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Effect of 2014 massive flood on well water qualities: A case study on Kelantan River basin, Malaysia

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Abstract

The effect of physical and biological qualities of wells after submergence was assessed following December 2014 flood in Kelantan. Studies were carried out on a total of 65 wells from 13 stations around Kelantan River basin in which the wells' water were sampled for pH, total dissolved solid (TDS), turbidity and microbial contamination. About 95% of the well showed to be contaminated, 7 out of 65 samples (11.1%) showed TDS values $>400 \mu\text{S}\cdot\text{cm}^{-1}$; and 19 samples (29.2%) recorded turbidity beyond 7.0 NTU. Statistical non-parametric tests carried out on independent groups showed that the status of well contamination was neither determined by both degree of submergence nor by the geographical location. Also the physico-chemical parameters are independent of flood inundation. However, TDS and turbidity values changed based on geographical location, at $p < 0.05$. Well from estuary recorded higher TDS ($241.2 \mu\text{S}\cdot\text{cm}^{-1} \pm 159.5 \text{ SD}$) and turbidity ($8.04 \text{ NTU} \pm 6.53 \text{ SD}$) compared to those from inner basin (TDS at $156.3 \mu\text{S}\cdot\text{cm}^{-1} \pm 88.9 \text{ SD}$; turbidity at $2.90 \text{ NTU} \pm 2.46 \text{ SD}$), respectively. The flood water had played significant role in the transmission of existing contaminant, and most of the wells were unsafe for drinking. We concluded that the degree of flood submergence does not necessarily determine the severity of the well contamination in Kelantan, but the existing contamination may exacerbate further the potential risk during post flood period.

Key words: *drinking well, flood inundation, Kelantan River basin, total coliform, water quality*

INTRODUCTION

Annually, the North-East monsoon triggers major rainy season in several regions in South East Asia. Monsoon weather systems usually develops in conjunction with cold air outbreaks from Siberia which produces heavy rain causing severe floods in East coast states of the Malaysian peninsular (Kelantan, Terengganu, Pahang and East Johore) and Sarawak in the East Malaysia [CHANG *et al.* 2006]. At the end of

2014, Kelantan and other eastern coast states were hit by a severe and unprecedented flood whereby it was reported that more than 200,000 were affected while 21 peoples were killed in the floods [AFP 2014; DAVIES 2015; STEPHEN 2015]. Heavier than normal rain, excessive lodging and 'the new moon' phenomenon whereby the moon is the closest to the earth causing high tide were among factors speculated to have triggered this extraordinary flooding. Moreover, the unexpected rise in Kelantan River (Mal. Sungai Kelan-

tan) water level along with water current culminated in catastrophic damages to residential, commercial and industrial buildings; and disabling electrical power, water supply and sewage systems. In the historical context, the detrimental effect of severe flood brought about by monsoon rain had received considerable attention even during the British Colonial era [WILLIAMSON 2016]. This indicates that throughout human history there has been a prolong battle in overcoming and handling the impact of flood. There have been more than 3000 major flood events recorded between year 1985 to 2010 [KUNDZEWICZ *et al.* 2014]. According to studies by ASHLEY *et al.* [2005] on UK catchments, in year 2000, the flood risk was predicted to increase by 30 times by 2080.

The impact of human health after flood could be equally catastrophic. There was immediate concern regarding the probable release and dispersion of biological contaminants such as coliform, cholera, hepatitis, leptospirosis, malaria; and chemical contaminants such as heavy metals and carcinogens in the flood water. Realising the potential hazards of exposure to pathogen or toxicant and long-term negative environmental impact from contaminated water, reliable samples from flood have to be immediately available for accurate assessment and evaluation. This is essential in assessing the public health risks from environmental threat. Faecal contamination of urban flood water was evaluated after severe flood in New Orleans, US, following hurricanes Katrina and Rita [SINIGALLIANO *et al.* 2007], and after Elbe flood in Germany in 2002 [ABRAHAM, WENDEROTH 2005]. Elevated level of faecal indicator bacteria and microbial pathogens were found in flood waters with the subsequent contamination of drinking water sources. For instance, *Vibrio cholera* and rotavirus have caused flood associated diarrhoea in 3 consecutive floods (1988, 1998 and 2004) that occurred in Dhaka, Bangladesh [BRIAN *et al.* 2006]. Faecal coliform and streptococci were found to contaminate water sources in Dhaka after 2004 flood [SIRAJUL *et al.* 2007]; and human enteric virus, hepatitis A and adenovirus, and coliform were prevalent after an urban flood in Jakarta, Indonesia [PHANUWAN *et al.* 2006]. Other studies have included physical and mental health effect associated with severe flood [FEWTRELL, KAY 2008; OHL, TAPSELL 2000; TUNSTALL *et al.* 2006]. During urban floods, the combined sewer-flood water spreads the contamination and poses further health risk. In places where water supply was tremendously affected, the surface water or groundwater supplies would become an option. Well water is the main source of drinking water in developing countries. In the state of Kelantan in particular, municipal water supply is still low and inadequate. Due to this condition, an estimated 35% of population, especially in the rural area were still rely on ground water for their daily activities [IDRUS *et al.* 2014].

Many studies have been carried out to evaluate the microbiological quality of drinking well [BENRABAH *et al.* 2016; CHIRANJAY *et al.* 2012; MUKHOPADHYAY *et al.* 2012; PRITCHARD, O'NEILL 2007; RAMESH *et al.* 2015] and on the impact of flood on river water quality [DEPETRIS, STEPHAN 1990; EMEKA, OSONDU 2016; YOUSAFZAI *et al.* 2013]. However, as far as our concern, there is a limited study carried out on well water quality with respect to flood event. A study on the impact of flood on well water quality was only limited to physical parameters [YOUSAF *et al.* 2013]. In this study, sampling strategy based on wells located in inundated and uninundated regions were used in assessing the microbial contamination and physico-chemical qualities during post flood period. The use of well as a source for analysis in this study is highly appropriate for two reasons. Firstly, unlike in many other states in Malaysia, wells are available throughout regions in Kelantan making them suitable for geospatial study; and secondly, the inundated well could represent an almost 'real time' sample which is likely to retain or preserve the flood water characteristic. The characteristic of well water during post flood period could provide a useful geospatial distribution of contamination and these can be used to interpret potential outbreak [INVIK *et al.* 2017]. In addition, previous studies showed that the turbidity values for Kelantan River were abnormally high (268.9–672.0 NTU), due to sand mining and upstream lodging activities [YEN, ROHASLINEY 2013]. Meanwhile, several series of waterborne disease outbreaks in Kelantan were correlated with poor water supply system [ANG *et al.* 2010; AZIMULLAH *et al.* 2016; ISA 1990; JA'AFAR *et al.* 2013; MALIK, MALIK 2001]. Eventhough extreme weather condition has been well accepted to have an impact on human water supply, the changes it causes to water quality is not fully elucidated. Climatic changes will result in increase or decrease in water flow that will inherently affect the transfer and dilution of contaminants [WHITEHEAD *et al.* 2009]. Due to the unpredictable nature of natural disaster, it is difficult to accurately measure the actual water flow during a disaster period. Groundwater sources such as inundated wells containing flood residues are available in some places for post flood analysis. Therefore, this study has attempted to find possible correlations between the well submergence, the biological contamination and the water qualities. Our prime focus is to find how the physical and biological qualities of the well vary with geographical distribution and the impact of flood inundation. These informations could be used to formulate some guidelines in developing better strategy in using well for drinking following Kelantan's 2014 massive flood. In the event of future flood, regions which are prone to contamination can be identified so that the safety use of well for drinking purpose can be followed.

METHODS

SAMPLING STATIONS

This study was carried out on Kelantan River basin which consist of Kelantan River and its main tributaries: Galas River and Lebir River (see Fig. 1b). Wells located in 10 districts (Mal. Jajahan) previously hit by flood i.e., Tumpat, Kota Bharu, Bachok, Gua Musang, Pasir Mas, Machang, Tanah Merah, Jeli, Kuala Krai and Pasir Puteh were selected (see Fig. 1). These stations were representative of different locations along Kelantan River. In the recent 2014 flood, the main body of flood water was assumed to have originated from the upstream region i.e., Gua Musang, that flowed along Kelantan River before finally reaching the estuary into South China Sea (Fig. 1b, 1c).

Based on geographical location, stations Rantau Panjang, Tumpat, Bachok, Pasir Mas, Pantai Cahaya Bulan, Wakaf Baharu and Pengkalan Chepa are located within 35 km distance from the shore and these stations were categorised as estuary region. Other stations such as Tanah Merah, Dabong, Jeli, Temangan, Pasir Puteh and Machang are located more than 35 km away from shore were categorised into non-estuary regions (see Fig. 1c). In 2014 December flood, stations Bachok, Tok Bali, Pasir Puteh, Machang and Temangan were unsubmerged, whereby all other stations have been submerged. By definition, the relative position of submerged and unsubmerged wells during flood are indicated in Figure 2. As shown in Figure 1c, selected location of sampling stations and their submergences during flood are indicated on the map.

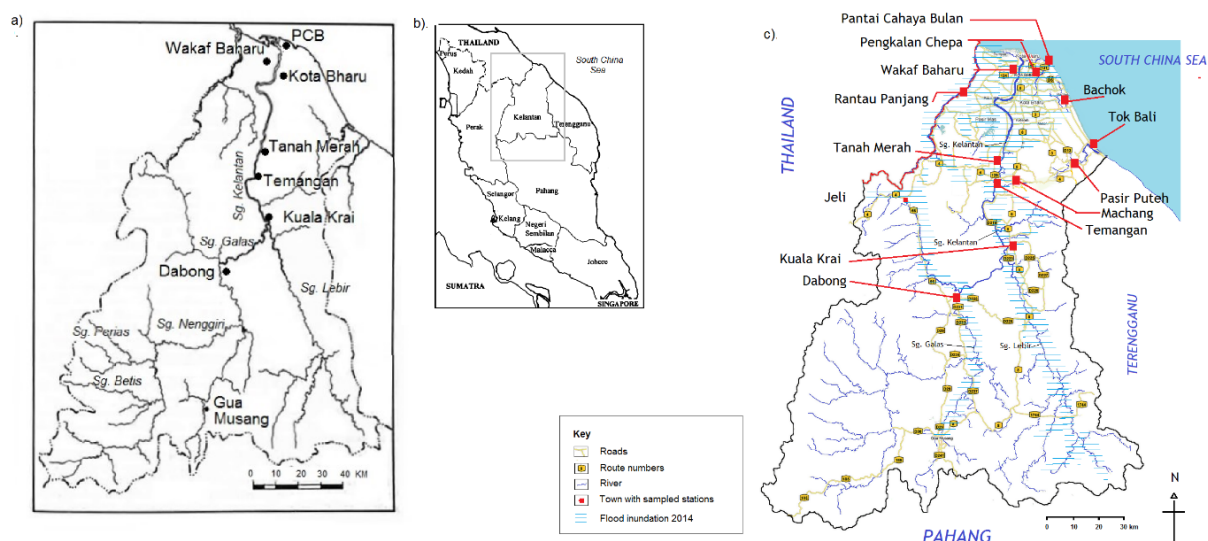


Fig. 1. Study location: a) Kelantan River basin (Kelantan River and its main tributaries – Lebir River, Galas River and others); b) relative location of Kelantan state in Malaysian peninsular, c) Kelantan inundation map during flood 2014; stations that were submerged during 2014 flood labelled on the left of the map (Pantai Chahaya Bulan (PCB), Pengkalan Chepa, Wakaf Baharu, Rantau Panjang, Tanah Merah, Jeli, Kuala Krai and Dabong) and unsubmerged regions labelled on right side of the map (Bachok, Tok Bali, Pasir Puteh, Machang and Temangan); ‘Sg.’ stands for ‘sungai’, a Malay word for river; source: own elaboration

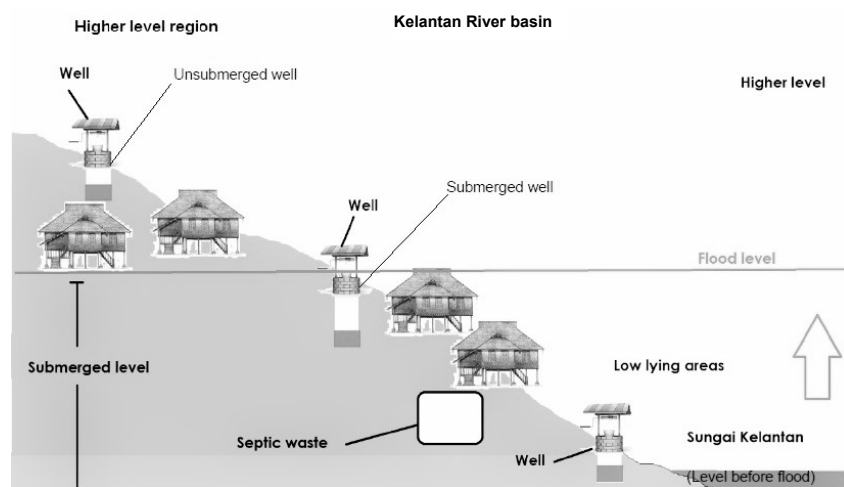


Fig. 2. Schematic representation of cross section for region in Kelantan River basin showing relative position of wells, sewage and the flood submergences; source: own elaboration

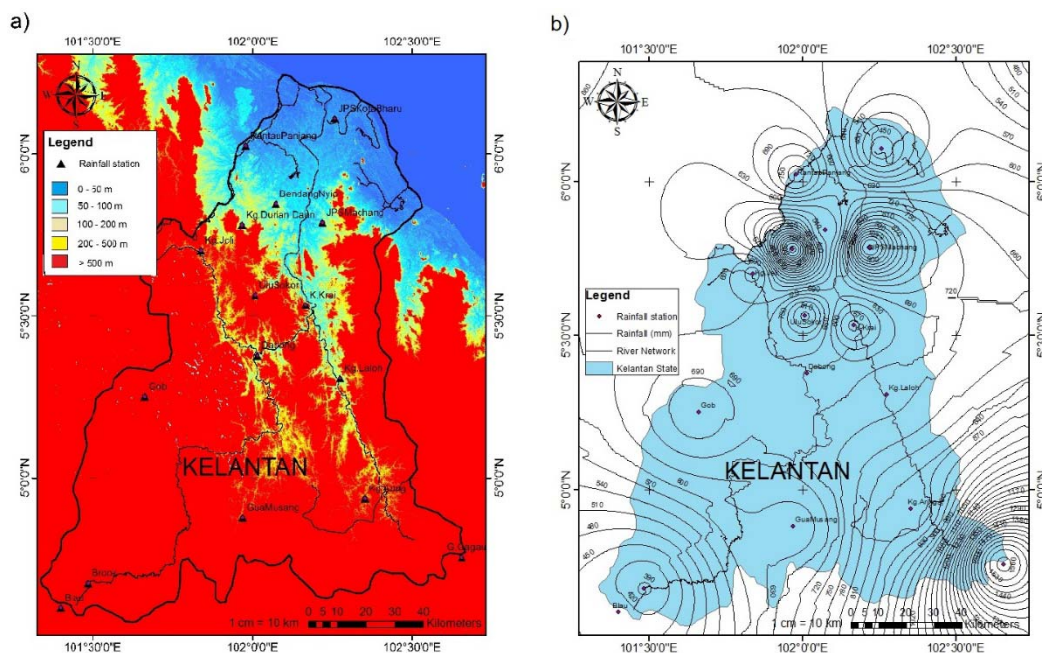


Fig. 3. Kelantan map: a) land form, b) total 7 days rainfall on December 2014; source: ALIAS *et al.* [2016], modified

LAND FORMS AND CLIMATIC CONDITION

Kelantan is a north-eastern state of peninsular Malaysia with a total area of 15,099 km² (see Fig. 1a). About 80% of Kelantan state was mainly drained by Kelantan River and its tributaries with a total catchment area of 11,900 km², forming Kelantan River basin. The river flows from mountainous and less-populous catchments areas in the South toward highly populous plain in the North called Kelantan Delta, through which it drains into the South China Sea (see Fig. 1b and 2a). Major cities, agricultural activities, industries were clustered in Kelantan River delta, where Kota Bharu, state administration centre is located. Annual rainfall in Kelantan was triggered by north-eastern monsoon that regularly resulted in end-year flood in several regions especially in the delta. Kelantan experienced an extraordinary rainfall that occurred in December 2014. The maximum rainfall distribution occurred in November and December 2014 documented total rainfall distribution of 690.6 mm and 1092.6 mm, respectively [ALIAS *et al.* 2016]. The rainfalls were in two phases, first on 15th–19th December 2014 (daily up to 100–300 mm), and second on 20th–24th December 2014 (daily reaching up to 500 mm). Figure 3b shows the spatial distribution of rainfall in Kelantan during for 7 days of the December.

PHYSICO-CHEMICAL PARAMETERS

Open dug wells from a total of 20 stations at 13 locations from 10 Kelantan's district (see Fig. 1c) were selected and 3 water samples were collected from each well. These non-longitudinal samplings were carried out from the month of January to March 2015. Physico-chemical analyses, i.e., pH, electrical

conductivity (*EC*), total dissolved solid (*TSS*) and the turbidity were determined *in situ* for each water sample [MOHAMMAD *et al.* 2007]. The sample pH was measured using portable pH meter (Lutron Electronic, Taiwan), electrical conductivity was measured using conductivity meter (Lutron) and reported in $\mu\text{S}\cdot\text{cm}^{-1}$; and the turbidity was measured using turbidity meter 2016 (Lutron) and reported in the unit of NTU. The *EC* value was converted into TDS based on equation $\text{TDS} (\text{mg}\cdot\text{dm}^{-3}) = \text{EC} (\mu\text{S}\cdot\text{cm}^{-1})\cdot 0.67$. In this study, data quality was ensured through necessary standardization, procedural blank measurements, spiked and duplicate samples.

MICROBIOLOGICAL ANALYSIS

For bacteriological analysis, the 0.5 dm³ samples were collected using sterile 1.0 dm³ Scott bottles. From each station, about 4–5 samples from a well and the nearby wells were collected. The bottles were tightly capped, labelled and kept on ice before being transported, as soon as possible, to laboratory at University Malaysia Kelantan (UMK) for further analysis. For microbiological analyses, 0.1 dm³ of each well water sample was filtered through a sterile membrane filter (cellulose acetate, 0.45 μm pore size, 0.47 mm diameter) by using a vacuum pump [CHEESBROUGH 2006]. The filters were placed centrally on solidified MacConkey agar medium and incubated at 44.5°C overnight and the total viable coliform count (TVC) were measured [EDBERG, EDBERG 1988]. The presence of bile salt and crystal violet enabled the selective growth of Gram-negative bacteria including enteric bacilli. The formation of pinkish colonies due to lactose fermenting *E. coli* distinguishes it from other Gram-negative bacteria. The average growth of coliforms in the form of colony

forming units per 0.1 dm³ – CFU·(0.1 dm³)⁻¹) was determined for each collected sample.

STATISTICAL ANALYSIS

Statistical analyses were carried out using statistical software SPSS package version 18 (SPSS Inc. Chicago). Each sample was grouped into either submerged or unsubmerged, and the well location along Kelantan River (i.e., either near or far from estuary (estuary versus non-estuary). Normality tests were carried out for each independent grouping and since the sample profiles were not normally distributed, non-parametric test (Mann–Whitney) were carried out on each test in order to evaluate the association between the total viable coliform (TVC), TDS and TSS with flood submergence, and the distance from estuary.

RESULTS AND DISCUSSION

From all of the stations, the pH, TDS (*EC*) and turbidity data were collected. Table 1 summarizes the average value of all the physico-chemical and biological parameters collected from all locations. The parameters and their respective locations were also represented into plots as shown in Figure 4a–d.

The acidity or pH values of the well water samples collected around Kelantan were recorded to be from 5.5 to 7.4 and these were within acceptable range for drinking water quality standard (pH 5.5–9) [ISSA 2012]. Samples at Tanah Merah recorded average values of slightly acidic of 5.5 average, while samples from Machang and Pasir Puteh recorded at an average of 7.4 (see Fig. 4a). In terms of electrical conductivity (*EC*), about 7 out of 65 samples (11.1%) collected recorded values exceeding permissible limit of more than 400 $\mu\text{S}\cdot\text{cm}^{-1}$. The lowest values of 53 $\mu\text{S}\cdot\text{cm}^{-1}$ was recorded at one of the well in Jeli, while

the highest values were recorded for samples from Pengkalan Chepa (575 $\mu\text{S}\cdot\text{cm}^{-1}$), Jeli (439 $\mu\text{S}\cdot\text{cm}^{-1}$), Pantai Cahaya Bulan (430 $\mu\text{S}\cdot\text{cm}^{-1}$) and Bachok (447 $\mu\text{S}\cdot\text{cm}^{-1}$) (see Fig. 4d). Given the linearity assumption that relates TDS and *EC*; any trend observed for *EC* values were also reflected in changes in the TDS. Therefore, the station which recorded high *EC* values above will also show to have high TDS values and *vice versa*. The variable presence of various dissolved minerals such as manganese, iron and others contribute to conductivity and TDS values [THAMER, ABDUL 2009]. A work on small number of wells in Kelantan had shown that high TDS values was due to the presence of ions resulted from weathering and leaching of the sedimentary rocks, as well as from human activities [HAMZAH *et al.* 2014]. The presence of nitrates beyond permissible level 10 $\text{mg}\cdot\text{dm}^{-3}$ was related to high usage of fertilisers and pesticides, especially on wells located in agricultural areas in Kelantan [SHAMSUDDIN *et al.* 2016]. There was a report on high concentration of Mn and Fe in some wells in rural Kelantan [YAP *et al.* 2017]. By analyzing the ground waters from different depth aquifers in Kelantan, the shallow groundwater (dug well) was dominated by Ca-HCO₃ and Na-CO₃, [SEFIE *et al.* 2015]. The high TDS and turbidity of the well near the coastal area were also associated with the brackish water character of groundwater in the coastal zones. About 19 out of 65 (29.2%) samples recorded turbidities beyond 7.0 NTU, with the highest values found in the most of samples from Pengkalan Chepa (from 19.2 to 20.87 NTU). These values have also exceeded 5.0 NTU limit if the drinking water standard limit is considered [WHO 2011]. The higher TDS and turbidity values in the downstream regions are also contributed by the presence of slits, clays and other particulate or suspended material released due to structural damages caused by flood.

Table 1. The list of average pH, electrical conductivity (*EC*), total dissolved solid (TDS), turbidity and total viable count of coliform (TVC) for well water samples collected around 13 stations in Kelantan

| Rainfall station | pH $\pm\Delta SD$ | Turbidity $\pm\Delta SD$ NTU | Conductivity $\pm\Delta SD$ $\mu\text{S}\cdot\text{cm}^{-1}$ | TDS $\pm\Delta SD$ $\text{mg}\cdot\text{dm}^{-3}$ | Total viable count $\pm\Delta SD$ $\cdot 10^4 \text{CFU}\cdot(0.1 \text{dm}^3)^{-1}$ |
|------------------|-------------------|---------------------------------|---|--|---|
| Wakaf Bharu | 6.3 \pm 0.18 | 4.61 \pm 4.88 | 171.2 \pm 30.81 | 114.7 \pm 20.64 | 7.14 \pm 4.10 |
| Tanah Merah | 5.5 \pm 0.65 | 0.34 \pm 0.09 | 157.4 \pm 34.24 | 105.5 \pm 22.94 | 0.45 \pm 0.63 |
| Pengkalan Chepa | 7.3 \pm 0.72 | 16.4 \pm 8.64 | 481 \pm 185.6 | 322.3 \pm 124.35 | 37.8 \pm 49.38 |
| Kuala Krai | 6.8 \pm 0.12 | 2.1 \pm 0.22 | 127.2 \pm 21.43 | 85.2 \pm 14.36 | 1.7 \pm 0.88 |
| Pcb | 7.3 \pm 0.15 | 6.8 \pm 3.94 | 295.8 \pm 83.43 | 198.2 \pm 55.9 | 6.6 \pm 13.1 |
| Dabong | 6.7 \pm 0.09 | 2.86 \pm 1.01 | 115.6 \pm 61.29 | 77.5 \pm 41.06 | 2.3 \pm 3.02 |
| Jeli | 6.1 \pm 0.09 | 8.24 \pm 1.58 | 139 \pm 167.82 | 93.1 \pm 112.44 | 1.48 \pm 0.79 |
| Rantau Panjang | 6.5 \pm 0.20 | 3.94 \pm 0.55 | 84.4 \pm 10.64 | 56.5 \pm 7.13 | 10.82 \pm 16.64 |
| Temangan | 7.1 \pm 0.06 | 2.35 \pm 0.25 | 126.4 \pm 10.81 | 84.7 \pm 7.24 | 4.46 \pm 0.61 |
| Pasir Puteh | 7.4 \pm 0.06 | 2.39 \pm 0.37 | 303.2 \pm 24.93 | 203.1 \pm 16.71 | 1.23 \pm 0.32 |
| Bachok | 6.6 \pm 0.62 | 3.06 \pm 1.67 | 279.6 \pm 114.23 | 187.3 \pm 76.53 | 0.64 \pm 0.86 |
| Tok Bali | 7.2 \pm 0.18 | 13.41 \pm 0.59 | 135.2 \pm 25.91 | 90.6 \pm 17.36 | 1.75 \pm 0.72 |
| Machang | 7.4 \pm 0.11 | 2.04 \pm 1.22 | 125.4 \pm 4.88 | 84 \pm 3.27 | 7.5 \pm 2.47 |

Explanation: *SD* = standard deviation.

Source: own study.

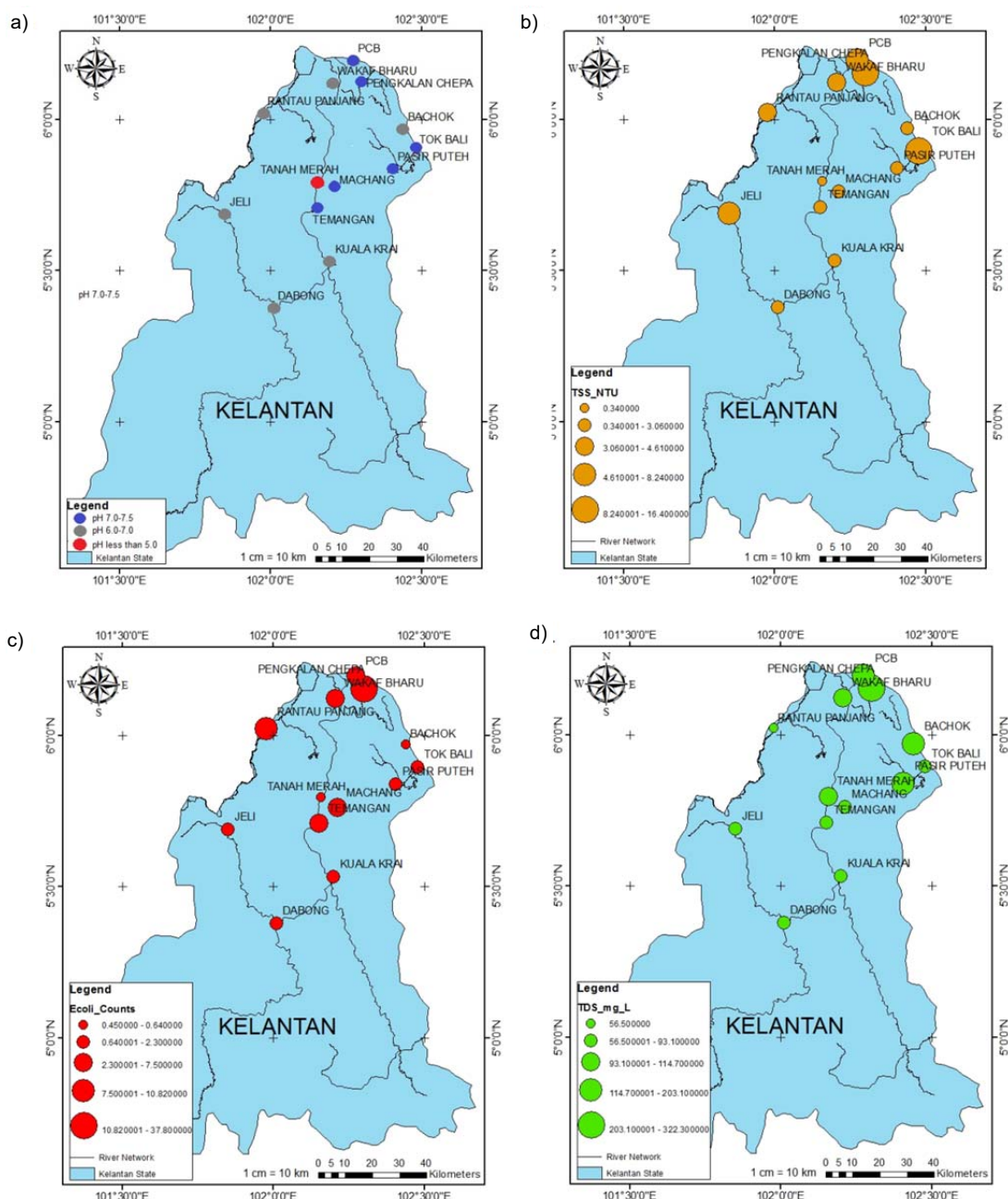


Fig. 4. Physical and biological parameters plotted based on their locations in Kelantan: a) pH, b) total suspended solid (TSS), c) total viable count (TVC), d) total dissolved solid (TDS); source: own study

The microbiological analysis on the total viable count (TVC) for coliform showed that coliform presented in most of the samples ($\sim 10^3$ – 10^4 $\text{CFU} \cdot (0.1 \text{ dm}^3)^{-1}$) except for 3 samples from Tanah Merah, and a sample from Pantai Cahaya Bulan which had no visible coliform growth. Therefore, in terms TVC count, 61 out of 65 samples (93.8%) in 13 stations from Kelantan had already violated the microbiology safety limit for drinking purpose according to Drinking Water Quality Standard [MOH 2005] and WHO [WHO 2011]. Pengkalan Chepa gave the highest average TVC value of $3.78 \cdot 10^5$ $\text{CFU} \cdot (0.1 \text{ dm}^3)^{-1}$, with a sample recorded a staggering TVC value of $7.2 \cdot 10^5$ $\text{CFU} \cdot (0.1 \text{ dm}^3)^{-1}$. High TVC were also recorded from several stations such as Wakaf Bharu

($1.00 \cdot 10^5$ $\text{CFU} \cdot (0.1 \text{ dm}^3)^{-1}$), Pantai Cahaya Bulan ($3.00 \cdot 10^5$ $\text{CFU} \cdot (0.1 \text{ dm}^3)^{-1}$), Rantau Panjang ($4.00 \cdot 10^5$ $\text{CFU} \cdot (0.1 \text{ dm}^3)^{-1}$) and Machang ($1.10 \cdot 10^5$ $\text{CFU} \cdot (0.1 \text{ dm}^3)^{-1}$). Interestingly, these stations, except Machang, were located in the estuary regions and were notorious for waterborne disease outbreak [ANG *et al.* 2010; ISA 1990; MALIK, MALIK 2001]. Nevertheless, it was impossible to compare these data with previous studies since other studies had used different well, collection time and enumeration method. The status of groundwater contamination in Kelantan has also been previously reported, without considering the flood. For instance, a detailed study on groundwater contamination in 9 districts in Kelantan, IDRUS *et al.* [2014] demonstrated that 221 out of 454 (49%) wells

under Water Supply and Sanitation Program (Mal. Bekalan Air dan Kebersihan Alam Sekeliling, BAKAS) were positive for total coliform. Meanwhile, there were reports on groundwater qualities in Kelantan without considering biological contamination. Due to high in hardness, salinity, and concentration of iron, manganese, ammonium and fluoride, the groundwater in Kelantan is unsuitable for drinking purpose [YAP *et al.* 2017]. Intermediate depth aquifers located within 8 km from coastal area were unsuitable for use [SEFIE *et al.* 2015]. In our study, the most of the wells showed physical parameters level within WHO permissible limit in which 70.8% turbidities were less than 5 NTU, and 100% EC was less than $1000 \mu\text{S}\cdot\text{cm}^{-1}$. However, due to the presence of TVC, these wells were considered unsafe for drinking purpose. Therefore, post flood study showed that TVC is an important parameters that determine the status of water quality.

For statistical analysis, each sample from every station was categorized into either: i) submerged and unsubmerged during the flood; or ii) located within (<35 km) or outside (>35 km) from estuary. For all of the parameters collected, non-parametric tests were carried out in order to evaluate the significant difference between degree of submergence and how far they are located from estuary. As shown on Table 2, result of the statistical analysis showed that the degree of submergence and the well location have no impact on the extent of well contamination ($p > 0.01$), proving the null hypotheses. Therefore for the future studies, we should address the main limitation of this studies which include increasing sample sizes, immediate samples collection following flood event; and incorporating other variables such as water quality index (*WQI*), land use and population densities.

Region located in the estuary frequently recorded high TVC values and these include Rantau Panjang and Pengkalan Chepa (see Tab. 1). Nevertheless, significant contaminations were also recorded in several

unsubmerged wells found scattered in non-estuary region such as in Machang and Pasir Puteh. Meanwhile, a few samples collected from non-estuary region (badly submerged i.e., Tanah Merah) showed no contamination. This indicated that the flood water itself was not necessarily the main source of contamination. Based on a study by URBANSKI and JAKUBIAK [2017], soil microbial activities and diversities were largely affected by the forms of land use. Land use will therefore determine the microbial diversity of the groundwater system in a particular region. Therefore, irregular trends observed on TVC were considered to be mainly due to intrinsic contamination rather than the one brought about by the flood. Other than watershed erosion, drainage from sewage is one of the main sources of bacterial contamination found in the well water [CHIRANJAY *et al.* 2012]. Because of this, proximity of wells to sewage or drainage system could consequently result in high TVC values, regardless of the well location. Kelantan is the only state in Malaysia that has an inadequate water supply network, poor drainage and sewage infrastructure. Consequently, being frequently exposed to monsoon flooding, Kelantan is highly vulnerable flood triggered contamination and this situation was exacerbated in the densely populated estuary regions.

In this study, there were no significant difference in EC values, total dissolved solid (TDS) and turbidity for wells exposed to different degree of submergence. Also, there was no correlation between microbiological contamination and physico-chemical parameters as similarly observed by IDRUS *et al.* in their studies [IDRUS *et al.* 2014]. However, the physicochemical properties of well water seemed to be significantly affected by the geographical location, with TDS at $p < 0.05$ and TSS at $p < 0.01$, respectively. Wells near estuary (Wakaf Baharu, Bachok, Pantai Cahaya Bulan, Rantau Panjang and Pengkalan Chepa) showed to have higher EC (or TDS) (mean of $241.2 \mu\text{S}\cdot\text{cm}^{-1} \pm 159.5 \text{SD}$) and turbidity ($8.04 \text{NTU} \pm 6.53 \text{SD}$) val-

Table 2. Statistical analysis using Mann–Whitney tests for several parameters against well submergence and geographical distance from estuary (total sample number = 65)

| Parameter | Analysis place | Sample number <i>N</i> | Mean rank | Sum of rank | Mann–Whitney test | Z values | Asymptote (2 tails) (<i>p</i> -value) |
|---|----------------|------------------------|-----------|-------------|-------------------|----------|--|
| Test on estuary versus far or non-estuary | | | | | | | |
| Total dissolved solids ($\text{mg}\cdot\text{dm}^{-3}$) | near estuary | 30 | 38.57 | 1 157.0 | 358.0 | -2.198 | 0.028 |
| | non estuary | 35 | 28.23 | 988.0 | | | |
| Turbidity (NTU) | near estuary | 30 | 42.53 | 1 276.0 | 239.0 | -3.764 | 0.000 |
| | non estuary | 35 | 24.83 | 869.0 | | | |
| Total viable coliform count $\text{CFU}\cdot(0.1 \text{dm}^3)^{-1}$ | near estuary | 30 | 34.60 | 1 038.0 | 477.0 | -0.632 | 0.527 |
| | non estuary | 35 | 31.63 | 1 107.0 | | | |
| Test on submergence versus non submergence | | | | | | | |
| Total dissolved solids ($\text{mg}\cdot\text{dm}^{-3}$) | submerged | 40 | 31.40 | 1 256.0 | 436.0 | -0.863 | 0.388 |
| | non submerged | 25 | 35.56 | 889.0 | | | |
| Turbidity (NTU) | submerged | 40 | 33.49 | 1 339.5 | 480.5 | -0.263 | 0.793 |
| | non submerged | 25 | 32.22 | 805.5 | | | |
| Total viable coliform count $\text{CFU}\cdot(0.1 \text{dm}^3)^{-1}$ | submerged | 40 | 32.03 | 1 281.0 | 461.0 | -0.526 | 0.599 |
| | non submerged | 25 | 34.56 | 864.0 | | | |

Source: own study.

ues compared to those from inner basin (Jeli, Tanah Merah, Kuala Krai, Pasir Puteh, Machang and Temangan) with lower mean for TDS (at $156.3 \mu\text{S}\cdot\text{cm}^{-1} \pm 88.9 \text{ SD}$); and TSS ($2.90 \text{ NTU} \pm 2.46 \text{ SD}$). During flood, there were two underlying processes; first, the flood water exchanged its content directly with the content of the well. Second, as the flood moved downstream it washed out dissolved and suspended materials along its flow path. Gradually, the flood water will be enriched with dissolved solutes and suspended sediment until it approached the densely populated estuary. As shown in Figure 5, this phenomenon is visible especially when all of the physico-chemical data for stations located consecutively along Kelantan River were plotted. However, an opposite trend was observed for TDS, TSS and turbidity values for direct river water sampling [YEN, ROHASLINEY 2013]. In this work, amongst 4 consecutive stations along Kelantan River, Kuala Krai (non-estuary) had recorded the highest values of TDS, TSS and turbidity values and this was attributed to the upstream sand mining and lodging activities. Therefore, the heavy 2014 flood has resulted in a different physico-chemical profile to the river as shown by the well water sample. This can only be compared or verified further with the available data prior to the flood event. Since this study was not conducted in longitudinal, the data on well prior to flood event were not available.

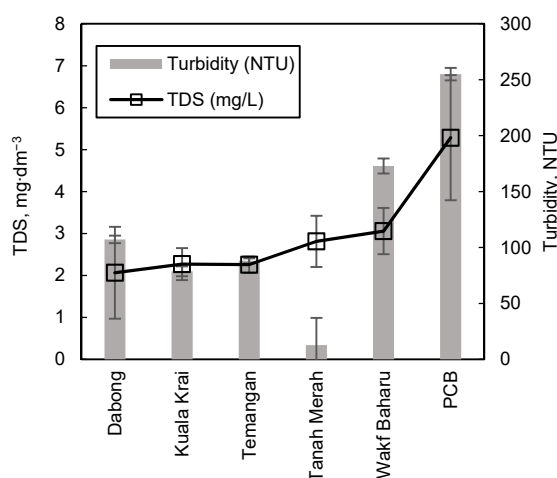


Fig. 5. Average values for total dissolved solids (TDS) and turbidity (TSS) on several stations located consecutively in upstream-downstream direction along the Kelantan River; source: own study

CONCLUSIONS

This is one of the first few studies using well water samples in evaluating the impact of flood. In this study, about 65 well water samples from 20 stations at 13 locations along Kelantan River were collected that were previously exposed to different degrees of submergence during the unprecedented 2014 flood. Most of the wells (93.8%) showed to have violated the microbiological safety limit for drinking purposes. Our study on

Kelantan River basin indicated that neither location nor inundation status of the well have a direct impact on the degree of microbiological contamination. Other physico-chemical parameters such as TDS and turbidity were also unaffected by the flood inundation. The wells in the delta showed to have significantly higher TDS and turbidity values than those of the inner basin. The 2014 flood had caused a trend change in the physical qualities and affected the biological qualities of the well. Consequently, in terms of well water quality, a greater health risk was found clustered on the densely populated region of the Kelantan River delta, regardless of well inundation. Kelantan River post-flood studies showed that the *status quo* of existing biological contamination could determine the severity of contamination and the ultimate post-flood health risk. Geographical location of the well determines the physical properties of the well, and this also has to be considered in assessing the overall quality of the well following a flood.

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Wpływ ekstremalnej powodzi z 2014 roku na jakość wód w studniach: Przykład basenu rzeki Kelantan w Malezji

STRESZCZENIE

Oceniano fizyczne i biologiczne właściwości wód w studniach zalanych w wyniku powodzi w grudniu 2014 r. w basenie rzeki Kelantan. Badania prowadzono łącznie w 65 studniach z 13 stanowisk w basenie rzeki. Analizowano pH, zawartość substancji rozpuszczonych (TDS), mętność i zanieczyszczenie mikrobiologiczne. Zanieczyszczenia wykryto w ok. 95% studni, w 7 z 65 stwierdzono wartości TDS > 400 $\mu\text{S}\cdot\text{cm}^{-1}$, a 19 próbek (29,2%) miało mętność ponad 7,0 NTU. Statystyczne testy dla zmiennych niezależnych wykazały, że poziom zanieczyszczeń nie zależał ani od stopnia zalania, ani od lokalizacji. Fizyczne i chemiczne parametry wody także nie były zależne od zalewu powodziowego, TDS i mętność zmieniały się wraz z położeniem geograficznym z istotnością $p < 0,05$. W wodzie ze studni z estuarium rzeki wartości TDS i mętność (odpowiednio 241,2 $\mu\text{S}\cdot\text{cm}^{-1} \pm 159,5$ SD i 8,04 NTU $\pm 6,53$ SD) były większe niż w wodzie ze studni w głębi basenu (TDS 156,3 $\mu\text{S}\cdot\text{cm}^{-1} \pm 88,9$ SD, mętność 2,90 NTU $\pm 2,46$ SD). Wody powodziowe odgrywały istotną rolę w przenoszeniu zanieczyszczeń. Większość wód studziennych nie nadawała się do picia. Stwierdzono ostatecznie, że stopień zalania studni niekoniecznie determinuje stopień zanieczyszczenia studni, ale występujące zanieczyszczenia mogą zwiększać potencjalne ryzyko po ustąpieniu powodzi.

Słowa kluczowe: bakterie typu coli, basen rzeki Kelantan, jakość wody, woda pitna, zalanie wodami powodziowymi