Towards Impact-Based Flood Forecasting and Warning in Malaysia: A Case Study at Kelantan River

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Abstract. Impact-based forecasting and warning services aim to bridge the gap between producers and users of warning information by connecting and increasing synergies between the components of effective early warning systems. In this research, we proposed an automated warning message based on colour codes to trigger risk mitigation actions at the local level in the flood-exposed communities of Kelantan river basin, Malaysia. With a community-based approach for different groups of users (i.e. sectors), flood-impact scenarios were determined from past events and related to colour codes. These were developed into impact-based forecasting and warnings that can connect water levels, through the colour code, to localised guidance information tailored to sectors' needs on how to respond to the expected flood. Overall, the colour coded impact-based warnings were found to be an easy and understandable way to link water level forecasts to the necessary risk mitigation actions. However, further investigation is needed to validate these findings under real-time conditions. IBF has vast potential in Malaysia, but its integration requires significant institutional changes, such as an inter-facing agency (long term) or team (short term), adjusted policy frameworks (standing orders on disasters), and new resource allocations for skills development and technological innovation from national to local levels. Overall, this paper aims to offer the first insight into impact-based forecasting and warning services in Malaysia to trigger further research and project developments.

1. Introduction
Flood disaster occurs quite frequently in Malaysia and has been categorised as the most threatening natural disaster compared to landslides, hurricanes, tsunami, haze and others. A study by JPS entitled National Register of River Basin, 2003 shows that 9% of land areas in Malaysia are prone to flood, which may affect approximately 4.9 million of the population [1]. This may result in a significant loss of RM 915 million per annum due to economic depletion of roughly RM 2 billion in a year [2-3]. Massive floods have been recorded since 1926, followed by 1967, 1971, 1973, 1970 and 1988. In 5 years between 2011 and 2015, a total of 714 floods have been recorded comprising flash flood (556), monsoon flood (147), mud flood (4), flood due to dam release (7) and more than 200 flash floods particularly in 2015. Moreover, the flood in Kelantan destroyed 2000 houses with a total loss of assets at RM 2.9 billion. It also reported 25 deaths and 500,000 house evacuations. The Red Flood which occurred in Kelantan back in 1926 recorded with continuous rainfall for 10 days which led to river overflow from Sg. Kelantan flooding Kota Bharu, Pasir Mas and Tanah Merah. After 40 years, heavy rain for five consecutive days from 2nd to 6th January 1967 has resulted in a massive flood of the same magnitude. It led to 38 deaths and affected approximately 37,000 (84%) people in Kelantan. In
2004, another major flood disaster occurred in Kelantan due to heavy rain at Sg. Kelantan river basin affecting Kota Bharu, Pasir Mas and Tanah Merah. Only 10 years later, the ‘Yellow Flood’ returned to Kelantan and destroyed houses at Kuala Krai and Tanah Merah. The flood overflowed above two-storey schools and covered Kuala Krai town beyond 5 metres. It resulted in 14 deaths and more than 339,703 people or 87,024 families moved to flood evacuation centres or stayed with nearby family members [4-5].

Early Warning Systems (EWS) are risk mitigation measures targeted to deliver information on an emerging hazardous event; to enable actions in advance that reduce the risks involved [6]. A complete and adequate EWS comprises of four inter-related elements: a) risk knowledge, b) monitoring and warning service, c) dissemination and communication, and d) response capability. A failure in one of these components determines the collapse of the whole system [7]. Risk knowledge refers to the combination of hazards and vulnerability at specific locations through systematic data collection and analysis targeted to understand the dynamic nature of risk. The monitoring and warning service includes the scientific aspects required to timely forecast the hazard and prepares accurate warnings in space and time. Dissemination and communication ensure warnings reach all those at risk and provide clear, useful and straightforward information through different channels. Response capability makes sure that alerts are received and understood activating all the actions needed to reduce the risk [7]. The World Meteorological Organization (WMO), conveying the outcomes of the Third UN World Conference held in Sendai [8], has highlighted the need for impact-based forecasting and warnings (IBFW) services to bridge the gaps hindering effective EWSs [9]. Although recently introduced, best practices can be found in national meteorological services, like the UK Meteorological Office [10] and the United States National Weather Service [11], as well as in international programs led by WMO through dedicated workshops [12].

Meteorology and Hydrology Agency has the primary responsibility for timely and accurate forecasts and warnings of hydro-meteorological hazards and events. However, the government and public are needed to know the impact of the hazard on lives, livelihood, property and economy. The expectation forecast warnings not just statements on dangers; however, understanding disaster risk and forecasting impact beyond remit of the weather and flood agencies [10].

Forecasting impact is more critical than pure meteorology forecasts [13]. Those at risk and those responsible for mitigating those risks more readily understand them. Meteorologists often are reluctant to forecast impact. Extensive knowledge of vulnerability and exposure is needed. For example, flood forecasting requires additional data such as ground cover, runoff, topography, roads and infrastructures, time of day and traffic conditions, crowdsourced information [14]. The data allows risks of impact to be forecast and warnings issued targeting those exposed to hazard. Authorities can take specific actions, for example, safe routes, closing schools etc.

UK has introduced an advanced concept of multi-hazard impact-based forecast and warning services that should be viewed as a central part of the effort to modernise National Meteorological and Hydrological Services (NMHSs). This requires a significant change in NMHSs’ operations, responsibilities, training and partnerships with other national and international actors. The expected benefit would be a considerable increase in the capacity of communities to take appropriate action to protect their families, livelihoods and property and therefore, a reduction in disasters. It would reach far beyond the technical improvement in services to strengthen resilience within communities [15].

The WMO guidelines define three forecasting paradigms a) Weather forecasts and warnings, which include information about the hazard only b) Impact-based forecasts and warning, which have information about the hazard and vulnerability to that hazard and c) impact forecast and alarms, which include information about the hazard, vulnerability and exposure [12]. IBF also arises naturally when the forecast output focuses on users’ needs. Typically, the meteorological forecast only produces the weather forecast in spatially location. Besides, the hydrological forecast or flood forecast relies on the forecast trend for water level and flood inundation map [16]. To have the combination of forecast between meteorology and hydrology is very challenging, especially in term on the accuracy. Lack of information on the risk and impact of flood victims is crucial. Most flood victims rely on more meaningful information.
Therefore, IBF and warning services aim to bridge the gap between producers and users of warning information by connecting and increasing synergies between the components of effective early warning systems. The aim is to prepare an understandable and useful warning message based on colour codes to trigger risk mitigation actions at the local level in the flood-exposed communities in Kelantan. The idea is to develop into impact-based forecasting and warnings that can connect water levels, through the colour code, to localised guidance information tailored to sectors needs on how to respond to the expected flood. It is hoped that the colour coded impact-based warnings will be an easy and understandable way to link water level forecasts to the necessary risk mitigation actions, especially under real-time conditions. Moreover, by using artificial intelligence techniques, the system can capable of reading interpolated maps and produce accurate results [17-19]. IBF has vast potential in Malaysia, but its integration requires significant institutional changes, such as an inter-facing agency (long term) or team (short term), adjusted policy frameworks and new resource allocations for skills development and technological innovation from national to local levels.

2. Study Area
Kelantan state covers an area of 15,099 km² at the northeastern region of Peninsular Malaysia bordered by parts of southern Thailand to the north, Perak to the west, and Pahang to the south and Terengganu to the south-east. Hilly terrains are found on the south of parts of the state, separated by the Titiwangsa Mountains Range, with fertile coastal plains downstream defining the geography of the region. Kelantan is the main river to discharges into the South China Sea during the wet season, which is caused by the northeast monsoon. The upland areas generally range from 1000mLSD to 1500mLSD in elevation with some peaks reaching more than 2000mLSD. The topography is less rugged towards the main drainage lines in the central part of the basin, where most of the land is below an elevation of 75m and consists of low hills. The major rivers of the riverine were including Sungai Nenggiri, Sungai Lebir, Sungai Galas, Sungai Pergau, Sungai Kelantan, Sungai Golok, Sungai Kemasin, Sungai Pengkalan Chepa, Sungai Pengkalan Datu and Sungai Semerak. Sungai Kelantan Basin, with a catchment area of approximately 12,981 km² comprises four main tributaries namely Sungai Nenggiri, Sungai Galas, Sungai Lebir and Sungai Pergau.

![Figure 1](image.png)

**Figure 1.** The Study area of the proposed research

The river mouth is situated about 15 km north of Kota Bharu. About 760 km² of the lower river basin has a low-lying flat terrain prone to annual flooding. Figure 1 depicts the topographical view of Sungai...
Kelantan river basin. Many factors contributed to the flooding. They are categorised into two leading causes, a) Caused by nature events and b) Caused by human activities. Flood causes by nature factors later divided into two a) Hydrological aspects and b) Topographic elements.

This country reported on flood issues since the 1800s with specific attention to monsoon and flash floods, and the very first severe flood event took place in 1886 was recorded in Kelantan that caused extensive damage [20]. In 1967, disastrous floods surged across the Kelantan, Terengganu and Perak state. The almost same magnitude of the flood as that occurred in 1971 swept across many parts of the country [20]. As for the Kelantan river basin, it has always become the main subject to the most severe monsoon flooding in Malaysia apart from Terengganu and Pahang. Flooding appears to be increasing in Kelantan in terms of frequency as well as magnitude. The worst flood experiences in the Sungai Kelantan basin were in 2010 and in 2014. Since then, and in between these years, minor floods have occurred occasionally. The overflowing from the upper catchments caused most of the inundations of the primary confluences of Sungai Kelantan. Table 1 shows the historical flood and its impact from 2001 to 2014.

The study area has been subjected to recurring flooding from its past. The nature of flooding in the study area consists of several aspects including due to the low-lying and rather flat terrain of the area and caused by relatively short duration with high rainfall intensity event, which inflicted flooding issues. Flood reports produced by DID were obtained for a range of flood events. These reports provided a useful summary of important historical events that have affected the study area.

| Year | Station Name | Date / Time | Danger Level (m) | Highest Water Level (m) | Flood depth (m) |
|------|--------------|-------------|------------------|------------------------|----------------|
| 2001 | Tamb. D’raja | 25/12/2001  | 5.00             | 5.44                   | 0.44           |
|      | Kuala krai   | 24/12/2001  | 25.90            | 26.65                  | 0.75           |
|      | Guillemard   | 25/12/2001  | 17.7             | 17.83                  | 0.13           |
| 2003 | Tamb. D’raja | 11/12/2003  | 5.00             | 5.59                   | 0.59           |
|      | Kuala krai   | 10/12/2003  | 25.90            | 26.20                  | 0.30           |
|      | Guillemard   | 11/12/2003  | 17.7             | 17.91                  | 0.21           |
| 2004 | Tam. D’raja  | 13/12/2004  | 5.00             | 7.00                   | 2.00           |
|      | Kuala Krai   | 12/12/2004  | 25.90            | 26.48                  | 0.58           |
|      | Guillemard   | 12/12/2004  | 17.7             | 20.63                  | 2.93           |
| 2005 | Tam. D’raja  | 24/11/2005  | 5.00             | 5.28                   | 0.28           |
|      | Kuala Krai   | 24/11/2005  | 25.90            | 25.96                  | 0.06           |
|      | Guillemard   | 24/11/2005  | 17.7             | 18.60                  | 0.90           |
| 2006 | Tam. D’raja  | 8/1/2006    | 5.00             | 5.05                   | 0.05           |
|      | Kuala Krai   | 8/1/2006    | 25.90            | 26.02                  | 0.12           |
|      | Guillemard   | 8/1/2006    | 17.7             | 18.06                  | 0.36           |
| 2007 | Tam. D’raja  | 12/12/2007  | 5.00             | 5.94                   | 0.94           |
|      | Kuala Krai   | 12/12/2007  | 25.90            | 27.32                  | 1.42           |
|      | Guillemard   | 12/12/2007  | 17.7             | 18.75                  | 1.05           |
| 2009 | Tam. D’raja  | 24/11/2009  | 5.00             | 5.39                   | 0.39           |
|      | Kuala Krai   | 23/11/2009  | 25.90            | 26.91                  | 1.01           |
|      | Guillemard   | 8/12/2009   | 17.7             | 18.66                  | 0.96           |
| 2014 | Tamb. D’raja | 25/12/2014  | 5.00             | 7.03                   | 2.03           |
|      | Kuala Krai   | 25/12/2014  | 25.90            | 34.17                  | 8.27           |

3. Methodology
Impact base forecast will be developed when we have an integration input from flood hazard maps and secondary data obtaining from Geographic Information System (GIS). It starts by reviewing other countries practice in implementing Impact Base Forecast (IBF) as we have shortlisted to five (5) countries: - United Kingdom (UK), Australia, Korea, India and Indonesia. All data collection is
needed to be in 1km x 1km grid cell. The maps that are not in scale outlined, it will undergo a reduction size process by using Global Mappers or ArcGIS. This is to ensure all the data has the same properties to give an accurate result.

All data obtained will be undergoing a flood risk assessment. This assessment is to identify the level of impact and likelihood each of point of interest (POI). Scoring will be evaluated to achieve the result on respective grid cell, whether in the green, yellow, orange or red categories. It will read several maps to be compared with other POI in a shorter time. Figure 2 shows the flow of a process in developing flood guidance statement through flood risk assessment and flood risk matrix.

Figure 2. Flow chart of the proposed methodology

The first step of this project will be the data collection that can be obtained from Jabatan Pengairan dan Saliran (JPS), National Disaster Management Agency (NADMA), MetMalaysia, Malaysia National Hydraulic Research Institute (NAHRIM) and other relevant agencies. There are few types of data requires for this proposed research such as River cross-section of the study area, soil/landuse/cadastral maps, population/road/railway/utility data.

The next step of this project will be the data preparation that can be started by obtaining 1km x 1km grid data and will be used during the analysis to meet the study requirement. In this research, the software that will be used for the analysis are ArcGIS or Global Mappers—either using ArcGIS or Global Mappers static map such as state maps (Kelantan), flood hazard maps (already in 1 km x 1 km resolution) to be used as the baseline in the software. Other variables maps will overlay this map. The variable maps will be overlaid onto the static map to identify the quantity of each item in the description list. This method is to identify the density in 1 km x 1 km area, which inclusive all Kelantan river basin. Each box of the map, all the numbers counted need to be measured and tabulate for further process and assessment for all point of interest (POI) data. Some critical POI Hospitals, Government Office, Petrol Stations etc.

After number in each box has been identified, the number will be ranging into few classifications. As per the UK standard, the research will use a 4 x 4 matrix (very low, low, medium, and high) and (Minimal, minor, significant, severe). This is to ensure that the result provided is reliable and can be used for the whole process.
Figure 3. Flood Risk Matrix [10]

An example of the probable Flood Risk Matrix is shown in Figure 3. The Impact threshold will be determined by dividing the maximum and minimum data. Six impacts already identified; utilities, agricultural, public facilities, housing & properties, transport infrastructure, and livestock. The range on POI should be reflected in the categories, respectively. After ranging the result. Each criterion will be scored accordingly, depending on the level of risk, as shown in Table 2. The threshold is calculated based on the maximum and minimum value of that particular POI in the study area.

| Likelihood | Impact | Scoring Each Criteria | Scoring Overall Criteria |
|------------|--------|-----------------------|--------------------------|
| Very Low   | Minimal| 0                     | 0-05                     |
| Low        | Minor  | 1                     | 06-10                    |
| Medium     | Significant | 2                   | 11-15                    |
| High       | Severe | 3                     | 16-18                    |

After scoring the result, each square of 1km x 1km will have final result base on the overall criteria. Figure 4 shows the example of colour distribution base on the overall scoring criteria.
At the end of the process, the IBF map will be produced. A sample IBF map is shown in Figure 5. Finally, each colour has its action to be taken.

4. Results and Discussion
This research aims to propose an IBF strategy for Kelantan River basin area. Therefore, to prove the concept, some preliminary results of FRM is shown in this paper. Two different impact based landuse maps are shown in Figure 6 and 7. Based on these impact-based maps, the scoring map will be produced.

Collected data in the impact library were overlaid with flood hazard map for each rainfall depth. Then, the impact level for each receptor is determined based on flood depth thresholds as described in National Flood Forecasting and Warning System (NaFFWS) project (Azad et al., 2019) and not through the number of POI affected by the flood except for agriculture. While for agriculture, the impact category is assigned based on the agreed impact threshold earlier in this project. Once the impact and likelihood are determined, UK standard 4 x 4 matrixes used to determine the preliminary result of a flood risk matrix for each polygon flooded. The following command was used to assess flood impact according to flood depth and flood impact threshold. Figure 8 and Figure 9 present the results obtained from the flood risk matrix generated using the Landuse Map in the year 2018 from
The flood risk map was derived from 1000 mm rainfall depth. They were overlaid with some selected POI that has been chosen.

![Figure 8. Flood Risk Matrix based on Housing/Properties Impact](image)

![Figure 9. Flood Risk Matrix based on Agricultural Impact](image)

Table 3 shows a sample flood guidance statement based on the criteria. (Operation activities will be amended base on Malaysia topography).

**Table 3. Example of the advisory table for dissemination**

| MINIMAL | MINOR | SIGNIFICANT | SEVERE |
|---------|-------|-------------|--------|
| ALERT: | ALERT: Likely the | WARNING: Likely the | WARNING: Certain |
| Unlikely the LIGHT RAINFALL will affect the designated region | MODERATE RAINFALL will cause some limited flooding and wind damage in the designated region | HEAVY RAINFALL will cause widespread flooding and wind damage in the designated region | VERY HEAVY RAINFALL will cause widespread flood and wind damage in the designated region |
| ACTION: | ACTION: Remain alert and ensure you access the latest weather forecast for up-to-date information. Prepare to act to protect life, livelihood and property in the designated region | ACTION: | ACTION: |
| Keep an eye on the weather and flood forecasts | | Secure property and livelihood assets. | Evacuate if ordered to do so by civil protection |
| | | Be prepared to evacuate. | Be prepared for extraordinary measures |
| | | Be aware of the potential risk of landslides and flash floods in your area. Follow civil protection orders. | to protect life and property |
| | | Maintain radio/media watch for latest updates. | |

Example of flood risk for the public associated with a heavy continuous rainfall
The dissemination messages also depend on the POI and the level of danger as well. Table 4 shows the example of dissemination messages that will be passed to the nearby community of the dam.

### Table 4. Sample dissemination messages based on the POI

| IMPACT                      | Dissemination Message                                                                                                                                 |
|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lives & livelihoods         | **Minimal** - Some minor injuries  
|                             | **Minor** - Many injuries, some critical/permanent; Local-scale economic impact on businesses.  
|                             | **Significant** - Missing people; Many critical injuries; Possible fatalities; Danger to life from water-borne diseases; District/state level economic impact.  
|                             | **Severe** - Some loss of lives/fatalities; People dying from water-borne diseases; National scale economic impact.                                         |
| Residential                 | **Minimal** - Minor damage to some properties  
|                             | **Minor** - Many minor damages, some major damages.  
|                             | **Significant** - Large numbers damaged, some destroyed  
|                             | **Severe** - Widespread destruction of properties and homelessness                                                                                 |
| Transport Infrastructure    | **Minimal** - Trees obstructing road/rail; Minor disruption to road/rail  
| (Land, sea & air)           | **Minor** - Few roads closed; Slight delayed flights; Some disruption road/rail.  
|                             | **Significant** - Bridge(s) fall/collapse; Many damaged roads; Access is limited (road/rail); Some roads damaged from floods; Debris on roads; Few damaged raingauge and water level instruments.  
|                             | **Severe** - Bridge(s) complete structural destruction (washed away); No access to areas; Widespread complete destruction; (major/widespread); Airport closure/cancelled; Many major airport shutdown, cancelled flights; Major roads/highways cut-off; Total destruction of raingauge and water level instruments |
| Health & Sanitation         | **Minimal** - Some minor disruption.  
|                             | **Minor** - Limited access to medicine/hospital and clean water; Shortage of clean water and medicine (short period) due to infrastructure disruption; Water-borne diseases spread to other areas.  
|                             | **Significant** - Difficulty obtaining medicine/hospital availability; Issues accessing clean water for prolonged period.  
|                             | **Severe** - Widespread water borne diseases; National shortage of medicine; Widespread no access to clean water.                                       |
| Utilities                   | **Minimal** - Temporary disruption to water, electricity and communication services to few areas  
|                             | **Minor** - Disruption to water, electricity and communication services to limited areas.  
|                             | **Significant** - Disruption to water, electricity and communication services to several areas for several days.  
|                             | **Severe** - Widespread water, electricity and communication services cut-off for several weeks  
|                             | **Minimal** - Temporary disruption to food supply; Slight shortage of food supply (eg rice)                                                          |
| Agri production / food security | **Minimal** - Some loss/disruption crop/livestock; Shortage of food supply (limited types)  
|                             | **Significant** - Loss of crops/livestock; Disruption of several food supply (certain crops are not available)  
|                             | **Severe** - Large/complete loss of crop/livestock; Financial implications (import-farmer); Agricultural land degradation; No food supply                  |

5. Conclusion

The proposed research shows that the development of IBF can be used with overall interference in GIS software. ArcGIS is the ace software that will be used in this project. This is because base on ArcGIS capabilities to include coding (python) to integrate various maps with lots of data in a short time. The expected result in this study is to develop IBF maps. By using ArcGIS, it is apt to produce the maps as required. Nevertheless, further steps to be explored is on how ArcGIS can read the impact base on...
1km x 1km grid cell maps. Moreover, a few items need to be focused more based on preliminary results shown in this paper. The project will develop 1km x 1km Grid Cell FRM as well as integrate impact threshold and scoring way of producing IBF maps using machine learning. Finally, the project outcome will be the development of a local Flood Guidance Statement for Malaysia.

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