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Rainfall Event Analysis for Urban Flooding Study Using Radar Rainfall Data

Rebar Muhammad Jaza Mahmmud

Directorate of Groundwater-Sulaimani, Kurdistan Region, Iraq
Email: rebar.mahmmud@gmail.com

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Abstract

Urban flooding is one of the most serious challenges facing urban areas and causes destruction of properties and major problems for people living in urban areas. It occurs in an urban area when intense convective rainfall happens that is higher than the capacity of the urban drainage system. Rainfall data can be recorded by radar and by rain gauge. It is essential for urban flooding studies to have access to high quality rainfall data in attempting to reduce and tackle this challenge. The main aim of this paper is to test the quality of radar data by means of rainfall event analysis. Radar data obtained from Yorkshire Water were analysed and compared to rain gauge data during selected rainfall events in a study area located in North Yorkshire in the UK. Rainfall intensity curves within 5 minute and one-hour intervals, cumulative rainfall depth curves and normalised bias were used as standard methods for comparison between radar and rain gauge data during the selected rainfall events. Available data were collected for June, July, and October 2008 and were recorded from Blackhill, Harrogate North, and Helmsley rain gauges, and radar data for these same locations were also collected. The results of this thesis show that certain errors might have an impact on radar data in terms of quality. Some such errors caused overestimation of radar rainfall data, such as anomalous propagation error and error related to thunderstorm. However, other errors, such as attenuation, caused underestimation in radar rainfall data.

Introduction

It is undeniable that urban flooding is one of the significant challenges facing people in the world today, especially in urban areas. In general, causes of flood could be natural factors such as heavy rainfall, or human factors, for instance, irritation of drainage channels, blocking of channels, inappropriate land use, etc. [1]. As Butler (2011) [2] explained, most storm water is the result of rainfall. Heavy rainfall events have a huge impact on society and can lead to loss of life and property. Storm design is one of the significant decisions related to drainage design. Flooding occurs in an urban area when intense convective rainfall happens that is higher than the capacity of the urban drainage system [3]. Rainfall event analysis is one of the most important tools that could be used for urban flooding study to predict floods in the future and prepare logical plans to reduce the impact of flooding in urban areas. Rainfall can be measured by rain gauge or by radar and these two forms of rainfall measurement differ in terms of quality [2] and [6]. Schellart (2006) [4] Added that different types of error affect these two types of measurement. To discover the differences between radar and rain gauge data in terms of quality, rainfall events are analysed in this study and comparisons are made of radar and rain gauge data. This comparison of the two types of data is intended, like several such previous studies, to test the quality of radar data for use in urban flooding study.

Stanzani et al. (2000) [5] is one of the studies to analyse differences between radar and rain gauge data. Two separate heavy rainfall events were analysed, one in November 1997 and the other in March 1998. After comparison of these two sets of data based on the Z-R relationship or Marshal and Plame, the result of this comparison showed that overestimation of radar data related to anomalous propagation impact.

Schellart et al. (2006) [4] is another study which made a comparison between radar and rain gauge rainfall data in the UK. The result showed that in some events rain gauges measure greater cumulative rainfall depths than radar. However, in other events radar measures greater cumulative rainfall depths than rain gauges. This is related to the sources of error and these sources of error possibly include anomalous propagation as well as snow and snowmelt [4].

Gires et al. (2014) [6], one of the most recent studies to compare radar and rain gauge data, discussed standard methods for comparison between these two types of data. The result of this study showed that around 50% of error was influenced by instrumental error [6]. Also, it can be said that bias of 10-20% in gauge based precipitation measurements could be caused by factors such as wind and evaporation [7].

Aim and Objective

The main aim of this study is to test the quality of radar data for use in urban flooding study, through analysis of rainfall events in a study area located in North Yorkshire in the UK. Analysis is conducted during different rainfall events and based on several methods. In addition, the quality of radar data and rain gauge data is compared in the study area. Such a comparison can be made using different types of plotting; for instance, radar and rain gauge data can be compared based on the intensity of rainfall and cumulative rainfall depth during the events as well as based on bias estimation.

Study area

The study area is located in North Yorkshire in the UK. Rainfall data were obtained from Yorkshire Water, and were derived from tipping bucket rain gauges at Blackhill, Harrogate North and Helmsley as well as from radar at points in the same places as these rain gauges. Fig (1) shows the area selected for this study and the data source locations listed below and geographical coordinates shown as (BNG) British National Grid.

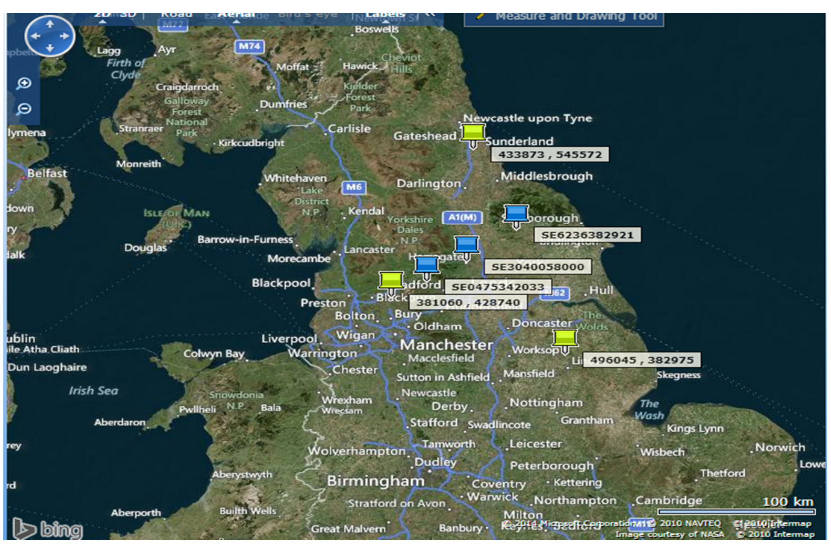

Figure (1) Study area and location of selected rain gages and nearest radar to rain gauges (blue colour are rain gauges, green colour are radar) (http://gridreferencefinder.com, Accessed 21 August 2014) [8]

Table (1) Information of selected rain gauges in the study area

NO.	Rain gauge name	Grid references	(BNG) Geographical Coordinates	
			Easting	Northing
1	Blackhill	SE0475342033	404753	442033
2	Harrogate North	SE3040058000	430400	458000
3	Helmsley	SE6236382921	462363	482921

BNG = British National Grid

Table (2) Information of nearest radar to the selected rain gauges in the study area

NO.	Radar name	(BNG) Geographical Coordinates	
		Easting	Northing
1	Hemeldon Hill	381060	428740
2	Ingham	496045	382975
3	High Moorsley	433873	545572

Methodology

According to [6] there are several standard methods that can be used to make a comparison between radar and rain gauge rainfall data, such as scatter plots, rain rate curves, cumulative rainfall depth curves and computation of various scores, such as normalized bias, correlation coefficient, root mean square errors, and Nash-Sutcliffe coefficient. The available data obtained from Yorkshire water were changed to rainfall intensity and cumulative rainfall depth data. The results of data analysis using these methods will be explained below in result and discussion section:

In this study, the four following main approaches are used to make a comparison between radar and rain gauges data:

A. *Comparison of rainfall intensity between radar and rain gauge data*

The first step was to select three rainfall events for each rain gauge per month. The data were selected from when the radar and rain gauges started recording data until the time when the rainfall stopped. Rainfall intensity curve was selected as a standard comparison method because urban flooding might be caused by high rainfall intensity that exceeds the capacity of the drainage system.

B. *Comparison of cumulative rainfall depth curves between radar and rain gauge data*

Cumulative rainfall depth curve is another standard method that can be used to compare radar and rain gauge data [6]. Cumulative rainfall depth curve method was selected for this study because it could give an indication of cumulative rainfall depth during rainfall events in the study area. It can then be used to explain the total rainfall amount for each rainfall event and to compare the capacity of drainage systems in the study area.

C. *Bias error*

This is another standard method that can be used in comparing the total rainfall intensity of radar and rain gauge data during rainfall events in a study area. According to several studies, such as [6] and [7], the best value of bias should be equal to one or very close to one. Also, bias values give an indication of the differences between total rainfall depth for radar and rain gauges. This information can then be used to explain the sources of error in radar rainfall data in the study area. Bias is a useful approach to determine sources of error because it gives the differences between the cumulative rainfall depths of radar and rain gauge rainfall.

The bias can be calculated as shown below:

$$\textit{Normal Bias} = \frac{\textit{Cumulative rainfall depth of radar}}{\textit{Cumulative rainfall depth of rain gauge}} \quad \text{---------Equation (1)}$$

D. *Radar Images*

Radar images from all over the UK were used to make comparisons with rainfall intensity curves in the selected rainfall events in the study area. Available rainfall data used to create radar images were obtained from the British Atmosphere Data Centre (2014). The data obtained from the British Atmosphere Data Centre were unzipped and then images were created using the Matlab program. An example of these radar images is shown below in fig (2).

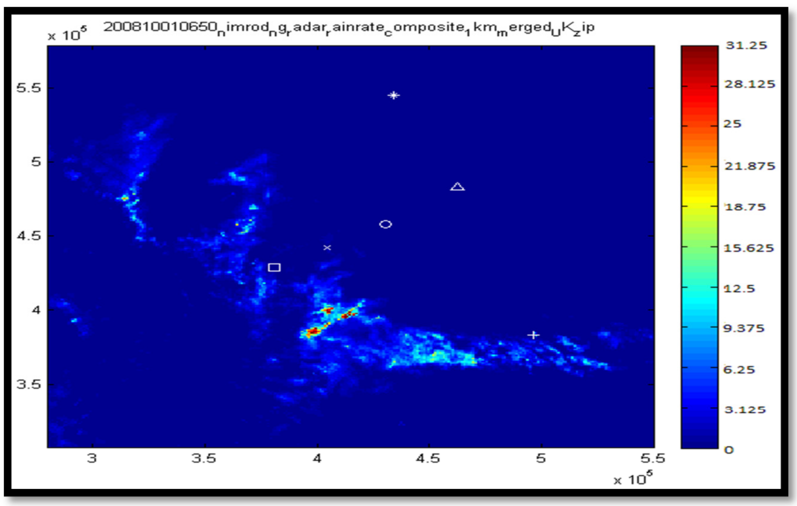

Figure (2) Radar image 1st October 2008 at 06:50 in Helmsley (x, ○ and Δ are rain gauges) (□, * and + are radar)

Result and discussion

A. *Comparison of radar and rain gauge by rainfall rate (intensity) for 5-minutes resolution*

Three rainfall events were selected for each of three months: June, July, and October, in Blackhill, Harrogate North and Helmsley. According to the result derived from rainfall event analysis of rainfall intensity data, the errors in radar data vary in relation to conditions that were present. For instance, as shown in fig (3), rainfall intensity as recorded by radar increased suddenly between 21:36 and 00:00 if compared to rainfall intensity recorded by rain gauge. The event that happened on 18-19th June 2008 in Helmsley shows that the error in the radar data was due to thunderstorm, because thunderstorm is usually very localised and might be missed and not recorded by a rain gauge. Also the radar images illustrated in fig (4 A and B) show that during this time high rainfall intensity occurred which was around 18.75 to 31.25 mm/h. According to the UK Met Office (2014), this amount of rainfall intensity might be accounted for by such as heavy rainfall caused by thunderstorm, for this reason higher rainfall intensity data were recorded by radar than in reality.

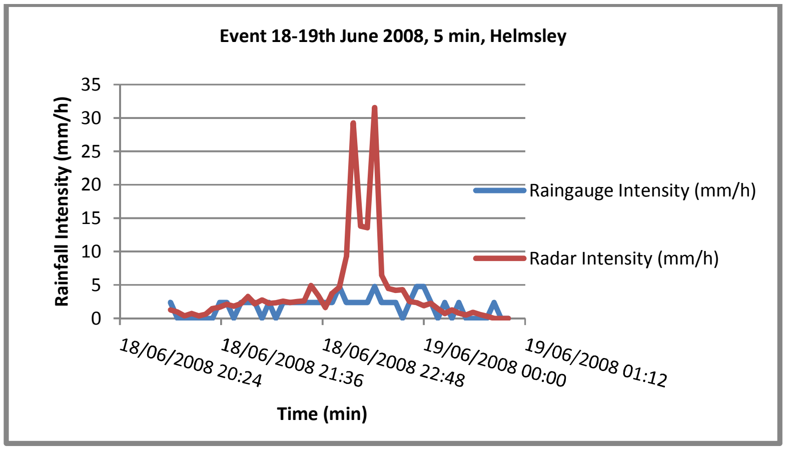

Figure (3) Radar rainfall intensity curve of Helmsley (18-19 June 2008)

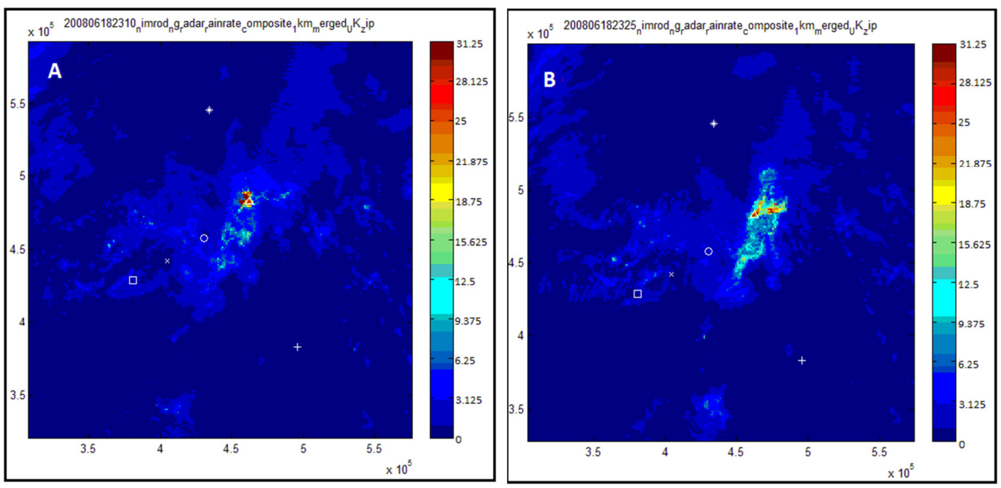

Figure (4, A and B) Nimrod radar composite 1 km images on 18th June 2008 at (23:10 and 23:50)

Moreover, in the rainfall event of 5th July 2008, as shown in fig (5), it can be seen that radar rainfall data increased suddenly between 07:12 and 09:36 in comparison to the rain gauge rainfall data. This rapid change might be related to anomalous propagation. It might be that the radar beam changed quickly due to a change in atmospheric conditions, such as a change in air density causing it to curve downwards and hit the ground and then a stronger radar beam returned to the radar, causing it to give a higher rainfall reading than the rain gauge [9]. Also, the radar images illustrated in fig (6 A and B) show that there was no heavy rainfall and this is evidence of anomalous propagation.

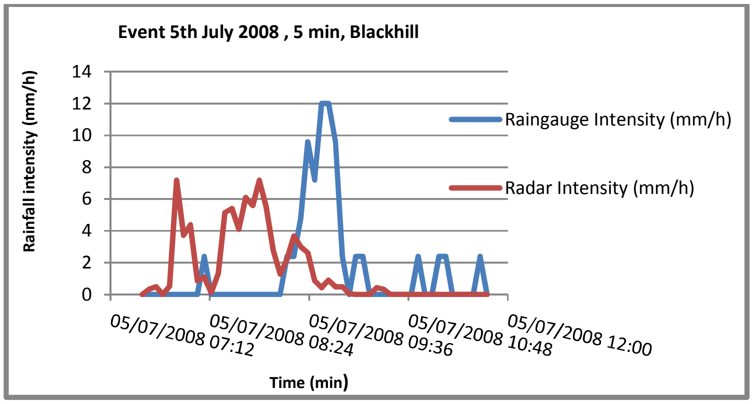

Figure (5) Radar rainfall intensity curve of Blackhill (5th July 2008)

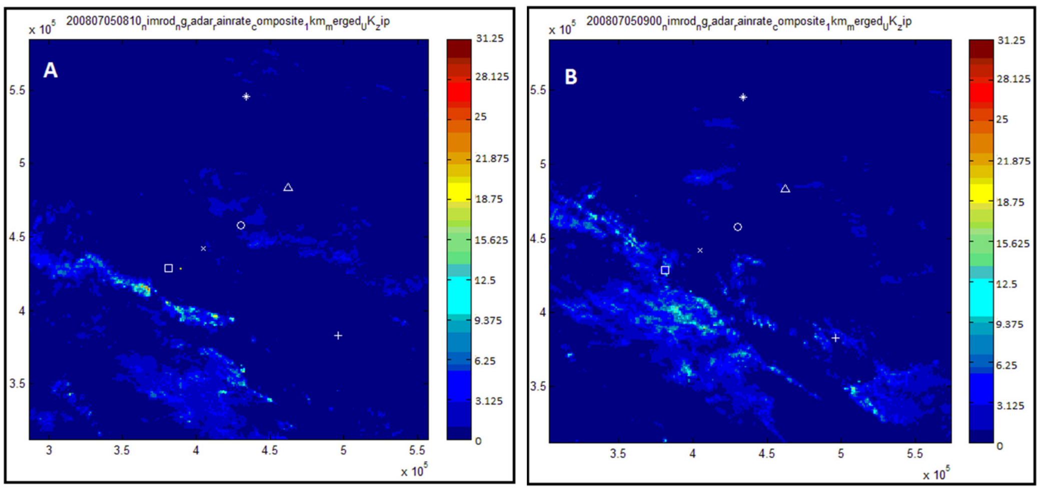

Figure (6, A and B) Nimrod radar composite 1 km images on 5th July 2008 at (8:10 and 9:00)

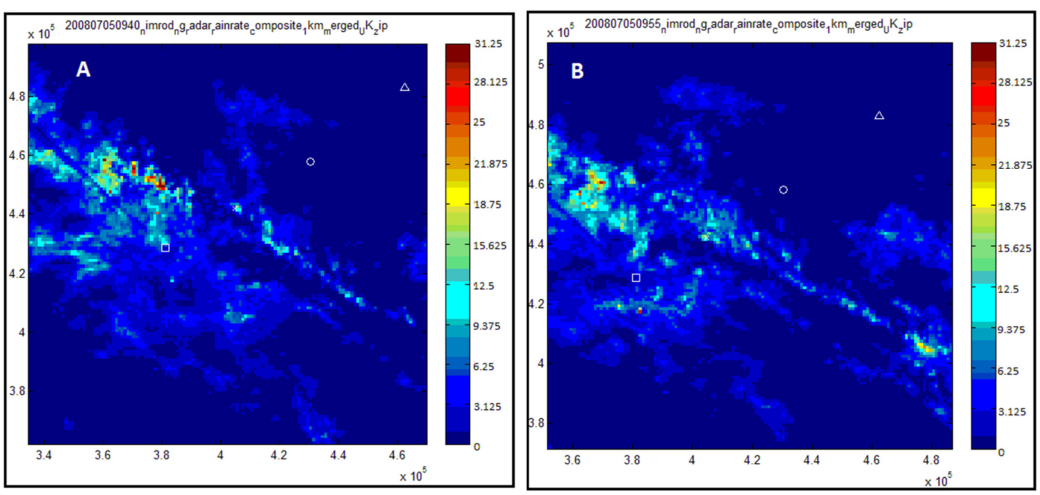

Figure (7, A and B) Nimrod radar composite 1 km images on 5th July 2008 at (9:40 and 9:55)

In addition, in the rainfall event on 1st October 2008 in Blackhill radar rainfall intensity was higher than rain gauge rainfall intensity between 04:48 and 07:12 o'clock, as shown in fig (8). This difference might be due to anomalous propagation or might have been due to windy conditions causing the radar signal to curve down, leading to the same situation that was explained before. Also, the radar images shown in figs (9 A and B) illustrate that heavy rainfall did not occur between the radar and rain gauge from 05:45 to 06:50 o'clock and this is also evidence of anomalous propagation.

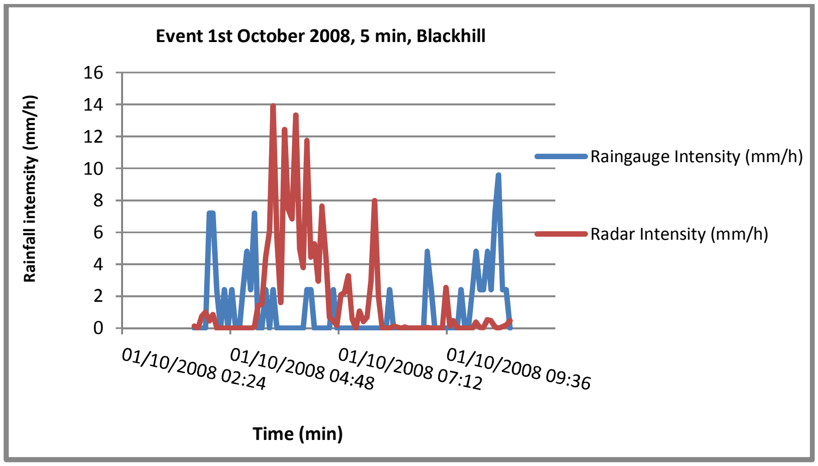

Figure (8) Radar rainfall intensity curve of Blackhill (1st October 2008)

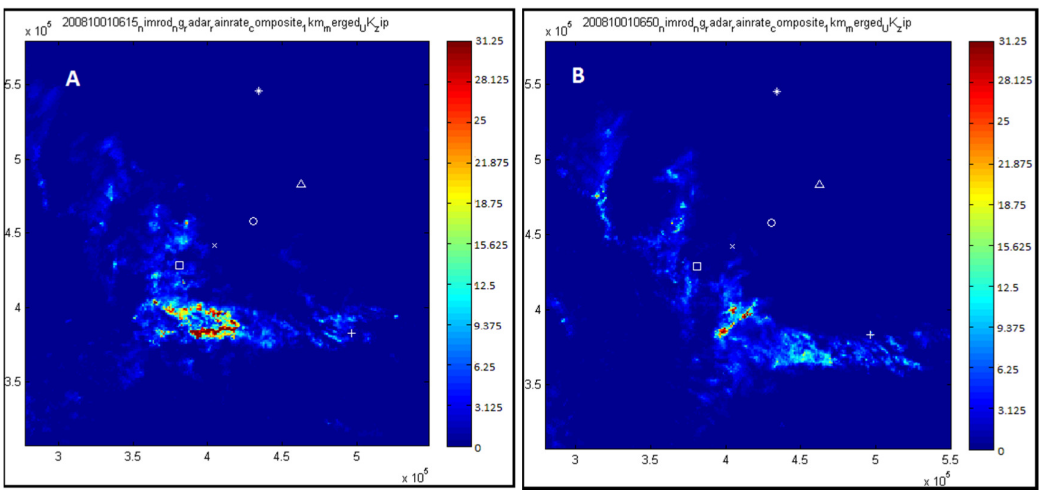

Figure (9, A and B) Nimrod radar composite 1 km images on 1st October 2008 at (6:15 and 6:50)

B. *Cumulative rainfall depth curves*

On 1st June 2008, higher cumulative rainfall depth was recorded by radar, which might have been because of rainfall variability within a radar pixel as shown in fig (10 A). However, as shown in figs (10 B and C) the cumulative rainfall depth of the radar is less than that of the rain gauge and this might have been due to attenuation in the radar data, although this cannot be confirmed.

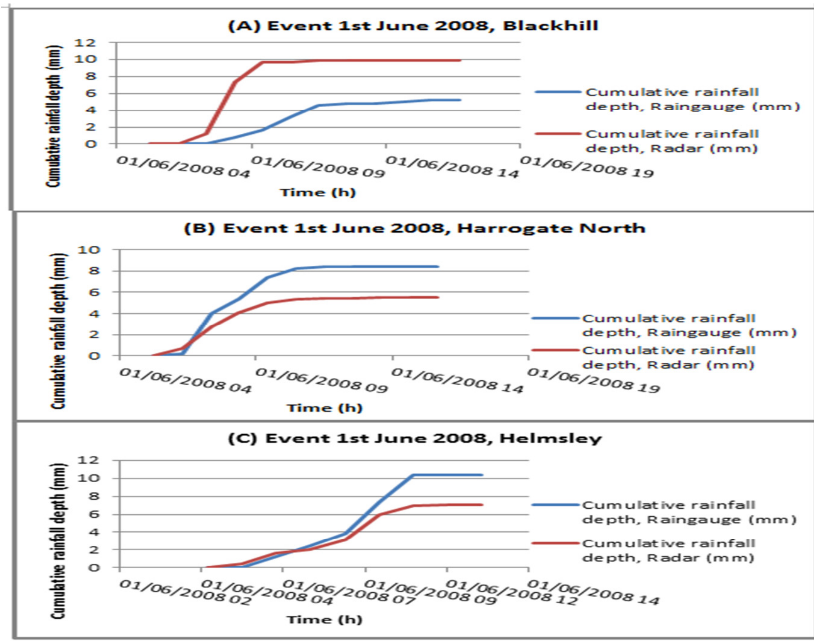

Figure (10, A, B and C) Cumulative rainfall depth curves for event 1st June 2008 in Blackhill, Harrogate North, and Helmsley

Cumulative rainfall depths on 11th July 2008 shows that the differences between radar and rain gauge data were high in Blackhill, as shown in fig (11 A). This difference might have been due to attenuation in the radar causing lower recording of rainfall by radar [10].

However, cumulative rainfall depth of the radar is higher than that in the rain gauge, as shown in fig (11 B). This might have been due to a fault in the rain gauge instrument or might be related to anomalous propagation.

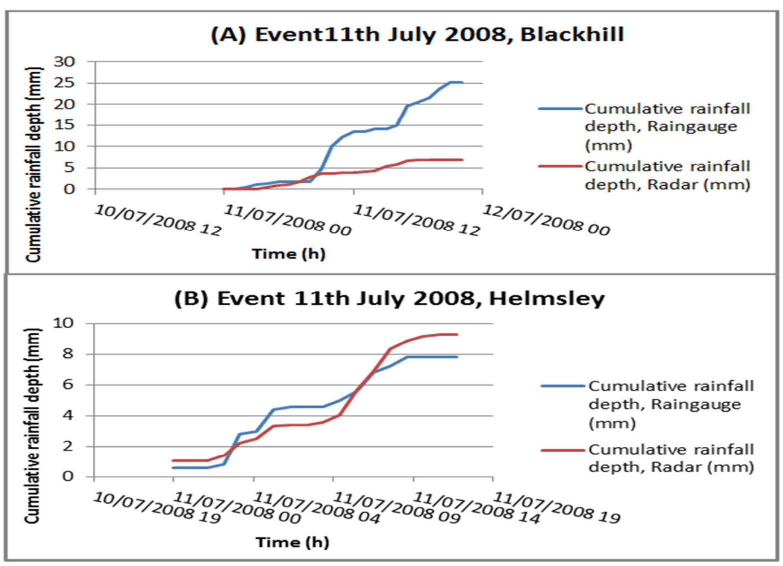

Figure (11, A and B) Cumulative rainfall depth curves for event 11th July 2008 in Blackhill, Harrogate North, and Helmsley

Moreover, cumulative rainfall depth on 14th October 2008 of the radar is less than in the rain gauge in Blackhill. This difference might have been due to rainfall inconsistency within a radar pixel or might be due to variability of temperature in the atmosphere, as shown in fig (12 A).

Nevertheless, in Helmsley the difference between the cumulative rainfall depths of radar and rain gauge is low, as shown in fig (12 B). It may well be the case that both the radar and the rain gauge recorded rainfall data properly and were not affected by errors such as attenuation or anomalous propagation.

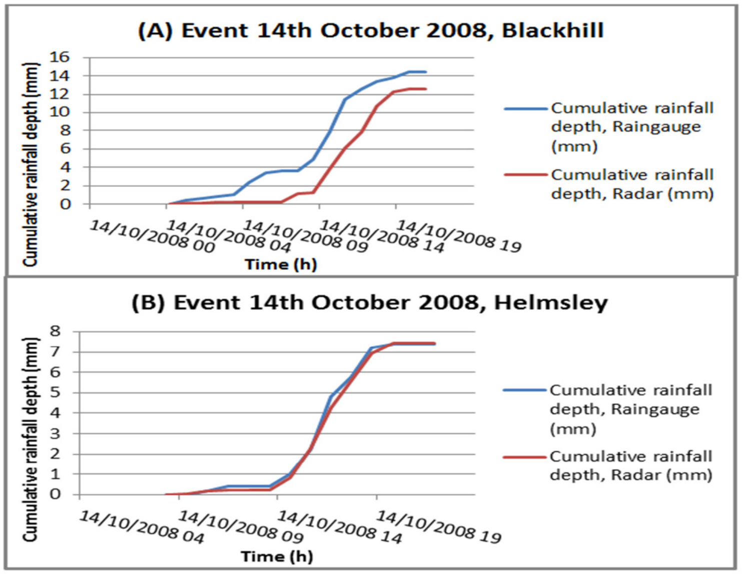

Figure (12, A and B) Cumulative rainfall depth curves for event 14th October 2008 in Blackhill, Harrogate North, and Helmsley

C. *Normalised bias*

Normalised bias will be calculated based on equation (1) as explained before in methodology, section (C) which shown below:

$$N\ B = \frac{cumulative\ rainfall\ depth\ of\ radar}{cumulative\ rainfall\ depth\ of\ rain\ gauge}$$

N B = Normalised bias

The results obtained from normal bias for analysis of radar and rain gauge rainfall data indicate that some of the error was bias error, whilst other error was random error. Bias error occurs if radar rainfall data are higher than rain gauge rainfall data from the beginning until the end of the event, as shown in fig (13 A). Also the error is bias if rain gauge rainfall data are higher than radar rainfall data from the beginning until the end of the event, as shown in fig (13 B).

However, as shown in fig (13 C), there was some random error because at the beginning of the rainfall event on 5th July 2008 in Helmsley, radar data were slightly higher than rain gauge data. Nevertheless, after that the rain gauge rainfall data were higher than radar rainfall data.

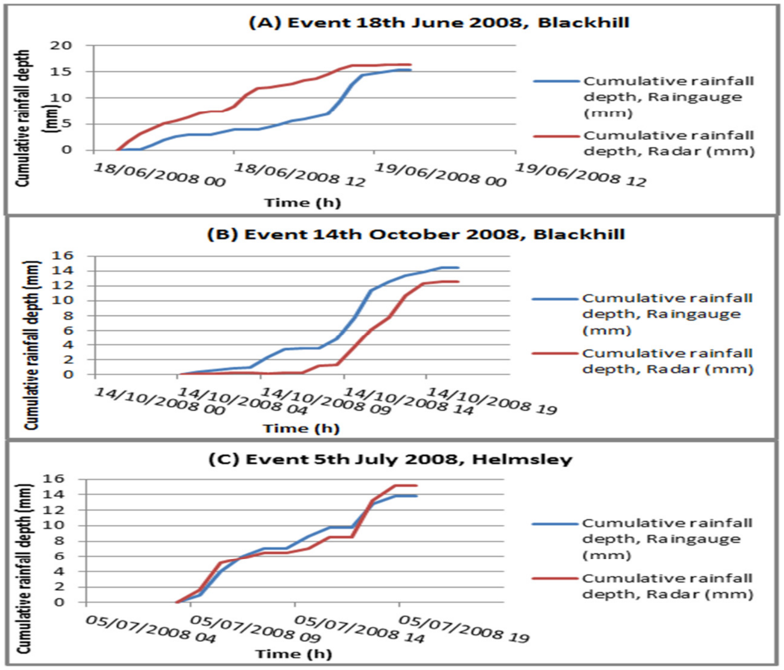

Fig (13, A, B and C) Bias and random error

Conclusions

According to the results obtained from analysis of data on rainfall intensity, cumulative rainfall depth, normal bias error and radar images it can be concluded that:

1- Comparison of radar and rain gauge rainfall data is one of the most important approaches to testing the quality of radar data for urban flooding study.
2- Errors in radar data could be due to systematic error such as the distance of radar and height of radar from the ground. However, error might be unsystematic error such as meteorological conditions for instance heavy rainfall for long time or thunderstorms.
3- Error might be caused by overestimation of radar rainfall data, due to such as anomalous propagation, thunderstorm and the influence of wind on rainfall.
4- Error might be caused by underestimation of radar rainfall data, due to such as attenuation and temperature change.
5- Results from normal bias error calculations showed that errors might be due to bias or random error.
6- Radar rainfall data encountered a larger amount of error than rain gauge rainfall data did.

Analysis of rainfall data should be undertaken for each 1 km in the study area and compared to the capacity of the drainage system as a means for future studies to obtain better understanding of radar rainfall data for urban flooding study.

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