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Original Research

Measuring Rain Rates Exceeding the Polish Average by 0.01%

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Abstract

Kielce University of Technology was a member of the international research project COST Action IC0802 – Propagation Tools and Data for Integrated Telecommunication, Navigation, and Earth Observation Systems, whose main goal was to analyze the impact of weather conditions on the quality of wireless satellite transmissions. Measurements in the region of Kielce city seem to be a good indication for rain rate exceeding the average year in Poland by 0.01%, especially due to a central location, environment, and morphology of terrain. Near the city since 1974 at Psary-Kąty was a large satellite ground station, operated by *TP SA*, with up to seven large parabolic antennae. The aim of this study was to present the rain rate (mm/h) exceeding the average year ($R_{0.01}$) in Poland by 0.01%. The part of results connected with measurements and data acquisitions and their processing for rain rate exceeding the average year by 0.01% is presented in this article. This $R_{0.01}$ parameter for Kielce was experimentally verified. Moreover, the $R_{0.01}$ parameters for the most important regions in Poland are also included in the article. On the basis of this we can predict, e.g., the availability of satellite systems within the whole territory in Poland to minimize the risk of lack or interruption of communications due to adverse weather conditions.

Keywords: meteorological characteristics, precipitation, rain rate $R_{0.01}$ (mm/h) exceeding 0.01% of the average year, propagation modelling

Introduction

Kielce University of Technology was a member of the research project COST Action IC0802 – Propagation Tools and Data for Integrated Telecommunication, Navigation, and Earth Observation Systems. Work on this project concentrated mostly on free space propagation, meteorology, and developing a coordinated set of models in order to improve the realization and design of Global Integrated Networks (including GMES and the Disaster Management and Relief System) [1-4]. This system is complicated, because it includes many types of instruments of labor (mobile and fixed communication systems, satellite, and terrestrial communication systems, satellite navigation systems, etc.).

To estimate a rain rate (mm/h) that exceeded the average year ($R_{0.01}$) in Poland (one-minute integration time) by 0.01% (meaning 53 minutes per year), we can use the data from the ITU-R recommendations (the last ITU-R updating characteristics of precipitation for propagation

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modelling are included in the recommendation of ITU-R No. P.837-6 (ITU-R Rec. P. 837-6)) [5]. In practice, long-term measurement data of rainfall rate could be available from local sources with more than one-minute integration time only. Therefore, ITU-R Rec. P. 837-6 provides a method for the conversion of rainfall rate statistics with a higher integration time to rainfall rate statistics with a one-minute integration time [5]. According to this recommendation, the cumulative distribution of rainfall rate at one-minute integration time may be acquired by converting local cumulative distributions measured at integration times between 5 and 60 minutes [5-6].

ITU-R Rec. P. 837-6 includes maps of meteorological parameters that have been received using the European Centre for Medium-Range Weather Forecasting (ECMWF) ERA-40 reanalysis database. These parameters are recommended for predicting rainfall rate statistics with a oneminute integration time. From contour maps of the ITU-R recommendation, we can only read the $R_{0.01}$ parameter to a selected world area. For example, the rain rate (mm/h) that exceeded the average year by 0.01% is estimated at 35 mm/h for a location of Poland as a region of Europe. Because of the lack of precise information about this parameter within Kielce or the other accurately described region in Poland (local measurements are missing), we must rise to the enormous challenge of bridging the gap.

To fill this gap and determine the rainfall rate statistics in Poland with a one-minute integration time we use records collected by the European Space Agency (ESA) and partner COST ACTION IC 0802 in cooperation with the Institute of Meteorology and Water Management (National Research Institute, IMGW) in Warsaw, which is the best Polish meteorological and hydrological source of information. Due to their data, the $R_{0.01}$ parameters are precisely determined within the whole Polish territory. In practice, the rain rate (mm/h) exceeding by 0.01% the average year in Kielce (one-minute integration time) is estimated at the Kielce University of Technology to be 34.4 mm/h, so the rainfall rate statistics will be greater than those reaching only 53 minutes per year (most accurately 52.56 minutes, assuming that the one year is equal to 365 days) derived from 40 years. This corresponds to the availability of a signal equalling 99.990% (percent average year) and 99.948% (percent worst month), as well as the downtime hours equalling 0.877 (average year) and 0.379 (worst month).

The aim of this study was to present the rain rate (mm/h) exceeding by 0.01% the average year in Poland in tabular form showing for each location the value of the $R_{0.01}$ parameter. The part of results connected with measurements and data acquisitions and their processing for rain rate exceeding by 0.01% the average year is presented in this article. Such analyses can be applied in link budgets to minimize the risk of lack of communication or interruption of communication due to adverse weather conditions.

Material and Methods

Due to lack of accurate data in the ITU-R recommendations, to achieve the values of $R_{0.01}$ parameters we used records collected by the ESA and partner COST ACTION IC 0802 in cooperation with the IMGW. In practice, the greater the duration of the data collection and the more data, the better. The method requires as input cumulative distribution and also the integration time between the source rainfall statistics and the geographical coordinates of the location. The measurements of $R_{0.01}$ were done based on a solid database derived over 40 years in accordance with the ITU-R model. Because the ESA data set is based on 40 years of global records, this model is also based on 40 years of records from weather stations. Due to these data, the $R_{0.01}$ parameters are precisely determined throughout Polish territory.

The model uses bilinear interpolation to achieve an improved evaluation for the adjacent grids within the selected region in Poland. Meteorological data are collected from meteorological stations, then quality checked and further processed, and finally analyzed. On their basis as part of this work methodology, the data about the rain rate exceeding by 0.01% of the average year in Poland were generated at 1.125x1.125° of longitude and latitude. The results are presented in Table 2. Even though not normally necessary, better accuracy may be achieved if a localized $R_{0.01}$ parameter is always obtained. The model of the ITU-R is based on the simulated movement of synthetic rain cells, whose parameters are derived from local input data and the European Centre of Medium-Range Weather Forecasting [5].

Results and Discussion

Average Year Signal Availability

The results of the tests may be different depending on the changes in climate. Therefore, on the basis of natural phenomena and their natural variability, which cannot be controlled, we can inspect the changes in the rain rate (mm/h) that exceeded by 0.01% the average year in the long-term perspective. The $R_{0.01}$ parameter corresponds to the average year signal availability, which is equal to 99.99% in this case (fault tolerant system).

Table 1 could be useful for estimating signal availability in terrestrial and satellite links. The results signify that the availability of a signal as a percentage of average year or worst month is connected with hours of downtime per average year or worst month, respectively. Because a system with fourth-class of availability was used in this research, the hours of downtime equalled 0.877 (average year) and 0.379 (worst month).

Rainfall Intensity in the Polish Region

The rain rate (mm/h) exceeding by 0.01% the average year ($R_{0.01}$) is not predictable with very good precision

Table 1. Average year signal availability on the basis of statistical processed data.

Availability of signal (% average year)	Availability of signal (% worst month)	Hours downtime (average year) [h]	Hours downtime (worst month) [h]
99.999	99.993	0.088	0.051
99.998	99.987	0.175	0.093
99.997	99.982	0.263	0.133
99.996	99.977	0.351	0.171
99.995	99.972	0.438	0.207
99.994	99.967	0.526	0.243
99.993	99.962	0.614	0.278
99.992	99.957	0.701	0.312
99.991	99.953	0.789	0.346
99.990	99.948	0.877	0.379

on the basis of contour maps in accordance with the series of ITU-R recommendations (even up-to-date). The recommendation presents only approximate $R_{0.01}$ parameters. As a consequence, the undervaluation or revaluation of this parameter may be received in a selected location. For example, the difference in $R_{0.01}$ parameter between actual data in the long-term perspective in Kielce (40 years in this case) and contour map of the ITU-R equals 0.6 mm.

All data were used to estimate the $R_{0.01}$ parameters within all of Poland. The results are presented in Table 2.

On the basis of analysis carried out so far we can conclude that the same $R_{0.01}$ parameter as from the contour map of ITU-R Rec. P. 837-6 was obtained in Jelenia Góra (35 mm). Because the long-term 1-min average rain-rate characteristic in Kielce is estimated to be 34.4 mm/h ($R_{0.01}$ = 34.4 mm/h), the actual rainfall rate statistics in Kielce are smaller at 0.6 mm than the $R_{0.01}$ parameter obtained on the basis of the ITU-R contour map.

The smallest differences in rain rates exceeding by 0.01% the average year were recorded in Gdynia and Wolin (0.1 mm); Braniewo, Brzeg, Lębork, Lublin, Oława, and Włodawa (0.2 mm); and Jędrzejów, Krapkowice, Opole, Sopot, Wejherowo, and Wrocław (0.3 mm).

The biggest differences between these parameters were observed in: Krzyż (6.8 mm); Nowy Targ (5.1 mm); Żywiec (4.9 mm), Sanok (4.5 mm), Bielsko-Biała, Nowy Sącz (4.1 mm); Gorzów Wielkopolski, Gubin, Przemyśl (4 mm); Krosno (3.9 mm); Cieszyn, Sulechów, Zielona Góra (3.8 mm); Jasło, Międzychód, Nowa Sól (3.6 mm); Żary (3.5 mm); Brodnica, Iława, Jarosław, Jeziorak, Ostróda, Włocławek (3.2 mm); Olsztynek, Sierpc, Toruń (3.1 mm); Działdowo, Grudziądz, Inowrocław, Kalisz, Konin, Kwidzyn, Przeworsk, Pyrzyce (3 mm); Gostynin, Grodzisk, Koło, Mogilno, Olsztyn, Pleszew, Płock, Solec Kujawski, Turek (2.9 mm); Bochnia, Kutno, Malbork, Rzeszów, Wronki (2.8 mm); Jarocin, Leszno, Mława, Nidzica (2.7 mm); Kraków, Łowicz, Ostrów Wielkopolski,

Table 2. Tabular overview of rain rate (mm/h) exceeding by 0.01% the average year ($R_{0.01}$) in Poland (one-minute integration time) on the basis of statistical processed data in alphabetical order derived from 40 years.

Location (city, lake)	Latitude (º)	Longitude (º)	Altitude (km n.p.m.)	$R_{0.01}$ (mm/h)
Augustów	53.85N	22.98E	0.148	32.8
Bartoszyce	54.27N	20.82E	0.078	33.5
Biała Podlaska	52.03N	23.10E	0.149	34.4
Białogard	54.00N	16.00E	0.057	33.0
Białystok	53.15N	23.17E	0.144	33.7
Bielsko-Biała	49.82N	19.03E	0.438	39.1
Bielsk Podlaski	52.78N	23.20E	0.150	34.1
Bochnia	49.97N	20.43E	0.272	37.8
Bolesławiec	51.27N	15.57E	0.281	33.3
Braniewo	54.40N	19.83E	0.034	34.8
Brodnica	53.27N	19.38E	0.114	31.8
Brzeg	50.87N	17.45E	0.160	34.8
Bydgoszcz	53.27N	17.55E	0.112	32.8
Bytom	50.37N	18.90E	0.282	36.1
Chęciny	50.80N	20.47E	0.273	34.5
Chełm	51.17N	23.47E	0.196	35.4
Chełmża	53.20N	18.62E	0.073	32.0
Chojnice	53.70N	17.53E	0.149	33.2
Chorzów	50.32N	18.93E	0.280	36.3
Ciechanów	52.88N	20.63E	0.124	32.8
Cieszyn	49.75N	18.63E	0.438	38.8
Czeremcha	52.53N	23.25E	0.160	34.2
Czersk	53.80N	18.00E	0.139	32.9
Częstochowa	50.82N	19.12E	0.259	34.3
Dębica	50.07N	21.40E	0.251	37.3
Dęblin	51.58N	21.83E	0.153	34.1
Działdowo	53.25N	20.17E	0.156	32.0
Dzierżoniów	50.73N	16.65E	0.316	35.9
Elbląg	54.17N	19.42E	0.044	33.0
Ełk	53.83N	22.37E	0.161	32.9
Gdańsk	54.37N	18.63E	0.034	34.2
Gdynia	54.52N	18.50E	0.038	34.9
Giżycko	54.05N	21.78E	0.135	33.0
Gliwice	50.28N	18.67E	0.248	36.4
Głogów	51.67N	16.10E	0.095	32.1
Głubczyce	50.22N	17.82E	0.277	36.1

Table 2. Continued

Location (city, lake)	Latitude (º)	Longitude (º)	Altitude (km n.p.m.)	$R_{0.01}$ (mm/h)
Gniewkowo	52.40N	18.42E	0.101	32.0
Gniezno	52.53N	17.53E	0.109	32.5
Gołdap	54.32N	22.32E	0.141	32.5
Goleniów	53.60N	14.83E	0.029	33.6
Gorzów Wielkopolski	52.70N	15.20E	0.069	31.0
Gostynin	52.47N	19.48E	0.101	32.1
Grodzisk	52.23N	16.37E	0.079	32.1
Grudziądz	53.48N	18.75E	0.075	32.0
Gryfice	53.93N	15.20E	0.025	33.9
Gubin	51.98N	14.70E	0.071	31.0
Hrubieszów	50.82N	23.92E	0.201	35.9
Iława	53.62N	19.55E	0.112	31.8
Inowrocław	52.82N	18.20E	0.081	32.0
Jarocin	51.98N	17.52E	0.111	32.3
Jarosław	50.03N	22.70E	0.216	38.2
Jasło	49.75N	21.48E	0.350	38.6
Jędrzejów	50.65N	20.30E	0.259	34.7
Jelenia Góra	50.92N	15.75E	0.422	35.0
Jeziorak	53.67N	19.07E	0.074	31.8
Kalisz	51.77N	18.03E	0.128	32.0
Katowice	50.25N	18.98E	0.278	36.7
Kępno	51.28N	17.98E	0.167	33.2
Kętrzyn	54.10N	21.38E	0.111	33.2
Kielce	50.87N	20.62E	0.283	34.4
Kłodzko	50.45N	16.65E	0.465	35.9
Kluczbork	50.98N	18.22E	0.202	33.9
Koło	52.20N	18.62E	0.111	32.1
Kołobrzeg	54.17N	15.58E	0.023	34.1
Koluszki	51.73N	19.82E	0.164	32.6
Konin	52.22N	18.27E	0.105	32.0
Końskie	51.20N	20.43E	0.250	33.7
Korsze	54.17N	21.15E	0.096	33.1
Kościan	52.10N	16.63E	0.086	32.5
Kościerzyna	54.13N	18.00E	0.163	33.5
Kostrzyn	52.40N	17.00E	0.089	32.9
Koszalin	54.20N	16.15E	0.041	34.2
Kraków	50.05N	19.92E	0.287	37.6
Krapkowice	50.48N	17.93E	0.194	35.3

Table 2. Continued

Location (city, lake)	Latitude (º)	Longitude (º)	Altitude (km n.p.m.)	$R_{0.01}$ (mm/h)
Kraśnik	50.93N	22.22E	0.218	35.5
Krosno	49.70N	21.77E	0.377	38.9
Krotoszyn	51.70N	17.43E	0.131	32.5
Krzyż	52.90S	16.02E	0.000	28.2
Kutno	52.25N	19.38E	0.114	32.2
Kwidzyn	53.75N	18.93E	0.060	32.0
Lębork	54.55N	17.73E	0.111	35.2
Legionowo	52.42N	20.93E	0.092	33.2
Legnica	51.20N	16.17E	0.207	34.0
Leszno	51.85N	16.58E	0.091	32.3
Łódz	51.82N	19.47E	0.164	32.5
Łomża	53.18N	22.07E	0.132	33.6
Łowicz	52.10N	19.92E	0.120	32.4
Lubin	51.40N	16.22E	0.137	33.2
Lublin	51.30N	22.52E	0.193	35.2
Lubliniec	50.67N	18.68E	0.254	34.6
Łuków	51.93N	22.38E	0.160	34.3
Malbork	54.03N	19.02E	0.026	32.2
Miechów	50.38N	20.02E	0.281	35.9
Międzychód	52.60N	15.92E	0.072	31.4
Mielec	50.30N	21.42E	0.209	36.4
Mława	53.10N	20.38E	0.144	32.3
Mogilno	52.67N	17.97E	0.092	32.1
Myślenice	49.85N	19.93E	0.405	38.5
Nidzica	53.37N	20.43E	0.154	32.3
Nisko	50.58N	22.12E	0.183	36.0
Nowa Ruda	50.57N	16.50E	0.456	36.1
Nowa Sól	51.82N	15.68E	0.092	31.4
Nowy Dwór Mazowiecki	52.43N	20.72E	0.093	32.9
Nowy Korczyn	50.32N	20.80E	0.216	36.3
Nowy Sącz	49.65N	20.67E	0.462	39.1
Nowy Targ	49.48N	20.03E	0.739	40.1
Nysa	50.48N	17.33E	0.253	35.7
Oława	50.95N	17.28E	0.149	34.8
Olecko	54.05N	22.50E	0.172	32.6
Oleśnica	51.22N	17.38E	0.142	33.9
Olsztyn	53.80N	20.48E	0.136	32.1
Olsztynek	53.60N	20.28E	0.156	31.9

Table 2. Continued

Location (city, lake)	Latitude (º)	Longitude (º)	Altitude (km n.p.m.)	$R_{0.01}$ (mm/h)
Opole	50.67N	17.93E	0.182	34.7
Ostróda	53.72N	19.98E	0.144	31.8
Ostrołęka	53.10N	21.57E	0.110	33.7
Ostrowiec Świętokrzyski	50.95N	21.38E	0.199	34.6
Ostrów Mazowiecki	52.83N	21.85E	0.120	33.9
Ostrów Wielkopolski	51.65N	17.82E	0.140	32.4
Pabianice	51.67N	19.37E	0.182	32.7
Piła	53.15N	16.73E	0.099	33.1
Piotrków Trybunalski	51.42N	19.70E	0.206	33.2
Pleszew	51.90N	17.80E	0.115	32.1
Płock	52.55N	19.72E	0.103	32.1
Płońsk	52.63N	20.38E	0.103	32.5
Poznań	52.42N	16.88E	0.087	33.0
Pruszcz Gdański	54.28N	18.67E	0.037	33.8
Pruszków	52.18N	20.80E	0.105	33.0
Przemyśl	49.80N	22.80E	0.277	39.0
Przeworsk	50.08N	22.48E	0.219	38.0
Puławy	51.42N	21.95E	0.163	34.4
Pułtusk	52.70N	21.03E	0.099	33.4
Pyrzyce	53.17N	14.92E	0.055	32.0
Racibórz	50.10N	18.22E	0.224	36.9
Radom	51.43N	21.17E	0.160	33.7
Radomsko	51.08N	19.42E	0.220	33.8
Rawicz	51.62N	16.87E	0.109	33.1
Rudnik	50.47N	22.25E	0.194	36.6
Rybnik	50.10N	18.53E	0.237	37.1
Ryki	51.65N	21.93E	0.157	34.1
Rzeszów	50.07N	22.00E	0.263	37.8
Sandomierz	50.68N	21.75E	0.174	35.4
Sanok	49.58N	22.17E	0.434	39.5
Siedlce	52.17N	22.30E	0.154	34.2
Siemiatycze	52.43N	22.88E	0.156	34.2
Sieradz	51.60N	18.75E	0.156	32.7
Sierpc	52.87N	19.68E	0.120	31.9
Skarżysko-Kamienna	51.13N	20.89E	0.256	34.0
Skierniewice	51.97N	20.13E	0.132	32.5

Table 2. Continued

Location (city, lake)	Latitude (º)	Longitude (º)	Altitude (km n.p.m.)	$R_{0.01}$ (mm/h)
Stalowa Wola	50.67N	22.08E	0.184	35.8
Słupsk	54.47N	17.02E	0.045	35.6
Jezioro Śniardwy	53.77N	21.73E	0.140	33.2
Sokółka	53.42N	23.52E	0.165	33.3
Solec Kujawski	53.10N	18.23E	0.073	32.1
Sopot	54.47N	18.57E	0.033	34.7
Sosnowiec	50.30N	19.13E	0.299	36.5
Starachowice	51.05N	21.07E	0.253	34.3
Stargard Szczeciński	53.35N	15.02E	0.055	32.5
Starogard Gdański	53.98N	18.55E	0.078	32.4
Sulechów	52.10N	15.62E	0.076	31.2
Sulejów	51.37N	19.88E	0.201	33.3
Suwałki	54.12N	22.93E	0.146	32.5
Świdnica	50.85N	16.48E	0.276	35.4
Świnoujście	53.92N	14.30E	0.000	34.2
Szczecin	53.42N	14.53E	0.026	33.0
Szczecinek	53.70N	16.68E	0.143	33.4
Szczytno	53.57N	21.00E	0.136	32.9
Tarnobrzeg	50.58N	21.68E	0.174	35.6
Tarnów	50.02N	20.98E	0.251	37.5
Tczew	54.10N	18.78E	0.038	32.8
Tomaszów Lubelski	50.47N	23.42E	0.247	36.8
Tomaszów Mazowiecki	51.53N	20.02E	0.181	33.0
Toruń	53.02N	18.58E	0.076	31.9
Turek	52.03N	18.50E	0.118	32.1
Ujście	53.07N	16.72E	0.091	33.0
Ursus	52.20N	20.88E	0.101	33.1
Ustka	54.58N	16.83E	0.014	36.2
Wałbrzych	50.80N	16.32E	0.342	35.6
Wałcz	53.28N	16.47E	0.115	32.8
Warszawa	52.25N	21.00E	0.097	33.2
Wejherowo	54.62N	18.25E	0.079	35.3
Wieluń	51.23N	18.57E	0.197	33.4
Władysławowo	54.82N	18.42E	0.017	36.2
Włocławek	52.65N	19.02E	0.097	31.8
Włodawa	51.55N	23.52E	0.163	34.8

Table 2. Continued

Location (city, lake)	Latitude (°)	Longitude (°)	Altitude (km n.p.m.)	$R_{0.01}$ (mm/h)
Wolin	53.85N	14.63E	0.004	34.9
Wrocław	51.08N	17.00E	0.128	34.7
Wronki	52.72N	16.38E	0.078	32.2
Września	52.33N	17.57E	0.110	32.4
Wyszków	52.60N	21.47E	0.108	33.8
Zabrze	50.30N	18.78E	0.262	36.3
Zambrów	53.00N	22.25E	0.132	33.8
Zamość	50.72N	23.25E	0.236	36.1
Żary	51.67N	15.17E	0.112	31.5
Zduńska Wola	51.60N	18.95E	0.163	32.8
Zgierz	51.87N	19.42E	0.156	32.5
Zgorzelec	51.20N	15.02E	0.288	33.0
Zielona Góra	51.95N	15.50E	0.088	31.2
Zwoleń	51.37N	21.58E	0.152	34.1
Żywiec	49.68N	19.20E	0.577	39.9

* Data about rain rates exceeding by 0.01% the average year in Poland were generated at 1.125x1.125° of longitude and latitude.

Stargard Gdański, Września (2.6 mm); Kościan, Krotoszyn, Łódź, Myślenice, Płońsk, Skierniewice, Stargard Szczeciński, Suwałki, Tarnów, Zgierz (2.5 mm); Koluszki (2.4 mm); Augustów, Bydgoszcz, Dębica, Pabianice, Sieradz (2.3 mm); Ciechanów, Tczew, Wałcz, Zduńska Wola (2.2 mm); and Czersk, Ełk, Kostrzyn, Nowy Dwór Mazowiecki, Rybnik, Szczytno (2.1 mm).

Significance of Results of Measurements

The collaboration between remote sensing and radiowave propagation experts will improve modelling by assessing the physical fundamentals of radiowave propagation using experimental climatic data and including results from new earth observation missions and new numerical weather forecast models [6-8]. Remote sensing is giving the rate of rain modelling by using GIS. Recently some studies have shown that one of the climatic factors is rain [9-13]. The use of climatic data, including rain, helped model suitable areas in cities. Modelling remote sensing is useful for determining rainfall [14-17]. The more countries in the European project, the better for the EU citizens who will benefit from the results. The resulting measurements of rate exceeding by 0.01% the average year can be found in specialized works (series of the ITU-R recommendations and elaborations of COST Action IC0802 – Propagation Tools and Data for Integrated Telecommunication, Navigation and Earth Observation Systems, especially) and are continuously updated in accordance with the advance of research. Statistical considerations have the benefit of presenting why experimental investigations are necessary (good knowledge about probability calculations is indispensable). Design of experiments must be long-range if their results of available knowledge of the media must to be sufficiently accurate and realistic for results.

Table 2 includes the tabular overview of rain rates (mm/h) exceeding by 0.01% the average year in Poland (one-minute integration time) on the basis of statistically processed data in alphabetical order derived over 40 years. It abundantly shows in many examples how the statistical data can be applied to provide information about rainfall intensity $R_{0.01}$ within all of Poland. These $R_{0.01}$ parameters can be useful for calculating signal quality in practice (e.g. to estimate the impact of rainfall intensity on the quality of received microwave satellite signals in Poland). It can be used for manufacturers and users of the equipment, such as: TV, radio, telephones, GPS systems, *etc*. Moreover, we can take full advantage of these data in the signal attenuation compensation systems to dynamical changes in parameters of transmissions in transmitters (the implementation of further policies on energy savings in automatic gain systems, in policies to improve energy efficiency). Ongoing research may be used to further combine the signal with the best possible quality by transmultiplexer, analysis of absorption, and many other factors affecting the propagation of radio waves to conduct regression analysis [18-20].

Conclusions

In practice, statistical description is the only satisfactory way to show the results of measurements in rainy weather. The rain rate (mm/h) exceeding by 0.01% the average year at one-minute integration time is not predictable with very good precision on the basis of contour maps of the ITU-R recommendation (even up-to-date), which present only approximate $R_{0.01}$ parameters (e.g. the $R_{0.01}$ parameter in Kielce on the basis of the contour map is estimated to be 35 mm/h, hence the difference in $R_{0.01}$ parameters in this location where $R_{0.01}$ = 34.4 mm/h equals 0.6 mm/h). Due to changes in rainfall statistics in Poland, the article presents important and very useful information about rainfall intensity $R_{0.01}$ in different parts of this country within the whole territory on the basis of data from 40 years. Because of the $R_{0.01}$ parameter obtained on the basis of the ITU-R contour map is greater or smaller than the $R_{0.01}$ parameter obtained on the basis of actual data from laboratory stations, accurate results can be used to determine the link budget analysis (e.g. it is possible to characterize the receiver by the minimum acceptable power level which takes into account adverse weather conditions and the quality desired by the end user). When we take into account the precise values of rainfall intensity derived from 40 years, we could get the most accurate results in signal attenuation due to precipitation in Poland.

The aspect of such indication provides essential information concerning practical application for measuring weather conditions. Therefore, all data may be accommodated by defining the terminal equipment, as well as the links that should meet the main quality of signal criteria. The data can be used as a reference for use in the link budget analysis at a later date and could be fully transferred to develop future radiowave systems (e.g. in systems with automatic gain control whose main aim is to provide a controlled signal amplitude, despite variation of the amplitude due to undesirable weather conditions). Hence, the current research has practical implications as well. Increasing rainfall intensity can reduce system performance, and consequently less service availability can be offered. The differences may result in interruptions of communications link performance. It is therefore necessary to compensate for the differences via radio frequency modifications, such as: antenna aperture, antenna efficiency, antenna mispointing, coupling loss, etc. In this context, system engineers need to be aware of these differences in rainfall intensity because they represent an uncertainty in the design of each downlink and uplink. The uncertainty can result in an over-cost, both in initial and periodic expenses [21]. Because the issue covered in the research is of great practical significance, it calls for further action.

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