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title: **The impact of recent urbanization on a hard rock aquifer in Malaysia**

author(s): **Norsyafina Roslan**
University of Birmingham, United Kingdom, NBR890@bham.ac.uk

Rae Mackay
University of Birmingham, United Kingdom, r.mackay@bham.ac.uk

John H. Tellam
University of Birmingham, United Kingdom, j.h.tellam@bham.ac.uk

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INTRODUCTION

In the last few years the world's proportion of urban dwellers has exceeded 50% (2850 million)(UN, 2009), with most of the most rapid expansions in urban populations taking place in developing nations. Most urban areas in developing countries are located on the coast or on major rivers, as they are in Malaysia (Noorazuan et al., 2003).

When an urban population is increasing, there will be more water consumption and waste production, causing greater pressures on urban water management (e.g. Chilton et al., 1997; Howard and Israfilov, 2002; Tellam et al., 2006). Besides this, urbanization encourages flooding to occur by reducing direct infiltration. It affects the groundwater system by changing, for example, groundwater recharge, modifying existing mechanisms and introducing new ones such that total recharge is often increased (Chilton et al., 1999). If urban water is to be efficiently managed, it is necessary to understand the impacts of urbanization on groundwater systems. In Malaysia, relatively little work has been done on urban groundwater, with most focus being on finding the groundwater sources. In addition, internationally most of urban groundwater research has been conducted in unconfined clastic sedimentary aquifers rather than in hard rock aquifers such as are found in certain of the urban areas of Malaysia. Thus a project has been initiated to provide the knowledge necessary to understand water impacts in urban, hardrock, Malaysia.

Shah Alam has been chosen as the study area since it is the first planned town in Malaysia (Fig. 1), experiencing since 1963 a rapid change from agricultural to industrial development and thus offering an excellent opportunity to study urban impacts as they develop.

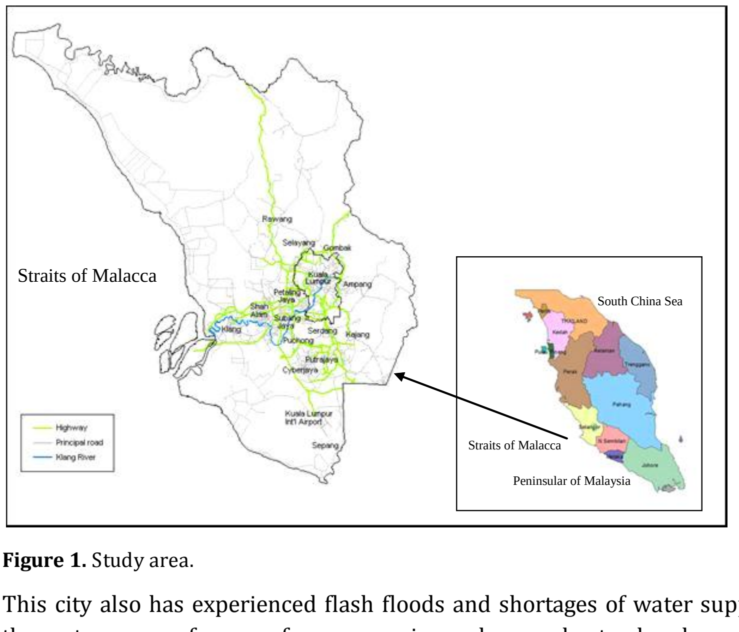

Figure 1. Study area.

This city also has experienced flash floods and shortages of water supply. At present, most of the water comes from surface reservoirs and groundwater has been only used for industry. Shah Alam is underlain by a hard rock aquifer, a type of aquifer also found elsewhere in Malaysia (including the states of Kedah, Selangor, Johor, Sabah and Sarawak), and infrequently studied in the context of urban hydrogeology. Any understandings and methods developed from the present study may therefore be expected to be of use in urban groundwater management elsewhere in Malaysia and internationally.

The aim of this paper is to present a conceptual model of the flow system of this relatively unusual urban aquifer.

HYDROGEOLOGY – DEVELOPING A CONCEPTUAL MODEL

Introduction

Currently, a conceptual model of study area has been developed using information mainly from borehole logs, meteorological data, pumping test data and water quality analyses. Later, this model will be used to develop a full numerical flow model of the flow system.

Borehole Log Evidence

The 31 borehole logs available for the study area have been examined. Table 1 shows the stratigraphy of Shah Alam area. Kuala Lumpur Limestone is overlain by the main aquifer unit, the Carboniferous-Permian Kenny Hill Formation, which consists of coarse- to fine- grained metasediments; overlying the sequence is alluvial deposits of Quaternary age.

Table 1. The stratigraphy of Shah Alam.

AGE	LITHOLOGY
Quaternary	Alluvium
Mesozoic or younger	Granitic rock
Permian - Carboniferous	Kenny Hill Formation (Gobbett & Hutchinson 1973). interbedded sandstone, shale and mudstone. Gentle dips (less than 30°) Geological structure: two sets of vertical joints arranged in north-northeast t south-southwest and east-west and faults
Silurian - Devonian	Kuala Lumpur Limestone

The depth of the boreholes varies, but most are more than 100 m deep. The thickness of alluvium varies, but at most is around 10 m, while the weathered bedrock is up to 30 m thick. The bedrock is fractured and veined with quartz. The lithology across the aquifer varies; with shale in the northern part, interbedded shale and sandstone in the middle part and carbonaceous shale in the eastern part. This variation may or may not indicate changes in aquifer properties. The main flow probably will be by fractures in the sequence underlying the alluvium.

The low permeability of alluvium layer will encourage much of the rainfall in the study area to flow as surface runoff rather than infiltrate to the Kenny Hill Formation below. There is a large river (Klang River), flowing east to west across Shah Alam, and two of the river's tributaries (Damansara and Renggam), flow north-northeast to south-southeast. All three rivers appear to be in direct contact with the Kenny Hill Formation systems, and therefore possibly recharge the aquifer.

Meteorological Evidence

Shah Alam receives on average over 2200 mm rainfall per year. It peaks in March and April and also in October and November. Potential evapotranspiration is around 1500 mm/y. Due to the low permeability of the alluvium, recharge is probably limited, and indeed much runoff is seen in the area. If water levels are lowered by abstraction, greater head gradients across the alluvium may well increase the recharge rates considerably; however, few data are available on the permeability of the alluvium.

Pumping Test Data Evidence

At this moment, abstraction from the aquifer in Shah Alam is only by industry. There are 35 pumping test data sets available from these industrial sites. Typical wells are > 100 m deep, drilled into the Kenny Hill Formation and extract at a rate, on average, of 250-350 m^3/day. There are a few tubewells with pumping rates as low as 170 m^3/day and a few with rates as high as 600 m^3/day.

From standard curve fitting interpretations of the pumping test data undertaken using Aquifer Win 32; transmissivity values are in the range 2 – 4 m^2/day, implying permeability values of 10^{-3} to 10^{-2} m/day. Thus the Kenny Hill Formation aquifer has only modest aquifer characteristics. Storage coefficient values interpreted from the same pumping test data set range from 10^{-3} to 10^{-2}.

Pumping test data from one borehole at a location where the Kuala Lumpur Limestone directly underlies the alluvium are available, and suggest that the limestone may well be more permeable: transmissivity is 160 m^2/day implying a permeability value of 4.2m/day, and the storage coefficient is 10^{-4}. If the permeability of the limestone is as high further south where it underlies the Kenny Hill, this could have a considerable affect on the flow system within the latter.

In addition, the patterns of the pumping test drawdown plots show some interesting features. More than 50% of the tubewells for which pumping test data exist, show recovery to levels below the initial piezometric surface (Figure 2).

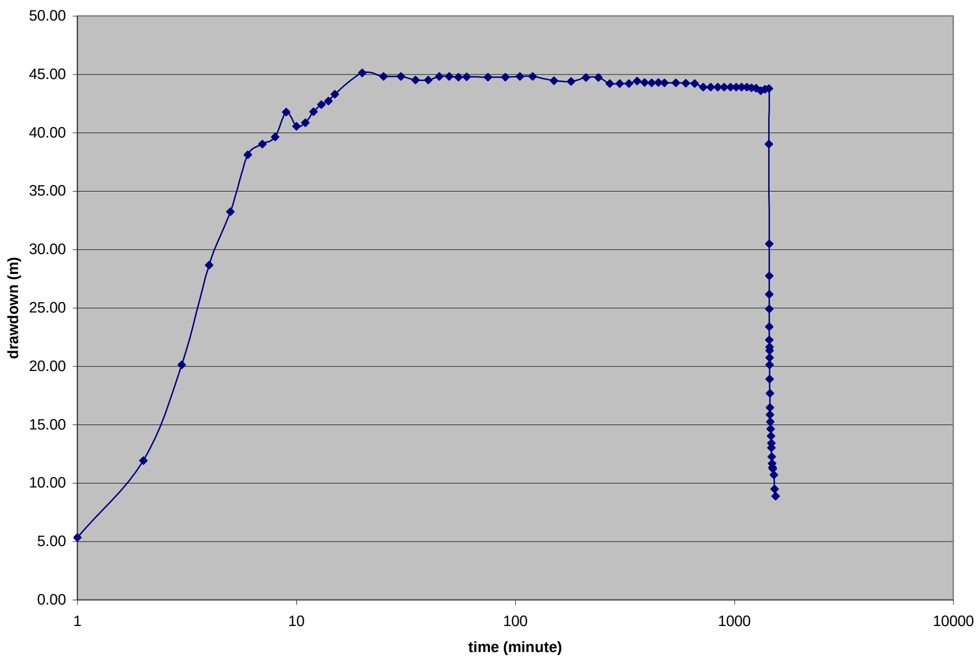

Figure 2. The interesting pattern of drawdown in study area.

This suggests that the pumping tests result in significant depletion of aquifer storage, a result consistent with a flow system compartmentalized perhaps by low permeability discontinuities. However, long term yields are not affected, and in many cases the same wells showing incomplete recover also display a flattening of the drawdown curves suggesting a nearby major source of water (Figure 2), possibilities including the rivers and the underlying Kuala Lumpur Limestone. These and other possible mechanisms are being investigated using numerical modelling of the pumping tests.

Water Quality Evidence

There are 38 tubewells located at industrial/commercial sites in Shah Alam. Water samples have been taken from each of these and analyzed in the laboratory.

The groundwater quality of the study area is characterized by total dissolved solids (TDS) values that are unusually low for an urban aquifer. Most waters have TDS < 100mg/l, as shown in Fig. 3.

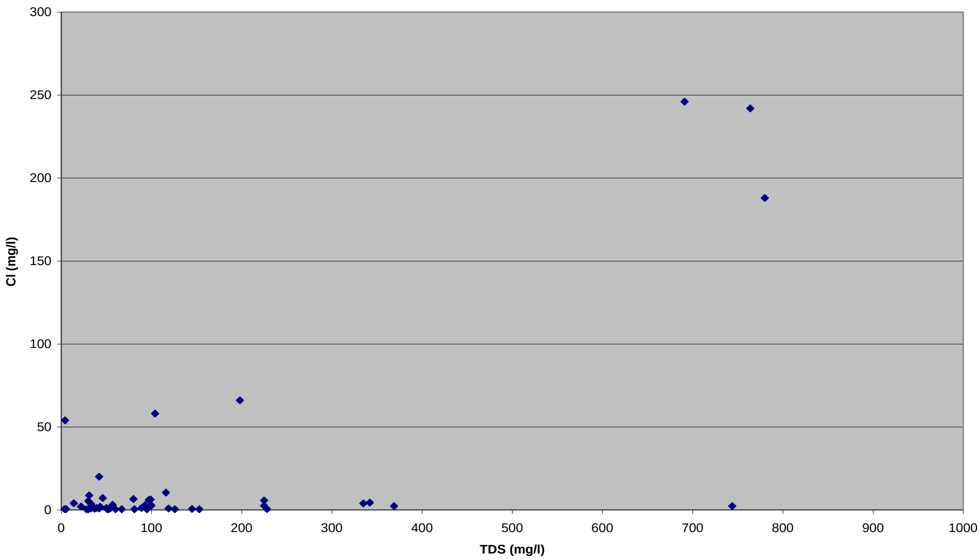

Figure 3. Low concentration of chloride and low total dissolved solid of groundwater sample in study area.

These waters are virtually unpolluted, despite their urban location, and in part this may reflect the young age of the city. Relatively low pP_{CO2} values (0.91- 2.5) suggest that the waters have, nevertheless, passed through a soil zone rather than directly from surface waters. Rainwater chemistry is even lower in concentration, averaging 120 μmol/l TDS, again suggesting that the groundwater has undergone some modification. The increase in TDS from rainwater to groundwater could be accounted for, using two extreme models, by either dissolution with no evaporative losses, or by no dissolution and with evaporation.

Although most water is unpolluted and has a very low TDS, some samples have much higher concentrations, especially in terms of NO_3, heavy metals and bacteria. These are clearly cases of local pollution, showing that the aquifer is far from fully protected by the presence of the alluvium, or by the limited time since urbanization. Viable bacteria suggest that times from surface to well are short, in keeping with fracture flow, though also implying fast pathways from ground surface through the alluvium.

CONCLUSION

This is an unusual urban aquifer that may well pose difficult questions for management. The system appears compartmentalized on a scale that is small compared with the amount of water abstracted by the industrial wells. This suggests that well catchment zones may be controlled by geology rather than by regional flow. Nevertheless, a significant number of wells have a major source of water available to them which limits the drawdown, and this may suggest that vertical flow may well be extremely important in this aquifer. Though water quality is at the moment generally excellent, pollution occurs locally and probably penetrates the aquifer system rapidly. If compartmentalization is occurring, the development of large scale pollution plumes is unlikely, and possibly pollution may be containable. Work continues.

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