Tájökológiai Lapok · Journal of Landscape Ecology 21(2): 116–135. (2023) DOI: https://doi.org/10.56617/tl.4958

A Review and Categorization of Rain Depth and Rainfall Intensity Measurement Methods

TIBOR RÁCZ, ISTVÁN WALTNER

Hungarian University of Agriculture and Life Sciences, Institute of Environmental Sciences, Department for Hydrology and Climate Adaptation, Páter Károly u. 1., 2100 Gödöllő, Hungary,
e-mail: Racz.Tibor.Ferenc@uni-mate.hu, Waltner.István@uni-mate.hu

Keywords: rainfall, measurement, accuracy, classification

Abstract: One of the essential factors shaping the Earth's surface and maintaining the life that has developed there is water. Water has a significant influence on the safety of human activity as well. The source of the surface water is mainly rainfall. Measuring the amount of rain has been an important issue for millennia and has become a scientifically based activity in the last few centuries. In the recent period, several methods have been developed for measuring and detecting precipitation and precipitation intensity, which provide data at different levels of accuracy. In addition to meteorologists and hydrologists, many disciplines use precipitation data included in professional publications without evaluating their accuracy. To evaluate the accuracy of precipitation data originating from a certain data source, the user needs to know its accuracy category and reliability. This article serves this purpose by presenting the rainfall measurement procedures from traditional catching measurements to radar, from satellite-based remote sensing to acoustic measurements, and estimation based on lightning statistics. It also presents the described procedures in tabular form, through which the user of the precipitation data can get an idea of the applied data's accuracy.

Introduction

Water lends a unique character to the Earth in the known world; its presence on the surface, in the near-surface crust, and especially in the atmosphere makes the Earth livable. Water is a transport medium for materials, substances and energy. Water is also vital in developing the landscape as a scene of ecological processes and in the human activity that shapes it.

The primary source of surface and near-surface water bodies is precipitation, in most cases. The amount of liquid precipitation is important in the simple replenishment of the medium that allows the life of the living material or causes damages during the runoff on the surface. These effects make it important to quantify rainwater and to analyze water recharge. Although water and precipitation provide the revenue side of environmental water use in many forms, such as dew, hoarfrost, and snow, this article deals with liquid precipitation focusing on its measurement methods. The importance of rainfall measurement is underlined by the demand for production safety and human life protection due to extreme phenomena.

Measurement of rainfall has accompanied the history of humankind. In this essay, an overview of the primary measurement methods is given, drawing attention to their accuracy and accessibility to practice which is going to be a limitation, as well. This article aims to present precipitation observation methods to those who are unfamiliar with meteorological measurement procedures, especially regarding the methods' accuracy issues, summarizing the results in a table.

Before the procedures are described, the units of precipitation measurement are reviewed. The amount of precipitation should always be tied to time. The measurement of precipitation is the measurement of the volume flux of precipitation at a certain time. The World Meteorological Organization defines rainfall intensity as the amount of precipitation collected per unit time interval (WMO 1992). In practice, it is not usual to mention that the precipitation intensity is the flux of the precipitation yield, so the volume flow and water flow are interpreted on a unit surface in a unit time. It is important to remember that the amount of precipitation in millimeters, or the depth of rain, is not a measure of length, but a volume of precipitation per unit area in a unit time, so its real unit is $[10^{-3}m^3/(m^2 \cdot s)]$. From a practical point of view, if the question is the volume of rainfall, the significance of the time seems to be small. The intensity of rainfall is the most important for short-term precipitation; hereafter, the rainfall intensity concept is concerned with the short, at most some hours duration rainfalls, but most characteristically, one-hour duration.

Measurement techniques of rainfall and rainfall intensity

Typology of rainfall measurement techniques

Direct, in situ measurements

The most obvious way of measuring rainfall or rainfall intensity is the direct collecting of the rainfall amount to be measured. The amount of rainfall is determined by the measurement of its volume or mass (weight). The direct measurement methods are those when rain is caught, and collected in a pot and the quantity of the collected rainwater is measured in some way (volume or mass measurement). The direct measurements take place at a point where the gauge is (point measurement), and the gained data is related exactly to the rain gauge site. The amount and intensity of rain vary from point to point, and this spatially and temporally varying phenomenon makes the rain field. The direct measurement devices cannot show the entire rain field, since the measurement units can collect data in a certain point only, but their data must represent some more extended part of the rain field. There can be an assumption of the equality of rainfall amount in a certain radius around the gauge, or there can be assumed some kind of variation of rain depth by the distance. The equality of rain depth within a few km circles around the gauge can be a relatively reasonable assumption in low-intensity rains, but the reliability of this is quite reduced for heavy rainfalls.

Indirect measurements and estimations, rain field measures

The indirect methods do not demand the collection of the rainfall, and the amount of precipitation is assessed on the base of sensing. These methods are based on the rainfall's physical characteristics, such as the shadowing or reflecting effect of raindrops relating to the electromagnetic ray beam of drops, electrical conductivity or capacitance, etc. which can be sensed remotely. In this case, there are any remotely measurable parameters and indirect empirical or well-explainable physical correlations of the applied process to the rainfall intensity and other rain parameters. The indirect measurement techniques can also be point measurements, similar to the direct catching methods, but there appears the possibility of gaining information about the entire rain field, and the indirect methods are mainly used for this last aim. In this case, the process results in an average characteristic of the rainfall (e.g., intensity) for pixels in a certain resolution, in the radius of applicability of the measurement method, depending on the sensor's sensibility. By non-point sensing, the amount and rate of rainfall can be estimated only, there is no possibility of determining an exact rainfall amount in some places of the terrain, but there will be more data about the rain field, at the time of sampling. This is quite important in investigating the heavy rainfalls that can be characterized by high spatial variability of rainfall amount and intensity.

Ground-based measurement techniques

The rainfall measurement can traditionally be performed on the surface of the Earth. It means that the measurement tools are placed in a standardized environment, fixed to the ground, where the falling raindrops can be collected. In the case of these catching methods, the positioning of the gauges is determined to ensure a less perturbed measurement environment where the splashing and other bias-causing effects cannot influence the accuracy significantly. In indirect measurement methods, the standards of ground-based observation depend on the used technology. In indirect point measurements, the rules are like those used in direct measurement methods to ensure the most exact sampling of rainfall, although here the rainwater is not collected. The several kinds of indirect Earth surface measurement techniques sensors can receive or investigate electromagnetic or acoustic signals to estimate or measure the rainfall amount or intensity, depending on the used physical or statistical (empirical) relationship.

Space-based measurement techniques

Space- or satellite-based measurement can only be indirect, based on the measurement of reflected electromagnetic waves. Based on the reflection, estimations can be done on the rainfall intensity or rainfall amount to determine the average precipitation of larger areas.

Point measurement of rainfall with direct measurement techniques

Some generalities about collecting rain gauges

As the most straightforward way of rainfall measurement is the direct collection of the rainfall, this is the most ancient procedure. The earliest records of rainfall measurement can be dated back to about 3100 years ago, in ancient China (Guowei, 2001). Rainfall measurements have been recorded for 2400 years in ancient India (NIH 1990, Kurytka 1953, Strangeway 2010) and for 2000 years in Palestine (Kurytka 1953, Strangeway 2010). Interestingly, there is no data from Mesopotamia, Egypt, or pre-Columbian America to measure precipitation, just as there is no data from ancient European cultures. The "modern" era of precipitation measurement began in the 1600s, with some delay than Eastern cultures (Kurytka 1953, Strangeway 2010). The beginning of modern measurements is attributed to Benedetto Castelli (1577-1644), who reported his precipitation measurement results in his letter addressed to Galileo (Kurytka 1953, Strangeway 2010).

The traditional rain gauges' reading period is generally not longer than one day, but if the rain gauge is placed in a far site, it can reach several months or one year. In these cases, the totalizers are used; these devices have a great enough tank to store the measurement for a more extended period, and after the reading, the tank must be emptied. In the case of the totalizers, evaporation can cause losses. A thin layer of oil is used to prevent the loss, dividing the water from the air (Kurytka 1953).

Regarding the accuracy of the traditional rain gauges, there are several issues. The primary source of inaccuracy is the wind. As it was found and verified, over the rain gauge, the wind bends the trajectories of raindrops, and the spatial distribution of the drops gets changed directly at the catchment surface. The phenomenon has been investigated since the 1700s and its prevention was invented by the end of the 1800s with the use of the Nipher type shields. However, this solution has a really good performance, it was not used for every measurement device generally. If there was no Nipher-type shield, correction is necessary to gain realistic rainfall data from a given measurement site. For the investigation of the correction methods, several investigations were performed, as field intercomparisons (Koschmieder, 1934, Vuerich et al. 2009), wind tube experiments (Mercanton 1937, Nešpor 1995, Nešpor and Sevruk 1999, Habib et al. 1999) and numerical modellings (Allerup and Madsen 1980) (Allerup and Madsen 1986) (Folland 1988, Habib et al. 2001). Despite these efforts, the correction of the sub-daily rainfall data is not solved yet. These researches focused on the cylindrical rain gauges, independently of the measurement methods detailed later (TBG, FRG, or WRG). Several other measurement errors are to be compensated or corrected with the adequate construction and positioning of the gauge (Nešpor 1995). The traditional collecting rain gauges' error can be 5-30% on the average of a longer measurement period (Sevruk 1982).

Rainfall writers, rain recorders

The rainfall writers (or ombrographs) are capable of recording the rainfall amount in the function of time. The recorders could appear with the development of mechanical clockworks. As the clock mechanisms became more and more accurate and more widely available, the sub-daily precipitation's measurement has become possible, thus the calculation and investigation of rainfall intensity have been made possible. Technical advancement is an ongoing process that results in more accurate, more detailed data and new measurement technologies. With the development of data processing, the measurement can be processed and checked more easily than ever before.

There are three widely used kinds of rainfall recorders, the tipping bucket rain gauges (TBG), the level recording gauges (LRG) and weight recording gauges (WRG). There were several other kinds of techniques, developed in the early period of the rain recording, but those could not remain in practice (Kurytka 1953).

As in the traditional rainfall measurement methods, accuracy issues are crucial for catching rainfall recorders. The observation, description, and elimination of wind, evaporation, and other perturbating factors that cause losses are practically the same as those at traditional measurements, and the correction is similar too, complementing the procedures concerning the characteristic systematic errors of the devices; numerous papers are dealing with this issue (e.g. Vuerich et al. 2009, Lanza and Stagi 2008, Lanza et al. 2010).

TBG Tipping bucket devices

The first TBG device can be traced to Sir Christopher Wren, who made a registering tipping bucket gauge in 1662 (Kurytka 1953). This device had a weight-driven clock-operated drum with holes struck on a paper tape and reading their position, and it was possible to calculate the intensity of precipitation (Strangeway 2010). The rapid development of electrical sensors and data recording units was a significant step forward in the twentieth century. Through the development of data recording, tipping bucket TBG instruments came to the fore in the 20th century, mainly in its last third. The TBG devices are popular because of their simple structure, ease of handling, simple way of data collection and data transmission in a handy format (Vasvári 2005). As a result of the development of relatively cheap gauges, the number of urban rain gauges increased. In many cases, there are more and more extended precipitation detection networks with devices manufactured in small series (Knolmár 2012, Rácz et al. 2012).

Over the usual, there is another kind of error related to the measurement technique, the counting error. It covers the measurement inaccuracy that comes from several factors, but mainly from the undermeasurement caused by the splashing out of the water from the bucket during intensive rainfall. This error depends on the intensity. This kind of error has been investigated and there are easy-to-use correction methods for these devices (Vuerich et al. 2009, Lanza et al. 2010).

LRG-level recording gauges

The first LRGs were developed parallelly with the TBG devices, but LRGs were accepted earlier. The LRGs measure the volume of the rainwater, expressing it in rain depth unit format. The water fills up a known geometry vertically positioned cylinder, and the water level is registered on a paper by a pen, or – in our epoch - by a sensor on a data logger. Since the cylinder's horizontal section is constant, the volume is linearly proportional to the depth. In the 1800s, the LRGs were the mainly used tool for rainfall recording, and this dominance has taken to the last third of the 20th century. The price of precipitation recording equipment was relatively high even in the 1860s, as reported by the leaders of one of the leading instrument construction companies of the age (Negretti and Zambra 1864). Still, the devices spread worldwide within decades, with the increasing demand for detailed rainfall data.

The limitation factors of the measurement are the width of the registration paper and the volume of the cylinder. To avoid these issues, the return of the pen was solved mechanically to the starting position (if the cylinder has been great enough), or the cylinder has been emptied.

One of the most extended solutions for emptying was the siphon. The siphoned devices (SRW) have been disappearing from the practice slowly, but these devices gathered a significant part of the historical (sub-daily) rainfall data. The SRW instruments are in operation in some places of the world, such as where the energy supply is not available. Attempts have also been made to provide SRW equipment with an electronic data logger, successfully (Hong-Yang L. et al. 2010). A significant proportion of rain gauges mounted on sea buoys or placed on ships are equipped with SRW equipment capable of digital data recording (Serra Y.L et al. 2001). The maritime rainfall measurement devices shown by the paper detect the change of capacitance in the measurement tank as the level of rainwater increases, so electronic signals are measured and collected, which have been calibrated to the collected rainfall quantity.

The issue of measurement accuracy of the level recording gauges is similar to the case of traditional gauges. The wind causes the primary measurement error if the device is deployed by the related standards. However, the measure of wind-induced perturbance is not known in its complexity yet, it would need detailed wind tunnel and computational fluid dynamics investigation for the unique devices. For an eventual statistical correction, the scarce sub-daily rainfall and the simultaneous wind velocity data cause difficulty. The case of the systematic error of SRW devices was investigated comprehensively by Luycks and Berlamont (Luyckx and Berlamont 2002); the research has resulted in a procedure for the correction of the undermeasurement during the siphoning period, related to the suspending water level registration.

WRG Weight measurement gauges

Weight measurement gauges use one of the simplest methods, which is a re-emerging since the accuracy of these devices is quite good. Several arrangements were developed to measure water's weight and record the rainfall amount in paper or as an electrical signal, in a digital data logger in our time. The WRG devices were investigated during the 2004-2008 campaign of intercomparison of the WMO (Vuerich et al. 2009, Lanza et al. 2010). The intercomparison of rainfall intensity measurement devices shows that the investigated weight measurement instruments had the best accuracy performance.

Indirect Point measurement techniques

As was shown earlier, the indirect methods are based on sensing some effect, related to the presence of raindrops. This principle can be used in point measurements too.

Disdrometers

The disdrometers are in situ measurement instruments to observe the rain rate, size, and velocity of any form of precipitation, raindrops, snowflakes, hail grains, etc. The measurement method can be based on the detection of the mechanical impact of the rainfall, optical shadowing of raindrops (normal light and laser), or the measurement of reflection on raindrops by microwave radar techniques. The output of the measurement is the distribution of raindrop size (DSD, drop size distribution)

Impact disdrometers can detect the mechanical impact of rainfall on the device's surface, and the effect of collision can be transformed into an electronic signal (Kurytka 1953, Habib et al. 2013). The magnitude of impact is in correlation with the size and velocity of the drop. The drop size influences the velocity, so the type of rain and its intensity can be inferred from the base of the signal.

The optical disdrometers can detect a light's scintillations (laser or usual light) between its source and a receiver. The scintillation is related to the drop size and the rainfall intensity so that these rainfall parameters can be estimated.

The radar disdrometers sense the radar reflection of the raindrops. The radar beam is emitted in the vertical direction, and the radar echo of falling raindrops can be detected. The velocity of the raindrops is calculated using the Doppler effect; the DSD can be inferred from the radar echo. About the measurement concept, its main characteristics, and sources of errors, a comprehensive description was made by Habib and his co-authors (Habib et al. 2013).

The performance of the disdrometers in the determination of rainfall intensity is good, and these devices can be handy for meteorologists, but specific calibration issues can occur. In a field intercomparison, a significant dispersion of data has been experienced, using the manufacturers' calibration parameters, and further investigation was proposed to determine better correction parameters (Lanza et al. 2008).

The acoustic signal analysis technique

The acoustic noise of the raindrop's collision on a solid surface is proportional to the drop size and drop density; therefore, it can be suitable for inferencing the rainfall intensity. The method is similar to the impact disdrometers; the difference is that the signal gets by acoustic way to a microphone, as presented by Lane et al. (1997) showing the ARGA (Acoustic Rain Gauge Array) experimental detector unit. The first instrument based on this method was a German device, the work of Schindelhaur from 1925, and in 1951 Maulard made another rain "listening" device in France (Kurytka 1953). A promising advantage of the acoustic measurement units is the cheaper device, suitable for DSD measurement. An example of the newest acoustic rainfall measurement method is the experiment with Android phone-based measurement (Trono et al. 2012). This solution can be cheap and straightforward to build more extensive urban measurement networks. There are no data about its accuracy yet.

Rain field sensing with ground-based measurement techniques

The ground-based rain field sensing techniques can be active or passive. In the active sensing technique, the echo of an artificially emitted signal is measured. The echo caught from a region of the rain field is characteristic of the drop size and rainfall intensity of a part of the rain field, in this way, the whole rain field can be surveyed region by region. The passive sensing methods can collect some effect arriving at the sensor caused or reflected by the rainfall. These effects can be e.g., radar (as active sensing) or acoustic signals (as passive sensing). In this chapter, some of these techniques are going to be mentioned.

Ground-based radar

The ground-based radar can sense the active rain field, and it has great relevance in rainfall observation. The sensing method is based on the radar echo of the different kinds of precipitation since the reflected signal is characteristic of the DSD. This method can be used for sensing solid and liquid precipitation, as well. The radar technology basics were invented in 1900, and it was used for military reconnaissance in the first part of the century, mainly during the Second World War. The beginning of meteorological use began in the first years of the Second World War when the echoes of rain fields were detected, and their analysis seemed to be essential for flying meteorology, too (Cifelli and Chandrasekar 2013). The meteorological use of radar technology is summarized in the book of AGU; for further technical details, the study of this collection is proposed (Cifelli and Chandrasekar 2013, Seo et al. 2013). As radar technology is developing, the echoes can give more and more detail about the rain amount and the rainfall intensity. Several phenomena can perturb the reflected signals, let it be meteorological or related to some physical characteristics of the attenuation of radar signals going through the varying intensity rainfall, varying state air, or the attenuation of electromagnetic signals in the rain field, the disturbance of the wireless tools in some cases (Hadvári et al. 2018, Seo et al. 2013). These kinds of perturbance can be filtered or corrected partially. In confront of the use of single radar, the network use of meteorological radars can decrease the propagation and attenuation-related problems. The accuracy of radar sensing can be increased using multisensory measurement. The radar observation can complement traditional rainfall measurement, so the sensed rainfall intensity can be calibrated more easily (Seo et al. 2013, Cifelli et al. 2013). On the other hand, the in-situ rainfall measurement can be complemented with radar sense since the synergy of these observations gives calibrated rain field data in a larger territory. The accuracy of rainfall radar can be improved with technical developments, such as the use of dual-polarization radars (Cifelli et al. 2013).

Lightning detection as an estimation of rainfall

The most intensive rainfalls generally occur with lightning. The heavier thunderstorms have generally higher lightning activity. A quantitative correlation can be assumed based on the statistics of lightning in a specific geographical region. For the verification of this theory, several investigations have been provided since the 1960s. The correlation between lightning activity and rainfall amount is based on the electric charge separation in the thunderstorm clouds caused by the raindrops. The heavier the precipitation, the more collisions occur, and the charge separation is higher. There are several difficulties in finding a clear correlation between rainfall amount and lightning intensity; for example, dry electric storms do not cause rainfall, and the exact positioning of lightning can be inaccurate, so the location of most intensive rainfall is not accurate, and finally, the flashes of lightning are not point-like phenomena, their length can reach the multiple kilometer magnitude, and this weakens its accurate localization, as well. The flashes of lightning can be detected by their radio frequency electromagnetic signal. The set of very high frequency (VHF) range signals induced by lightning show different strengths of correlation to the rainfall, as presented by Soula and Chauzy (2001). The spatial correlation between the temporal evolution of rain and the number of lightning flashes was found very consistent. The main issue was the variability of rain yield per flash storm by storm and region by region. Tapia and Smith elaborated a model for the Florida storms (Tapia and Smith 1998). One of their conclusions was that the rainfall-lightning ratio (RLR) is well correlated in a given storm. At the same time, the RLR varies from storm to storm. The variability of RLR is lower in convective systems, as they constated it. The RLR varies with the lightning intensity of the storms too.

At the end of the 1970s, in Florida, an investigation resulted in a relatively good correlation between the lightning number and rainfall amount in 5-minute clusters. A lag analysis was performed, resulting in a good correlation (r=0.79-0.95) with the 5-10-minute clusters, taking into consideration a certain time lag between rainfall intensity and lightning frequency. The research results verified the correlation of lightning with rainfall amount during the storm (Piepgrass and Krider 1982). Petersen and colleagues investigated the relationship in other geographical and climatic regions (Petersen and Rutledge 1998). The relationship was analyzed on a monthly average, and the result was expanded to different climatic regions, introducing the concept of rain yield. The rain yield is the ratio of the number of cloud-ground flashes and rain flux, over 10^5 km^2 territory, for a monthly average period. For the mid-continental USA, the relationship seemed to be surprisingly stable for given rainfall regimes, here regimes mean characteristic periods of the year with different rain-yield values of the given geographic region. In the USA, for different geographic regions (arid, midcontinent and humid) the r values were found between 0.71 and 0.90. For the northern continental territories, the r was less favorable with its 0.41 value. For the investigated tropical territories, the relationship seemed less robust.

Based on the ZEUS lightning detection data of Europe and the related gauge network of the Cyprus Meteorological Service, a study was published by Michaelides et al. (2010). They investigated the radius of higher reliability of the relationship between the number of lightning and rainfall amount for the rains over the 5 mm hourly rain depth, for 10 and 15 km radius, with 5-, 10-, and 15-minute steps. The correlation seemed not too convincing. The results showed a nice 0.8-1 correlation only for 42% of rainfalls for the 10 km radius and 5 minutes lags. The ratio decreased to 37% and 32% in the longer time lags, respectively. For the 15 km radius, a high correlation was verified only for one quart of the data. In Switzerland, a method was developed to select the convection rainfalls from the whole set of rainfall events based on the lightning data (Gaál et al. 2014). The research was based on the 1989-2005 lightning and rainfall database of the inspected weather station. The method has been developed to determine a threshold value of the 10-minute peak rainfall intensity, which can separate the data of convective rainfall events in the dataset. This threshold intensity seemed to be robust. The investigated stations have represented four meteorological regions, and the results related to the storm parameters have shown these differences quite well, using the correlation.

Generally, the accuracy of the method is not high enough for practical use, but in some cases, it can be a tool of estimation to complement rainfall data.

Microwave telecommunication signal-based technique

The rainfall perturbs microwave communication. The intensive rainfall attenuates the radio waves, and this attenuation can be measured between radio towers. The attenuation is proportional to the rainfall intensity, and so it can be calculated, at least with an average value on the line between the towers. Several investigations were performed to integrate the existing surface microwave telecommunication networks into the rainfall observations. The idea is not entirely new; there are articles from 1977 on this topic (Atlas and Ulbrich 1977), but the expanded use of microwave telecommunication tools has brought a renaissance of this possibility. In Pakistan, a short experiment was done (Waqas et al. 2020). In Uruguay, there is an investigation for utilizing these data in the rainfall measurement to cancel as much as possible the gap of earth surface measurement and meteorological radars. In Burkina Faso, the research resulted in auspicious data for the case of one cloudburst (Doumounia et al. 2019). In Wageningen, the Netherlands, an experiment was done between 2014 and 2016; the rainfall intensity was measured using five disdrometers and gauges in a 2.2 km long-distance microwave ray beam. The results of this experiment are promising (van Leth et al. 2018). Generally, there are good results for the regular and systematic measures.

Acoustic signal for sea surface rainfall measurement

The rainfall measurement on the ocean surface is not solved completely, so any indirect method can help gather data. There have been trials since the 1980s to estimate rainfall using acoustic signals of rainfall. The subsurface sound detection in the ocean can supply data on rainfall intensity and drop size distribution. The first idea originates from the 1980s (Nystuen 1981). As Nystuen constated, the underwater ambient noise spectrum generated by rain has a unique spectral shape that differs from other noise sources. On this basis, the rainfall can be quantifiable. A numerical acoustic study was performed on drop splash to explain the observed spectra (Nystuen 1986). The differences in drop size result in differences in the induced acoustic effect, so the raindrop classification is possible based on hydroacoustic measurement (Nystuen et al. 1993). An algorithm was soon developed to analyze the underwater sounds for rainfall identification, and this algorithm (ARA = Acoustical Rainfall Analysis) was completed with a rainfall estimation module (Nystuen 1994). The procedure was developed and used; on the topic, several articles were written by Nystuen. An experiment has been performed in the USA, Virginia Key, where two rain gauges provided control data for the validation of acoustic sensing. The correlation between the data of the control disdrometer and the acoustic device was r=0.97 for forty rainfall events, for the total rain depth estimation. For one-minute rainfall depths, the correlation was r=0.90 in six subtropical convectional rainfalls (Nystuen 1996, Nystuen et al 1996).

The importance of rainfall over the oceans has a climatological relevance, and acoustic measurement can have importance in climatological research.

Satellite-based rain field sensing

Over the ground-based measurements, there are advancing satellite-based rainfall sensing methods too.

Satellite imagery-based techniques

The beginning of satellite technology was in 1957, when Sputnik, the first satellite, was launched by the Soviet Union. Since the middle of the 1960s, satellite imagery has become a new tool of remote sensing. The satellite observation of the atmosphere permits a comprehensive view of meteorological phenomena (Kidd et al. 2013). It is essential in remote territories where ground-based observation is impossible (over the oceans or inhabited lands). For rainfall data that can be used to solve engineering problems, very frequent sampling is needed, the needed frequency would be in the order of a couple of minutes. For this task, the geostationary satellites are suitable; however, the frequency of imaging can reach at most the quarter-hour, practically.

The estimation of precipitation is based on four methodologies: the visible (VIS) and infrared (IR), passive microwave, active microwave and multisensory techniques. The geostationary satellites are commonly equipped with VIS and IR sensors with spatial resolutions of about 1 – 4 km, taking images usually every 30 minutes. Only some satellites can refresh the images every 15 minutes (Kidd et al., 2013). Some other missions (mainly military and research satellites) that are equipped with special sensor microwave imagers or special sensor microwave image sounders are capable of estimating rainfall. A more detailed list of these missions can be found in the related sources (e.g. Kidd et al. 2013).

The Geostationary Operational Environmental Satellite's (GOES) satellite imagery can estimate real-time precipitation by estimating cloud top temperature and measuring the outgoing longwave radiation, which negatively correlates with the cloudiness and precipitation in the tropics. In extratropics, there is a strong positive correlation between surface temperature and precipitation. The GOES satellites have five channels to extract information to estimate rainfall. The night rainfalls can be estimated by the brightness temperature difference method, but this method is applicable mainly for delineating rainfalls rather than for a reliable quantity estimation.

Another method was developed to estimate the stratiform cloud precipitations based on the methods mentioned above, combined with the conceptual model that precipitation clouds must have a sufficient vertical extent and large enough droplets. An auto-adaptive threshold was computed every time and linking optical thickness and cloud microphysics to precipitation potential at the ground.

A method was developed for Meteosat Second Generation (MSG) satellite data to determine the rainfall intensities in a mixed situation: for advective-stratiform cloudiness and convective clouds. Based on this algorithm, rains are separated into areas of short duration, high intensity, and large extension, less intensive ones (convective and advective-stratiform precipitation). The areas are divided into subareas of differing rainfall intensities. The advective-stratiform areas can be differentiated by cloud water path (CWP) which is the water mass over 1 m^2 of the surface between the cloud base and cloud top, and particle phase in the upper cloud portions, and ground radar data can calibrate the rainfall intensities.

Another method was developed to estimate the stratiform cloud precipitations based on the methods mentioned above, combined with the conceptual model that precipitation clouds must have a sufficient vertical extent with large enough rain droplets.

The spontaneous microwave (sMWE) emission of Earth's surface can be applied in the estimation of the precipitation, as well. There are two ways of processing, the first is based on the measurement of sMWE emission from raindrops, and the second measures the attenuation caused by scattering on ice particles. The estimation of precipitation is less reliable over the land surface because its emission is poorly known. There are further uncertainties in this method, e.g., the emission-based techniques measure the rainfall in the whole atmospheric column. These measures can be provided only by LEO satellites, which can measure only two times a day, with coarse spatial resolution. There are several other algorithms for data proceeding not detailed here; these can be found in Kidd's publication (Kidd et al. 2013).

Generally, satellite imagery can give a comprehensive view of rainfall, but the production frequency of images ('measurements') is currently limiting the more accurate estimation. The methods are currently applicable to estimate primarily spatial and temporal averages (Mazzoglio et al. 2019). The accuracy of the results is enough for applications that demand average rainfall values.

Satellite-based radar echo detection

The active microwave emission (aMWE) technique is the most straightforward of all satellite-based precipitation estimation methods, but its use is limited. It can be done with Tropical Rainfall Measurement Mission Precipitation Radar (TRMM PR) in a narrow 215 km wide lane. The method is based upon the radar echo of rainfall drops, sensing particle size and rainfall intensity.

The satellite-based radar sensing of rainfall cannot give data in the necessary density and resolution; however, it could have been an excellent tool to gain data on rainfall extremities in remote areas. It has an essential role in the measurement of global water balance.

A summarizing classification of rainfall measurement, sensing and estimation methods

The precipitation measurement and precipitation estimation methods presented in the first part of this paper provide data with varying degrees of accuracy and different applicability. Some of them may give a reasonably accurate picture of precipitation at some sites but provide little information about regional precipitation. In contrast, other methods give a picture of regional precipitation in certain time averages but do not provide accurate local data.

To summarize the information about the achievable rain depth and rainfall intensity measurement data and their accuracy, a table was made by the points below (Table 1).

In the table, there are 11 rows, and 10 contain the evaluation categories and one the name of the procedure. The first five lines refer to the detection and data collection characteristics of the measurement procedure. The sixth and seventh refer to the physical basis of the measurement, in general. The eighth line contains the names of the procedures. The remaining three lines contain application information. These lines present the experimental or accepted practical nature of the use, a description of its overall measurement accuracy, and the area of applicability.

The content of rows is detailed in the following.

1. Families of Measurement Procedures. Precipitation measurement procedures can be divided into two large families. On the one hand, some procedures were planned as direct precipitation measurements, and to use these methods, precipitation must be collected. The other group includes procedures that do not require the collection of precipitation, the data estimation is performed by some indirect sensing procedure.
2. Position of measurement device: Earth's surface or satellite. The measurement or sensing can be performed on a ground-based or satellite-based method; in this classification, those operative meteorological measurement procedures are

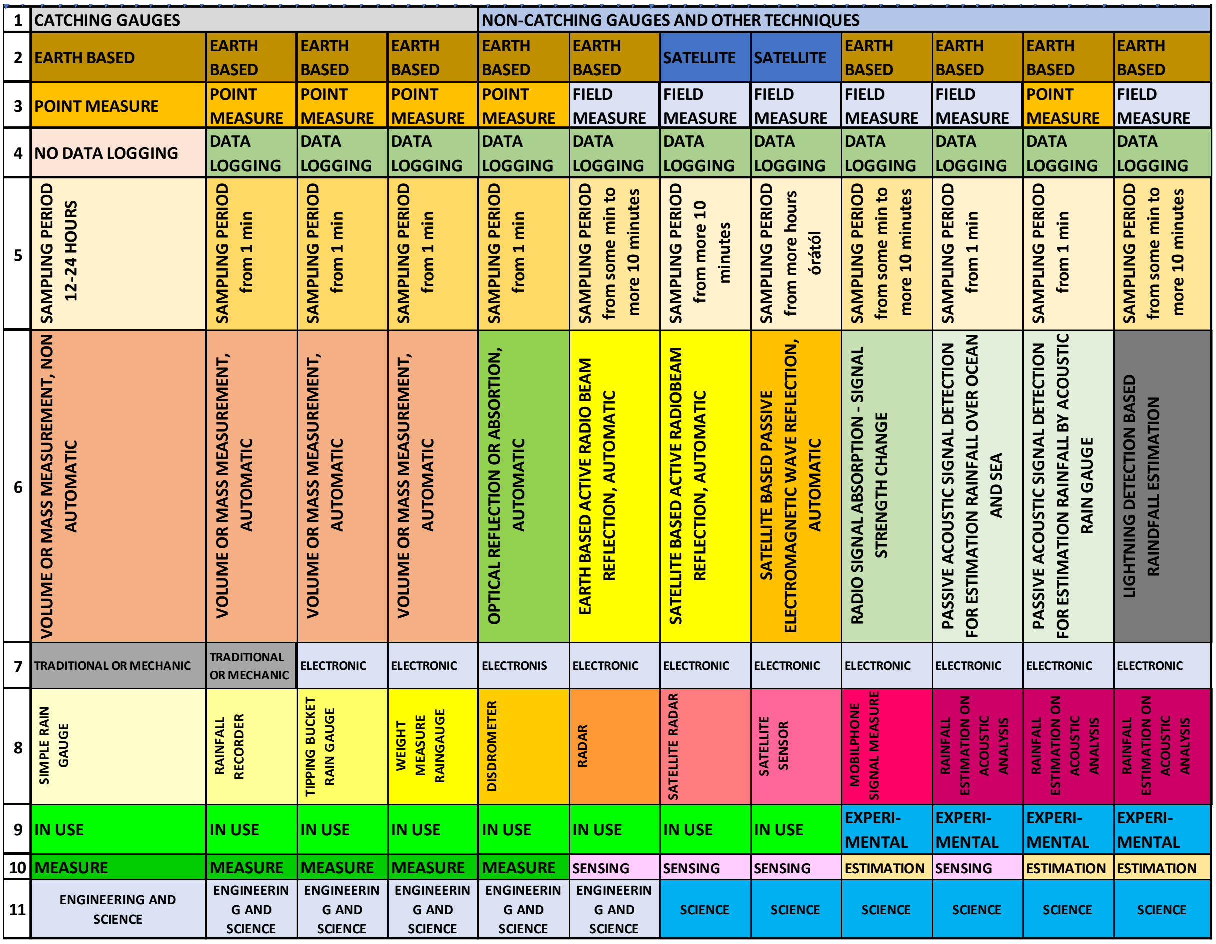
not enumerated, targeting the forecasting or nowcasting in sea navigation aeronavigation.

3. Point measure or Field measure. An essential issue in the classification of measurement procedures is that they will provide point-measured or sensed average values of precipitation fields. Accordingly, the procedures were grouped into categories suitable for in situ point measurements and precipitation field detection. It must be noted that the interpretation of point measurements in a network can also provide information about precipitation fields in a network arrangement.
4. Availability of data logging. One of the criteria for the classification of procedures is the possibility of data recording and whether it is in use during the measurement. The possibility of data recording is generally an issue for devices that were developed in the period before electrical data recording. For indirect measurements, analog or digital electrical data recording is nowadays almost always the default.
5. The sampling period. The sampling period, or frequency is an essential feature of each method. This also affects the quantities that can be detected in some cases, and the extent to which they can characterize the course of precipitation over time. Perception may relate to the occurrence of the phenomenon (yes/no), its magnitude, or a complex detection of detailed spatial and temporal variability. In the case of ground-based gauges, the sampling density can be very high. In contrast, in the case of non-geostationary satellites, the sampling density is fundamentally influenced by the returning frequency of the satellite over the study area. The density of detection also significantly limits the usability of the resulting data.
6. Volume or mass measure, and automatized measure or not. The presented methods cover a wide range of detection technologies. Direct detection methods are based on mass or volume measurement, while indirect methods are based on the detection of electromagnetic or acoustic signals. Volume or mass measurements can be performed on the Earth's surface and these can be automatized, but not necessarily. The Earth surface sensing technologies must be automatized as a default, as the satellite-based sensing methods, as well.
7. Way of operation. The way, or nature of the equipment's operation in terms of the typical energy source (does not require an energy source, mechanical or electrical).
8. Name of the method.

9. Status of applicability. Some of the presented methods can be considered traditional ones, while others seek to use the latest technical development trends in precipitation measurement. In the latter case, it is impossible to speak of practical use in some cases, since the methods are not yet at most professions' accuracy expectations since the gathered variance of the gathered data is too high.
10. Judgement of the accuracy. The accuracy of observations determines the range of applicability. For engineering applications, reliable, validated procedures can be selected to provide adequate accuracy and density of data. (However, it can be seen that in conventional precipitation measurements, significant errors also occur due to wind and systematic errors.) Remote sensing procedures provide information on precipitation by sensing several other characteristic physical quantities (electromagnetic reflection or, less frequently, emissions or acoustic effects, etc.). The quantitative reliability of sensing technologies is generally lower than the direct measurements, in most of the cases. Improvements are expected concerning the development of technology. Based on the above, the categories of measurement, sensing and estimation can be distinguished.
11. Application fields. Based on the above points, the scope of applicability can also be limited. Engineering applications require high accuracy, so ground-based, near-surface observations typically fall into this range. Ground-based radar detection, which can provide data based on indirect measurements, can be used well in flood control, in the nowcasting with a reasonable estimate of the movement of precipitation fields and the magnitude of falling precipitation. The accuracy of some further remote sensing procedures is lower, but they are excellent for determining the average values of regional processes.

Table 1 Rainfall and rainfall intensity measurement methods; a classification based on the measurement characteristics and applicability

1. táblázat. Csapadék és csapadékintenzitás mérő módszerek a mérési jellemzők és az alkalmazhatóság szerint csoportosítva



1	CATCHING GAUGES				NON-CATCHING GAUGES AND OTHER TECHNIQUES							
2	EARTH BASED	EARTH BASED	EARTH BASED	EARTH BASED	EARTH BASED	EARTH BASED	SATELLITE	SATELLITE	EARTH BASED	EARTH BASED	EARTH BASED	EARTH BASED
3	POINT MEASURE	POINT MEASURE	POINT MEASURE	POINT MEASURE	POINT MEASURE	FIELD MEASURE	FIELD MEASURE	FIELD MEASURE	FIELD MEASURE	FIELD MEASURE	POINT MEASURE	FIELD MEASURE
4	NO DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING	DATA LOGGING
5	SAMPLING PERIOD 12-24 HOURS	SAMPLING PERIOD from 1 min	SAMPLING PERIOD from 1 min	SAMPLING PERIOD from 1 min	SAMPLING PERIOD from 1 min	SAMPLING PERIOD from some min to more 10 minutes	SAMPLING PERIOD from more 10 minutes	SAMPLING PERIOD from more hours órától	SAMPLING PERIOD from some min to more 10 minutes	SAMPLING PERIOD from 1 min	SAMPLING PERIOD from 1 min	SAMPLING PERIOD from some min to more 10 minutes
6	VOLUME OR MASS MEASUREMENT, NON AUTOMATIC	VOLUME OR MASS MEASUREMENT, AUTOMATIC	VOLUME OR MASS MEASUREMENT, AUTOMATIC	VOLUME OR MASS MEASUREMENT, AUTOMATIC	OPTICAL REFLECTION OR ABSORTION, AUTOMATIC	EARTH BASED ACTIVE RADIO BEAM REFLECTION, AUTOMATIC	SATELLITE BASED ACTIVE RADIOBEAM REFLECTION, AUTOMATIC	SATELLITE BASED PASSIVE ELECTROMAGNETIC WAVE REFLECTION, AUTOMATIC	RADIO SIGNAL ABSORPTION - SIGNAL STRENGTH CHANGE	PASSIVE ACOUSTIC SIGNAL DETECTION FOR ESTIMATION RAINFALL OVER OCEAN AND SEA	PASSIVE ACOUSTIC SIGNAL DETECTION FOR ESTIMATION RAINFALL BY ACOUSTIC RAIN GAUGE	LIGHTNING DETECTION BASED RAINFALL ESTIMATION
7	TRADITIONAL OR MECHANIC	TRADITIONAL OR MECHANIC	ELECTRONIC	ELECTRONIC	ELECTRONIS	ELECTRONIC	ELECTRONIC	ELECTRONIC	ELECTRONIC	ELECTRONIC	ELECTRONIC	ELECTRONIC
8	SIMPLE RAIN GAUGE	RAINFALL RECORDER	TIPPING BUCKET RAIN GAUGE	WEIGHT MEASURE RAINGAUGE	DISDROMETER	RADAR	SATELLITE RADAR	SATELLITE SENSOR	MOBILPHONE SIGNAL MEASURE	RAINFALL ESTIMATION ON ACOUSTIC ANALYSIS	RAINFALL ESTIMATION ON ACOUSTIC ANALYSIS	RAINFALL ESTIMATION ON ACOUSTIC ANALYSIS
9	IN USE	IN USE	IN USE	IN USE	IN USE	IN USE	IN USE	IN USE	EXPERI-MENTAL	EXPERI-MENTAL	EXPERI-MENTAL	EXPERI-MENTAL
10	MEASURE	MEASURE	MEASURE	MEASURE	MEASURE	SENSING	SENSING	SENSING	ESTIMATION	SENSING	ESTIMATION	ESTIMATION
11	ENGINEERING AND SCIENCE	ENGINEERING AND SCIENCE	ENGINEERING AND SCIENCE	ENGINEERING AND SCIENCE	ENGINEERING AND SCIENCE	ENGINEERING AND SCIENCE	SCIENCE	SCIENCE	SCIENCE	SCIENCE	SCIENCE	SCIENCE

Summary

The palette of the possible methods of the data collection of precipitation has been enlarged significantly in the past century. The development of the methods, altogether, does not result in necessarily similar quality data, let it be the issue of accuracy, spatial or temporal characteristics, or other important parameters. The collected parameters can be studied in Table 1 and the used data quality can be classified from the point of view of the planned data application. If the planned data application demands higher quality than the available data-gaining method's parameters can ensure, a decision is needed about the changing of the dataset to another, to guarantee the necessary quality in itself. In another case, the reliability of the available data will not be satisfying without the possibility of involving another database, the demanded quality of the actual research must be released to a lower level. The table promotes the checking of the data in the mirror of the planned application.

References

Alleru, P., Madsen H. 1980: Accuracy of point precipitation measurements. Nordic Hydrology 11(2): 57–70. DOI: https://doi.org/10.2166/nh.1980.0005

Allerup, P., Madsen H. 1986: On the correction of liquid precipitation. Nordic Hydrology 17(4–5): 237–250. DOI: https://doi.org/10.2166/nh.1986.0016

Atlas, D., Ulbrich, C. W. 1977: Paths and area integrates rainfall measurement by microwave attenuation in the 1–3 cm band. Journal of Applied Meteorology 16(12): 1322–1331. DOI: https://doi.org/10.1175/1520-0450(1977)016<1322:PAAIRM>2.0.CO;2

Cifelli, R., Chandrasekar, V. 2013: Dual-polarization radar rainfall estimation. In: Testic, F. Y. (ed.): Rainfall: state of science. Geophysical Monograph 191, American Geophysical Union, Washington DC, pp. 105–127. DOI: https://doi.org/10.1029/2010GM000930

Doumounia, A., Sawadogo, M., Roland, S., Zougmoré, F. 2019: Rainfall estimation using commercial microwave links (CMLs) attenuation: Analyses of extreme event of 1st September 2009 in Ouagadougou. American Journal of Environmental Protection 8(1): 1–4. DOI: https://doi.org/10.11648/j.ajep.20190801.11

Folland, C. 1988: Numerical models of the raingauge exposure problem, field experiments and an improved collector design. Quarterly Journal of the Royal Meteorological Society 114(484): 1485–1516. DOI: https://doi.org/10.1002/qj.49711448407

Gaál, L., Molnár, P., Szolgay, J. 2014: Selection of intense rainfall events based on intensity thresholds and lightning data in Swizzerland. Hydrological and Earth System Sciences 18(5): 1561–1563, DOI: https://doi.org/10.5194/hess-18-1561-2014

Guowei, L. 2001: Hydrology in ancient time in China. Colloque International OH$_2$ « Origines et Histoire de l'Hydrologie », Dijon, 9–11 Mai 2001.

Habib, E., Krajewsky, W. F., Nešpor, V., Kruger, A. 1999: Numerical simulation studies of rain gage data correction due to wind effect. Journal of Geophysical Research 104: 19723–19733, DOI: https://doi.org/10.1029/1999JD900228

Habib, E., Krajewsky, W. F., Kruger, A. 2001: Sampling errors of tipping bucket rain gauge measurements. Journal of Hydraulic Engineering 6(2): 159–166. DOI: https://doi.org/10.1061/(ASCE)1084-0699(2001)6:2(159)

Habib, E., Lee, G., Kim, D., Ciach, G. J. 2013: Ground-based direct measurement. In: Testic F.Y. (ed.): Rainfall: state of science. Geophysical Monograph 191, American Geophysical Union, Washington DC, pp. 61–78. DOI: https://doi.org/10.1029/2010GM000953

Hadvári M., Szegedi Cs., Csirmaz K., Németh P. 2018: Országos Meteorológiai Szolgálat időjárási radarhálózatának mérései. Országos Meteorológiai Szolgálat Hungarian Meteorological Service, Budapest.

Hong-Yang, L., Qing, L., Xiong, L., Jia-Long, S. 2010: Compensation algorithm of a new siphon rain gauge. International Conference on Instrumentation, Measurements, Circuits and Systems. Hangzhou People's Republic of China.

Kidd, Ch., Levizzani, V., Laviola, S. 2013: Quantitative precipitation estimation from Earth observation satellites. In: Testic F.Y. (ed.): Rainfall: state of science. Geophysical Monograph 191, American Geophysical Union, Washington DC, pp. 27–158. DOI: https://doi.org/10.1029/2009GM000920

Knolmár, M. 2012: Cost effevtive rainfall monitoring. Hydrology and Water Resources, 15th International SGEM GeoConference, Sofia, Bulgaria, 3(1): 183–190. DOI: https://doi.org/10.5593/SGEM2015/B31/S12.024

Koschmieder H1934: Methods and results of definite rain measurements. III. Danzig report. Monthly Weather Review 62(1): 5–7. DOI: https://doi.org/10.1175/1520-0493(1934)62<5:MARODR>2.0.CO;2

Kurytka, J. C. 1953: Precipitation measurements study. Department of Registration and Education, State Water Survey Division, Urbana, Illinois, USA.

Lane, J., Kasparis, T., McFarquhar, G. 1997: Acoustic rain gauge array experiment: Phase I. Orlando, FL, USA.

Lanza, L. G., Stagi, L. 2008: Certified accuracy of rainfall data as a standard requirement in scientific investigation. Advances in Geosciences 16: 43–48. DOI: https://doi.org/10.5194/adgeo-16-43-2008

Lanza, L. G., Vuerich, E., Gnecco, I. 2010: Analysis of high accurate rain intensity measurements from a field test site. Advances in Geosciences 25: 37–44, DOI: https://doi.org/10.5194/adgeo-25-37-2010

Luycks, G., Berlamont, P. 2002: Accuracy of siphoning rain gauges. American Society of Civil Engineers, Portland USA. DOI: https://doi.org/10.1061/40644(2002)251

Mazzoglio, P., Laio, F., Balbo, S., Boccardo, P., Disabato, F. 2019: Improving an extreme rainfall detection system with GPM IMERG data. Remote Sensing 11: 677. DOI: https://doi.org/10.3390/rs11060677

Mercanton P. L. 1937: La Mesure correcte des precipitations atmospheriques. La Meteorologie: 136–139.

Michaelides, S., Savvidou, K., Nicolaides, K. 2010: Relationships between lightning and rainfall intensities during rainy events in Cyprus. Advances in Geosciences 23: 87–92. DOI: https://doi.org/10.5194/adgeo-23-87-2010

Negretti, H., Zambra, J. 1861: A treatise on meteorological instruments. Explanatory of their scientific principles, method of construction and practical utility. Negretti and Zambra Establishments, London.

Nešpor, V. 1995: Investigation of wind-induced error of precipitation measurements using a three-dimensional numerical simulation. Dissertation. Zurich: ETH.

Nešpor, V., Sevruk, B. 1999: Estimation of wind induced error of rainfall gauge measurements using numerical simulation. Journal of Atmospheric and Oceanic Technology 16(4): 450–464. DOI: https://doi.org/10.1175/1520-0426(1999)016<0450:EOWIEO>2.0.CO;2

NIH 1990: Hydrology in the ancient India. Nationa Institute of Hydrology, Roorkee - Uttharakhand, India.

Nystuen, J. A. 1981: Using underwater ambient noise levels to measure rainfall rate: a review. In: Atlas, O. D. (ed.): NASA. Goddard Space Flight. Greenbelt, Maryland, USA: NASA. Goddard Space Flight.

Nystuen, J. A. 1986: Rainfall measurements using underwater ambient noise. Journal of the Acoustical Society of America 79: 972–982, DOI: https://doi.org/10.1121/1.393695

Nystuen, J. A., McGlothin, C. C., Cook, M. S. 1993: The underwater sound generated by heavy rainfall. Journal of the Acoustical Society of America 93: 3169–3177. DOI: https://doi.org/10.1121/1.4050701

Nystuen, J. A. 1994: Acoustical rainfall analysis. Journal of the Acoustical Society of America 95: 2882–2883. DOI: https://doi.org/10.1121/1.408719

Nystuen, J. A. 1996: Acoustical rainfall analysis: rainfall drop size distribution using the underwater sound field. Journal of the Atmospheric and Ocean Technology 13: 74–84. DOI: https://doi.org/10.1175/1520-0426(1996)013<0074:ARARDS>2.0.CO;2

Nystuen, J. A., Proni, J. R., Black, P. G., Wilkerson, J. C. 1996: A comparison of automatic rain gauges. Journal of the Atmospheric and Ocean Technology 13: 62–73. DOI: https://doi.org/10.1175/1520-0426(1996)013<0062:ACOARG>2.0.CO;2

Petersen, W. A., Rutledge, S. A. 1998: On the relationship between cloud-to-ground lightning and convective rainfall. Journal of Geophysical Researches103(12): 14025–14040., DOI: https://doi.org/10.1029/97JD02064

Piepgrass, M. V., Krider, E. P. 1982: Lightning and surface rainfall during Florida thunderstorms. Journal of Geophysical Research 87(13): 11193–11201. DOI: https://doi.org/10.1029/JC087iC13p11193

Rácz T., Bana Zs., Székely Á. 2012: Csapadékmérő hálózatok fejlesztése Budapesten. Magyar Hidrológiai Társaság Vándorgyűlése. Magyar Hidrológiai Társaság. Budapest. pp. 1–9.

Serra, Y. L., A'Hearn, P., Freitag, H. P., McPhaden, M. J. 2001: ATLAS Self-siphoning rain gauge error estimates. Journal of Atmospheric and Oceanic Technology 18: 1989–2002. DOI: https://doi.org/10.1175/1520-0426(2001)018<1989:ASSRGE>2.0.CO;2

Seo, D-J., Seed, A., Delrieu, G. 2013: Radar and multisensor rainfall estimation for hydrologic application. In: Testic F.Y. (ed.): Rainfall: state of science. Geophysical Monograph 191., American Geophysical Union, Washington D.C., 79–105. DOI: https://doi.org/10.1029/2010GM000952

Sevruk, B. 1982: Methods of correction for systematic error in precipitation measurement for operational use. World Meteorological Organisation, WMO-No. 589, Geneva.

Soula, S., Chauzy, S. 2001: Some aspects of the correlation between lightning and rain activities in thunderstorms. Atmospherical Research 56: 355–373. DOI: https://doi.org/10.1016/S0169-8095(00)00086-7

Strangeway, I. 2010: A history of rain gauges. Weather 65(5): 133–138, DOI: https://doi.org/10.1002/wea.548

Tapia, A., Smith, J. A. 1998: Estimation of convective rainfall from lightning observation. Journal of Applied Meteorology 37(11): 1497–1509. DOI: https://doi.org/10.1175/1520-0450(1998)037<1497:EOCRFL>2.0.CO;2

Trono, E. M., Guico, M. L., Libatique, N. J. C., Tangonan, G. I., Baluyot, D. N. B., Cordero, T. K. R., Geronimo, F. A. P., Parreras, A. P. F. 2012: Rainfall monitoring using acoustic sensors. The 2012 IEEE Region 10 Conference (TENCON 2012) "Sustainable Development through Humanitarian Technology". Manila, Philippines: IEEE. DOI: https://doi.org/10.1109/TENCON.2012.6412284

van Leth, T. C., Overeem, A., Leijnse, H., Uilenhoet, R. 2018: An urban microwave link measurement campaign. Atmospheric Measurement Techniques 11: 4645–4669. DOI: https://doi.org/10.5194/amt-11-4645-2018

Vasvári, V. 2005: Calibration of tipping bucket rain gauges in the Graz urban research area. Atmospheric Research 77: 18–28. DOI: https://doi.org/10.1016/j.atmosres.2004.12.012

Vuerich, E., Monesi, C., Lanza, L. G., Stagi, L., Lanzinger, E 2009: WMO field intercomparison of rainfall intensity gauges. WMO/TD-No.1504 World Meteorological Organisation, Geneva.

Waqas, M. M., Awais, M., Shah, S. H. 2020: Estimation of high-resolution rainfall using microwave links data of cellular system. Big Data In Agriculture (BDA) 2(1) 13–15. DOI: https://doi.org/10.26480/bda.01.2020.17.19

WMO 1992: International Meteorological Vocabulary WMO-Nr.182. World Meteorological Organization, Geneva.

A csapadékösszeg és csapadékintenzitás mérés eljárásainak áttekintése és osztályozása

Rácz T., Waltner I.

Magyar Agrár- és Élettudományi Egyetem, Környezettudományi Intézet, Vízgazdálkodási és Klíma-adaptációs Tanszék, 2100 Gödöllő, Páter Károly u. 1.,
e-mail: Racz.Tibor.Ferenc@uni-mate.hu, Waltner.István@uni-mate.hu

Kulcsszavak: csapadékmérés, folyékony csapadék, pontosság, alkalmazhatóság

Összefoglalás: A földfelszín alakításának és az ott kialakult élet fenntartásának egyik legfontosabb tényezője a víz. A víz nagy hatással van az emberi tevékenységre, így a biztonságára is. A Föld felszínén a víz forrása elsősorban és leginkább nyilvánvalóan a csapadék. A csapadékok közül az eső az egyik leglényegesebb megnyilvánulása. Az eső mennyiségének mérése évezredek óta fontos kérdés, habár csak az utóbbi évszázadokban vált tudományosan megalapozott tevékenységgé. Az elmúlt négy évszázad során számos módszert fejlesztettek a csapadék mennyiségének és intenzitásának mérésére, becslésére, és e módszerek különböző pontosságú adatokat szolgáltatnak. A meteorológusok és hidrológusok mellett számos tudományterület használja a csapadék adatokat, amelyeket a szakmai publikációk sok esetben anélkül hivatkoznak, hogy azok pontosságát értékelnék. Ahhoz, hogy a felhasználók értékelhessék a csapadék adatok megbízhatóságát, ismerni kell a mérési eljárások pontossági kategóriáját, alkalmazhatósági körét. A cikk ezt a célt szolgálja azáltal, hogy áttekinti a csapadékmérési eljárásokat a hagyományos gyűjtéses elven működő berendezésektől a radaros érzékelésig, a műholdas távérzékeléstől az akusztikai mérésig, valamint a villám statisztikákon alapuló becslésig.