IMPROVING EFFECTIVE RAINFALL USING VIRTUAL STATIONS WITH RADAR DERIVED-DATA

Amin M.S.M. [1, 2], Waleed A.R.M [1], Aimrun W. [1]
[1] Smart Farming Technology Laboratory, Institute of Advanced Technology,
Universiti Putra Malaysia, Serdang, 43400, Selangor, Malaysia
[2] Department of Biological and Agricultural Engineering, Faculty of Engineering
Universiti Putra Malaysia, Serdang, 43400, Selangor, Malaysia
Email: amin@eng.upm.edu.my
Tel. (603) 89466427; Fax (603) 89466425

ABSTRACT

The measurement of rain falling in a rice growing area is based solely on the available rain gauge network. These gauges are located at convenient locations which may not be representative of the whole rice growing area. Hence, under or over estimation of runoff occurs and consequently affects the management of floods during rainy seasons or base flow for irrigation during dry seasons. Therefore, better estimates of mean areal rainfall are needed as contribution of effective rainfall in the water balance during the irrigation season. A new technique to improve rainfall distribution estimation based on weather radar-derived rainfall throughout the rice growing area was developed. Using GIS tools, virtual rainfall stations are created uniformly throughout the area. The rainfall data for these virtual stations are estimated from raw weather radar data using a newly developed Program called RaDeR ver1.0. The calibrated radar-derived rainfall is used as input data in the rainfall-runoff model. Results show that virtual rainfall stations distributed throughout a watershed can be used to derive a more representative rainfall distribution. The watershed river flow can be better estimated by using the virtual rainfall stations with radar-derived rainfall data. This in turn will help to improve the contribution of effective rainfall in the overall water management of a rice granary area.

Keywords: virtual rainfall stations, radar-derived rainfall, effective rainfall, rice granary

INTRODUCTION

Rainfall is one of the most important sources of the water for irrigation. It is vitally important to quantify it accurately. Good estimates of mean rainfall are needed for irrigation water management, flood estimation, and watershed modelling. The measurement of rain falling in a watershed is based solely on rain gauges network. When based on ground measurements, their accuracy depends on the spatial variability of the rainfall process and on the rain gauges network density [1]. Generally, these gauges are located at convenient locations which may not be well representative of the whole area.

Knowing the amount of rainfall that has occurred is very important for on-farm paddy irrigation water management. The idea is to capture more rainfall as “effective rainfall”, thereby reducing the amount diverted from rivers or dam reservoirs. When rainfall occurs in adequate amounts during major portions of the crop season, irrigation is used on a supplemental basis (in the event that rainfall is not timely or adequate). In areas of high rainfall, adequate drainage is mandatory for crop production [2]. Similarly, the management of irrigation water supply needs a good estimation of river flow, while the estimation of flow quantity is sensitive to the spatial distribution of rainfall, it is essential to quantify it accurately.

Normally rain gauges are installed at convenient and accessible locations (out of forest) as shown in Figure 1. Therefore using limited number of rain gauges to determine the spatial distribution of rainfall may not be the best technique for accurate distribution pattern.

The primary advantage of radar observations of precipitation compared to traditional rain gauge measurements is their high spatial and temporal resolution and large areal coverage. Unfortunately, radar data require high quality control before being converted into precipitation values that can be used as input to hydrologic models [3].

The main aim of this study was to more accurately determine the spatial distribution of rainfall over a watershed or agricultural lands using the ViRaS-RadeR (virtual rainfall stations with the radar derived rainfall data) system for better on-farm paddy irrigation water management.

MATERIALS AND METHODS

To achieve the objectives of this study, the rainfall data was estimated using raw weather radar data and then calibrated based on actual available rain gauge measurements. GIS tools were used to create the virtual rainfall stations and develop the rainfall distribution maps.

Six weather radar stations are available in peninsular Malaysia as shown in Figure 2, operated by the Malaysian Meteorological Department (MMD). The MMD provides maps of radar-derived rainfall estimated from S-band conventional pulse radar station using 3D-Rapic program.

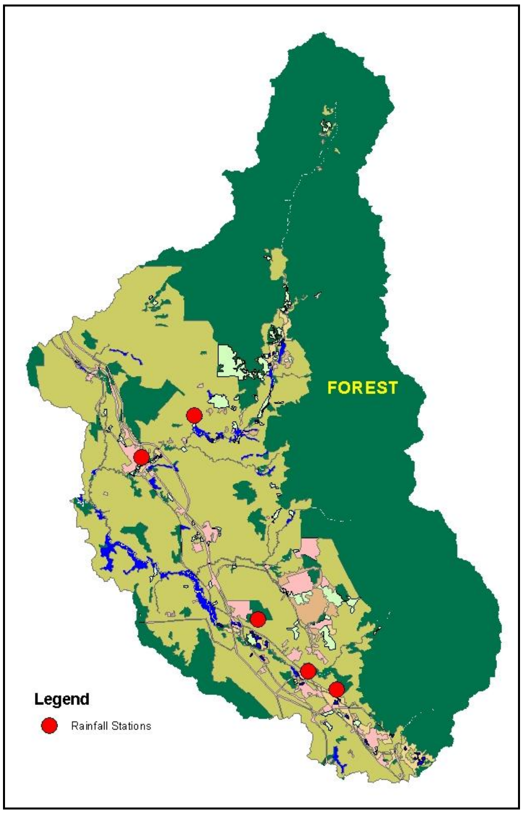


Figure 1: Locations of rain gauges outside the forested areas of UBRB

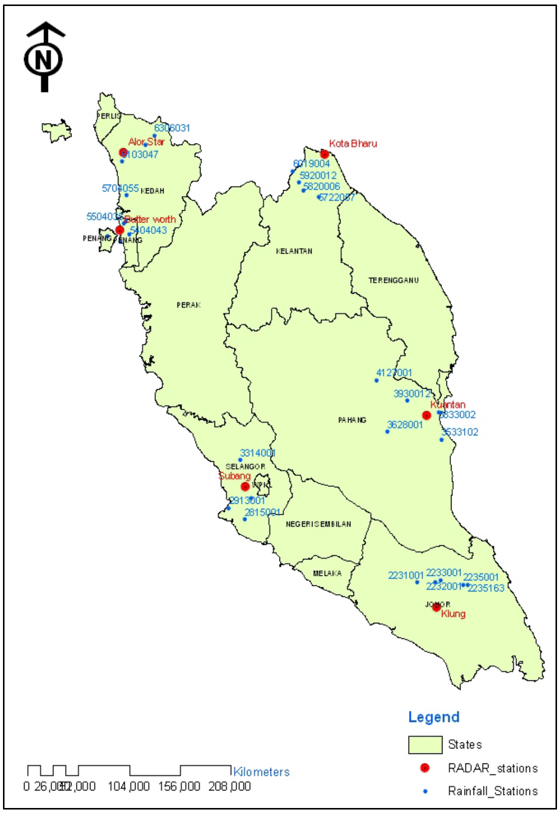


Figure 2: Locations of weather radar stations available in Peninsular Malaysia

The $1^{o}\times2$ km resolution maps are produced every ten minutes and converted into rainfall intensity by means of the classical Marshall and Palmer relationship ($Z = 200R^{1.6}$) using 3-D Rapic Program. The radar data are collected up to effective range of 230 km for three elevation scan angles of 1.0^{o}, 2.0^{o} and 3.0^{o} [4]. The hydrological data such as rainfall, river discharge and water levels were obtained from the Hydrology Division, Department of Irrigation and Drainage (DID), Malaysia.

ViRaS-RadeR system

Due to constraints in installation of rain gauges within the tropical forested watersheds, a limited number of rain gauges (Figure 3) cannot represent the real distribution and variability of rainfall. Therefore, a new method and system was developed to improve the rainfall distribution mapping based on the Virtual Rainfall Stations (ViRaS) network with weather Radar-derived Rainfall data (RadeR) using RaDeR©ver1.0 program.

ViRaS-RadeR is a system developed to improve the rainfall distribution mapping based on the virtual rainfall stations (ViRaS) network together with weather radar-derived rainfall data (RadeR) using RaDeR©ver1.0 program

The ViRaS-RadeR system involves the following procedure: 1. Creation of virtual rainfall stations (ViRaS) uniformly distributed throughout the whole watershed or the required agricultural area (rice granary) using GIS software tools (Figure 4). 2. The virtual rainfall stations are centres of the spatial grids covering the selected area. The size of the grids can be 4 km, 6 km or bigger depends on the watershed size, while the minimum square grid size is 2 km (similar to the radar rainfall pixel size). 3. Estimation of radar-derived rainfall for the virtual rainfall stations using RaDeR©ver1.0 computer program (Figure 5). 4. Development of a rainfall distribution map of the selected area for any rainfall event or any date.

Using ArcMap (GIS) interpolations tools, Kriging was applied for interpolating the radar-derived rainfall data for the virtual rainfall stations to generate the rainfall variability zones.

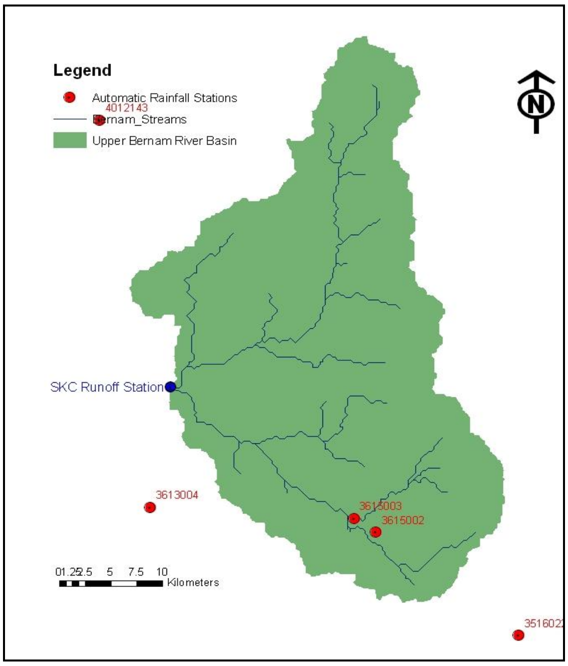


Figure 3: Upper Bernam River Basin (UBRB) with limited rain gauge network

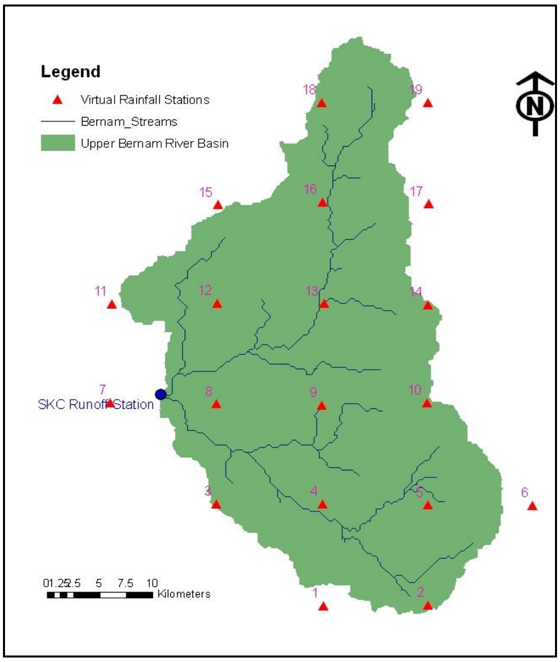


Figure 4: Virtual rainfall stations created uniformly in the watershed

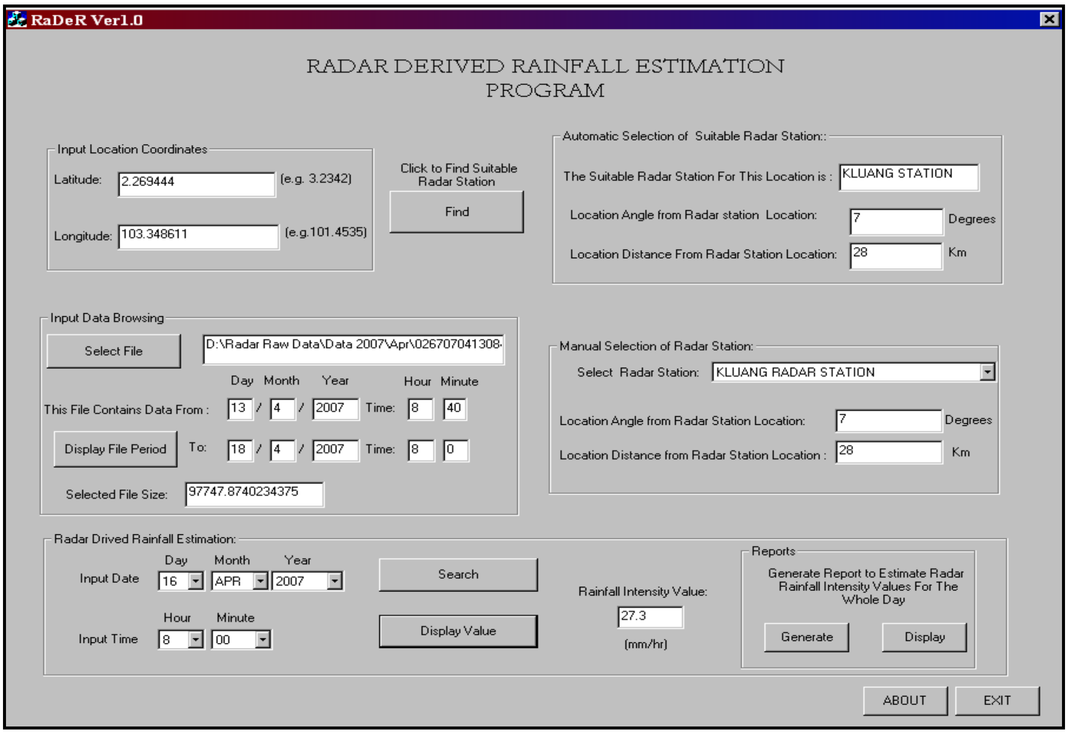


Figure 5: RaDeR©ver1.0 Program Interface

RaDeR©ver1.0 program was designed to estimate the radar-derived rainfall value using the raw radar data. The program can estimate the 10 minutes interval rainfall for a specific time and date; it also can generate a report of radar-derived rainfall for the whole day.

Many applications using radar-derived rainfall are possible. Some of these are used in hydro infrastructure design, irrigation water management, landslide assessment, watershed management, rainfall variability mapping and flood forecasting operations.

Study area

The ViRaS-RadeR system was implemented on an agricultural project of the Tanjong Karang Rice Irrigation Scheme (TAKRIS) to develop the rainfall distribution maps. TAKRIS has a total area of 20,000 ha and it is one of the eight rice granaries in Malaysia. The area of Sawah Sampadan was considered as a pilot area (2300 ha).

The Bernam River is considered as the main source of irrigation water supply for TAKRIS. It comes from the watersheds in the Upper Bernam River Basin (UBRB) as shown in Figure 6.

To develop a more representative rainfall distribution maps for the Sawah Sampadan, 17 virtual rainfall stations were created uniformly in grids size of 2 km as shown in Figure 7.

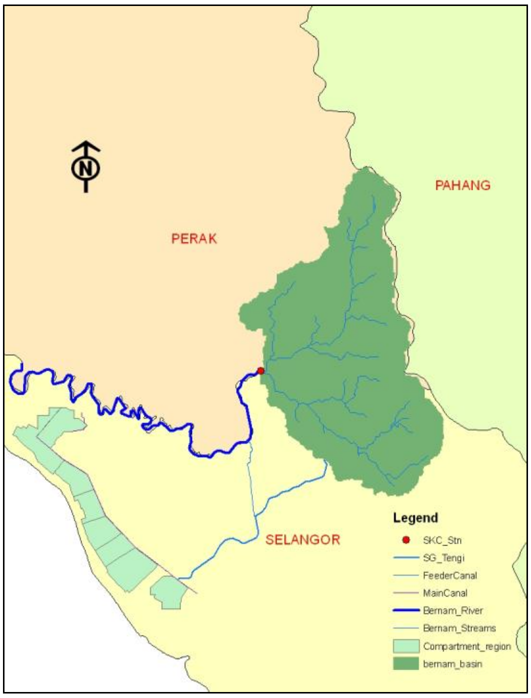
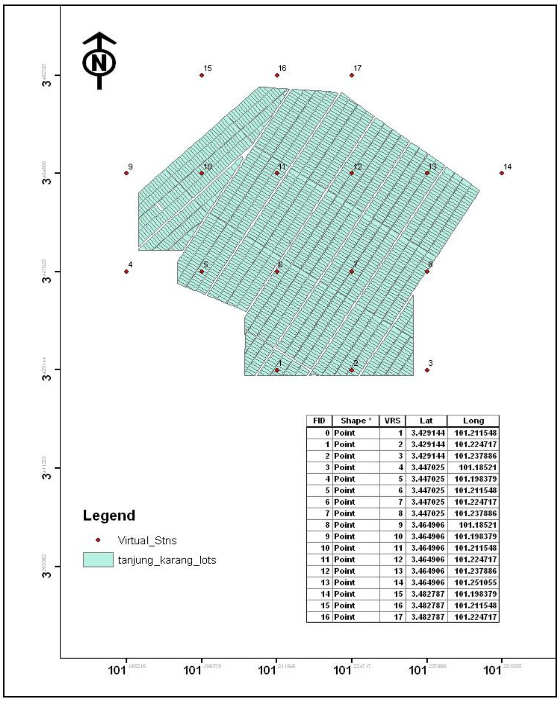


Figure 6: TAKRIS and irrigation water supply system from UBRB



FID	Shape *	VRS	Lat	Long
0	Point	1	3.429144	101.211548
1	Point	2	3.429144	101.224717
2	Point	3	3.429144	101.237886
3	Point	4	3.447025	101.18521
4	Point	5	3.447025	101.198379
5	Point	6	3.447025	101.211548
6	Point	7	3.447025	101.224717
7	Point	8	3.447025	101.237886
8	Point	9	3.464906	101.18521
9	Point	10	3.464906	101.198379
10	Point	11	3.464906	101.211548
11	Point	12	3.464906	101.224717
12	Point	13	3.464906	101.237886
13	Point	14	3.464906	101.251055
14	Point	15	3.482787	101.198379
15	Point	16	3.482787	101.211548
16	Point	17	3.482787	101.224717

Figure 7: Virtual rainfall stations created in the Sawah Sampadan Compartment

RESULTS AND DISCUSSION

The rainfall data for the 17 virtual rainfall stations were derived from the Subang weather radar station data using RaDeR©ver1.0 program. The daily radar-derived rainfall data (Table 1) were used to develop the daily rainfall distribution maps. Kriging tool was used for interpolating the radar-derived rainfall; while inverse distance weight (IDW) was used for interpolating the gauge rainfall data from five rain gauges. Kriging can interpolate the minimum of ten points.

The daily rainfall distribution maps created for different days (24 Feb., 16 Mar. and 16 Apr. of 2007) are shown in Figures 8, 9 and 10.

Effective rainfall is that part of the rainfall beneficially used to meet the crop water requirement. Being able to capture more "effective rainfall" will save irrigation water stored in reservoirs or river diversion hence can be used by other users or for other purposes especially during dry months of the year. The rainfall variability map made available by ViRaS-RaDeR will be very useful for the irrigation managers in their daily canal gate operation.

In rice granaries of Malaysia, water management in paddy fields with perimeter bunds are varied according to the growth stage of the crop. Water level in the field is controlled via flash boards in drainage boxes at downstream end of the paddy field. The maximum depth is typically set at 15 cm, the height of the perimeter bund, and any additional rainfall is drained out, and considered as "not effective". Under normal irrigation condition, water level in the initial stage of crop growth can be up to 10 cm to control competing weeds, low depths (2-5 cm) at tillering stage and again up to 10 cm at reproductive stage. The irrigation period where standing water is present in the field is about three months. Water is completely drained out about 3 weeks before harvest to facilitate dry field condition for the combine harvester.

Table 1: Daily rainfall data (mm) for the 17 virtual rainfall stations

ViRaS No.	Latitude	Longitude	Daily Rainfall (mm)		
			24/2/2007	16/3/2007	16/4/2007
1	3.4291	101.2115	11.3	4.3	9.2
2	3.4291	101.2247	11.1	8.5	3.6
3	3.4291	101.2379	6.5	13.3	5.8
4	3.4470	101.1852	10.5	6.1	6.9
5	3.4470	101.1984	8.8	8.1	5
6	3.4470	101.2115	4.3	10.8	3.6
7	3.4470	101.2247	13.4	11	2.4
8	3.4470	101.2379	9.3	14.1	2.6
9	3.4649	101.1852	11.2	8.2	7.1
10	3.4649	101.1984	12.5	8.6	7
11	3.4649	101.2115	2	17	1.8
12	3.4649	101.2247	2.2	13.9	1.8
13	3.4649	101.2379	7.5	19.5	1.6
14	3.4649	101.2511	7.5	22.3	1.4
15	3.4828	101.1984	42.7	8.5	5.8
16	3.4828	101.2115	18.8	12.7	3.2
17	3.4828	101.2247	25	9.8	3

Knowing the amount of rainfall that has occurred in the agricultural field, a suitable amount of irrigation water can be supplied precisely and better irrigation water management can be adopted. Hence some amount of irrigation water supply can be saved and used for other agricultural lands or other purposes.

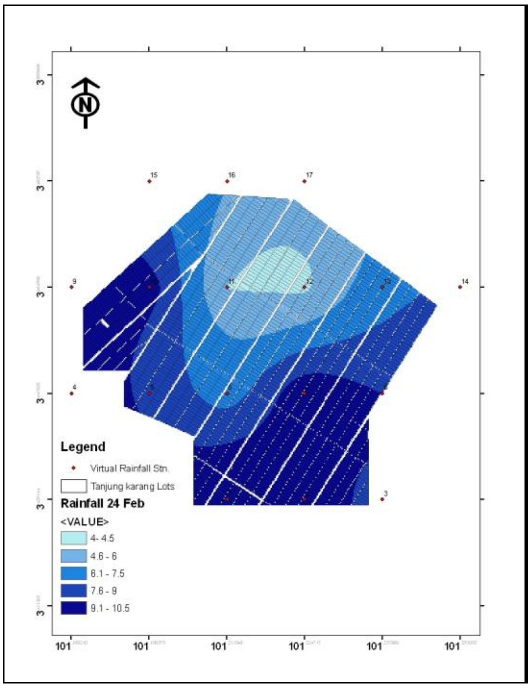


Figure 8: RadeR Rainfall distribution using ViRaS for 24 Feb. 2007

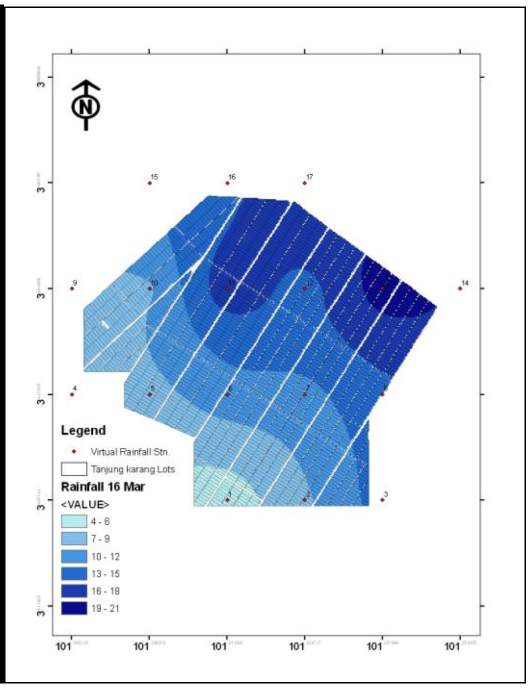


Figure 9: RadeR Rainfall distribution using ViRaS for 16 Mar. 2007

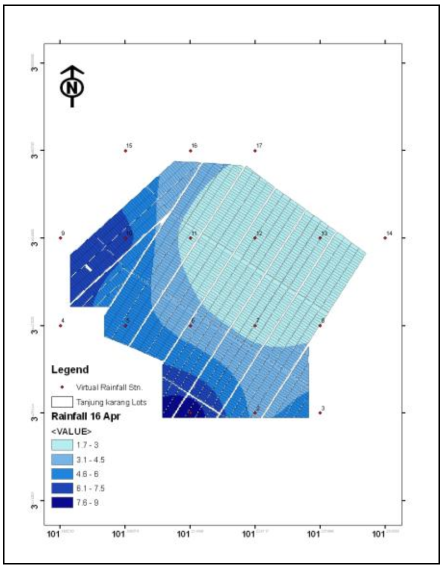


Figure 10: RadeR Rainfall distribution using ViRaS for 16 Apr. 2007

Similarly the radar-derived rainfall data were used to estimate the flow of Upper Bernam River Basin (UBRB). For more representative rainfall distribution in the watershed of UBRB with limited rain gauge stations, virtual rainfall stations were created uniformly in whole watershed.

The estimated radar rainfall data for the virtual rainfall stations were used to develop the radar-derived rainfall distribution map. Both rain gauges and radar-derived rainfall data were used as rainfall input data to the runoff hydrological model. Samples of rainfall distribution maps developed from rain gauges and radar are shown in Figures 11 and 12 respectively.

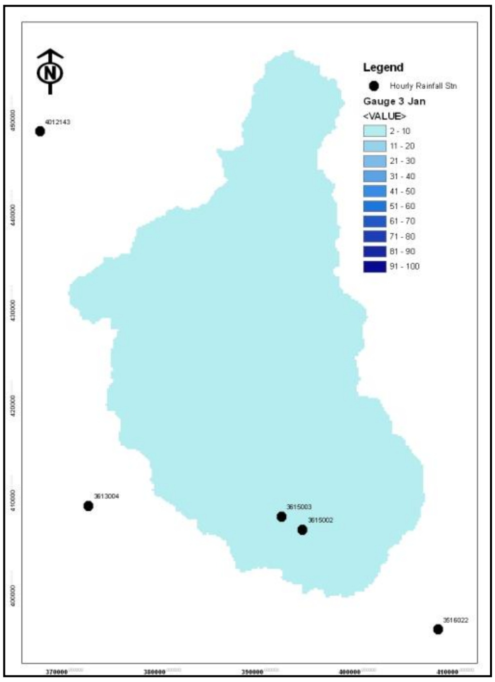


Figure 11: Rainfall distribution map using rain gauges data, 3 Jan. 2006

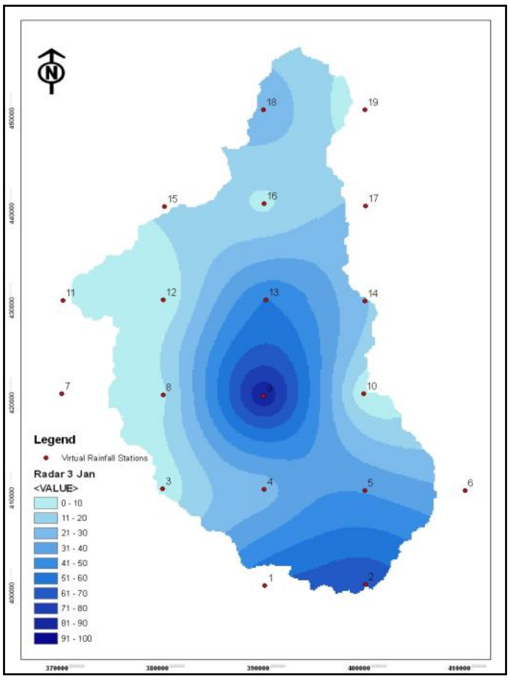


Figure 12: Rainfall distribution map using ViRaS with radar data, 3 Jan. 2006

The comparisons between the measured runoff (direct runoff) and the estimated runoff using gauge rainfall and calibrated radar-derived rainfall are shown in Figure 13.

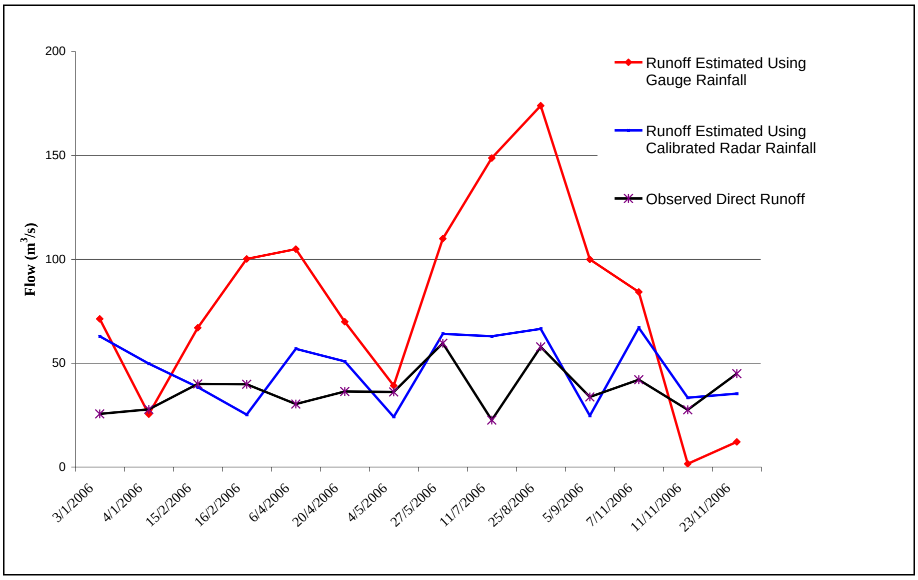


Figure 13: Comparisons between measured and estimated runoff using different rainfall inputs

It was found that, using the radar-derived rainfall data for watershed runoff estimation gave better results compared to rain gauge data. The coefficient of determination (R^2) increased from 0.47 for runoff estimated using gauge rainfall to 0.84 for runoff estimated using calibrated radar-derived rainfall. The application of the ViRaS-RadeR system to generate rainfall distribution map from the virtual rainfall stations using weather radar rainfall data will be a significant contribution to flood estimation applications, flood early warning, as well as better on-farm irrigation water management, especially in the rice granaries.

CONCLUSIONS

The virtual rainfall stations created throughout the study area using GIS tool with radar-derived rainfall data can produce more representative rainfall distribution maps compared to data obtained from the limited rain gauges available. Therefore better watershed runoff can be estimated. Irrigation water supply can be better managed by using data from virtual rainfall stations with radar derived rainfall. This study can be considered as a major step in Malaysia towards the applications of the radar-derived rainfall that may prove useful in advancing flood estimation and forecasting, irrigation water management and other hydrological applications.

ACKNOWLEDGEMENTS

The Authors wish to thank MIMOS for providing grid computing facilities; Radar Division (MMD), for their help and cooperation in providing the raw radar data; Hydrology Division (DID), for providing the hydrological data; Special thanks to SFTL-ITMA (UPM) staff for their valuable support.

REFERENCES

[1] Gerstner E. M, Heinemann G. (2008) Real-Time Areal Precipitation Determination from Radar by Means of Statistical Objective Analysis. Journal of Hydrology 352, 296: 308.
[2] Izuno F.T. (2002) Principles of on-Farm Water Management. (http://edis.ifas.ufl.edu.)
[3] Sharif H.O., Ogden F.L., Krajewski W.F., and Xue M. (2002) Numerical simulations of radar rainfall error propagation. Water Resources Research. Vol. 38, No. 8.
[4] MMD Info. (2007) Radar stations site data, file and data format. Technical report from Malaysian Meteorological Department, MMD.