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Rainfalls and salinity effects on fecal coliform Most Probable Number (MPN) Index distribution in a beach ridge-shore ridge system in Mengabang Telipot, Terengganu, Malaysia

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Abstract: A Holocene beach ridge and present day shore ridge system located in a rural area north east of Kuala Terengganu was studied. The relation between fecal coliform (FC) MPN Index (Most Probable Number) distribution with rainfalls and saline intrusions into the unconfined aquifer of the beach ridge–shore ridge system was examined. The probable primary source of the pollutants was also investigated in order to highlight the susceptibility of such aquifers to pollution. Six sampling sessions were made from September 2009 to January 2010. Three represent drier conditions and the other 3, heavier rainfalls corresponding to the northeast monsoon season. This sampling period represent a condition when this area was still not subjected to major coastal erosions and subsequent rock revetment work. Altogether, water samples were taken from 13 wells and 3 river stations. Physical-chemical measurements were made in-situ, while FC was tested at UMT laboratory. Essentially, the results indicated that the groundwater in the unconfined aquifer layer of the beach ridge was moderately to highly polluted with FC (up to 1600 MPN). In contrast, the shore ridge was only slightly polluted, whereas river stations had mixed conditions but generally worse than the beach ridge and shore ridge. These phenomena could be associated with salinity spatial-temporal variations. Samples from heavy rainfall conditions indicated lower pollution levels compared to drier conditions. This phenomenon could be associated with the availability of more infiltrated atmospheric water to dilute pollutants in a high hydraulic conductivity environment as the ridges are made of fine to coarse sands. The results underscore the sensitivity of such environment to pollution transport and distribution and hence implied special attention with regards to water resource management.

Keywords: Beach ridge, shore ridge, fecal coliform

INTRODUCTION

Holocene beach ridges and present shore ridges are typical landforms in a wave dominated coastal area along the coastal plains of east coast of Peninsular Malaysia. Typically, they have a narrow and elongated shape and could be a few hundred meters wide and few kilometres long (Raj *et al.*, 2007; Roslan *et al*., 2010; Parham, 2016). Some of them are in a strand plain set up, while some could be delineated as a set of individual units separated by well defined swales. These series of beach ridges or strand plains are usually parallel or almost parallel to the modern coastline. They represent paleo coastlines seaward progression after the Holocene high stand (Raj *et al.*, 2007; Mallinson *et al.*, 2014; Hassan *et al.*, 2016; Parham, 2016). Mallionson *et al.* (2014) and Hassan *et al.* (2016) indicated that older depositions were found further from the present coastline via age dating of their field core samples from Setiu wetlands (strand plains and swales), Terengganu.

These beach ridges are relicts, where waves are no longer acting on them while shore ridges are still actively influenced by wave actions (Hesp, 2006; Octvos, 2007). They formed the present day back shore zone and are normally vegetated as they have been stable for a long time. They are mainly made of sand sediments just like the shore ridges (Roslan *et al.*, 2010). These sand ridges found along the east coast of Peninsular Malaysia evidently are under laid with a layer silty-clayey layer probably deposited during the late Pleistocene to Mid Holocene period when eventual sea level rise submerged the coastal plains. This notion is based on studies done in Kelantan, Terengganu and Pahang (Suntharalingam & Ambak, 1986; Hamzah *et al.*, 1999; Ali, 2002; Hassan, 2002; Samsudin *et al.*, 2008; Mallinson *et al.*, 2014; Parham *et al.*, 2014; Parham, 2016; Koh *et al.*, 2018). This is also consistent with general sequence stratigraphic model for such environment (SEPM, 2020).

The silty-clayey layer found under a beach-shore ridge system acts an upper confining layer separating the predominantly sand layer above from sand layers below with several lower confining layers before reaching the rock basement (Mohammad *et al.*, 2002; Samsudin *et al.*, 2008; Koh *et al.*, 2018). Silty-clayey sediments are low in hydraulic conductivity whereas sand sediments generally have very high hydraulic conductivity (Rawls & Brakensiek, 1983).

Hence, the ridges tend to have excessive drainage whereas the silty-clayey layer could become a confining layer. It could impede exchange of fresh groundwater (atmospheric source) from the upper sand layer that acts as an unconfined aquifer with the lower layers (Roslan *et al.*, 2010). In the fore shore and immediate back shore areas where shore ridges are found, saline intrusions are active however further intrusions into beach ridges could be limited (Robinson *et al.*, 2007; Koh *et al.*, 2018; Sathiamurthy & Pauzi, 2020).

These coastal unconfined aquifers formed by the beach ridges are an important source of freshwater to villages in the east coast of Peninsular Malaysia because the groundwater zone is within the reach of shallow wells (Samsudin *at al.*, 2008; KeTTHA, 2011a, 2011b, 2011c). These ridges being higher than the lower and flood prone swales are naturally suitable for settlements historically (Dobby, 1951). Hence, it is common that villages, and even towns and some industrial areas could be found on them. In turn, they become the sources of pollution (Hamzah *et al.*, 2003). Pollutants could easily infiltrate from the surface and upper subsurface and percolate through the vadose zone, and eventually transported to nearby wells or streams by groundwater flow as sand sediments have high hydraulic conductivity (Koh *et al.*, 2018). Consequently, the groundwater found in the unconfined aquifers of these beach ridges is susceptible to pollution coming from sources such as sewers and septic tanks. In the lack of centralized wastewater treatment plant or effective modern sanitary system, village houses usually employ conventional system using septic pit and tanks. Poor design and lack of maintenance causes leakages, overflows or even direct contact of waste materials with groundwater (Butler & Payne, 1995).

Fecal coliforms (FC) could be used as a pollution indicator originating from sewage and septic tank or pit discharge (Kirchman *et al.*, 1991; DOE, 2019; Seo *et al.*, 2019). FCs originate from the intestines of warm blooded organisms, e.g. humans (Kirchman *et al.*, 1991; Boualam *et al.*, 2002; Doyle & Erickson, 2006). The extent of FC contamination in well waters may change with rainfalls and salinity levels (Lipp *et al.*, 2001; Toothman *et al.*, 2009).

This paper examined the effects of rainfalls and salinity on the spatial and temporal distribution of FCs in a beach ridge-shore ridge system considering the importance of such ridges as a groundwater resource area.

Study area: Mengabang Telipot

The study area is a beach ridge with adjacent shore ridge (Figure 1). It is located on the northeast coastal plain of

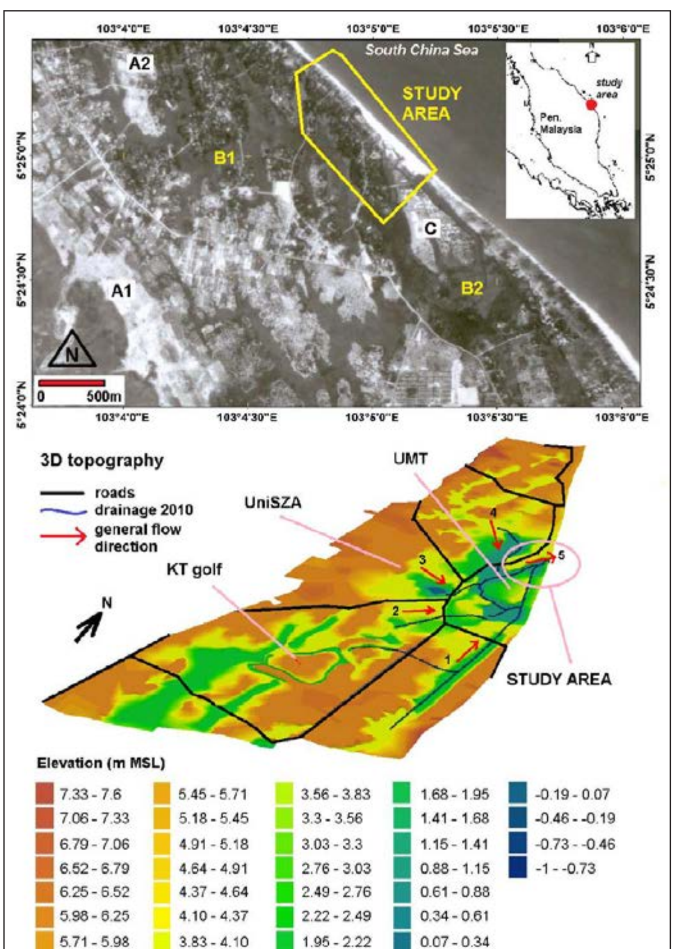


Figure 1: Aerial photograph (1984) of study area and its surrounding environment with topography (source: modified from JUPEM and DID).
Note: A1 - sparsely vegetated beach ridges with some buildings; A2 - vegetated beach ridges with settlements; B1 - freshwater wetlands (swales); B2 - brackish to saline water wetlands (swales); C - UPMT or Universiti Pertanian Malaysia, Terengganu which today has become UMT. UMT - University Malaysia Terengganu; UniSZA - University Sultan Zainal Abidin; KT Golf - Kuala Terengganu golf club.

Peninsular Malaysia in the state of Terengganu (5°25'2.71" N, 103°4'57.8" E). It has a south southeast – north northwest orientation, with an approximate length of 750 m, 200 m width and elevations between 3 to 5 m NGVD (National Geodetic Vertical Datum). It is occupied by a village, i.e. Kampung (village) Pak Tuyu, with a population of around 300 people estimated through a social economic survey carried out during field work.

The general environment consists of several Holocene beach ridges interspersed with swales or BRIS. They could be easily identified from the 1984 aerial photograph and 3D topography (Figure 1). This 1984 photograph is used because the ridges are clearly identifiable as there were not many man-made structures existed yet then. The 3D topography is based on late 1980s topographic survey data and 2008 field work. More recent topographic data are not available. This data was still valid in 2009 when this research on FC was done as the general topography has not changed essentially.

The swales between ridges are wetland areas drained by tidal creeks and man-made channels. The surface water drainage outlet is a TOCE (temporary open/close estuary) type and located beside the study area (Figure 2). Further

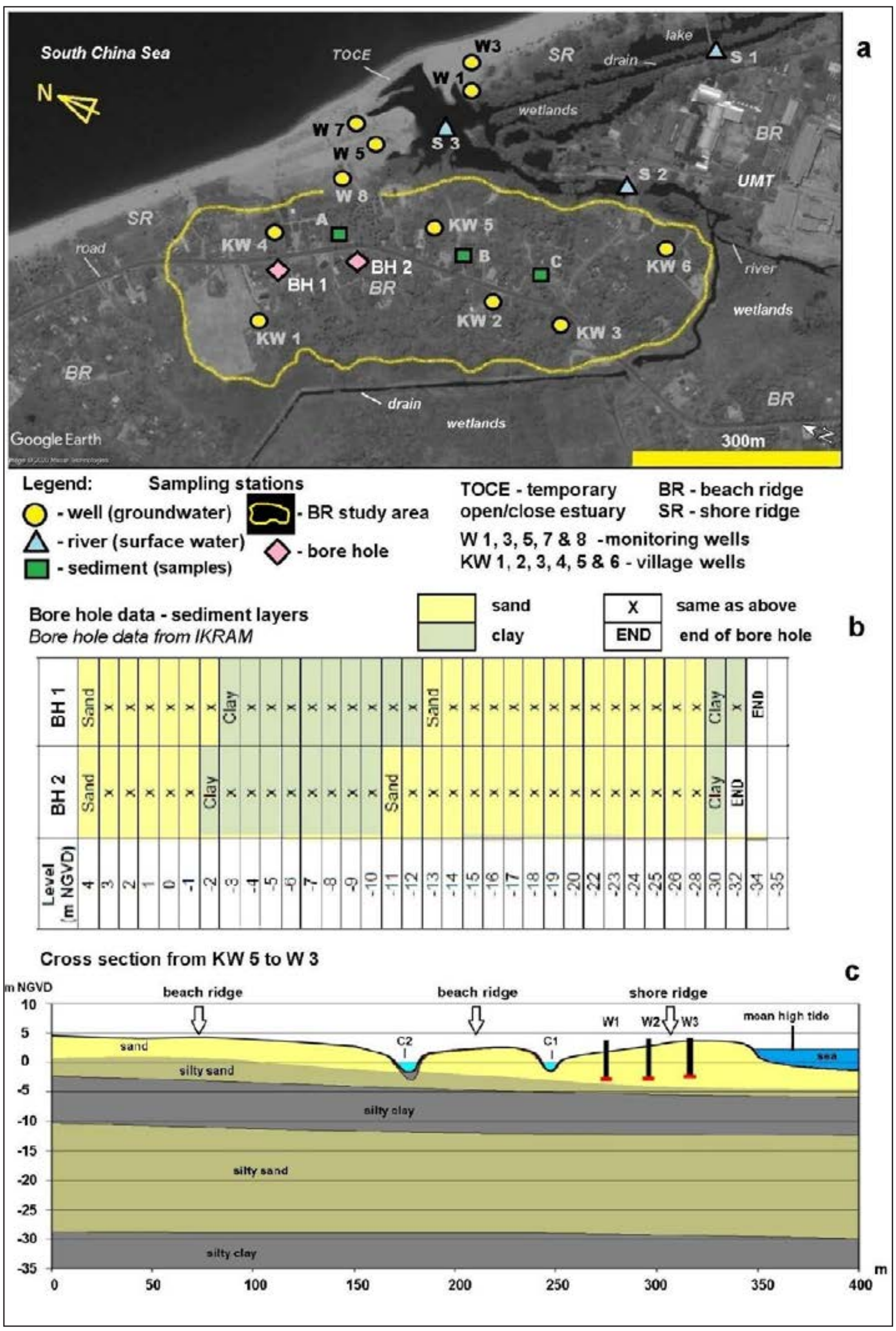


Figure 2: Study area details: a - sampling stations; b - beach ridge lithology; c - beach-shore ridge lithology (source: Google Earth, 2011; IKRAM; field work). Note: NGVD – National Geodetic Vertical Datum.

discussions on the TOCE system for this area could be found in Sathiamurthy & Pauzi (2020), and Koh *et al.* (2018).

With reference to Figure 2 and Figure 3, based on bore hole data (BH 1 and BH 2), field work data (sediment samples collected from sites A, B and C during this study), and an earlier study reported in Koh *et al.* (2018), the beach ridge is generally composed of coarser sand on top and finer sand towards the underlying first confining layer. The thickness of this sand layer is about 4 to 7 m thick. The shore ridge area, silty sand could be found on top of the first confining layer. Below the first confining layer (silty clay), there are silty sand and silty clay layers creating semi-confined aquifers on top weathered granite bedrock layer located approximately around -40 to -45 m NGVD (Koh *et al.*, 2018). The layer of interest for this paper is the upper most layer (unconfined aquifer).

METHODOLOGY

The study consisted of three major components, i.e. background study, sampling and laboratory analysis of FC, and secondary data analysis, i.e. rainfall and borehole logs.

Six daily sampling sessions were done from September 2009 to January 2010. Three sessions represented drier period (i.e. 17/9/09, 30/9/09 and 14/10/10) and the others, the wet northeast monsoon (i.e. 15/11/09, 21/11/09 and 26/11/09) based on rainfall data. Year 2009 represented a condition when the beach ridge and shore ridge were not yet subjected to aggravated coastal erosions and subsequent coastal protection work. Hence, FC distributions presented is for an insignificantly disturbed beach ridge-shore ridge system.

With reference to Figure 2, there were 6 village wells (i.e. KW1, KW2, KW3, KW4, KW5 and KW6) on the beach ridge and 5 monitoring wells (i.e. W1, W2, W5, W7 and W8) on the shore ridge used for groundwater sampling; 3 river stations (i.e. S1, S2 and S3) were used for surface water sampling; and 3 locations (i.e. A, B and C) on the beach ridge were used for sediment sampling. The wells had depths between 4 to 6.5 m below ground level, hence normally they were half filled with water as water table was generally 1 to 2.5 m below ground level. Water table levels were estimated from the depths of well water surfaces using a measurement tape fixed with a float.

Background study

Information of well depth, diameter, water depth and GPS coordinates were obtained in order to select suitable representative village well to be used in this research. Obviously, there were more than six village wells on the beach ridge, however it is not possible to sample all of them because of the work load involved and also accessibility issues (some wells were located inside bathrooms and kitchens).

Selected village wells, i.e. KW1- KW6, had sufficient depth so that they would not be dry during sampling and were in good condition. Their locations basically covered the northern, central and southern sections of the beach ridge, hence spatially representative. The coordinates of all the septic tanks were also recorded using a GPS unit in order to identify the proximity of pollutant sources to the village wells used for sampling (Table 1).

There were also seven monitoring wells constructed on the adjacent shore ridge including a village well. Four of them, i.e.W1, W3, W5 and W7 were used for this study. Those wells were perforated HDPE tubes used for a hydro-chemistry and hydrodynamic study associated with the TOCE system (Koh *et al.*, 2012 and 2018; Sathiamurthy & Pauzi, 2020). W8 was an unused village well utilized as a monitoring well for this study.

Location		A			
level (m NGVD)		4.5-3.5	3.5-2.5	2.5-1.5	1.5-0.5	0.5- -0.5
sediment type		MS	CS	CS	FS	VFS
Location		B				
level (m NGVD)		4.5-3.5	3.5-2.5	2.5-1.5	1.5-0.5	
sediment type		MS	FS	CS	FS	
Location		C				
level (m NGVD)		4.0-3.0	3.0-2.0	2.0-1.0	1.0-0	0- -1
sediment type		MS	FS	MS	FS	FS
CS - coarse sand			FS - fine sand			
MS - medium sand			VFS - very fine sand			

Figure 3: Sand ridge sediment types diagram on the sand ridge (source: field work).
Note: Location A, B and C – see study area map in Figure 2.

Table 1: Proximity of septic tanks to sampling wells.

Well site	Proximity of well to septic tank	No. of septic tank in 20 m radius	General Environment
KW1	2-20 m	4	fresh water; beach ridge
KW2	60-70 m	0	fresh water; beach ridge
KW3	1- 20 m	5	fresh water; beach ridge
KW4	5-20 m	8	fresh water; beach ridge
KW5	2-20 m	2	fresh water; beach ridge
KW6	3- 5 m	1	fresh water; beach ridge
S1	20- 30 m	1	fresh- seawater; drain
S2	20- 30 m	1	fresh- seawater; river
S3	60-70 m	0	fresh- seawater; estuary
W1	60-70 m	0	seawater; shore ridge
W3	60-70 m	0	seawater; shore ridge
W5	60-70 m	0	seawater; shore ridge
W7	60-70 m	0	seawater; shore ridge
W8	20- 30 m	2	fresh water; shore ridge

KW–villagewells;W–monitoringwells;S–surfacewaterstations

Topographic survey was conducted in August 2009 and January 2010. It was carried out to measure the ground elevation of the study area. Both manual leveling and DGPS (differential GPS) survey technique was used.

Sediment samples were collected from three selected locations on beach ridge in order to be as spatially representative of the sand ridge as possible taking into account ground conditions and accessibility into private lands (Figures 2 and 3). Samples from the shore ridge were collected and analyzed in an earlier research as the monitoring wells were built. Samples were retrieved for every meter depth down to 5 m deep using a manual soil auger. The samples were separated into size classes using a dry sieving machine.

Social economic survey was carried out in 45 households (about 82% of the estimated total number of household) in the study area. The survey was conducted to investigate the possible sources of fecal coliform contamination. Details of the survey and its results are not discussed in this paper as that would require another paper by itself.

Groundwater and surface water sampling

Salinity vertical profiling that was carried out in all sampling wells and river stations to determine the salinity level. Salinity profiling was conducted using a CTD (conductivity-temperature-depth) probe. Water samples were taken using a pump from about 1 m below the water surface. The pumps and connecting hoses were rinsed after each station with distilled water for one to two minutes to avoid cross contamination. Samples were poured sterilized bottles and capped. All samples were stored in a cooler box to slow down microbial activity and degradation of organic matter. Simultaneously, parameters like pH, temperature and dissolved oxygen were recorded using a multi-parameter YSI unit.

Laboratory analysis

The microbiological analysis of FC was determined according to the American Public Health Association method (APHA, 1999). FC analysis applied the multiple tube fermentation technique (5 tubes per dilution; 3 dilutions. i.e. 10 ml, 1 ml and 0.1 ml into 100 ml) for each sample and reported in terms of the Most Probable Number (MPN) index of organisms present per 100 ml of sample. Detailed procedure could be found in APHA (1999).

Secondary data

Hourly rainfall data for August 2009 to January 2010 was obtained from the Malaysia Meteorological Department station at the Sultan Mahmud Airport, Kuala Terengganu, 10 km from the study area. The data was used to determine dry or wet weather periods and rainfall amount during the sampling sessions.

Bore hole logs were obtained from IKRAM's soil investigation reports for development projects inside and nearby the study area. Sub-surface sediment types and thickness data were extracted from the logs (see Figure 2).

RESULTS AND DISCUSSION

Sampling session 1, 2 and 6 were conducted during drier periods, whereas Sampling 3, 4 and 5, wet period (Figure 4). The sampling results are shown in Table 2 and Figure 5.

Table 2 and Figure 5 shows the FC MPN Index during the drier and wet periods in the study area. FC MPN was higher in the beach ridge during the drier period. This could be caused by the lack of rainfall input to dilute FC concentrations and to transport them out effectively as groundwater discharge is usually lower during drier periods. The shore ridge also recorded higher FC MPN during drier period but much lower compared to the beach ridge. Probably, these lower values were result of higher salinity in the shore ridge. FC MPN was insignificant in the shore ridge during wet periods with average values lower than 4 MPN. This could be associated with the combined effect of high rainfall inputs and higher salinity. Surface water samples did not show significant difference between drier and wet periods for S2 that was located in a drainage line that does not service the study area's beach ridge. Its very high FC concentrations were most likely input from its upstream where this drainage line served several settlements and a golf course (Figure 1). S1 and S2 stations located beside the beach ridge have higher FC MPN during wet period in contrast to the lower values for the beach ridge. This implied that with higher rainfall input, there were greater groundwater discharge to transport out FC from the beach ridge to the river via river bank exfiltration. As a whole, the results indicated that FC MPNs were higher during drier periods than wet periods. This implied that rainfalls could lower FC concentration especially on a beach ridge.

Figure 6 shows the relation between salinity and distance from the shoreline. As a whole, it indicates that the salinity concentration is decreasing inland. All sampling sessions showed a negative correlation between salinity and distance. In Sampling 2 and 6 there seems to be an anomaly. Surface water could record higher salinity even further from the shoreline as

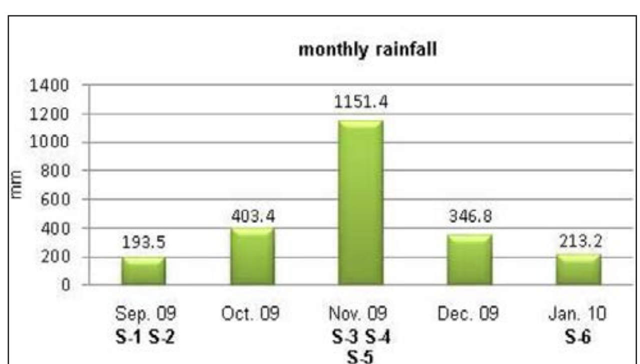


Figure 4: Monthly rainfalls and sampling sessions (Rainfall data source: Malaysia Meteorological Department).

Table 2: TC and FC MPN index for drier and wet periods compared to salinity.

DRIER PERIOD **Sampling 1 on 17/9/09**				**Sampling 2 on 30/9/09**			**Sampling 6 on 14/1/10**		
parameter	TC	FC	Salinity	TC	FC	Salinity	TC	FC	Salinity
unit	MPN	MPN	ppt	MPN	MPN	ppt	MPN	MPN	ppt
surface water									
S1	1600	48	26.18	1600	430	32.29	1600	1600	13.35
S2	1600	1600	9.84	1600	1600	35.47	1600	1600	9.86
S3	1600	1600	0.07	1600	240	14.28	1600	1600	27.91
average	*1600*	*1083*	*12.03*	*1600*	*757*	*27.34*	*1600*	*1600*	*17.04*
beach ridge									
KW1	1600	240	0.21	1600	280	0.33	220	130	0.11
KW2	1600	1600	0.08	1600	540	0.23	170	170	0.13
KW3	1600	1600	0.14	1600	170	0.16	110	79	0.06
KW4	1600	1600	0.19	1600	430	0.28	1600	540	0.09
KW5	1600	1600	0.12	1600	1600	0.16	1600	1600	0.09
KW6	47	34	0.09	350	170	0.18	4170	130	0.05
average	*1341*	*1112*	*0.14*	*1392*	*532*	*0.22*	*1312*	*442*	*0.09*
shore ridge									
W1	49	13	12.92	79	12	34.03	2	1.8	16.98
W3	1600	540	24.38	240	27	22.4	240	10	25.52
W5	280	22	7.41	240	1.8	9.72	13	4.5	8.79
W7	240	240	12.52	1600	5.6	27.24	na	na	na
average	*542*	*204*	*14.31*	*540*	*12*	*23.35*	*85*	*5*	*17.1*
W8	1600	1600	0.05	1600	540	0.09	79	79	0.04
WET PERIOD **Sampling 3 on 15/11/09**				**Sampling 4 on 21/11/09**			**Sampling 5 on 26/11/09**		
parameter	TC	FC	Salinity	TC	FC	Salinity	TC	FC	Salinity
unit	MPN	MPN	ppt	MPN	MPN	ppt	MPN	MPN	ppt
surface water									
S1	1600	1600	0.19	920	920	0.3	1600	1600	0.38
S2	1600	1600	0.52	1600	1600	0.03	1600	920	0.17
S3	1600	1600	1.91	1600	1600	1.9	1600	170	0.77
average	*1600*	*1600*	*0.87*	*1373*	*1373*	*0.74*	*1600*	*897*	*0.44*
beach ridge									
KW1	1600	240	0.14	540	140	0.12	1600	7.8	0.11
KW2	1600	350	0.12	1600	1600	0.12	1600	79	0.12
KW3	920	920	0.04	920	240	0.03	1600	49	0.03
KW4	240	240	0.04	540	240	0.05	350	15	0.05
KW5	540	na	0.08	1600	350	0.07	920	63	0.08
KW6	350	240	0.06	350	110	0.06	240	49	0.05
average	*875*	*485*	*0.08*	*925*	*447*	*0.08*	*1052*	*44*	*0.07*
shore ridge									
W1	350	3.6	27.83	79	1.8	28.45	130	1.8	0.48
W3	1600	6.1	24.16	350	4.5	13.68	1600	1.8	10.5
W5	4.5	1.8	3.25	4.5	2	11.36	33	2	3.64
W7	7.8	4.5	1.23	11	4.5	2.57	130	1.8	4.22
average	*491*	*4*	*14.12*	*111*	*3.2*	*14.02*	*473*	*2*	*4.71*
W8	540	9.2	0.05	350	130	0.07	79	18	0.07

Note: TC, FC - total coliform, fecal coliform; MPN - Most Probable Number index; ppt - parts per thousand (g/l); na – not available a result of more effective saline intrusion. Moreover, both were measured during drier period when river flows were weaker in offsetting saline intrusions. Overall, salinity concentrations were higher during Sampling 1, 2, and 6 compared to Sampling 3, 4, and 5. This indicates that salinity concentration was higher during drier condition and lower during wet condition.

Comparing with Table 2, this indication seemed to contradict the findings that FC MPN values were higher during drier condition since salinity was known to have adverse effect on FC (Toothman *et al.*, 2009). However, a closer look showed that the beach ridge where higher MPN were recorded was a freshwater environment (salinity less

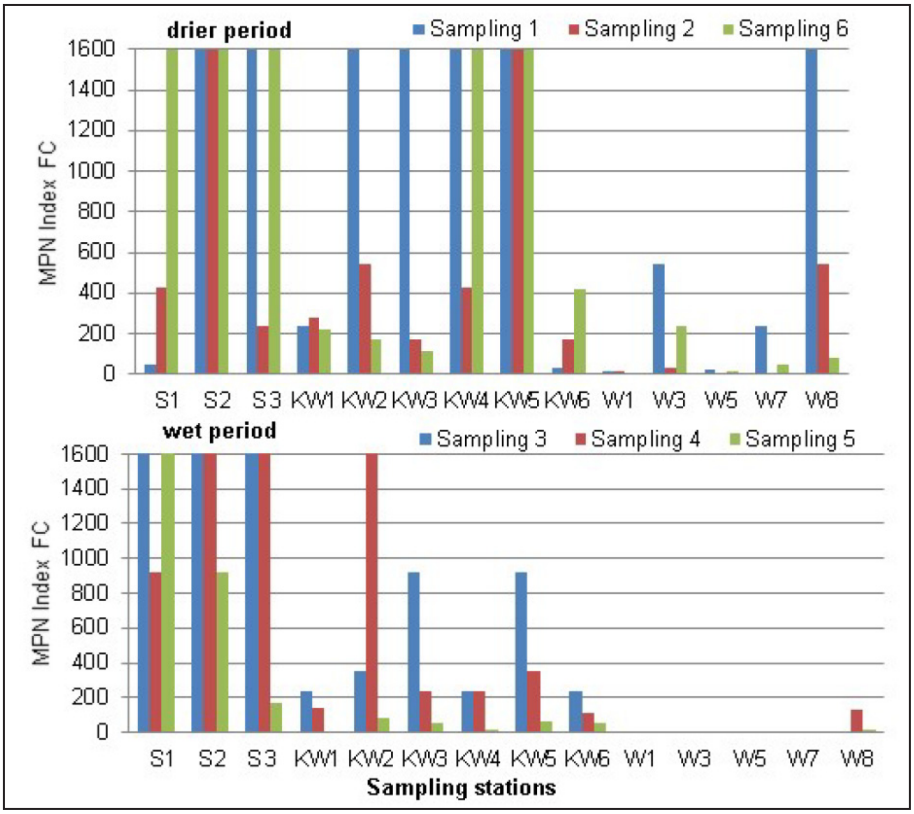
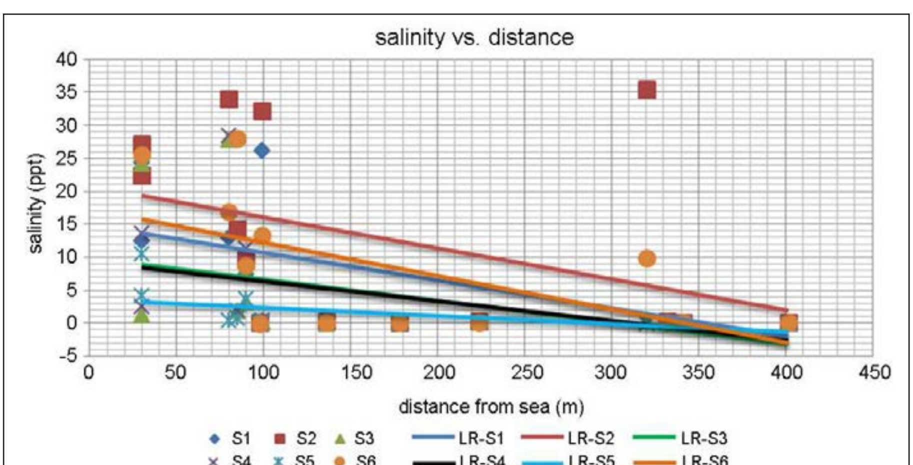


Figure 5: MPN index of FC during drier period and wet period.



	S1	S2	S3	S4	S5	S6
distance *	-0.671	-0.605	-0.637	-0.654	-0.725	-0.607
p-value	0.04	0.05	0.05	0.03	0.05	0.03

*correlation values LR - linear regression S1-S6 - Sampling 1 to Sampling 6

Figure 6: Salinity versus distance from shoreline and their correlation values.

than 0.21 ppt) regardless of weather conditions. The saline intrusion into the unconfined aquifer was limited to the shore ridge area (Koh *et al.*, 2018; Sathiamurthy & Pauzi, 2020). This can be supported by the records of W8 which was located about 80 m from the shoreline (Figure 2). Throughout the sampling periods, it remained a freshwater well.

It should be noted that W8 had maximum FC MPN for Sampling 1 (Table 2). This could be caused by large input of FC from the beach ridge during that period. In Sampling 1, the beach ridge wells recorded maximum FC MPN for all wells except for KW1. W8 had two septic tanks within 30 m on the beach ridge side (Table 1). The sand sediment with its high hydraulic conductivity enabled quick pollutant transfer.

The shore ridge had higher salinity throughout the sampling periods with average salinity of 17 ppt except for Sampling 5 where the salinity was lower. The shore ridge recorded much lower FC MPN values compared to the beach ridge and river/drain. This implied the adverse effect of salinity on FC mortality (Lipp *et al.*, 2001; Toothman *et al.*, 2009).

Comparatively, the surface water samples recorded highest FC MPN values with Sampling 3 and 6 reaching maximum MPN on average. There could be two reasons for this. First, surface water received base flows polluted with FC from the immediate beach ridges along the river banks as non-point source pollutants. Second, it also received pollutants from upstream. Interestingly, in Station S2 and S3 for Sampling 2 and Sampling 6 respectively, maximum MPN was recorded even under higher salinity conditions. This seemingly contradicted the above implications that salinity has adverse effect on FC. It should be noted that FCs have a range of tolerance and salinity was found to have no significant effect fecal enterococcus as indicated in the results of Toothman *et al.* (2009).

In general, higher FC MPN index during drier periods indicated that the monsoon season have significant effects of reducing the FC concentrations especially in the beach ridge giving rise to seasonal variations as indicated in Table 2 (Lipp *et al.*, 2001). Table 3 showed that salinity was found to have an adverse effect on FCs population although not very strong for areas that were susceptible to saline intrusions. This finding is consistent with other published works on the effect of salinity on FC (Solic & Krstulovic, 1992; Mallin *et al.*, 1999; McLaughlin *et al.*, 2007).

The correlations between FC MPN and salinity in the shore ridge and river were -0.2 and -0.24 respectively (p value less than 0.5) where the average salinity was about 78 times higher than the beach ridge. However, the surface water had the highest FC MPN compared to shore ridge and beach ridge area. The probable reasons for this apparent contradiction to published work is discussed earlier. The beach ridge had FC MPN 5 times higher than the shore ridge. The beach ridge's freshwater environment is hospitable to FC compared to the shore ridge that is subjected to sub-daily saline intrusions. As mentioned earlier, its lower FC MPN index compared to the immediate surface water was most likely caused by the high hydraulic conductivity of the beach ridge sediment layer (i.e. sand) that enable effective pollutant transport. The positive correlation value for beach ridge area (i.e. 0.14) cannot be taken as to suggest FC MPN increases with salinity because the salinity range in the beach ridge was just between 0.03 to 0.33 ppt. Its salinity sample variance is almost 0, indicating that the records have almost the same values.

It should be noted that solar radiation, availability of nutrients and temperature among other factors do affect the growth and mortality of FC (Toothman *et al.*, 2009). In this research, the measured physical-chemical parameters such as temperature, dissolved oxygen (DO) and pH did not show significant variation between stations and sampling periods. The mean temperature was 28.3 °C with a standard deviation (SD) of 1.3 °C. Mean DO was 3.74 mg/l with a SD of 1.7 mg/l; and pH had a mean value of 7.3 with a SD of 0.7. In contrast, salinity showed greater variation with a mean value of 6.3 ppt but a SD of 10 ppt and range of 0.03

Table 3: Overall physical-chemical averages and their correlations with FC MPN.

Averages	**T (°C)**	**Salinity (ppt)**	**DO (mg/l)**	**pH**	**FC (MPN)**
surface water	28.0 (3.3)	10.2 (149.6)	4.4 (2.5)	7.1 (0.3)	1218 (351372)
beach ridge	28.0 (0.7)	0.1 (0.004)	3.8 (2.7)	7.3 (0.3)	510 (338722)
shore ridge	29.1 (1.5)	11.5 (117.6)	3.1 (3.02)	7.4 (0.5)	114 (101889)
Note: Data in bracket – sample variance					
Correlations ($p < 0.5$)	**T (°C)**	**Salinity (ppt)**	**DO (mg/l)**	**pH**	
FC-surface water	-0.07	-0.24	0.28	-0.38	
FC-beach ridge	0.05	0.14	-0.31	0.11	
FC-shore ridge	0.03	-0.20	0.12	-0.18	

(freshwater) to 35.5 ppt (seawater). FC MPN showed a very weak correlation with temperature because the latter showed very low variations. DO and pH seem to have a significant influence on FC MPN as implied by their correlation values. However, this implication cannot be ascertained here as both DO and pH did not have significant variations in those three areas compared to FC sample variations that showed very high variations (Table 3). Further work using longer sampling periods and highly sensitive probes may be required to ascertain their influence. Salinity however showed high variance in the shore ridge and river corresponding to FC's variance indicating that their correlations do indicate the influence of salinity on FC MPN.

It is obvious the study area was polluted with FC. The bacteria which is a subset of total coliforms only exist in human intestine or warm blooded animals and usually found in fecal material from the host organism. Hence, the presence of septic tanks or pits on the beach ridge that contained human feces strongly suggests that these were the main source of FC. Moreover, there were no livestock activities, manure spreading practices or other activities that could be significant sources of FC.

Village houses on the beach ridge, i.e. Kampung Pak Tuyu used conventional septic pits that were old, run down and lacked maintenance. The septic tanks were incapable of treating raw sewage effectively. The questionnaire survey conducted during sampling showed that 80% out of 45 households interviewed, regardless socio-economic background responded that their septic tanks/pits would only be serviced when they overflow or full. About 11% of the households interviewed had not service their septic tanks since occupancy. Worse, about 4.4 % of the residences interviewed do not have septic tank or sewage containment system. These findings gave a clear picture why the beach ridge groundwater and its receiving surface water was very polluted with FC, i.e. poor sewage system in a very high hydraulic conductivity environment that enable fast pollutant transport. Poorly maintained tanks hold the risk of leakages resulting from broken or failing septic system. Partially or untreated sewage effluents could easily leach into the shallow groundwater table (< 2 m from ground level). In addition, many septic tank or pits were constructed relatively near (< 20 m) to wells (Table 1). Thus, increased the risk of FC pollution of domestic water supply.

CONCLUSIONS

As a whole, the surface water (drain and river) was the most polluted by FC followed by the beach ridge. The shore ridge was the least polluted throughout the sampling period. This spatial variation could be associated with salinity levels and hydrologic processes. The beach ridge was more polluted than the shore ridge because its groundwater was fresh hence suitable to FC survival and growth. The shore ridge was subjected to sub-daily saline intrusions hence more saline and less suitable for FC. The source of freshwater in the beach ridge was from rainfalls that could easily infiltrate and percolate into its unconfined aquifer through its highly permeable uppermost sand sediment layer. Moreover, saline intrusions did not reach the beach ridge. The surface water had much higher FC levels even though its salinity was higher than the beach ridge. This apparent contradiction to other published works mentioned in this paper could be explained by looking at the hydrologic processes of pollutant transport. The beach ridge sediments mainly consisted of fine to coarse sand. Sand has very high hydraulic conductivity. Consequently, FC pollutants could be transported out from the sand ridge into the receiving surface water quickly. Moreover, there were also upstream input of FC into the surface water sampling stations downstream.

Temporal variations in FC levels were found also. Overall, sampling results from drier periods showed higher FC MPN compared to results from wet periods. The beach ridge had lower FC levels compared to the surface water during wet period. Most likely, more rainfalls caused greater dilution of FC pollutant concentration and greater removal via greater groundwater discharge from the beach ridge into the receiving surface water. The shore ridge had negligible FC levels during wet periods. This can be the result of both dilution effect from direct rainfall input combined with higher salinity as the shore ridge was directly exposed to rainfalls being without vegetation and to sub-daily saline intrusions.

Further research could be made on the influence of parameters like temperature, DO, pH, dissolved organic carbon etc. on FC spatial-temporal distribution in a beach ridge-shore ridge system by using longer data sets that could better capture their variability.

The beach ridge aquifer was and still is an important freshwater resource for the villagers living on it. The understanding of the causes of spatial and temporal variations of pollutants like FC in the beach ridge-shore ridge system is vital for the sustainability of groundwater resource. One important factor that must not be neglected is the combination of anthropogenic pollutant source with the physical environment characteristics such as lithology, rainfalls and salinity, and their processes.

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