

Kelantan central basin flood, December 2014: Causes and extend

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Abstract: A combination of meteorological and river basin's physical factors caused a very severe flood in the central part of Kelantan River basin on December 2014. Rainfall-runoffs parameters analysis found that continuous high rainfalls, geological setting and topography triggered the basin wide extreme event which only occurred twice in 88 years of flood records (1926-2014). A regional flood map was generated to demonstrate the extent of the flood within the central and upper Kelantan River basin. The map was generated using water surface gradient interpolation extracted from water level data of existing telemetry stations located along the river system while the lower basin used radar satellite data. Based on this map, the estimated size of flooded areas was 220 km² with flood depths ranging from 1.5 m to 9.5 m. The flood map was overlaid on a mosaic of fine scale Google Earth images for Dabong, Manik Urai and Kuala Krai area in order to visualize the human landscape affected by floods. It is concluded that physical factors, i.e. geological setting and topography are crucial in the analysis of the cause and effect of severe floods, and spatial distribution of flood depths when the terrain characteristics are considered.

Keywords: Kelantan River, flood map, geological setting, basin topography, extreme rainfalls

INTRODUCTION

Flood causes one of the most significant natural losses in Peninsular Malaysia in terms of economic losses (Abdullah, 1999). Analysis of the flood patterns in Malaysia since 1925 indicated that major floods occurred in Peninsular Malaysia with sub-decadal frequency (Sooryanarayana, 1995; Chan, 1997). Most floods in Peninsular Malaysia are caused by heavy rainfalls due to monsoonal and convectional rainstorms. Likewise, previous studies have identified heavy monsoonal rainfall as the main cause of severe floods in Kelantan (Sani, 1973; Pradhan & Youssef, 2011).

Monsoons in particular influence the rainfall temporal pattern of Malaysia which reflects strong seasonal characteristics (Ooi, 1999a). Consequently, floods in Peninsular Malaysia show a strong seasonal pattern also. The northeast monsoon (November to March) is largely responsible for the extensive floods on the east coast while the occurrences of floods on the west coast are associated with the southwest monsoon season (May to September) and two relatively short inter-monsoon periods (April and October) (Chan, 1997). In comparison, the west coast is less affected by monsoonal rainfalls than the east coast because it is protected by the Minangkabau Range on Sumatera and the Titiwangsa Range on Peninsular Malaysia.

The magnitude of floods varies annually because monsoon intensity fluctuates from year to year. ENSO or El Nino Southern Oscillation was identified as a dominant factor in modulating the monsoons causing extreme events such as prolonged dry spells and unusual torrential downpours. It

was found that El Nino generally exerts drier than climatic normal rainfall especially on the north western part of the peninsula. In comparison to ENSO years, extreme rainfall events usually occur during La Nina or non-ENSO years although the effect of La Nina is not clearly evident over Peninsular Malaysia compared to East Malaysia (Ooi, 1999b). As for the threat of direct tropical cyclone attack it is virtually non-existent on Malaysia. However, the intensification and dissipation of tropical cyclones in the western North Pacific and South China Sea region tends to deteriorate the weather condition over the Malaysian region causing heavy rains (Lim, 1980).

Meteorological factor is not the only reason why floods occurred. Floods in Peninsular Malaysia are also caused by surface factors such as low lying topography, poor drainage system and design, coastal areas located below high tide level and the loss of natural retention areas resulting from urbanization (Low & Leigh, 1973; Sooryanarayana, 1995; Chan, 1997; Sathiamurthy *et al.*, 2007; Sathiamurthy, 2013).

Floods are natural phenomena that are directly related to rainfall and discharge processes and the mechanisms that regulate these processes in a river basin. A river basin, such as the Kelantan River basin, is the boundary of the process. A hydrological system behaves either at normal or extreme conditions mostly depend on natural factors such as weather and climate, the ENSO cycle (El-Nino and La-Nina), and so forth (Mirza, 2003; Zhang *et al.*, 2017). These natural factors can happen randomly and repetitively. Thus, this makes the efforts to predict the system behaviour more complicated.

Kelantan River basin

The International Hydrological Programme (IHP United Nations) stated that Kelantan River basin as a whole is about 11,900 km² (Ibbitt *et al.*, 2002). It is located at the north eastern part of Peninsular Malaysia. The central part of the river basin consist of two main tributaries of the Kelantan River are the Galas River (7,770 km²) and the Lebir River (2,430 km²). The length of the main river is 248 km. Its average annual rainfall is 2,505 mm (1970-1997) while average discharge is approximately 558 m³/s (1950-1990). Galas and Lebir River meet at Kuala Krai. Generally, this river basin has a triangular shape (Figure 1). It has a broad upstream and a relatively small downstream.

The upper-central basin is a highland with steep slopes and narrow river valleys whereas the central-lower basin is undulating and flanked by steep hill slopes almost parallel with the river course. The lower basin starts with an undulating region of gentler slopes and becomes almost flat in the floodplain. The coastal plain is characterized by a delta and BRIS (bridge ridges interspersed with swales) topography. These physical characteristics imply great vulnerability to flooding for the middle and lower basin regions. The high and steep sloped upper basin could form large discharges that converge in the narrower middle basin resulting in severe flooding. Furthermore, the nature

of orographic rainfall during the monsoon season causes the highland areas to receive heavy rains. The upper basin also experience changes in land use from natural rain forest area that has the capacity to accommodate heavier rainfalls to logging, agriculture and settlement areas that reduce storage capacity.

This paper discusses the physical factors that caused the December 2014 flood events and proposed a flood map modelled using water surface gradient interpolation technique. It is a simple approach to identify and demarcate affected areas.

METHODOLOGY

Pre modelling stage involved analysis of existing data (present and past records) and information on floods. Factors such as extreme rainfalls, geologic control, land cover, boundary conditions, climate variability and change were examined. Stage hydrographs for 2004 and 2014 obtained from 11 telemetric stations were analysed for peak stage, time to peak, flood stage travel time and attenuation sequence (Figure 1) (Drainage and Irrigation Department, 2016). Flood depths and duration were also extracted. Flood frequency analysis was conducted based on flood data from 1926-2014. The EV1 (Extreme Value Type 1) or GEV (Gumbel Extreme Value) method was used to study

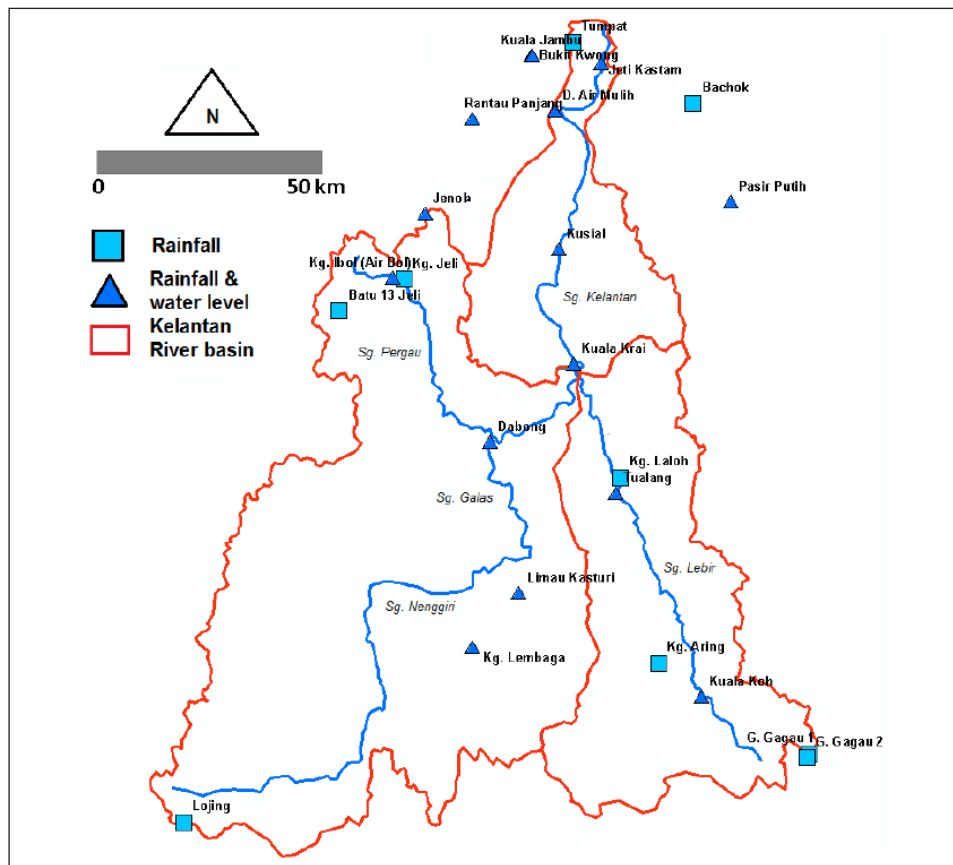


Figure 1: Telemetric rainfall and water level stations of Kelantan (Data source: Drainage and Irrigation Department, 2016).

flood return periods or recurrence intervals (Chow *et al.*, 1988; Toonen, 2015).

Peak stages from existing telemetric stations for the central and upper regions of Kelantan River basin were interpolated based on water surface gradient concept. The interpolated layer was compared with detailed topographic data (LIDAR). The topography was represented as a digital terrain model or DTM. The difference between the interpolated water surface and the underlying topography represents flood depths that were subsequently used for generating a flood map. As for the lower basin of Kelantan, a flood map was generated from radar satellite images obtained from ANGKASA (*Agensi Angkasa Negara* i.e. National Space Agency). The flood map was laid upon high resolution RGB satellite images obtained from Google Earth (Google Earth, 2016). The images were firstly merged using GIS software. This step was made in order to show the human landscape affected by floods.

RESULTS AND DISCUSSION

The December 2014 Kelantan floods occurred in two sequential waves (Table 1). The first wave occurred from 18 to 19 December. It was a small event with flood levels not exceeding 2 m. The affected areas were limited to parts of Tualang, Kuala Krai, Kusial and Kota Bahru. The second wave was a very large event that occurred from 22 to 31 December. The second flooded areas were extensive covering upper-central basin, lower and coastal plains, more than 220 km² in total area. Maximum flood depths ranged from 1.5 m to a striking 9.5 m. The worst hit area was the upper to central basin region, i.e. Kuala Balah, Gua Musang, Dabong, Manik Urai, Tualang and Kuala Krai. High rainfalls were recorded from 14 December to 28 December. They occurred almost daily. Heavy orographic rainfall concentrated on the upstreams of Kelantan Basin. This pattern resembles the spatial distribution of Kelantan's annual rainfall (Ibbitt *et al.*, 2002). Coupled with steep topography, they generated high flood flows from upstreams of Galas and Lebir sub-basins. Gunung Gagau (headwater of Lebir River) received about 1237 mm of rainfall in just a week, i.e. 20-26 December that accounted for more than 47% of its annual mean. Whereas, Lojing (headwater of Galas River) received about 361 mm for the same period that accounted for 14% of its annual mean. While it is generally accepted that exceptional heavy rainfalls was the main factor, the geological setting and topography of Kelantan Basin are key mechanisms.

With reference to Table 2 and Figure 2, while the rainfall events may have exceeded 100 years ARI, the resulting flood recurrence intervals do not follow rainfall ARI because floods are not caused by rainfall alone but a combination of factors (e.g. rainfalls, geological setting, topography, land cover etc.). The flood sizes recurrence intervals range from 35 to 45 years return periods. Hence, care must be exercised not to equate both. In the 88 years of stage records for various stations, extreme flood events

(within top 5%) accounted for 3 to 4 flood events. Kuala Krai has the highest flood frequency, i.e. 1 event in every 1.4 year. This could be attributed to the location of Kuala Krai. It is the confluence of Lebir and Galas sub-basin (85.7% of the whole Kelantan River basin) and being located on the central part of the basin it has a narrow undulating valley on the eastern side and a steeper western flank (Figure 3). This hydrologic and physical setting made it susceptible to floods. In general the central basin, i.e. Kuala Krai-Kusial route and coastal plain, i.e. Kota Bahru, have higher flood frequency, ranging from 1/1.4 to 1/1.8 (flood event/year) or almost more than once in two years. As for Kota Bahru, its proximity to the estuary probably make impediment of flood flows by tidal intrusion to be the aggravating factor (Sathiamurthy *et al.*, 2007; Hoitink & Jay, 2016).

With reference to Table 3, the peak stage rise rate of the 2014 event is compared to a smaller recent event of 2004. The 2004 event was chosen because it was assumed that the hydrologic system and topography of Kelantan River basin remained essentially the same over that short period, hence the events could be validly compared. In general, the peak stage rise rates are not extreme, i.e. ranged between 0.03 to 0.23 m/hr and do not differ significantly between both events. The time to peak is generally the same for both events except for Tualang and Kuala Krai that had longer time to peak for 2014.

The upper Lebir sub-basin received very heavy rainfall compared to other areas in the 2014 event, hence higher outflows were generated and the rising limbs of Tualang and Kuala Krai stage hydrographs were sustained longer before reaching peak stage. These analyses suggest while rainfalls played a significant role in determining outflow volume as demonstrated by the high river stages, surface conditions like storage (surface and sub-surface) and topography exercise control over discharge characteristics (Zhang *et al.*, 2014; Phillips *et al.*, 2018).

Figure 3 shows the geological setting, topography and river system of the basin. The highlands are set up almost parallel to each other in a north-south orientation with the Titiwangsa range on the western flank (Western Belt) and Kelantan highlands (Eastern Belt) on the eastern flank corresponding to major fault lines (Harun, 2002; Khoo & Tan, 1983). This setting creates elongated river systems with long trunk rivers and shorter tributaries mainly occupying a lower Central Belt region. The steep slopes and short tributaries ensure quick outflows from sub-catchments into the trunk river system, i.e. Pergau, Nenggiri, Galas, Lebir and Kelantan. Hence, the trunk rivers could be overloaded quickly, overflow and cause flooding (Phillips *et al.*, 2018; Teng *et al.*, 2006). Furthermore, the river valleys are narrow being flanked by steep hill slopes causing greater vertical diffusion of flood waters resulting in severe floods. This phenomenon becomes even worst in river confluences where flood flows combined. The worst affected areas in the 2014 events, e.g. Dabong and Kuala Krai, are situated on such

Table 1: Peak stage and flood duration of Kelantan flood, December 2014.

1 st Wave 18/12-19/12/2014						max H	max f H	Flood duration		
Station	cum D	Date & time	WL	NWL	DWL	WL- NWL	WL- DWL	Start	End	No. days
Galas River pathway										
Kg. Lembaga	0	17/12 10:00	8345	8000	8700	345	X	X	X	X
Limau Kasturi	0	17/12 23:15	5506	5300	5900	206	X	X	X	X
Dabong	48	18/12 9:00	3672	2800	3800	872	X	X	X	X
Kuala Krai	84	18/12 17:00	2668	1700	2500	968	168	18/12 9:00	19/12 15:00	1
Pergau River pathway										
Kg Ibol	0	17/12 2:15	7457	7000	7470	457	X	X	X	X
Dabong	56	18/12 9:00	3672	2800	3800	872	X	X	X	X
Kuala Krai	92	18/12 17:00	2668	1700	2500	968	168	18/12 9:00	19/12 15:00	1
Lebir River pathway										
Kuala Koh	0	17/12 12:00	6680	6200	7500	480	X	X	X	X
Tualang	66	18/12 9:00	3615	2700	3500	915	115	18/12 9:00	19/12 8:00	1
Manik Urai	80	No station								
Kuala Krai	105	18/12 17:00	2668	1700	2500	968	168	18/12 9:00	19/12 15:00	1
Kelantan River pathway										
Kuala Krai	0	18/12 17:00	2668	1700	2500	968	168	18/12 9:00	19/12 15:00	1
Kusial	34	18/12 9:00	1784	1000	1600	784	184	18/12 9:00	19/12 22:00	1
Air Mulih	72	18/12 14:30	729	100	1065	629	X	X	X	X
Jeti Kastam	90	18/12 21:00	564	100	500	464	64	18/12 6:00	19/12 18:00	1
2nd Wave 22/12-31/12/2014										
Station	cum D	Date & time	WL	NWL	DWL	WL- NWL	WL- DWL	Start	End	No. days
Galas River pathway										
Kg. Lembaga	0	23/12 15:00	9022	8000	8700	1022	322	22/12 19:00	24/12 17:00	2
Limau Kasturi	0	23/12 14:45	6025	5300	5900	725	125	?	?	?
Dabong	48	24/12 12:00	4589	2800	3800	1789	789	22/12 14:00	?	?
Kuala Krai	84	25/12 15:00	3417	1700	2500	1717	917	22/12 10:00	31/12 15:00	9

(Continued on next page)

Table 1: Peak stage and flood duration of Kelantan flood, December 2014 (*continued*).

Pergau River pathway										
Kg Ibol	0	24/12 9:45	7325	7000	7470	325	X	X	X	X
Dabong	56	24/12 12:00	4589	2800	3800	1789	789	22/12 14:00	?	?
Kuala Krai	92	25/12 15:00	3417	1700	2500	1717	917	22/12 10:00	31/12 15:00	9
Lebir River pathway										
Kuala Koh	0	22/12 1:30	6569	6200	7500	369	x	x	x	x
Tualang	66	27/12 4:00	4451	2700	3500	1751	?	22/12 9:00	27/12 10:00	5
Manik Urai	80	No station								
Kuala Krai	105	25/12 15:00	3417	1700	2500	1717	917	22/12 10:00	31/12 15:00	9
Kelantan River pathway										
Kuala Krai	0	25/12 15:00	3417	1700	2500	1717	917	22/12 10:00	31/12 15:00	9
Kusial	34	25/12 23:00	2273	1000	1600	1273	673	22/12 17:00	31/12 17:00	9
Air Mulih	72	25/12 22:30	1210	100	1065	1110	145	24/12 22:45	28/12 7:00	4
Jeti Kastam	90	26/12 16:00	699	100	500	599	199	23/12 10:50	30/12 16:00	7

Note: Cum. D – cumulative distance in km; WL – water level in cm NGVD recorded at time of monitoring; NWL – normal water level, i.e. long term average; DWL – danger water level or significant flood level; max H – maximum water depth during flood, i.e. WL-NWL; max f H – maximum flood depth, i.e. WL-DWL. DWL and NWL are set by DID Malaysia; Water levels data source: Drainage and Irrigation Department, 2016.

Table 2: Extreme flood events of Kelantan River basin.

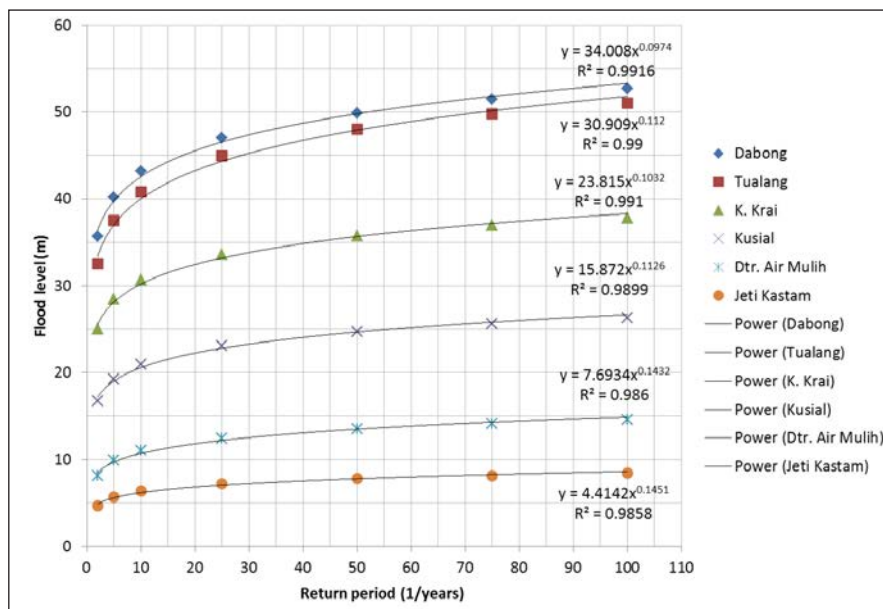
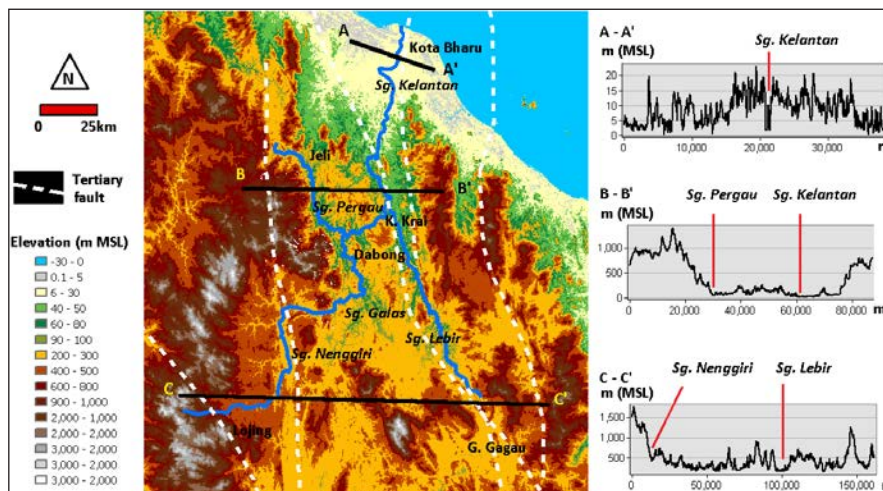
Year of extreme event	Locations and water level (m NGVD)*					
	Dabong	Tualang	K. Krai	Kusial	Dtr. Air Mulih	Jeti Kastam
1926	50	45	35.4	22.9	11.6	6.4
1967	44.5	x	33.6	22.4	x	x
1979	x	x	32	x	11.4	x
1988	x	x	x	x	x	6.4
2004	x	39.9	x	x	x	7
2014	46.5	44.5	34.2	22.8	12.2	7
Statistical analysis	Dabong	Tualang	K. Krai	Kusial	Dtr. Air Mulih	Jeti Kastam
No. extreme events	3	3	4	3	3	4
Flood frequency (1:years)	1:2.7	1:3.1	1:1.4	1:1.8	1:2.3	1:1.7
Total no. events	33	28	61	50	38	51
Mean stage (m NGVD)	36.5	33.5	25.6	17.2	8.5	4.9

Note: No. extreme events – within top 5% of the total number of flood events; Flood frequency – 1 event in how many years, e.g. 1:2.7 means 1 flood event in 2.7 years; Data length is 88 years; x - no extreme event. Total no. events – total flood events recorded from 1926 to 2014, i.e. in 88 years. Mean stage – average water level for total flood events recorded.

Table 3: Peak stage rise rate – upstream to downstream of Kelantan River system.

Station	Year	Time to peak (days)	Level change	Rise rate (m/hr)	Flood days	Flood max. depth (m)
Tualang	2004	2.2	12.1	0.23	2.8	4.9
	2014	6.0	17.0	0.12	5.0	9.5
Dabong	2004	4.3	13.2	0.13	>5	2.1
	2014	4.6	15.5	0.14	>7	8.4
K. Krai	2004	2.6	10.0	0.16	3.2	4.5
	2014	4.6	12.8	0.12	9.2	9.2
Kusial	2004	4.8	11.2	0.10	3.8	4.7
	2014	4.8	9.2	0.08	13.8	6.8
Jeti Kastam	2004	4.7	7.0	0.05	4.0	2.0
	2014	5.0	4.1	0.03	12.4	2.0

Note: Level change is the difference between the level at the stage hydrograph rising limb's inflection point and the peak level.
Rise rate is the level change divided by time to peak.

**Figure 2:** Flood level and return period for water leveling stations of Kelantan River system.**Figure 3:** Kelantan River basin cross sections (Topographic data source: USGS, 2004).

setting. As a result of smaller lateral diffusion in central-upper basin valleys, the flood peak was not attenuated effectively until it went into the lower basin region, i.e. Kusal to Kota Bahru. The almost flat coastal plain ensured effective lateral diffusion and flood peak attenuation (Figure 4). The trunk rivers themselves have steep upstream gradient. Based on long profile analysis using LIDAR data, bed gradient of the trunk rivers taken from upstream to the central basin ranges from 16.4 m/km for Gua Musang section; 1.0 - 1.2 m/km for upper Pergau and Lebir to a gentle gradient of 0.4 - 0.2 m/km for the central basin; and from Kuala Krai to Kota Bahru, about 0.2 m/km. The steeper bed gradient of the trunk rivers on the upper basin generate higher flow velocities hence larger flow rates with shorter conveyance time into the central basin.

The general flood map for the upper to central basin section is shown in Figure 5. The water surface elevation

interpolation technique yielded acceptable results for areas with greater vertical diffusion. For coastal plains, the results were not satisfactory as the effect of unsteady lateral diffusion over wider river corridors or floodplains is significant hence making interpolation approach unsuitable (Afshari *et al.*, 2018). Thus, for the coastal plain, radar satellite images were used to demarcate flooded areas (Figure 6). Based on the flood maps, the approximate total flooded area for central basin was 173 km² whereas the coastal plain was 150 km².

The flood map indicated that the central-upper basin area being the most affected region. The general flood map is a GIS based map that could be zoomed in to see details (Figure 7). It could be overlaid on satellite images extracted from Google Earth and other data sets such as topography and geology for the purpose of studying the relation between the spatial distribution of flood with

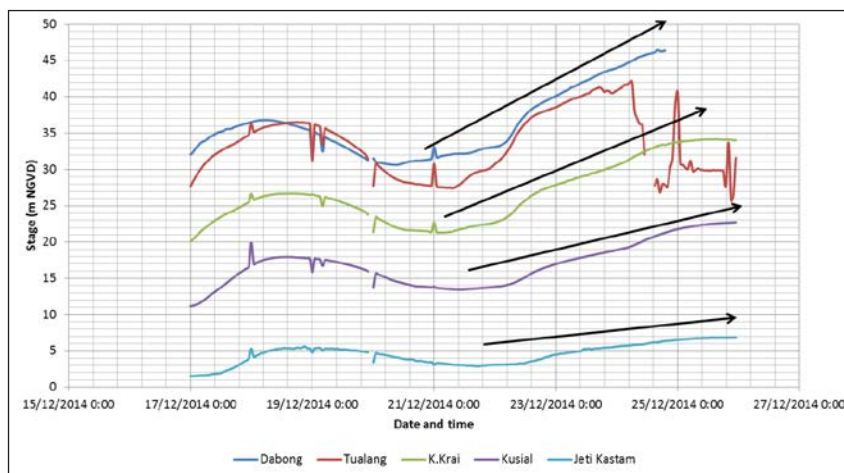


Figure 4: Flood peak attenuation from Galas River and Lebir River to the lower course of Kelantan River.

Note: Arrows are showing a drop in rising limb gradient as flood peak travelled downstream. Falling limb could not be compared because no data is available for Tualang and Dabong.

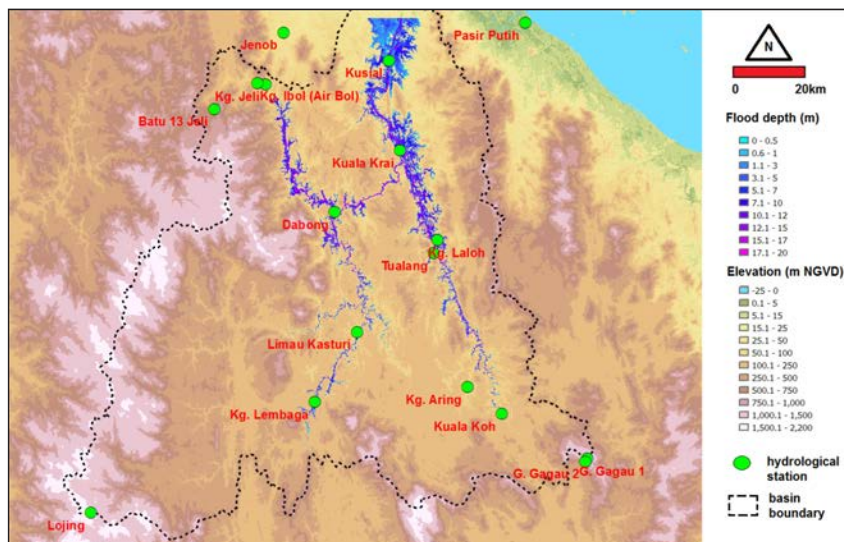


Figure 5: Flood map of upper and central Kelantan River basin.

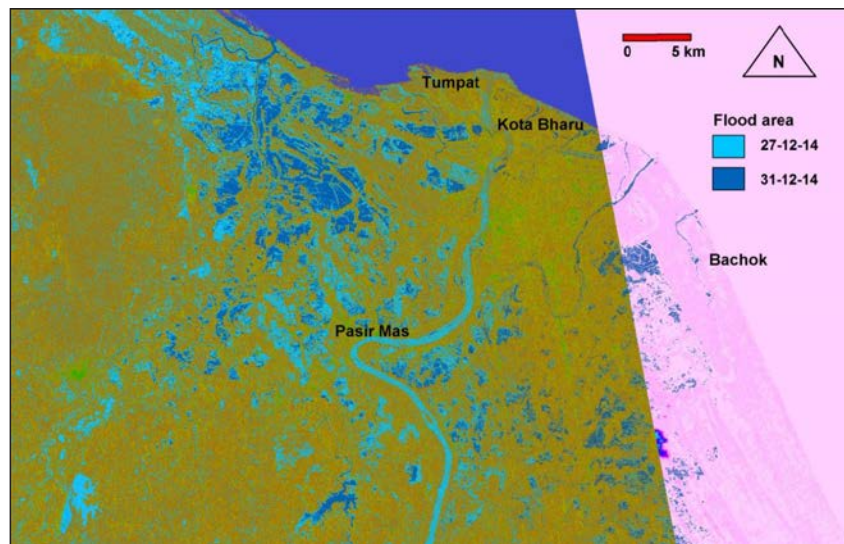


Figure 6: Flood map of Kelantan plain produced from radar satellite images. (Data source: ANGKASA, 2015).

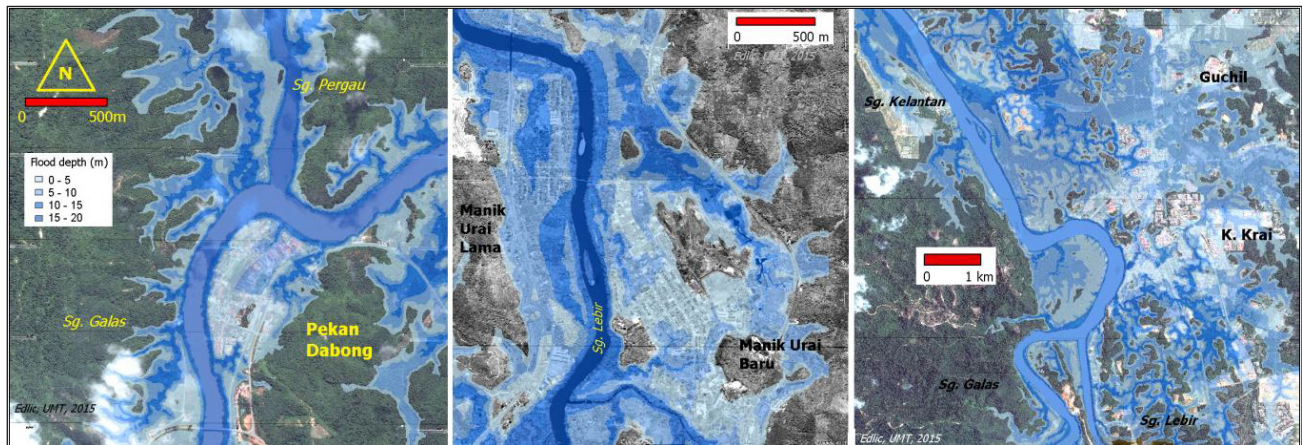


Figure 7: Flood map of Dabong, Manik Urai and Kuala Krai.

physical factors (discussed earlier in Figure 3) as well as its impact on human landscape (Figures 8 and 9).

The detailed flood contour map as shown in Figures 8 and 9 exemplifies how the map could aid in examining the flood impact by simply overlaying the flood map on a high resolution satellite image. It could be easily identified and computed that Kuala Krai town was almost completely inundated (about 80%) with flood depths between 5 to 10 m whereas Dabong town was almost completely inundated. By simply relating key infrastructures with the flood map, the effect of flood on the human landscape could be examined. Kuala Krai functions as a socio-economic, transportation and public services hub were completely crippled. Its key infrastructures as indicated in the map were either completely flooded or became inaccessible as their surrounding areas were flooded. For example, Kuala Krai Hospital was not flooded but it became inaccessible whereas the Fire and Rescue Department completely submerged. In the case of Dabong, it is a

railway connection between Gua Musang in the south of Kelantan with the rest of the state in the north. Its railway station and track were completely submerged under 5 to 10 m of flood water.

CONCLUSION

This paper discussed several key factors such as rainfall, geological setting and topography. Prolonged heavy daily rainfalls on the upstream catchments of Lebir and Galas Rivers overcame the ability of storage systems to cope with the exceptional rainfall event. In areas like Aring, Gunung Gagau, Lojing and Gua Musang, storage capacity was reduced partly as a result of land cover change from natural forest to agriculture. The Lebir and Galas sub-basins are located on highlands with steep gradient (reaching 1/3 m/m) and bed slope ($> 1/1000 - 1/500$ m/m). Hence, large outflows were generated. The narrow river valleys (upper to central basin) limited the storage areas for lateral diffusion of flood water compared to the wide coastal

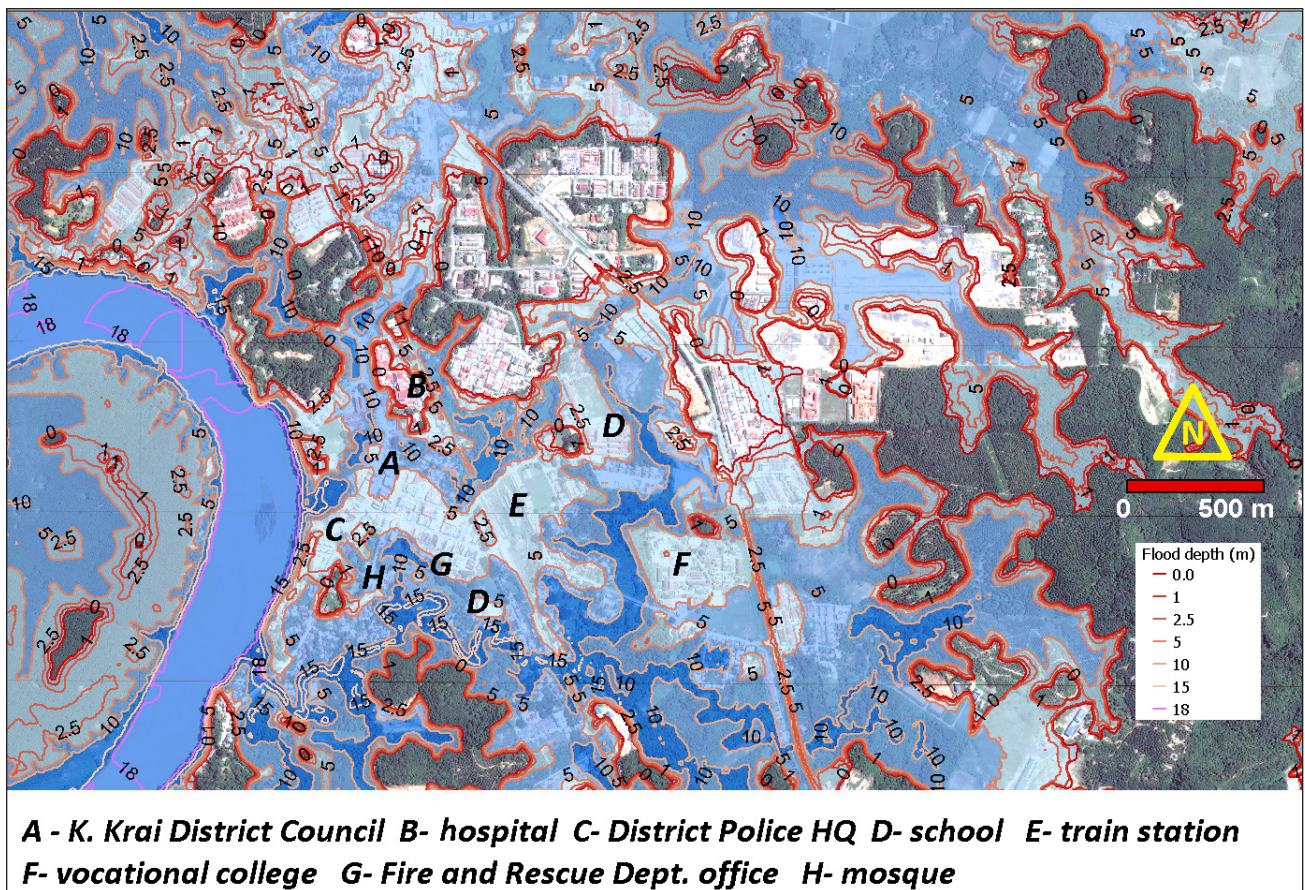


Figure 8: Flood contour of Kuala Krai town.

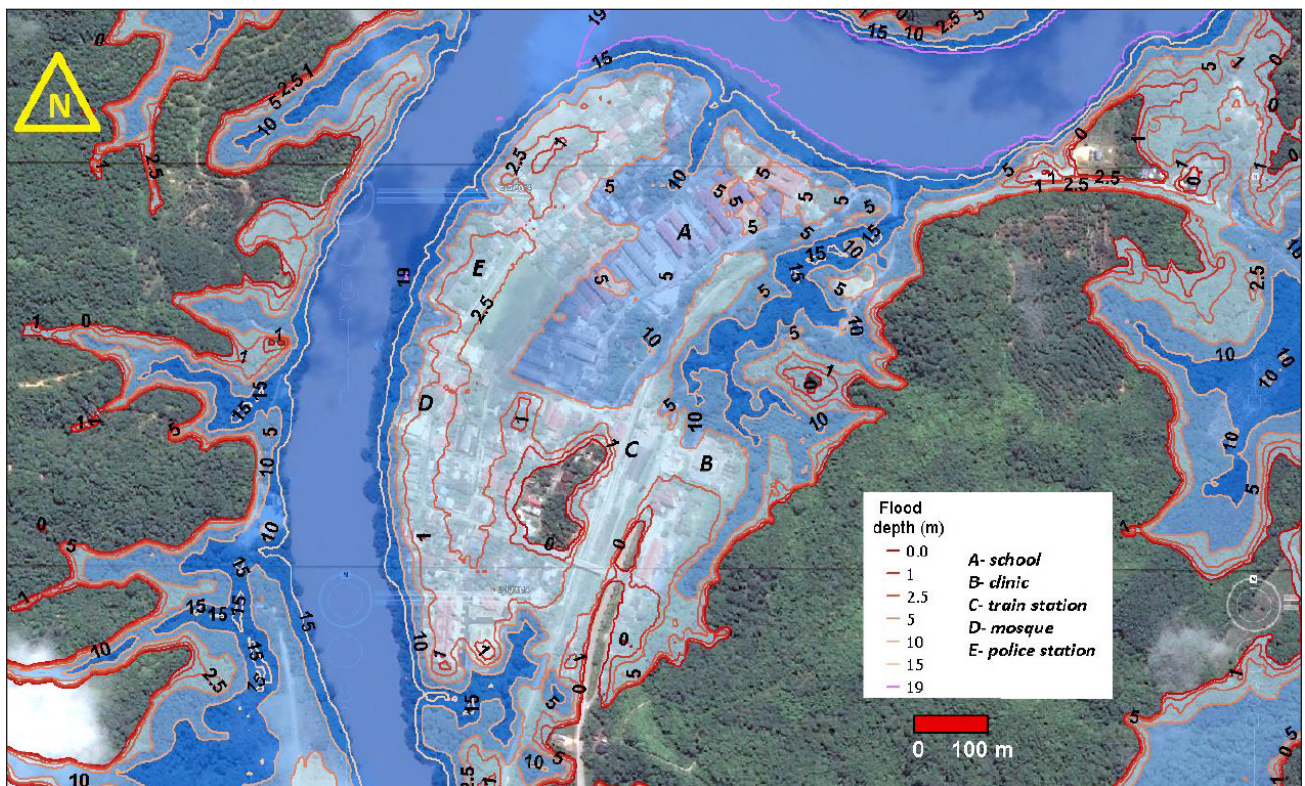


Figure 9: Flood contour of Dabong.

flood plain. Consequently, exceptionally high flood stages were produced (at major river confluences). Other factors that also influenced the flood phenomenon such as land cover change, high sediment load and debris flow are not covered in this paper. Two important points to note from the discussion are: the flood recurrence interval analysis implied that the 2014 event although severe, it may not be considered as extreme beyond current records, hence not an exceptional event; comparative stage hydrograph analysis indicated that although the event was severe, it may not have exceeded the feedback mechanisms of the hydrologic system, hence in a physical-natural sense may not indicate a new system equilibrium. Further studies are needed to ascertain whether the 2014 event could indicate system imbalance. The spatial relation between the flood event and physical factors shown by the flood maps indicate that the geological setting (i.e. steep floods and narrow valleys) was a crucial factor in causing high flood levels. The high flood levels as shown by the detailed flood maps inundated most of the human landscape along the narrow valley corridors and consequently characterized the spatial distribution of flood depths.

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