33.339	0.014	0.346	0.151	0.129	0.103	0.081	0.073	0.042	0.047	0.028
Bulgaria	-	Y	1194	46	61	0.048	9.217	0.010	0.040	0.039	24.370	0.012	0.341	0.153	0.121	0.108	0.072	0.059	0.049	0.052	0.044
Bahamas	-	Y	368	31	142	0.081	9.860	0.007	0.072	0.071	70.910	0.017	0.372	0.177	0.098	0.101	0.073	0.065	0.054	0.016	0.043
Algeria	+	Y	897	24	173	0.062	17.434	0.000	0.047	0.045	41.616	0.017	0.329	0.156	0.082	0.099	0.071	0.060	0.059	0.070	0.072
Mauritius	-	Y	188	35	114	0.116	9.613	0.008	0.103	0.099	145.528	0.029	0.404	0.154	0.133	0.069	0.059	0.043	0.021	0.059	0.059
Eritrea	+	Y	180	22	178	0.089	2.842	0.241	0.106	0.101	85.701	0.026	0.356	0.228	0.106	0.083	0.039	0.050	0.067	0.044	0.028
St. Vincent & the Grenadines	-	Y	162	34	117	0.135	11.659	0.003	0.113	0.107	194.677	0.033	0.414	0.111	0.093	0.080	0.074	0.080	0.037	0.074	0.037
Jordan	-	Y	904	42	80	0.069	2.339	0.311	0.048	0.045	50.371	0.016	0.289	0.237	0.100	0.104	0.062	0.071	0.044	0.051	0.043
Kyrgyzstan	-	Y	677	49	47	0.078	25.854	0.000	0.057	0.052	64.878	0.022	0.244	0.208	0.151	0.121	0.095	0.062	0.058	0.038	0.024
Seychelles	+	Y	173	32	133	0.096	8.408	0.015	0.115	0.103	99.877	0.026	0.382	0.208	0.127	0.087	0.052	0.046	0.046	0.023	0.029
Andorra	+	Y	394	31	143	0.057	12.815	0.002	0.078	0.069	34.776	0.017	0.325	0.185	0.135	0.132	0.076	0.056	0.033	0.033	0.025
Yemen	+	Y	548	19	190	0.057	6.733	0.035	0.066	0.058	35.325	0.015	0.349	0.193	0.126	0.086	0.055	0.058	0.049	0.047	0.036

Table 3. *Cont.*

Location	Improve	Flag	N	GHSI Score	GHSI Rank	d*	Chi Square	*p*-Value	K-S	Cut-Off	SSD	MAD	1	2	3	4	5	6	7	8	9
South Sudan	-	Y	384	22	180	0.092	11.672	0.003	0.079	0.069	91.440	0.023	0.380	0.138	0.107	0.091	0.096	0.049	0.049	0.060	0.029
Poland	+	Y	1296	55	32	0.060	25.505	0.000	0.043	0.038	38.032	0.019	0.261	0.200	0.140	0.110	0.097	0.080	0.047	0.029	0.036
Nepal	-	Y	1170	35	111	0.056	11.773	0.003	0.046	0.040	33.148	0.014	0.347	0.148	0.118	0.103	0.078	0.055	0.051	0.061	0.040
Zambia	+	Y	1010	29	152	0.054	0.012	0.994	0.050	0.043	31.699	0.014	0.302	0.137	0.114	0.125	0.100	0.080	0.057	0.050	0.036
Cambodia	+	Y	300	39	89	0.075	13.945	0.001	0.092	0.079	60.309	0.025	0.280	0.200	0.160	0.117	0.097	0.083	0.030	0.017	0.017
Ireland	-	Y	1208	59	23	0.062	12.574	0.002	0.046	0.039	41.844	0.015	0.347	0.137	0.132	0.109	0.076	0.059	0.043	0.047	0.050
Vietnam	+	Y	452	49	50	0.081	12.304	0.002	0.075	0.064	70.418	0.019	0.376	0.155	0.131	0.086	0.062	0.058	0.049	0.033	0.051
Brazil	-	Y	888	60	22	0.051	8.189	0.017	0.055	0.046	28.303	0.014	0.262	0.160	0.127	0.098	0.100	0.083	0.075	0.054	0.039
Djibouti	-	Y	432	23	175	0.068	7.371	0.025	0.079	0.065	49.710	0.017	0.356	0.199	0.111	0.095	0.053	0.049	0.046	0.049	0.042
Morocco	+	Y	1308	44	68	0.049	6.044	0.049	0.045	0.038	26.028	0.011	0.300	0.222	0.116	0.096	0.070	0.050	0.060	0.046	0.041
Congo	+	Y	1145	27	160	0.038	12.849	0.002	0.049	0.040	15.226	0.011	0.304	0.182	0.152	0.110	0.072	0.063	0.045	0.034	0.038
South Korea	+	Y	1299	70	9	0.061	1.826	0.401	0.046	0.038	40.559	0.017	0.298	0.133	0.129	0.126	0.105	0.085	0.049	0.042	0.033
Lebanon	-	Y	807	43	73	0.057	14.883	0.001	0.058	0.048	34.396	0.014	0.346	0.188	0.125	0.090	0.079	0.074	0.045	0.029	0.024
Sudan	-	Y	847	26	163	0.061	13.935	0.001	0.058	0.047	40.087	0.014	0.359	0.165	0.115	0.084	0.083	0.058	0.048	0.051	0.038
Paraguay	+	Y	1228	36	103	0.058	3.315	0.191	0.049	0.039	36.169	0.017	0.314	0.196	0.140	0.056	0.059	0.092	0.052	0.052	0.038
Azerbaijan	-	Y	888	34	117	0.057	13.634	0.001	0.058	0.046	34.794	0.013	0.306	0.177	0.177	0.092	0.075	0.046	0.051	0.043	0.033
Iceland	-	Y	797	46	58	0.071	20.778	0.000	0.062	0.048	54.824	0.020	0.331	0.124	0.094	0.088	0.093	0.077	0.078	0.061	0.054
Cuba	-	Y	1117	35	110	0.061	11.846	0.003	0.052	0.041	40.132	0.018	0.346	0.184	0.098	0.089	0.063	0.045	0.073	0.064	0.039
Angola	-	Y	677	25	170	0.061	16.569	0.000	0.067	0.052	40.082	0.015	0.301	0.227	0.140	0.095	0.075	0.047	0.044	0.046	0.024
Niger	-	Y	423	32	132	0.078	13.168	0.001	0.086	0.066	65.329	0.019	0.371	0.191	0.106	0.092	0.073	0.057	0.040	0.028	0.040
New Zealand	-	Y	711	54	35	0.079	16.060	0.000	0.066	0.051	66.206	0.019	0.235	0.205	0.120	0.105	0.108	0.084	0.060	0.044	0.038
Uzbekistan	-	Y	655	34	116	0.095	31.531	0.000	0.069	0.053	96.707	0.027	0.232	0.192	0.168	0.130	0.096	0.078	0.058	0.027	0.018
Monaco	-	Y	335	33	125	0.084	13.777	0.001	0.097	0.074	75.835	0.021	0.373	0.197	0.128	0.084	0.069	0.039	0.033	0.045	0.033
Peru	-	Y	1216	49	49	0.062	19.499	0.000	0.051	0.039	40.612	0.014	0.352	0.142	0.112	0.095	0.070	0.068	0.061	0.058	0.043
Philippines	-	Y	1329	48	53	0.074	28.708	0.000	0.050	0.037	58.785	0.019	0.272	0.192	0.188	0.082	0.087	0.053	0.044	0.046	0.037
Italy	-	Y	1401	56	31	0.053	28.798	0.000	0.049	0.036	30.554	0.016	0.284	0.205	0.158	0.091	0.089	0.065	0.044	0.032	0.032
Mali	+	Y	641	29	147	0.069	17.817	0.000	0.072	0.054	50.585	0.016	0.360	0.189	0.125	0.094	0.070	0.039	0.058	0.034	0.031
Colombia	+	Y	1247	44	65	0.057	0.907	0.636	0.052	0.039	35.473	0.014	0.289	0.136	0.164	0.111	0.074	0.062	0.065	0.057	0.043
Chile	+	Y	1310	58	27	0.055	8.617	0.013	0.052	0.038	32.810	0.017	0.269	0.156	0.152	0.116	0.092	0.082	0.063	0.035	0.035
United States	-	Y	1389	84	1	0.070	38.599	0.000	0.050	0.036	52.595	0.019	0.351	0.150	0.088	0.084	0.071	0.082	0.065	0.048	0.060
Rwanda	-	Y	917	34	117	0.048	14.015	0.001	0.062	0.045	25.234	0.014	0.334	0.178	0.133	0.117	0.067	0.051	0.058	0.031	0.033
Croatia	-	Y	1216	53	38	0.049	15.050	0.001	0.054	0.039	26.076	0.013	0.260	0.182	0.121	0.082	0.095	0.076	0.064	0.065	0.055
Canada	-	Y	1373	75	5	0.062	24.887	0.000	0.052	0.037	41.817	0.015	0.307	0.121	0.122	0.111	0.067	0.090	0.066	0.059	0.058
Togo	-	Y	951	33	129	0.086	37.973	0.000	0.063	0.044	79.918	0.023	0.364	0.146	0.080	0.078	0.074	0.064	0.070	0.055	0.069
Belgium	+	Y	1341	61	19	0.052	35.970	0.000	0.053	0.037	29.543	0.017	0.278	0.195	0.139	0.128	0.092	0.059	0.042	0.040	0.028
Guinea-Bissau	-	Y	209	20	186	0.113	18.146	0.000	0.135	0.094	135.866	0.032	0.364	0.249	0.120	0.081	0.086	0.038	0.014	0.033	0.014
Uruguay	-	Y	1013	41	81	0.062	12.697	0.002	0.062	0.043	41.453	0.017	0.301	0.146	0.115	0.075	0.098	0.111	0.068	0.057	0.030
Hong Kong	-	Y	574	28	156	0.092	21.168	0.000	0.084	0.057	89.973	0.022	0.385	0.153	0.108	0.078	0.057	0.066	0.051	0.064	0.037
Bosnia and Herzegovina	-	Y	1030	43	79	0.050	21.187	0.000	0.063	0.042	26.605	0.014	0.305	0.208	0.152	0.089	0.081	0.051	0.042	0.038	0.034

Table 3. *Cont.*

Location	Improve	Flag	N	GHSI Score	GHSI Rank	d*	Chi Square	p-Value	K-S	Cut-Off	SSD	MAD	1	2	3	4	5	6	7	8	9
Nicaragua	-	Y	132	43	73	0.211	19.536	0.000	0.176	0.118	476.672	0.052	0.477	0.083	0.076	0.098	0.106	0.015	0.023	0.045	0.076
Mexico	+	Y	1412	58	28	0.063	2.001	0.368	0.055	0.036	43.110	0.020	0.287	0.156	0.105	0.128	0.106	0.096	0.059	0.042	0.021
Argentina	-	Y	1369	59	25	0.046	13.457	0.001	0.056	0.037	23.115	0.013	0.307	0.213	0.137	0.099	0.063	0.047	0.053	0.046	0.036
Bahrain	+	Y	1115	39	88	0.070	22.249	0.000	0.063	0.041	53.038	0.017	0.364	0.157	0.120	0.078	0.066	0.062	0.055	0.038	0.060
San Marino	+	Y	290	31	139	0.100	19.638	0.000	0.125	0.080	106.677	0.028	0.379	0.197	0.134	0.114	0.055	0.062	0.031	0.014	0.014
Romania	+	Y	1251	46	60	0.054	5.123	0.077	0.061	0.038	31.636	0.014	0.306	0.220	0.137	0.089	0.053	0.070	0.043	0.044	0.039
Liberia	-	Y	281	35	111	0.135	26.918	0.000	0.130	0.081	195.629	0.029	0.431	0.171	0.125	0.078	0.064	0.043	0.028	0.028	0.032
Guatemala	-	Y	1295	33	125	0.061	29.478	0.000	0.061	0.038	40.320	0.017	0.261	0.165	0.141	0.097	0.053	0.098	0.076	0.052	0.056
Guinea	-	Y	1044	33	125	0.072	30.669	0.000	0.068	0.042	55.286	0.016	0.369	0.171	0.117	0.093	0.083	0.051	0.042	0.043	0.031
Suriname	-	Y	521	37	100	0.115	25.926	0.000	0.096	0.060	142.452	0.026	0.397	0.173	0.071	0.058	0.081	0.077	0.069	0.036	0.038
Saint Lucia	-	Y	236	34	117	0.115	13.386	0.001	0.144	0.089	143.057	0.032	0.390	0.225	0.131	0.068	0.047	0.030	0.047	0.038	0.025
Sierra Leone	+	Y	399	38	92	0.101	15.642	0.000	0.112	0.068	109.284	0.025	0.391	0.198	0.110	0.070	0.048	0.060	0.045	0.038	0.040
Haiti	-	Y	440	32	138	0.077	14.272	0.001	0.109	0.065	63.501	0.024	0.350	0.207	0.155	0.080	0.059	0.057	0.039	0.025	0.030
South Africa	-	Y	1307	55	34	0.051	9.914	0.007	0.064	0.038	27.618	0.014	0.323	0.208	0.135	0.094	0.054	0.047	0.049	0.050	0.040
Timor	-	Y	139	73	6	0.210	25.374	0.000	0.195	0.115	472.994	0.046	0.496	0.151	0.086	0.029	0.065	0.029	0.036	0.065	0.043
Guyana	-	Y	577	32	137	0.077	14.948	0.001	0.096	0.057	63.211	0.021	0.315	0.236	0.144	0.101	0.049	0.042	0.050	0.036	0.028
India	+	Y	1320	47	57	0.085	52.542	0.000	0.064	0.037	77.131	0.024	0.345	0.116	0.108	0.092	0.064	0.057	0.073	0.072	0.074
Moldova	-	Y	884	43	78	0.085	29.256	0.000	0.079	0.046	78.338	0.019	0.380	0.160	0.102	0.075	0.064	0.072	0.053	0.049	0.045
Trinidad and Tobago	-	Y	853	37	99	0.066	15.502	0.000	0.081	0.047	47.259	0.019	0.347	0.211	0.101	0.086	0.083	0.050	0.047	0.042	0.033
Armenia	-	Y	1063	50	44	0.059	32.450	0.000	0.074	0.042	37.683	0.017	0.324	0.217	0.134	0.099	0.077	0.049	0.050	0.030	0.021
Egypt	+	Y	901	40	87	0.139	30.916	0.000	0.081	0.045	206.061	0.038	0.382	0.088	0.070	0.127	0.115	0.092	0.039	0.048	0.040
Austria	-	Y	1265	59	26	0.066	8.700	0.013	0.068	0.038	47.003	0.017	0.295	0.226	0.149	0.064	0.074	0.066	0.053	0.047	0.026
Bhutan	-	Y	636	40	85	0.082	23.532	0.000	0.097	0.054	71.710	0.022	0.366	0.208	0.124	0.088	0.063	0.035	0.042	0.038	0.036
Kazakhstan	+	Y	1160	41	83	0.061	18.710	0.000	0.072	0.040	40.319	0.017	0.313	0.222	0.139	0.095	0.061	0.043	0.040	0.034	0.053
Dominican Republic	-	Y	1205	38	91	0.069	14.702	0.001	0.071	0.039	51.746	0.019	0.255	0.151	0.163	0.122	0.090	0.078	0.051	0.052	0.037
Macedonia	-	Y	1273	44	67	0.055	13.658	0.001	0.070	0.038	32.322	0.015	0.339	0.184	0.149	0.087	0.056	0.046	0.049	0.047	0.043
Mauritania	-	Y	621	28	157	0.089	26.356	0.000	0.100	0.055	85.478	0.022	0.382	0.192	0.129	0.077	0.066	0.052	0.034	0.040	0.029
Libya	-	Y	1032	26	168	0.061	13.766	0.001	0.078	0.042	40.384	0.017	0.267	0.132	0.135	0.103	0.096	0.080	0.069	0.065	0.053
Jamaica	-	Y	911	29	147	0.081	18.392	0.000	0.083	0.045	70.719	0.022	0.245	0.149	0.132	0.102	0.104	0.114	0.053	0.064	0.037
Antigua and Barbuda	-	Y	167	29	147	0.182	28.846	0.000	0.194	0.105	354.099	0.044	0.467	0.174	0.156	0.060	0.054	0.030	0.012	0.036	0.012
Panama	-	Y	1327	44	68	0.053	24.376	0.000	0.071	0.037	30.231	0.016	0.285	0.137	0.109	0.103	0.087	0.075	0.070	0.064	0.069
Mongolia	-	Y	528	50	46	0.127	32.670	0.000	0.114	0.059	172.786	0.030	0.415	0.133	0.095	0.072	0.093	0.044	0.061	0.055	0.034
Japan	-	Y	1403	60	21	0.062	13.994	0.001	0.071	0.036	40.952	0.017	0.256	0.161	0.114	0.117	0.109	0.086	0.063	0.045	0.050
Palestine	-	Y	1025	22	179	0.086	20.281	0.000	0.084	0.042	78.862	0.022	0.243	0.150	0.133	0.150	0.107	0.074	0.060	0.043	0.040
Switzerland	-	Y	1132	67	13	0.058	23.038	0.000	0.082	0.040	36.236	0.018	0.337	0.205	0.141	0.085	0.067	0.046	0.045	0.037	0.036
Barbados	+	Y	318	32	133	0.144	37.916	0.000	0.156	0.076	224.021	0.035	0.431	0.192	0.126	0.107	0.041	0.044	0.016	0.028	0.016
Cote d'Ivoire	-	Y	985	45	62	0.070	25.310	0.000	0.089	0.043	52.255	0.020	0.338	0.221	0.132	0.090	0.062	0.037	0.041	0.039	0.041
Zimbabwe	-	Y	1004	38	92	0.089	38.520	0.000	0.089	0.043	85.562	0.020	0.386	0.179	0.111	0.080	0.073	0.057	0.041	0.036	0.038

Table 3. *Cont.*

Location	Improve	Flag	N	GHSI Score	GHSI Rank	d*	Chi Square	*p*-Value	K-S	Cut-Off	SSD	MAD	1	2	3	4	5	6	7	8	9
Estonia	-	Y	1145	57	29	0.080	9.786	0.007	0.084	0.040	69.405	0.023	0.263	0.130	0.145	0.121	0.123	0.080	0.062	0.046	0.030
China	-	Y	572	48	51	0.127	39.363	0.000	0.120	0.057	173.961	0.027	0.421	0.171	0.100	0.084	0.040	0.045	0.054	0.042	0.042
Sri Lanka	+	Y	1105	34	120	0.094	38.592	0.000	0.087	0.041	95.596	0.019	0.386	0.177	0.083	0.080	0.072	0.057	0.058	0.048	0.038
Taiwan	+	Y	853	20	188	0.089	27.857	0.000	0.100	0.047	85.408	0.022	0.381	0.196	0.113	0.074	0.059	0.059	0.042	0.049	0.028
Hungary	-	Y	1299	54	35	0.079	23.001	0.000	0.081	0.038	66.352	0.022	0.362	0.196	0.113	0.074	0.048	0.054	0.038	0.051	0.064
Montenegro	-	Y	707	44	68	0.105	16.849	0.000	0.111	0.051	119.439	0.029	0.232	0.134	0.130	0.141	0.132	0.088	0.065	0.038	0.040
France	-	Y	1281	68	11	0.094	76.522	0.000	0.082	0.038	94.449	0.028	0.258	0.212	0.188	0.123	0.071	0.046	0.032	0.045	0.024
Gambia	-	Y	614	34	117	0.091	30.900	0.000	0.123	0.055	88.921	0.027	0.370	0.204	0.151	0.081	0.059	0.046	0.034	0.021	0.034
Denmark	-	Y	1256	70	8	0.096	49.049	0.000	0.088	0.038	98.450	0.021	0.389	0.142	0.105	0.084	0.067	0.051	0.061	0.055	0.047
Iran	+	Y	1127	38	97	0.112	5.333	0.069	0.093	0.041	135.330	0.028	0.304	0.265	0.073	0.062	0.048	0.065	0.072	0.071	0.040
Cyprus	-	Y	1029	43	77	0.070	44.142	0.000	0.100	0.042	52.767	0.022	0.339	0.208	0.152	0.100	0.065	0.043	0.035	0.035	0.023
Gabon	-	Y	293	20	186	0.148	30.780	0.000	0.190	0.079	234.031	0.042	0.416	0.235	0.140	0.065	0.038	0.034	0.024	0.034	0.014
Honduras	-	Y	803	28	156	0.084	27.827	0.000	0.116	0.048	75.724	0.026	0.280	0.125	0.081	0.122	0.093	0.097	0.075	0.072	0.055
United Arab Emirates	-	Y	1313	47	56	0.078	51.925	0.000	0.102	0.038	66.126	0.023	0.349	0.223	0.132	0.096	0.059	0.043	0.037	0.034	0.027
Venezuela	-	Y	793	23	176	0.119	22.070	0.000	0.137	0.048	151.751	0.031	0.252	0.088	0.130	0.155	0.087	0.096	0.078	0.071	0.043
Finland	-	Y	1121	69	10	0.093	38.588	0.000	0.116	0.041	93.114	0.026	0.371	0.222	0.100	0.085	0.063	0.043	0.036	0.039	0.041
Syria	-	Y	704	20	188	0.136	24.703	0.000	0.162	0.051	198.265	0.036	0.250	0.071	0.119	0.138	0.125	0.112	0.074	0.057	0.054
Saudi Arabia	-	Y	1345	49	47	0.128	37.702	0.000	0.125	0.037	176.310	0.037	0.251	0.100	0.178	0.153	0.129	0.073	0.042	0.025	0.048
Ethiopia	-	Y	1222	41	84	0.112	37.873	0.000	0.147	0.039	134.157	0.033	0.259	0.102	0.094	0.123	0.128	0.104	0.083	0.063	0.044

Table 4. Abbreviations.

ABBREVIATION	DESCRIPTION
Location	Country or territory
Improve	Development of Benford's Law in reporting, including positive and negative development
Flag	Red, Green, and Yellow
N	Number of sample
d*	d-factor
Chi square	The Chi square goodness of fit test
p-value	*p*-value of the Chi square
K-S	Kolmogorov-Smirnov statistic
Cut-Off	Kolmogorov-Smirnov cut off
SSD	Sum of Squares Difference
MAD	Mean Absolute Deviation
1	Leading digit frequency with 1
2	Leading digit frequency with 2
3	Leading digit frequency with 3
4	Leading digit frequency with 4
5	Leading digit frequency with 5
6	Leading digit frequency with 6
7	Leading digit frequency with 7
8	Leading digit frequency with 8
9	Leading digit frequency with 9

4. Conclusions

Can we rely on COVID-19 data? To address the central question of this study, we investigated data from 182 countries worldwide. To improve the accuracy of the statistical measurements, we applied five statistical tests. Farhadi applied K-S, chi-square, and *d** statistics in a timeframe of nine months [2]; Koch and Okamura used the Kuiper test (a modified K-S test), chi-square, and *d* for* [4]; Wie and Vellwock operationalized *d** statistics for circa eight months [7]. The results confirm that 15.34% of countries do not adhere to BL at all. This is, to some extent, in agreement with prior research [2–9]. Most European countries, except Latvia, Luxembourg, the Netherlands, and Sweden, demonstrated conformity by satisfying at least one of the tests. This is also true for the Americas and APAC regions. Apparently, the US revealed a declining pattern of BL reliability. Remarkably, the UK (*n: 1358*, *d*: 0.022; K-S: 0.015*), Australia (*n: 878, d*: 0.025, K-S: 0.021*), Spain (*n: 690, d*: 0.026, K-S: 0.028*), and Israel (*n: 1335, d*: 0.028, K-S: 0.026*) overwhelmingly conform to BL. This group could evidently maintain or improve the quality of COVID-19 incident reports compared to prior research; in a nine-month study of COVID-19 data, Farhadi identified the following measures for the UK (*n: 593, d*: 0.076; K-S: 0.051*), Australia (*n: 497, d*: 0.029, K-S: 0.031*), Spain (*n: 353, d*: 0.086, K-S: 0.074*), and Israel (*n: 597, d*: 0.081, K-S: 0.087*) [2]. This development goes in line with the organizational learning theory suggesting that proficiency in the fight against pandemics grows by gaining experience in managing pandemics over time. These countries introduced advanced programs to counter the epidemic within their national borders, such as non-pharmaceutical measures (lockdowns, travel bans, and social distancing) or progressive vaccinations. Consistent with Farhadi's results, Germany was able to maintain the BL reliability (*n: 911, d*: 0.040; K-S: 0.043* as of June 6, 2021, versus *n: 408, d*: 0.032; K-S: 0.026* as of September 22, 2020). The US, which was identified as one of the champions of Benfordness by Farhadi, could partially pass the goodness-of-fit tests. With a non-confirmatory K-S-statistic (*n:1389, cut-off: 0.036, K-S: 0.050*), the null hypothesis for the US was rejected based on one test in our study. This suggests a decreased Benfordness of the US data over the past nine months from 24 February 2020 to 6 June 2021. Similarly, China conformed to BL in prior studies [2,4,5,24]; according to our results, however, China with 572 observations did not pass three tests applied in our evaluation.

Furthermore, 14.8% of the countries did not pass any of the tests applied in this study. Therefore, we rejected the null hypothesis for these cases. The most significant irregularities occurred in Tajikistan, Belarus, Myanmar, Turkey, Bangladesh, and El Salvador. In January 2021, Tajikistan declared itself COVID-19 free, which explains the lack of BL conformity in our assessment [25]. Distressed social-economic conditions can explain the poor reliability of pandemic data in Belarus and Myanmar [26,27]. Experts posit that Bangladesh has seen a decline in COVID-19 incidents as it reduced the number of tests affecting the recorded infection rates [28]. Turkey, which could not pass any goodness-of-fit test in our study, strives for a speedy recovery of its suffering hospitality industry [29]. It is noteworthy that 70% of El Salvador's population work in an informal economy [30]. These distressed countries have been facing major economic, social, or political challenges during the course of the pandemic.

Notably, Johns Hopkins University (JHU) studied national capabilities, procedures, systems, and policies to respond to epidemic challenges across 195 countries [24]. Considering the Global Health Security Index of JHU (GHSI), we recognize consistency in the case of Tajikistan, ranked 144 for early detection and reporting. However, Latvia remains questionable. As a former member of the Soviet Union, it was placed second in the GHSI after the US and Australia; surprisingly and contrary to the JHU's results, Latvia significantly violates BL. This was also confirmed in prior research [2]. Furthermore, JHU identified the highest scores for "early detection and reporting for epidemics of potential international concern" for the countries with significant BL conformity, such as Australia (ranked 2nd), the UK (ranked 6th), Germany (ranked 10th), or Spain (ranked 7th). However, countries with poor BL conformity demonstrated much weaker epidemic reporting capabilities worldwide. We conducted Farhadi's approach [2], and in a further attempt, operationalized Pearson's product-moment correlation analysis to explore the relationship between the GHSI scores and the goodness-of-fit tests. Preliminary analyses were conducted to ensure no violation of assumptions of normality, linearity, and homoscedasticity. We identified a negative partial correlation between the GHSI score and K-S statistic, which suggests correlation at a moderate level (r: -0.27, n: 176, $p < 0.0005$) that all countries with a high GHSI score provide reliable COVID-19 data. Our results are consistent with prior investigations [2].

Contradictions with the law may be an indicator of data manipulation or the act of creating artificially fabricated data [2–9]. If so, there is a strong need to understand the actual numbers of the death cases. Irregularities with BL may pertain to varying national policies and limited preventing capacity to detect and report COVID-19 incidents; the WHO claimed early on that some nations do not have sufficient access to testing kits [31]. To effectively fight the spread of any disease in the future, we recommend establishing global governance for pandemic measurement [2,32,33]. Having access to reliable data is vital in the fight against disastrous pandemics and submicroscopic infectious organisms.

5. Future Research

In our study, we identified tangible improvements in the quality of pandemic data, as well as diminishing data reliability in the context of COVID-19 data in several countries worldwide. It is of particular importance to understand the formative indicators and causality of these developments. To address this issue accurately, one shall further examine the economic, political, and social conditions of these jurisdictions and the impact of the COVID-19 pandemic on Benfordness. In the case of the red-flagged countries, we still need to gain a deeper understanding of the domestic healthcare processes and epidemic reporting policies. Based on the key results of this study, the authors recommend reproducing the forensic BL assessment in a later re-examination of the pandemic data. Ensuring BL reliability may be a fundamental step in the fight against epidemics in general, as well as COVID-19 in particular. We further recommend investigating the regressive and correlative relationships of our results with the social-political and economic transformation indices, e.g., the Bertelsmann Transformation Index (or BTI). Through this approach, evidence may be found for a causal relationship between the social-economic and political variables and the phenomenon of BL non-conformity of epidemic data. Ultimately, we hope to have contributed to the combat against SARS-CoV-2 with this paper.

6. Limitation

The data gathered from all countries in our study are affected by diverging public health systems and data reporting policies. Lack of common policies for reporting on a global basis, particularly in developing countries, may have affected the efficiency and effectiveness of COVID-19 reports.

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