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Threats faced by groundwater: A preliminary study in Kuala Selangor

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Abstract: Coastal ecosystems are particularly vulnerable to climate change as the rise in sea level will lead to damage of infrastructure, degradations of agricultural areas, contamination of surface and groundwater and loss of biodiversity; which covers a wide range of negative impacts to various socio-economic sectors. Preliminary findings indicate that Kuala Selangor, which hosts several groundwater aquifers and serves as a significant "rice bowl" for the nation is susceptible to groundwater salinization and other impacts of sea level rise. A comprehensive assessment is required to evaluate the potential impacts of sea level rise in the area so that appropriate adaptation measures can be identified and implemented to ensure sustainable socio-economic development.

Keywords: groundwater, climate change, sea-level rise, saltwater intrusion, Kuala Selangor

Abstrak: Paras air tanah di kawasan pantai yang meningkat selari dengan paras air laut boleh menyebabkan berlakunya inundasi air tanah. Hal ini boleh mengakibatkan gangguan kepada infrastruktur bawah tanah seperti tapak pelupusan sampah dan tangki septik lalu mendedahkan air tanah dan lapisan geologi kepada pencemaran. Kenaikan paras air laut merupakan ancaman kepada ekosistem pantai dan melibatkan pelbagai sektor sosio-ekonomi seperti kerosakan infrastruktur, pencemaran kawasan pertanian, air permukaan serta air tanah, dan kehilangan biodiversiti. Dapatan awal kajian menunjukkan kawasan Kuala Selangor yang mempunyai akuifer pantai dan merupakan salah satu kawasan penghasilan utama padi di Malaysia terdedah kepada ancaman kenaikan paras air laut. Penilaian secara menyeluruh perlu dijalankan di kawasan ini bagi mengenal pasti potensi impak kenaikan paras air laut supaya langkah adaptasi boleh dikenal pasti dan dijalankan bagi memastikan kelestarian pembangunan sosio-ekonomi.

Keywords: air tanah, perubahan iklim, kenaikan paras air laut, intrusi air masin, Kuala Selangor

INTRODUCTION

The Earth's climate is unequivocally warming and many unprecedented changes have been observed since the 1950s (IPCC, 2013). These changes include atmospheric and oceanic warming, the melting of snow and ice, sea level rise and increased greenhouse gases. The long-term changes in the components of climate such as temperature, precipitation and evapotranspiration is primarily due to increase of greenhouse gases in the atmosphere (Panwar & Chakrapani, 2013). The current warming of the climate may correspond to natural warming but it is exacerbated by anthropogenic activities such as industrialisation, urbanisation, use of fossil fuel and excessive agriculture and livestock that release high amounts of greenhouse gases into the atmosphere.

Eustatic sea level is rising in response to warming of the oceans and melting of Polar ice caps. The rise in sea level is expected to accelerate through the 21st century and beyond due to continued global warming (Nicholls & Cazenave, 2010). Although sea level rise will only directly impact coastal zones, the impacts are huge and cover an extensive range of sectors. Considering that 10% of the world's population lives in coastal areas, sea level rise is seen as a major threat (McGranahan *et al*., 2007). Coastal ecosystems comprise valuable resources including fertile land, groundwater and high-level biodiversity. Such conditions attract human activities which lead to rapid development and hence many major cities are located on coastal plains.

The purpose of this paper is to present current knowledge on the implications of climate change and sea level rise on groundwater and coastal resources and to highlight the urgent need for local level information. The paper commences with an overview of the threats faced by groundwater and other coastal resources due to climate change and sea level rise. This is followed by a summary of groundwater resources in the country and a cursory review of the Kuala Selangor area, which is susceptible to the negative impacts of sea level rise. The last section briefly discusses adaptation measures in response to the rising sea level specifically in preserving groundwater resources.

THREATS TO GROUNDWATER

Stability of water resources is fundamental to cater for the needs of an increasing population, industry and agricultural activities. Surface water is the main supply of water resource in Malaysia despite its small amount relative to groundwater. Surface water is generally polluted due to improper urbanisation practices and this deteriorates the quality and quantity of usable surface water. Groundwater is a major freshwater resource and could serve as a cost effective alternative source of water. However, groundwater is facing several natural and anthropogenic threats. Particularly, coastal groundwater aquifers are threatened by the effects of rising sea levels and changes in the hydrologic regime associated with a changing climate.

Groundwater is being threatened by anthropogenic activities. Major threats to groundwater quality are from point sources resulting from urbanisation and industrial waste-waters (bacteria, detergents, industrial chemicals) and non-point (diffuse) sources from agricultural activities (fertilisers and pesticides) (Chu, 2004). Industrial types of waste are diverse, ranging from inorganic contaminants associated with mining and foundry wastes to organic compounds produced by the petrochemical and pharmaceutical industries. Coastal groundwater aquifers, which form the most productive groundwater in the country are facing the threat of saltwater intrusion. Groundwater salinization occurs as seawater displaces or mixes with fresh groundwater. It often results from overexploitation of fresh water aquifers, which reduces or reverses groundwater flow towards the sea. Climate change is projected to exacerbate these impacts in terms of sea level rise due to increase in temperature resulting from a warmer atmosphere. Higher sea levels pose negative impacts to coastal areas including coastal aquifers. Climate change will alter the hydrological cycle with associated influences on aquifer recharge. The implications of climate change, sea level rise and alteration of the hydrologic cycle will have serious implications to various socio-economic sectors (Figure 1).

THREATS OF CLIMATE CHANGE TO HYDROLOGICAL CYCLE

Over the last three decades, the Earth's surface has warmed with the warmest decade represented by the 2000s (Stocker *et al*., 2013). Climate change may affect the components of the hydrologic cycle (Ranjan *et al*., 2006). These components include evaporation, precipitation, evapotranspiration, and soil moisture which in turn influence the quantity of water present in glaciers, rivers, lakes, oceans, etc. (Panwar & Chakrapani, 2013). Climate change impacts on the hydrological cycle is initiated by higher evapotranspiration rates and temperatures resulting in lower soil moisture content (Panwar & Chakrapani, 2013). Decreased soil moisture allows solar radiation to penetrate into the Earth, increasing soil dryness and eventually resulting in drought (Kumar, 2012). Changes in evapotranspiration patterns affect rainfall patterns while transpiration will show various changes depending on regional vegetation cover.

Climate change impacts on subsurface water can affect groundwater recharge and discharge rates as well as the quantity and quality of water in aquifers (Taylor *et al*., 2013; Panwar & Chakrapani, 2013). According to Taylor *et al*. (2013), groundwater recharge is mainly through diffusion of surface run-off and percolation of surface waters such as streams, wetlands, and lakes. These mechanisms are largely influenced by climate and vegetation and subsurface

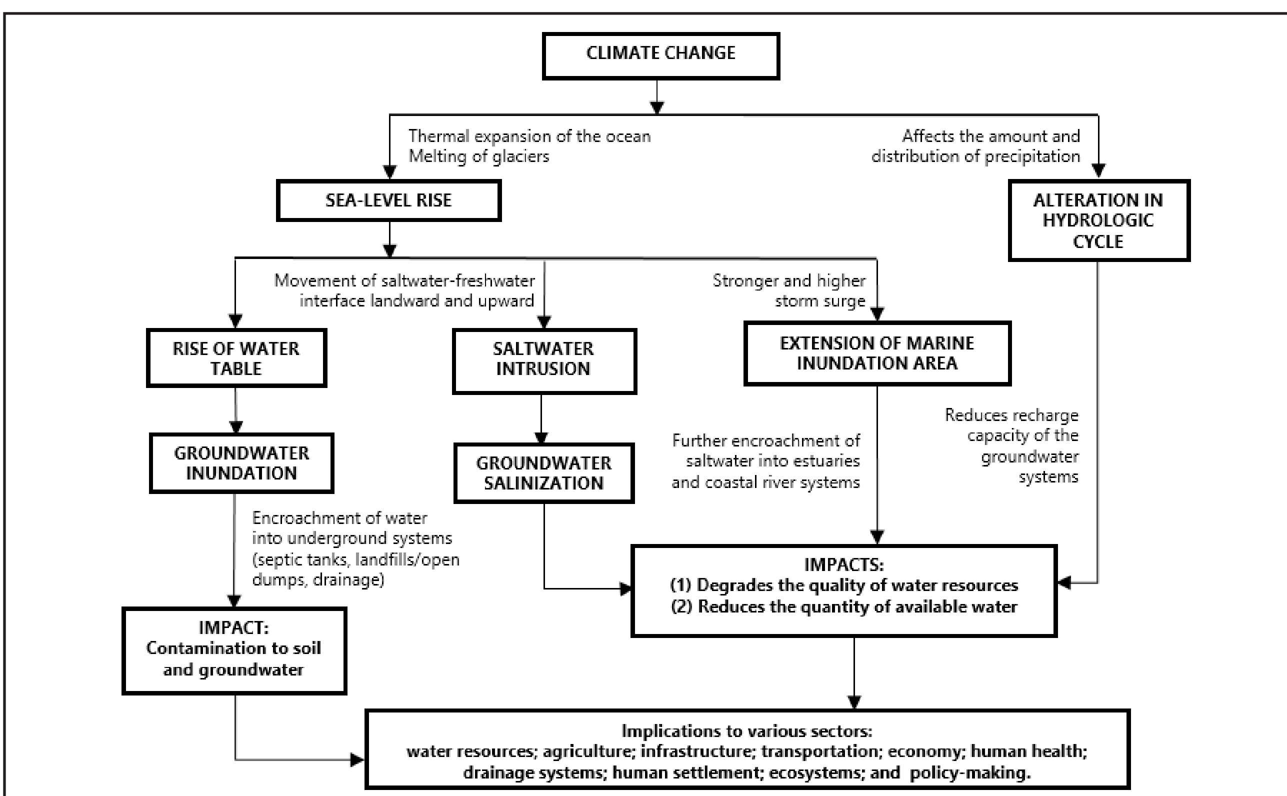

Figure 1: General implications of climate change to various sectors.

properties respectively (Taylor *et al*., 2013). During global warming, some regions will certainly experience increased precipitation while others decreased precipitation or little change at all since changes in average precipitation are not expected to be uniform (Stocker *et al*., 2013). Depending on climate change scenarios and changes in precipitation, the effects of climate change on groundwater recharge will vary regionally (Sen, 2009).

The quality of groundwater depends on the physical, chemical, and biological properties of the aquifers which vary with climate (Panwar & Chakrapani, 2013). Changes in the recharge rate and the groundwater temperature in the vadose zone will affect the groundwater quality as pore-water chemistry, contaminant transport, and residence time are also modified (Glassley *et al*., 2003). Climate variability can modify aquifer properties such as transmissivity and storativity (Panwar & Chakrapani, 2013). This is further explained by the fully saturated conductive channels during wet seasons and thus transmitting pressure rapidly. During dry periods, water within aquifer is transmitted slowly due to desaturated conductive channels and lower pressure.

THREATS OF SEA LEVEL RISE TO GROUNDWATER

The Fifth Assessment Report (AR5) by IPCC (2013) states that the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia, and over the 1901-2010 period, global mean sea level has risen by 0.19 m. Ocean thermal expansion and the melting of glaciers are suspected to be the dominant contributors to global mean sea level rise during the 20th century (Sherif & Singh, 1999; IPCC, 2007; Nicholls & Cazenave, 2010; Nicholls, 2011a; IPCC, 2013). Global mean sea level is expected to continue rising during the 21st century in response to the continued global warming with increasing impacts on coastal regions. Sea level rise might only directly impact coastal zones but these areas are often the most densely-populated and economically active areas (Nicholls, 2011b). Nicholls & Cazenave (2010) categorised the effects of sea level rise on coastal zones into two time range categories: (i) short-term effects such as submergence, increased flooding of coastal land (inundation), saltwater intrusion of surface water, and higher water table; and (ii) long-term effects that take place as the coast adjusts to new environmental conditions such as ecosystem change, erosion, and saltwater intrusion into groundwater. Among these major biogeophysical impacts, inundation or coastal flooding, saltwater intrusion, and rising of water tables are highly detrimental to groundwater resources (Figure 2).

Stronger and higher storm surges are expected in relationship to rising sea levels, making coastal areas susceptible to episodic and extensive marine inundation (Hay & Mimura, 2005; Ferguson & Gleeson, 2012). As sea levels continue to rise, the coastal inundated area is translated inland with further encroachment of tidal waters into estuaries and coastal river systems creates a condition known as marine transgression. This can lead to damage of infrastructures, degradation of agricultural areas, salinisation of surface water, and loss of biodiversity. As the coast adjusts to the new environmental conditions, long-term effects are expected to emerge which include the change of ecosystems, erosion of beaches and soft cliffs, and saltwater intrusion into groundwater (Nicholls, 2011b).

Saline intrusion occurs when saltwater replaces the freshwater in coastal aquifers (Ranjan *et al*., 2006). It can threaten aquifers especially when fresh groundwater is actively extracted. With the rise of sea level, the saltwater-freshwater interface moves landward and upward, accelerating saltwater intrusion into the freshwater aquifer and resulting in groundwater salinisation. Saltwater intrusion is controlled by a variety of factors which includes coastal topography, recharge, and groundwater extraction (Oude Essink *et al*., 2010; Ferguson & Gleeson, 2012). It has been observed that saltwater intrusion related to groundwater extraction of coastal aquifers was more significant than the impact of sea level rise (Ferguson & Gleeson, 2012). Rising sea levels accompanied by excessive groundwater extraction can also lead to land subsidence as seen in coastal mega cities such as Tokyo, Shanghai, Indonesia and Bangkok (Nicholls, 2011b; Panwar & Chakrapani, 2013).

The rise in sea level will raise the water table in coastal regions (Hay & Mimura, 2005; Nicholls, 2011a). Depending on subsurface conditions, rising water tables can extend inland up to tens of kilometres and may cause expansion of existing water bodies (Hay & Mimura, 2005). New wetlands are formed when the water table reaches the land surface, creating groundwater inundation. Rotzoll & Fletcher (2012) defined groundwater inundation as localised coastal-plain flooding due to a rise of the groundwater table with respect to sea level. These situations lead to impeded drainage in the area (Hay & Mimura, 2005) causing underground services such as septic tanks, landfills, and other waste disposal systems can be compromised and contaminate the

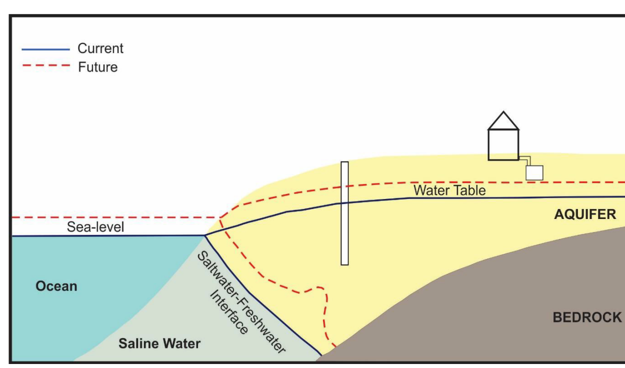

Figure 2: Conceptual diagram of the impacts of sea level rise at coastal aquifer area. (1) Higher sea levels promote stronger and higher surge that lead to frequent inundation, which over time may become permanent and extensive; (2) The movement of saltwater-freshwater interface landward and upward accelerates saltwater intrusion; affecting the interface if the well is actively abstracted; and (3) Rise of water table disturbs underground systems (i.e. septic tanks, landfills/open dumps, etc.) and may result in groundwater inundation at worst.

Table 1: Potential impacts of sea level rise on socio-economic sectors in coastal zones (Source: Nicholls, 2011).

Coastal Socioeconomic Sector	SEA LEVEL RISE NATURAL SYSTEMS EFFECT				
	Inundation/ Flooding	Wetland Loss	Erosion	Saltwater Intrusion	Impeded Drainage
Freshwater Resources	X	x	-	X	X
Agriculture and Forestry	X	x	-	X	-
Fisheries and Aquaculture	X	X	x	X	x
Health	X	X	-	-	-
Recreation and Tourism	X	X	X	X	X
Biodiversity	X	X	X	X	X
Settlements/Infrastructure	X	X	X	X	X

X = strong x = weak - = negligible or not established

groundwater aquifer, surface water, and geological strata. Unengineered landfills are already a threat through leachate formed by the wastes which can percolate geological strata and contaminate groundwater systems (Mohd Raihan Taha *et al*., 2011).

Sea level rise has an overall negative impacts on a wide range of sectors (Table 1). Changes to the natural system due to coastal flooding or inundation will contaminate freshwater, degrade soil fertility for agriculture, affect biodiversity, and damage infrastructure. Indirect or secondary impacts are likely to occur where subsurface flooding may spread contaminants from waste sites and impact human health. Wetland change and erosion may cause a significant alteration to coastal morphologies subsequently impacting tourism. Saltwater intrusion into groundwater will reduce freshwater supply available for consumption. The severity of these impacts are controlled by local variability and the manner in which particular coastal systems respond to sea level rise (Cazenave & Cozannet, 2013).

GROUNDWATER AND CHARACTERISTICS IN KUALA SELANGOR

Over 90% of the freshwater resources in Malaysia are groundwater (Chu, 2004). Part of these reserves are unavailable due to the existing development and difficulties for detailed groundwater assessment in certain areas (Yunus Abd. Razak & Mohammed Hatta, 2009). The Mineral and Geoscience Department of Malaysia (JMG) is the leading government agency in hydrogeological investigation. The first groundwater potential investigation was carried out in the early 1900s in Kelantan.

In 2009, approximately 0.2 million m^3/day of groundwater was acquired in Peninsular Malaysia (Yunus Abd. Razak & Mohammed Hatta, 2009). Groundwater distribution in Malaysia are allocated to three major sectors: (i) domestic (65%); (ii) industry (35%); and (iii) agriculture (5%). Groundwater usage in Malaysia has been rising since the last century due to several factors: (i) surface water is severely depleted during the dry season in some areas such as Kedah, Perlis, Melaka and within the Klang Valley; (ii) water demand has been increasing rapidly due to rapid growth of population, agriculture and industrialisation; and (iii) frequent lack of viable source of surface water from either reservoirs or lakes in newly developed areas (Chu, 2004; Suratman, 2004).

Kuala Selangor is a coastal area that hosts extensive groundwater aquifers and serves as an important granary area for Malaysia (Figure 3). Part of the Northwest Selangor Integrated Agriculture Development Area (IADA) is situated in this area. It is about 40 km long and 50 km wide with some 19,000 hectares allocated for paddy cultivation. The area extends along the coast of the district of Kuala Selangor and Sabak Bernam in the northwest-southeast and represents one of the most significant national “rice bowls” due to the high productivity of paddy yield. Part of the district is classified as flood-prone as depicted in the environmentally-sensitive area map of the Town and Country Planning Department of Peninsular Malaysia (JPBD, 2005). The agricultural sector

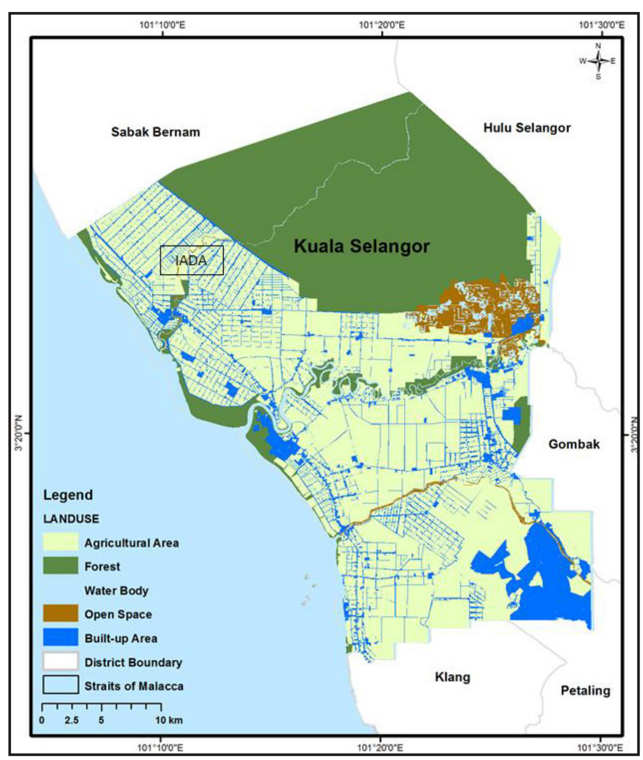

Figure 3: Location and land use of the study area.

dominates land use in the area and plays a major role in economic development.

In 2000, a hydrogeological investigation was carried out by JMG, covering an area of 400 km^2 that includes the vicinity of Kuala Selangor to Bestari Jaya and parts of Tanjung Karang (JMG, 2000). Hydraulic rotary drilling was performed for 16 boreholes of which 13 were constructed as exploration wells ranging from 15 m to 45 m in depth. The area comprises Quaternary alluvium overlying meta-sedimentary strata of Devonian-Silurian age (Hamzah *et al.*, 2007). The alluvium covers the eastern part of the study area (Figure 4). The aquifer is made up of layers of clay, sand, and gravels with meta-sedimentary strata as bedrock (JMG, 2000). Water tables of the exploration wells are recorded between 0.33 m to 4.02 m (Figure 5). The groundwater in the area has been classified as fresh,

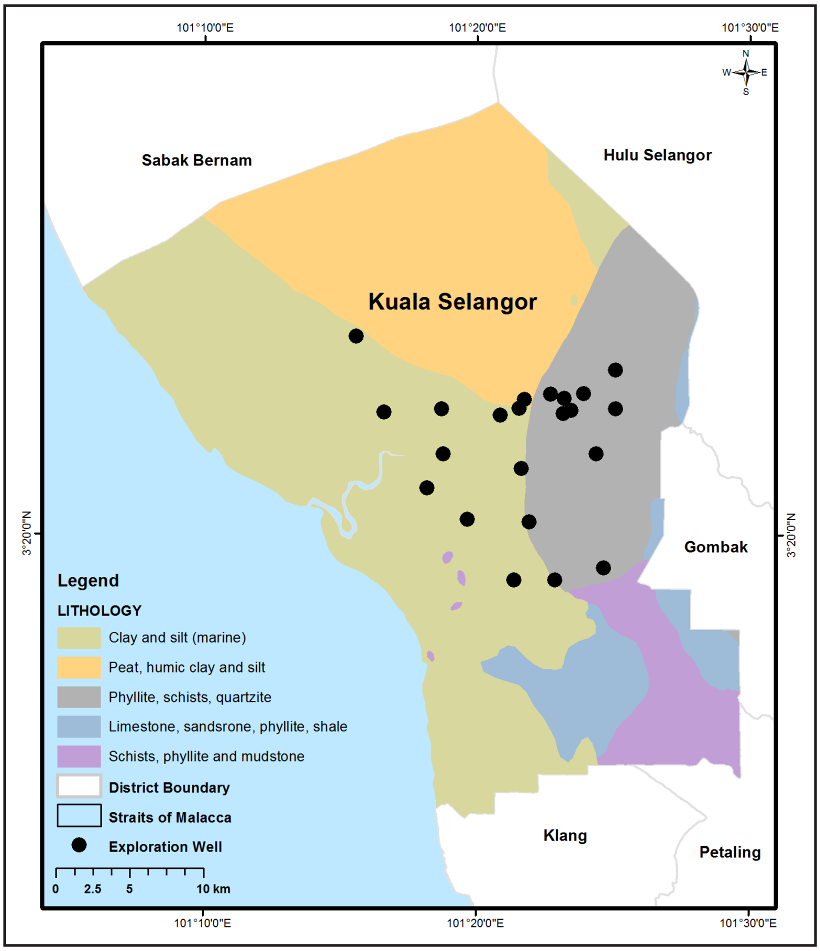

Figure 4: Geological map of the study area showing location of the JMG exploration wells.

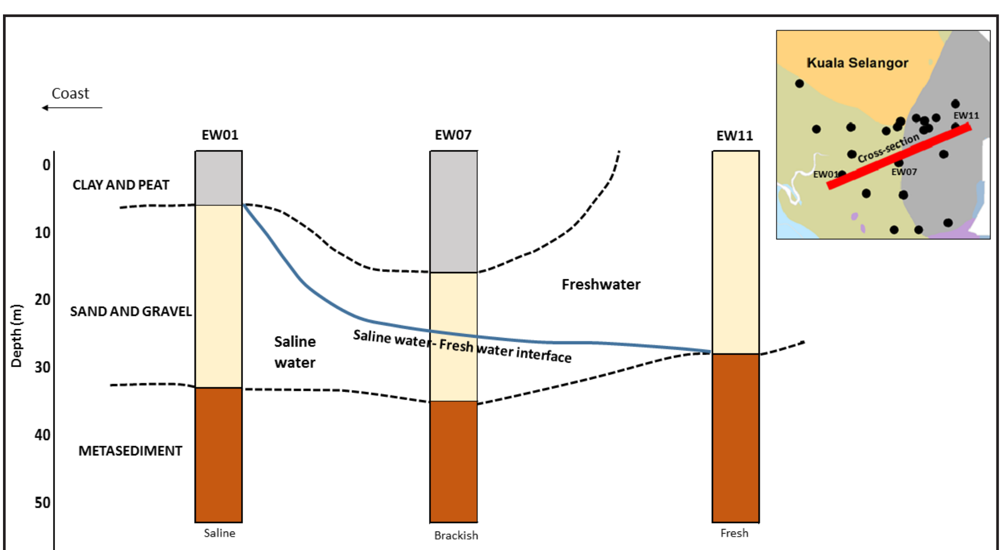

Figure 5: Cross-section of the aquifer based on information from the exploration wells.

brackish and saline, where the saline zone is located near and parallel to the coast and extends about 2 km to 4 km inland (Hamzah *et al*., 2007).

A Vertical Electrical Sounding (VES) survey was conducted in the area to characterise the groundwater quality by resistivity variations where 45 VES stations were built in three arrays parallel to each other and almost perpendicular to the coast (Hamzah *et al*., 2007). Based on the classification by Bugg and Lloyd (1976), a profile for subsurface groundwater type was established for every array. The survey found that the upper part of the profile is dominated by brackish layer that is thickening towards the coast with resistivity value ranging from 1 Ωm to 48 Ωm. A fresh water zone was found underneath the brackish layer that is represented by resistivity values of 48 Ωm to 500 Ωm. In some cases, fresh water lenses are found in the brackish zone and vice versa.

Preliminary assessments indicate that the Kuala Selangor area is susceptible to influence from climate change, particularly sea level rise. The National Hydraulic Research Institute Malaysia (NAHRIM) carried out a study on the impact of climate change on sea level rise in Malaysia in 2010. Based on tidal gauge records, the general trend in the recent five years' data is significantly higher than the previous 20 years (NAHRIM, 2010). It is observed that the rate of sea level rise in Peninsular Malaysia based on satellite altimetry data from 1993 to 2010 is 4.28 mm/year, which is higher than the global rate of 3.2 mm/year as reported by the IPCC (2013). NAHRIM has projected sea-level rise over 20 years in Malaysia from 2021 to 2100. The mean sea level rise in Peninsular Malaysia is projected to be 2.19 mm/year from 2001 to 2020, 3.02 mm/year for 2021 to 2040, 4.06 mm/year from 2041 to 2060, 4.77 mm/year from 2061 to 2080, and 5.10 mm/year from 2081 to 2100. For the overall hundred years, the estimated sea level rise is 3.87 mm/year. By 2100, sea level is expected to rise about 0.517 m (NAHRIM, 2010). On the other hand, global sea level is projected to increase around 0.52 m up to 0.98 m by the year 2100 (IPCC, 2013). Whilst the projection of sea level rise is available, the extent of the areas that may be inundated, exposed to coastal hazards and impacted at the sub-surface level has not been investigated in detail. Local level studies are urgently required for this purpose.

POTENTIAL ADAPTATION MEASURES

Groundwater, as a valuable and renewable fresh water resource, should be managed properly and sustainably to ensure a long-term supply of fresh water to meet the needs of the growing population. IPCC Coastal Zone Management Subgroup (CZMS) introduced three types of adaptation strategies namely: (i) planned retreat; (ii) accommodation; and (iii) protection (Dronkers *et al*., 1990). Retreating and accommodating strategies allow natural processes to take place while human impacts are minimised. By planned retreat, human impacts are minimised by preventing development in areas near the coast susceptible to the impacts of rising sea level. Accommodation requires advanced planning and acceptance that some coastal zone land values could be diminished. Protection focuses on defensive measures to control the natural system through either soft engineering (e.g. beach nourishment, dune building, etc.) or hard engineering (e.g. seawalls, revetments, bulkheads, etc.) strategies that protect human-related infrastructure. Real-world responses are commonly hybrids, combining elements of more than one approach (Nicholls, 2011b).

The most prominent step in ensuring sustainable groundwater development is by integrating and mainstreaming adaptation strategies into water management plans while coordinating institutional arrangements in adaptation implementation (IGES, 2008). There is no rigid way of classifying the adaptation measures, but they can be categorised into three general categories: (i) structural; (ii) social; and (iii) institutional (Noble *et al*., 2014).

STRUCTURAL

Structural adaptation involves the development of physical infrastructure or methods either in the form of a built environment, technology, ecosystem-based, or service. In the water resources sector, rainwater harvesting has been practical as it is simple and cost effective. It operates by collecting and storing rainwater in surface or subsurface catchments to reduce the loss of water to surface run-off and evaporation (Stiefel *et al*., 2009). Through rainwater harvesting, water availability in any specified area is enhanced (IGES, 2008), thus making water available for artificial groundwater recharge (Stiefel *et al*., 2009). One of the rising structural strategies is ecosystem-based such as mangrove planting. Duarte *et al*. (2013) states that marine vegetated habitats such as seagrasses, salt-marshes, macroalgae, and mangrove are vital in preventing flooding and erosion resulted from waves and storm surges. These coastal ecosystems pose high capacity to protect the tidal area from sea level rise impacts. Seagrasses is very effective in dissipating wave energy. Salt-marshes and mangroves function as protection from surges. This vegetation also helps in the formation of dune, beach nourishment and sediment accretion hence slowing the rate of coastal erosion (Duarte *et al*., 2013). These strategies are believed to reduce the vulnerability by strengthening coastal embankments (Sovacool *et al*., 2012). Biological adaptation measures offer conservation and protection of the ecosystems at low costs. It has been reported that in Vietnam, mangrove plantations have reduced the dyke maintenance cost by USD 7.3 million a year (Duarte *et al*., 2013). Similar adaptation measures have been carried out in Bangladesh and Maldives, to create natural buffers to the related climatic hazards (Sovacool *et al*., 2012). By nature, coastal vegetation ecosystems adapt to sea level and surge variations, which contributes to the cost effective options compared to artificial structural infrastructure (Duarte *et al*., 2013).

SOCIAL

For developing countries to cope with current and projected climate change especially in adaptation, capacity building is vital especially in higher education and government agencies, as well as local communities (IGES, 2008). Education and training can contribute to capacity development of community and further improve and enhance various adaptation options suitable for local implementations. Awareness raising also improves the understanding of science behind climate impacts and adaptation proficiencies and should be performed by institutions at local, national, and regional levels (Niang, 2014). Governments must take action in providing learning and training facilities so that all stakeholders and water users are well educated of the importance, threat, and sustainable management and development of groundwater resources.

INSTITUTIONAL

A key solution to groundwater emerging issues is transitioning groundwater management to groundwater governance, which stresses the participation of multilevel stakeholders (IGES, 2008). Global Water Partnership (2000) defines groundwater governance as a coordination of a range of stakeholders from political, social, economic, and institutional sectors in managing water resources and providing water supply to different societal levels (GWP, 2000). This system must involve scientist, policy makers, and users by considering each of their concerns on the freshwater supply. Each stakeholder should be appointed on specific roles with an authorised agency to carry out the development, implementation, and enforcement of sustainable groundwater strategy. Local groundwater management however needs supervision from the local governments. While reducing the burden of responsibilities the government carry, sustainable groundwater resources management is ensured.

There is a diversity of adaptation measures to address the threat of sea level rise to coastal zones. The measures to be deployed will depend on the local context and area that is exposed. This calls for a detailed study in Kuala Selangor to systematically identify future hazards and assess the level of risk as well as the most appropriate adaptation measure in conjunction with multiple stakeholders. The local authority and other local level decision-makers in the area have a critical role to play in this regard. More policy relevant research should be conducted to support their decision making process.

CONCLUDING REMARKS

Climate change and sea level rise pose several negative consequences to coastal environments and aquifers. Groundwater is affected in terms of both quality and quantity of reducing reserves for industrial, agricultural, and domestic use. To fulfil the needs of development and urbanisation, groundwater as an alternative freshwater resource should be protected so that the high reliance on surface water that is facing deterioration in quality and quantity due to improper practices of development and natural stresses such as climate change can be augmented. Coastal areas, such as the agriculturally-active Kuala Selangor, are susceptible to impacts from sea level rise. This has future implications on the demand for irrigation water and food productivity. Detailed comprehensive research is required to assess the impacts of climate change to groundwater resources and coastal ecosystems so that appropriate adaptation measures can be identified as early as possible.

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