Preventing saltwater intrusion in the Coastal of Terengganu, can BRIS soil system help?

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Abstract. Coastal zone is among the most heavily populated areas across the world. The increasing population and rapid development in this area could lead to the possibility of over pumping groundwater. If the groundwater extracted excessively, the saltwater could intrude into the groundwater system and cause the problem. Thus, to prevent this situation from happen, the coastal wetland which known as the beach ridges interspersed with swales (BRIS) soil system area need to be taken care of, as it can recharge the groundwater. Even though this area has been neglected and undervalued for their ecosystem services (purifying groundwater), there are the potential of this area to prevent the saltwater intrusion from happened. Hence, this paper will highlight the potential of BRIS soil system in preventing the saltwater intrusion.

1. Introduction
Along the east coast of Peninsular Malaysia from Pahang in the south and Kelantan in the north, beach ridges interspersed with swales (BRIS) soil system is dominating, particularly in the state of Terengganu. In Terengganu alone, it is estimated that the BRIS soil coverage is about 67 582.61ha [1]. Soil composition is mainly consisted of sand (more than 90%), covering from a series of entisol, spodosol and a spodic layer [2]. Due to the sandy texture, this soil has a poor cation exchange capacity (CEC) and is heavily subjected to leaching, which also reduce the nutrient and moisturiser of the soil. Natural vegetation is dominated Melaleuca cajuputi from Myrtaceae family or locally known as Gelam or Gelam putih (in Malay). Short stature Gelam and other short adapted vegetation from a sparse heath like vegetation on the ridge part of the soil, while higher stature of Gelam and swampy plant species distinctly grow in the waterlogged swamp of the depressed or swales part of the BRIS soil.

BRIS soil is acknowledged to be very poor in plant nutrients and unsuitable for farming [3]. The typical land use changes for this soil are mainly for settlements, sand mining for silica extraction, wasteland (mostly illegal) and latest for the solar panel field. However, instant cash crops (for example melon
and sweet potato) are still grown by the locals, but with the help of additional mulches and fertilizer. Ecologically, pocket of coastal wetland in the form of Gelam swamp, undoubtedly contributing to the local hydrology regulation. BRIS soil groundwater system provide freshwater for the local livelihoods. Other than, coastal freshwater wetland is preventing saltwater intrusion into the groundwater system. Excessive groundwater exploitation resulted the volume of groundwater to decline. Saltwater also has an impact on vegetation development and human health and wellbeing. However, the above-mentioned ecological functions by the BRIS soil are still under investigated. Thus, this paper aims to discuss the potential of the BRIS soil system in preventing saltwater intrusion along Peninsular Malaysia’s east coast.

2. Beach ridges interspersed with swales (BRIS) soil system

In Peninsular Malaysia, there are about 155 400 ha of BRIS with 40 000 ha is in Sabah, 67 582.61 ha in Terengganu, 17 806.2 in Kelantan and 36 017.17 ha in Pahang [1][4]. This type of soil has been categorized into seven varieties which depend on their depth, drainage, and serial profile namely as Rusila, Rhu Tapai, Rompin, Rudua, Baging, Jambu and Merchang [5][6]. The BRIS soil was divided into two orders: Entisol (new soil lacking in podogenetic horizon) and Spodosol (sandy and acidic soil with a high concentration of acidic humus) and additional of spodic layer, which located above the groundwater level [7][3].

During Holocene era, the sea level has arisen due to the presence of notches – like features and the presence of sandy beach ridges along the coastal plain in Peninsular Malaysia[8][9]. Inundation caused the coastal zone to degrade, resulting in the construction of broad beach ridges plains throughout the east-coast of Peninsular Malaysia, which are today known as beach ridges interspersed with swales (BRIS) soil system [10].

The land-ocean interfaces serve as multi-level complex environments that are influenced by both natural and manmade influences, and coastal ecosystems are located at the interface between land and water [11][12]. They became the most dynamic locations on the planet because of the complicated link between physical and biological processes [13]. There are coastal dunes in an exposed area that is subject to natural phenomena such as storms, wind erosion and wave overflow. These dunes serve as a buffer to prevent the effects of seashore hazards from having a large impact on ecosystems, communities, and economies [14]. In addition to the predisposition of the human population to reside in coastal areas, climate change has exacerbated the situation by causing sea-level rise and shrink the water catchment area [15]. All these interventions increase the vulnerability of the coastal environment to erosion and flood effects, as well as the reduction of key ecosystem services such as saltwater intrusion into groundwater storage [16].

3. Saltwater intrusion

The passage of seawater carrying salt into the coastal environment is referred to as saltwater intrusion [17]. This process is caused by the prolonged changes in coastal groundwater levels due to over pumping, land-use change, climate variation and sea-level fluctuation. The major effect of this phenomenon is reduction in the available freshwater storage volume [18]. Among the natural processes that can cause salinization include weathering, which includes both physical and chemical weathering of the parent material.

Other than that, the rising sea levels, saltwater intrusion is becoming more common. In some areas, the absolute sea-level increase has been measured at 0.32 cm per year, with land elevation loss as a result [19]. Because of the loss, flooding will become more severe, as evidenced by research conducted in the Mekong Delta, where extended flooding increases the incursion of saline surface water into the delta [20]. With the addition of a storm surge, which would result in the salinization of surface water
and soil, the situation could deteriorate even further. Because stagnant water can permeate into the soil, this is applicable to the saltwater that has been held and finally reaches the water table [21].

When it comes to the estuary area, marine (saltwater) and river water (freshwater) interact with one another [22]. It is quite complicated, and because of the density differences between freshwater and seawater, it often results in a two-layer circulation [23]. The tide encourages the movement of saltwater, which then propagates up the estuary with flood currents [24]. As a result, the groundwater system is currently experiencing saltwater intrusion activity.

This has consequently disturbed the human well-being and surrounding. The most significant inducers were anthropogenic activity and climate change [25]. Agriculture and manufacturing have raised the need for freshwater for multipurpose use because of rapid expansion and population growth in agriculture and manufacturing. As a result, there has been an excessive amount of deep groundwater exploitation [26]. Since the 1990s, groundwater has been depleted because of its use; in 2015, it was estimated that groundwater usage was 25 times larger than in the previous year [27].

This causes the alteration of soil characteristics and plant composition of the wetland. The fertilisers, salt-rich irrigation, and the leaching of excessive salt cause excessive salinity of the water might have a negative impact on plant growth and development [28]. As these actions can influence the management of hydrology in the wetland, it should not be overlooked that human disorders such as hypertension, (pre) eclampsia in pregnant women, and infant mortality will manifest themselves in the future and will create problem that effect on environment and human wellbeing [29][30].

4. Effect of saltwater intrusion

According to the Intergovernmental Panel on Climate Change (IPCC) climate change assessment published in 2014, the coast is vulnerable to climate phenomena such as drought, rising temperatures, and saltwater intrusion [31]. The human population has grown, and the increased demand has resulted in a slew of large-scale projects that have had an impact on hydrological flows [32]. This condition leads in habitat fragmentation, habitat loss, and the emergence of intolerant species because of indirect effects. Aside from that, the salinity-driven flocculation process has resulted in the proliferation of hazardous algae and a deterioration of the ecological health of the aquatic habitat, among other consequences [33]. Furthermore, salinity has an influence on the soil surface, causing soil erosion and a reduction in the soil's ability to absorb rainfall, which results in surface runoff and flooding as a result [34]. Saltwater intrusion also has the additional effect of altering nitrogen mineralization, which is critical for plant productivity in wetlands and crop plantations [35].

The consequences of climate change and rising sea levels intensify the problem of saltwater intrusion into buildings [36]. It is believed that variations in diazotrophic microorganisms, which regulate nitrogen availability for plant uptake by turning atmospheric nitrogen into ammonia, are responsible for the low nitrogen content of soil [37][38]. The severe salinity is reducing the diversity and abundance of these animals’ populations, which will eventually have an impact on their communities [39]. This indicates how saltwater intrusion can have an impact on N availability and the growth of plant tissues. It also has an impact on the wetland through increased ionic strength and sulphate concentration, and the formation of sulphide is hazardous to many different types of organisms [40][41]. This results in pollution from developed land in the upstream area and saltwater intrusion from downstream coastal systems, which may result in changes in ecosystem function as well as greenhouse gas emissions [42].

Moreover, the salinity also releases the dissolved organic carbon (DOC) that store in the soil [43]. The DOC is defined as organic molecules that pass through a filter of 0.45µm and usually transport with soil solution and in streams. The DOC can be classified as either labile or recalcitrant, with labile DOC can be consumed by microbial and lost as CO₂ but not for recalcitrant DOC [44]. The recalcitrant DOC
is difficult for bacteria to digest and assimilate. This type of DOC can persist in the soil for an extended period, having an impact on the carbon budget by locking up carbon and preventing it from being released back into the atmosphere [45].

Soil is considered as carbon sink as more than 75% of terrestrial carbon is stored in the soil, with approximately 1500 Pg carbon stored as SOC with top 1 meter [46]. However, the amount of SOC is differed by soil orders. They are affected by soil texture and aggregation, where the entisol soil type is mentioned to have low amount of SOC. The silt and clay size fractions are needed as they have ability to protect SOC from decomposes, as the organic matter binds with silt and clay [47]. This combination will form aggregates, that protect the organic matter from decomposition [48]. However, in the sandy soil, the number of silt and clay is low, cause the low number of SOC [49].

This can be reflected to BRIS soil system, as BRIS dominated by sand, with the presence of clay and spodic layer. The spodic layer that contain of organic matter in is believed to be originated from the decomposition of leaf litter and marine sediments [50]. As the BRIS soil formation is presence due to the fine sea sand sedimentation by wave and wind, some spodosols are contain of orstein, with clay texture that make the structure become crumpled and fluffy [51]. It also distributed on the ridges and this soil is susceptible to the forest fire [52]). Moreover, as a sandy dominated soil, the excessive rain and high temperature have exacerbated the leaching process and increase the soil erosion [53].

The range of spodic layer (m) in BRIS soil system are depending on their series; Baging had no spodic layer, Rudua and Rusila series had 50-100 m layer, and Baging had no spodic layer [51]. There is, however, a Rusila series that does not have a spodic layer at all. Spodosols are classified according to the presence or absence of the spodic horizon at various levels. Entisols are classified according to the absence of the spodic horizon [54]. Organic material and clay were found in abundance in the spodic horizon, which was overlain by a yellowish-red layer.

A silty-clayey layer lies beneath the sand ridges in the BRIS soil system. This layer is located beneath the beach – shore ridges system, which serves as an upper limiting layer. Before reaching the rock basement, it divides the dominant sand layer from the sand layer below [55]. The poor hydraulic conductivity of silty-clayey sediments, compared to the high hydraulic conductivity of sand sediments, causes excessive drainage with the silty-clayey layer acting as a restricting layer [56].

This revealed that, BRIS soil system may contain high number of DOC with the present of clay and also can prevent fresh groundwater from flowing from the higher sand layer (unconfined aquifer) to the lower layers [54]. Even the saltwater intrusion can occur along the beach and along the shore ridges, but it is likely to be limited to the beach ridges [57]. The unconfined aquifers generated by the coastal ridges are important water sources for the locals since they can be accessed by shallow wells.

Even though the freshwater and saltwater were separated by a transition zone containing brackish water, this zone is not permanent (can move further inland or towards the sea). In typical circumstances, freshwater will flow into the sea; yet there are times when saltwater will flow into freshwater [58]. To ensure that only freshwater is present in the groundwater, the volume of freshwater should be sufficient to prevent saltwater from mixing with the fresh groundwater. This is related to the BRIS soil system's ability to store flood water, which can then be used to recharge the groundwater. Groundwater will be recharged as surface water infiltrates and percolates through the soil [59].

5. Conclusion

BRIS soil system contains confined and unconfined fresh groundwater that could maintain the groundwater volume. By having this property, BRIS soil could help in prevent saltwater intrusion into the
groundwater system. This is very important, particularly in the coastal areas. As the salinity can give effect to other ecosystem services, the environmental parameters linked with the possible wetland site would need to be extensively monitored and checked on a regular basis. This will help to verify the soil chemistry inside the system that is favourable to retain salt. Finally, when evaluating whether to use wetlands to decrease the dispersal and harm associated with saltwater runoff, the local ecosystem would be a key determining element. The coastal wetland on BRIS soil should conserve to safeguard their ecological services and those services should not be neglected.

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