A Preliminary Drought Mitigation Plan for Hong Kong

Chen, J. and F.P. Chan

Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong, China
Email: jichen@hkucc.hku.hk

Keywords: *Drought, mitigation plan, indicators, trigger levels, Hong Kong*

EXTENDED ABSTRACT

For preventing and alleviating the potential drought damages, many cities and states in the USA have developed their drought mitigation plans. It is observed that the plans are usually composed of three to four drought severity levels and the respective mitigation measures are then taken. However, for a drought mitigation plan, how to define drought indicators for identifying different drought severities is critical. Mainly, the indicators are established according to streamflow, precipitation, water levels in lakes and reservoirs, soil moisture content, and groundwater level. In this study, developing a drought mitigation plan for the city of Hong Kong is attempted, especially with the analysis of a severe drought that occurred in the year 1963.

The study firstly examines the social impacts of the 1963 drought and explores the relationship between the impacts and the water rationing. The survey shows that the most suffering to the society mainly occurred in June of that year, even though the tightest water rationing, once water supply for four days with a four-hour slot, was lasting a year long from June 1963 to May 1964. This result reveals that the time needed for Hong Kong to adjust to the severe drought situation like in 1963 might be about one month.

With understanding the social impacts of the drought on Hong Kong in 1963 and drought mitigation plans developed in the USA, a preliminary drought mitigation plan, which has not been developed in Hong Kong yet, is designed. This plan includes the stepwise triggering mitigation measures according to different drought severities. According to the water resources features in Hong Kong, the drought severity is determined using rainfall information and the amount of fresh water stored in the local reservoirs. Then, the mitigation measures are considered with the design of polices of water price, water supply and allocation.

Precipitation in the next few months is forecasted to predict the drought duration and to determine the subsequent actions. However, in this preliminary plan, the uncertainty of precipitation prediction is not taken into consideration, and a further study on the prediction is underway. Nevertheless, for evaluating the relationship between the precipitation and drought, the Standardized Precipitation Index (SPI) developed by the Colorado Climate Center in the USA is used. With the SPI, the respective trigger levels in Hong Kong for different drought situations are obtained. With skipping the uncertainty analysis of the rainfall prediction, the effect of rainfall alone on the drought of 1963 is analyzed herein.

Further, in this preliminary plan, the trigger levels of water storages in the reservoirs for Hong Kong are divided into different months. Certainly, how to develop a rational storage-related drought trigger level relies on the total storage capacity and the water demand. In this study, some assumptions are adopted for developing these trigger levels.

After the establishment of the mitigation plan, it is implemented with the 1963 drought as a possible scenario. The results show that the drought mitigation plan could reduce the water shortage due to the drought and attenuate possible damage losses.

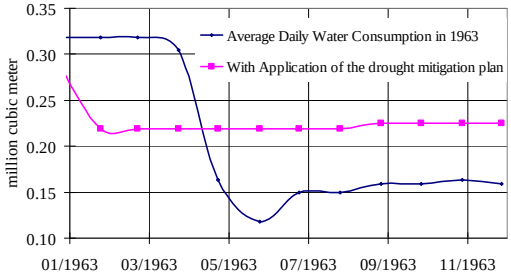

Figure 1. Average daily water consumption with and without application of the preliminary drought mitigation plan.

1. INTRODUCTION

A drought is defined as a prolonged, abnormally dry period when there is not enough water for meeting water demands in a region. In 1963, Hong Kong suffered from a serious drought. It was found that the government at that time might be lacking mitigation plans towards such a drought, which led to enormous impacts on the socio-economic activities (Fessler 1974, Chau 1993, Ho 2001).

If a drought mitigation plan were developed for a region like Hong Kong, an early alarm system could be developed and sequent actions would be taken for gradually reducing water supply and water demand. In turn, it would be expected that the impacts towards the society would be reduced. However, such a drought mitigation plan has not been developed in Hong Kong yet even though the territory has experienced drought damages several times, such as in 1929 and 1963 (Ho 2001). Therefore, this study will explore how to define drought severities in Hong Kong and to develop a preliminary plan for mitigating potential drought damages in the region. For this, the drought of 1963 is considered as a reference event.

2. HONG KONG'S DROUGHT IN 1963

In 1963, the whole society and economy in Hong Kong were either directly or indirectly affected by a severe drought. Table 1 shows the water rationing from May 1962 to August 1964, and the residents suffered from inadequate water supply dramatically especially since June 1963.

Table 1. Water rationing in Hong Kong from 5/1962 to 8/1964 (from SDD, SCMP and HKTS)

Restriction Date	Water supply hours
21/5/62	4 hours per day
26/7/62	5 hours per day
31/8/62	3 hours per day
16/9/62	4 hours per day
2/5/63	3 hours per day
26/5/63	4 hours per 2 days
1/6/63	4 hours per 4 days
29/5/64	4 hours per day
1/9/64	Whole day

Due to the severe water rationing in that period, the public spent a lot of time and money for acquiring water and even changed their living habits in order to reduce water consumption (Ho 2001). In addition, due to lack of sufficient water for cleaning, some of the residents in Hong Kong extracted water from the contaminated well, resulting in cholera-infected cases discovered on June 28, 1963.

The 1963 drought seriously damaged the harvests of livestock, agriculture and fishery. Many animals died due to the summer heat and the lack of drinking water. Due to insufficient water, the first and the second autumn growth of vegetables and crops were unable to survive. In the industrial sector, the drought effect was particularly critical in the dyeing and the bleaching industries. The textile industry section, which accounted for 20% of total labour in Hong Kong, suffered from a cut of 35% to 40% production. Labourers suffered from wages cut and even unemployment.

For representing the effects of drought on the society, Figure 2(a) shows the number of news articles related to drought during the 1963 drought period. Figure 2(b) gives the percentage of news articles on drought, computed by the number of articles on droughts divided by the total number of articles. The data in the figure are taken from Sing Dao Daily, which was a dominant newspaper for the local people during the 1960s. The figure reveals that the peak of the social response to the drought is during the month of June in 1963, which could be interpreted as the beginning of functioning of the most severe water supply scheme in the 1960s.

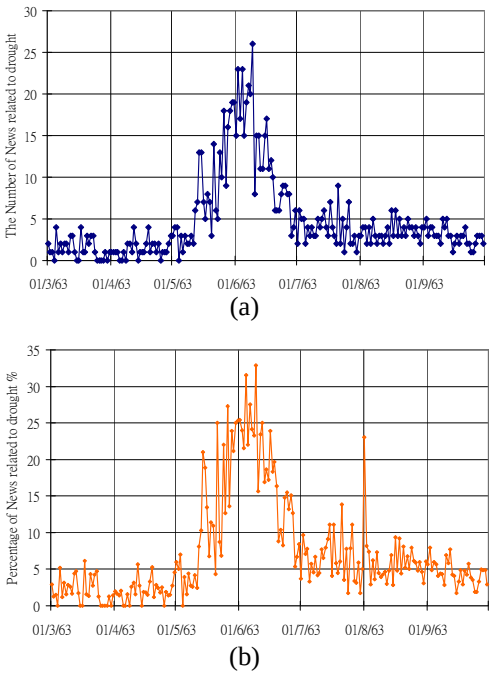

Figure 2. (a) The number of daily news and (b) the percentage of the news related to drought from 1 March to 30 September 1963 (collected from Sing Dao Daily).

Figure 3 presents the water stored in the reservoirs and daily water consumption from May 1962 to the end of 1963, which indicates the lowest volume and the severest drought condition occurred in June 1963. The figure 3(b) also shows that in 1963 the daily water consumption dropped drastically since March and reached its trough in June. Comparing with Figure 2, we can observe that the news reflected the drought seriously as about one month, but the water consumption and drought condition lasted much more than that; it actually lasted for a year until the end of May 1964 (Table 1). Therefore, we may infer that the society might normally need one month to adjust to the severe water rationing.

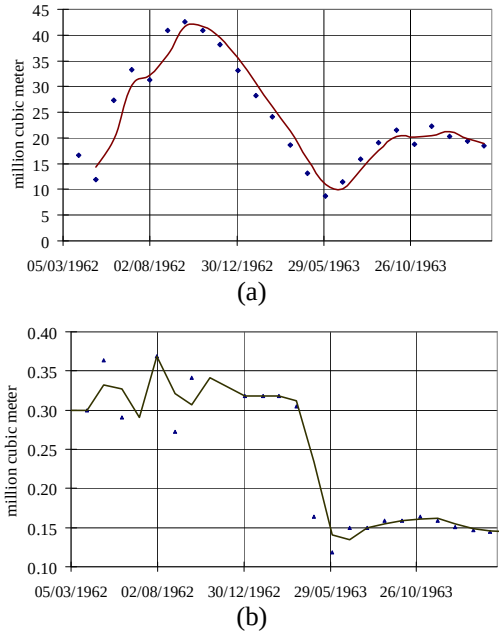

Figure 3. (a) Total water storage level and (b) the average daily water consumption from 1962 to 1964 (collected from SDD, SCMP and HKTS).

From the above figures, it can be concluded that the government might be lacking early planning for such a severe drought like in 1963, which in fact made the drought impacts became serious suddenly in the early June of 1963. So, if the drought could be identified at an early stage, the impacts and related damages could be reduced.

3. DROUGHT MITIGATION PLANS IN THE UNITED STATES

The concept of drought mitigation plan was developed in Colorado, USA, as early as 1981, while most USA drought mitigation plans were developed in the 1990s. Nowadays, in the USA, there are 17 states and 12 cities that have developed drought mitigation plans (check http://www.tag.washington.edu/links.html for details).

The major difference in drought plans between states and cities in the USA is that the states' drought plans have the organisation structure of the drought management team and the respective responsibilities of each organising committee are clearly stated. However, drought plans of the cities mostly focus on the mitigation measures during different drought stages. This study focuses on the design of a preliminary drought mitigation plan for Hong Kong and follows the city plan to define the trigger levels and measures.

The mitigation measures taken at each drought stage are similar in most mitigation plans in the USA. During early stages of droughts, voluntary reduction of water consumption is encouraged, and when the drought condition gets worse mandatory restriction is implemented. While some mitigation plans just present the actions taken without any target reduction of water consumptions, some plans provide a concise reduction strategy including the reduction in water supply hours during each response stage.

Apart from the mitigation measures taken at each stage, the major component of a plan is to define the drought stages. All mitigation plans classify the drought into three to four drought stages using certain indices. The three most widely used indices for synthesizing complex water availability data are SPI, Surface Water Supply Index (SWSI) and Palmer Drought Index (PDI).

SPI can provide early warning of drought by measuring the precipitation deviation from the average for a particular location. SWSI is an indicator of surface water conditions for each major river basin in a region, and summarizes snowpack, streamflow, precipitation and reservoir storage for a particular month. PDI is used to gauge impacts on agriculture, and is based on precipitation, temperature and local available soil water content.

4. A PRELIMINARY DROUGHT MITIGATION PLAN FOR HONG KONG

Based on the functions of the drought mitigation plan and the lessons of starting severe water rationing in Hong Kong in 1963, it is possible that the drought sufferings be reduced if the drought situation could be identified at an early stage. Following many states and cities in the USA, this section develops a preliminary drought mitigation plan for Hong Kong.

4.1. Trigger Level

To develop the mitigation plan, defining the trigger level for determining different drought severities is crucial. The drought is usually caused by the water supply side and can be mitigated by controlling the demand side, and drought can be divided into four to five trigger levels. In this study, four trigger levels are used. In this preliminary plan, the four trigger levels and their respective water consumption reduction aims are proposed as below, which follows the Colorado drought mitigation plan:

I. No drought
II. Moderate drought (with a water consumption reduction aims of 15%)
III. Severe drought (with a water consumption reduction aims of 20%)
IV. Extreme drought (with a water consumption reduction aims of 25%)

4.2. Drought Indicators

Even though several hydrologic and climatic parameters, such as precipitation, ground water table, water levels in reservoirs and lakes, soil moisture content, temperature, and streamflow, are used for defining drought severity, according to water resources features in Hong Kong (Chen 2007), this preliminary drought mitigation plan only considers precipitation (only rainfall considered for Hong Kong) and the volume of water stored in the reservoirs.

Precipitation prediction

Precipitation prediction is important for evaluating the drought duration and determining the subsequent measures for alleviating possible drought damages at an early stage. However, long-term, usually monthly to seasonal, precipitation prediction is full of uncertainty. How to apply such predictions to judge the drought severities needs specific explorations, and this study will skip this uncertainty component and focus on scaling the rainfall for different drought triggering levels at a monthly scale.

The SPI is used in the study. It is assumed that when the rainfall sample size is large enough the probability of monthly rainfall values will follow normal distribution. Then, the SPI value, *Z*, makes use of the cumulative probability below the mean identifies the respective drought category. The value of *Z* is computed as follows:

$$z = \frac{x - \mu}{\sigma} \qquad (1)$$

where x is the monthly precipitation, μ the mean precipitation for the month, and σ standard deviation. Table 2 gives the range of different drought levels according to the Colorado Climate Center standards.

Table 2. The SPI and Drought Category (according to Colorado drought mitigation plan)

SPI	Drought Category
Above -1.0	No Drought (ND)
-1.0 to -1.49	Moderate Drought (MD)
-1.5 to -1.99	Severe Drought (SD)
-2 or less	Extreme Drought (ED)

In this preliminary drought plan, rainfall observations in Hong Kong for the period from 1961 to 1990 are used to compute the rainfall distribution, and the trigger level for each month,, and Table 3 shows the monthly rainfall values for different drought severities.

Table 3. Trigger level of droughts for monthly precipitation in Hong Kong

month	MD (mm/day) Less than	SD (mm/day) Less than	ED (mm/day) Less than
Jan	0.451	0.288	0.125
Feb	1.061	0.715	0.370
Mar	1.425	1.018	0.611
Apr	3.840	3.133	2.427
May	7.699	6.431	5.163
Jun	10.036	8.786	7.536
Jul	8.281	7.169	6.058
Aug	10.059	8.783	7.508
Sep	6.936	5.495	4.054
Oct	3.004	2.125	1.246
Nov	0.805	0.574	0.343
Dec	0.323	0.077	-0.169

Rainfall in December is insignificant, making the extreme drought indicator negative, which is theoretically impossible. Therefore the extreme drought indicator in December is assumed zero.

Reservoir storage levels for defining drought severities in Hong Kong for 1962-1964

In Hong Kong, there are 17 major reservoirs that contribute to a total reservoir capacity of about 586

Mcm (million cubic meter) for storing fresh water for water supply (WSD, 2005). Water levels in reservoirs can reflect the drought situation that may have happened in the previous months. However, in this study, the 1963 drought is studied and the storage capacity 46.43 Mcm at that time (Chen 2007) is used.

Presently, water storage in Hong Kong's reservoirs is affected by the imported East River (call Dongjiang in Chinese) water and is highly seasonal dependent (Chen 2001). However, in this preliminary plan, we only focus on the local reservoir water storage for determining drought severity for the drought situation in 1963.

In determining the trigger level of reservoir water storage, the duration that the stored water can be used to support the public consumption is considered. Three concerns, the current water consumption, drought plans in other countries and the experiences in dealing with drought, are used to determine the triggering levels of water storage.

Similar to Table 3, Table 4 gives the percentage of water storage in the reservoirs for determining the drought severities in the twelve months (of a year) for the period of 1962 to 1964 in Hong Kong.

Table 4. Trigger levels of drought with monthly reservoirs storage percentage at the begging of each month for 1962-1964

month	MD (%) Less than	SD (%) Less than	ED (%) Less than
Jan	90.0	80.6	37.4
Feb	67.1	46.8	26.7
Mar	56.3	45.8	16.1
Apr	53.9	40.0	10.0
May	56.1	42.4	12.0
Jun	76.8	57.1	17.0
Jul	90.6	79.6	27.0
Aug	100.0	80.6	31.3
Sep	100.0	90.4	70.3
Oct	100.0	98.6	64.7
Nov	100.0	96.0	55.8
Dec	100.0	90.1	44.1

The trigger levels listed in this table are derived according to some assumptions. First, the water daily consumptions per capita per day for moderate, severe and extreme droughts are adapted according to the water consumption levels in the 1960s. It is observed that in Hong Kong until 1965 there was no water rationing (Fessler 1974), and in that year the water consumption was 142 liter/day/capita. In addition, from 1961 to 1963, restriction of water supply was getting worse, from 117 in 1961, 96.5 in 1962 to 50.6 liter/day/capita in 1963. Therefore, we assume that when the daily water consumption was below 142 liter/day/capita it was a moderate drought condition, below 105 (near the average of 117 and 96.5) liter/day/capita it was a severe drought, and below 75 (near the average of 96.5 and 50.6) liter/day/capita it was an extreme drought period. Then, the amount of monthly water consumption can be computed using the population 3.462 million in 1963.

Second, the precipitation conditions, with normal, moderate, severe and extreme droughts (see Table 3), are considered for determining the trigger level of water storage. In this preliminary plan, a simple method is used to estimate the storage ratio for meeting the water demand in the next several months a month in advance when water consumption can be fully supplied by the rainwater collection. However, a further study is underway for considering the uncertainty of monthly rainfall information and the diverted water from the East River, details of which will be reported elsewhere.

Table 4 shows that from August to December even with full water storage in the reservoirs Hong Kong would still have been under moderate drought. This is caused mainly due to three reasons, the shortage of the reservoir storage in the early 1960s, the long dry season (from October to March) and high water demand.

4.3. Policies for Reducing Water Demands

When the drought trigger levels of precipitation and water storage are defined, for reducing water demands, the policies, which will be acted at different drought severities, should be designed. In this preliminary drought mitigation plan, water price policy and water allocation and supply policy are discussed.

Water price policy

During a drought period, water price should be adjusted. This will mainly serve the purpose of reducing water consumptions.

As water is a necessity for life, water price can not be dramatically increased for a basic required water volume. Currently, in Hong Kong, the amount of free rationing is determined mainly by a rough estimation on the average number of people

in a household. However, when serious droughts occur, the exact number of each household becomes critical in judging the amount of free rationing as water supply becomes tight. Then, the stepwise water price, which is used presently, will be revised. How to reset water price will need further research.

Water Allocation and Supply Policy

In this part, the discussion follows the study of Woo (1992). When a severe or extreme drought happens, water rationing will be effective. However, the amount of water reduction normally is not linearly related to cutting water supply hours because the affected users can reschedule the water use habits and alleviate the impact of service interruption.

Woo (1992) suggested that the effectiveness of cutting water supply hours could be formulated by an equation. The following discussion is adopted from Woo (1992) for this preliminary plan. The monthly per capita use of water $Q(\lambda)$ is affected by many factors, as shown in the equation below (Woo 1992):

$$Q(\lambda) = \text{intercept} + \alpha P_t(\lambda) + \beta Y_t(\lambda) + \phi S_t(\lambda) + \sum_j a_j w_{jt} + \sum_k b_k D_{kt} + u_t \quad (2)$$

where P_t is monthly average price, Y_t is monthly per capita income, S_t is monthly supply hours, W_{1t} is rainfall net of evaporation, W_{2t} is average temperature, and D_{kt} is monthly binary variables accounting for seasonality and variations in the number of calendar days in a month. ϕ is estimated as 0.153, the reduction in monthly per capita use due to supply interruption equals to 0.153ln(supply hour/24). To achieve the same amount of reduction in monthly per capita use due to supply interruption, the water price can be increased by ln(supply hour/24) ϕ/α . We will carry out a further study to investigate the relationship among the variables in the equation, and the results will be reported later.

The timing of water restriction could be a critical factor in considering the effectiveness of water restriction. If the drought situation is not so severe (e.g. a moderate drought), water restrictions at night can be functioned, which can alarm the public without bringing serious inconvenience.

5. APPLICATION OF THE PLAN: A CASE STUDY OF THE 1963 DROUGHT

During the 1963 drought, from the rapid drop of water consumption in June (Figure 3(b)), we would infer that the government might not have had any suitable plans for dealing with such a severe drought. In this part, the effects of applying the preliminary drought mitigation plan are explored.

Table 5 shows the average precipitation of each month and the reservoirs' storage percentage at the beginning of each month with a total capacity of 46.43 mcm in 1963. According to the drought trigger levels listed in Tables 3 and 4, the table also gives the drought severities during the period.

Table 5. Precipitation and reservoir storage percentage at the beginning of each month in Hong Kong from Oct 1962 to Dec 1963, and related drought severities.

	Precip (mm/d)	Storage Ratio (%)	Drought Severity	
			Precip	Storage
Oct-62	5.43	89.1	ND	SD
Nov-62	1.13	88.1	ND	SD
Dec-62	0.00	82.1	SD	SD
Jan-63	0.32	71.3	MD	SD
Feb-63	0.05	60.7	ED	MD
Mar-63	0.30	51.9	ED	MD
Apr-63	0.45	40.1	ED	MD
May-63	0.19	28.4	ED	SD
Jun-63	6.82	18.6	ED	SD
Jul-63	10.44	24.7	ND	ED
Aug-63	5.87	34.3	ED	SD
Sep-63	2.77	41.2	ED	ED
Oct-63	1.13	46.2	ED	ED
Nov-63	1.05	40.3	ND	ED
Dec-63	0.03	48.0	SD	SD

As there are two indicators showing drought severities, the worse condition will be taken for triggering related water rationing. The monthly precipitation should be obtained through predictions; however, in this study we skip the consideration of the uncertainty of monthly predictions.

As shown in Table 5, severe drought occurred from October 1962 to January 1963, and December 1963. Extreme drought occurred from February to November 1963. As proposed in the

drought mitigation plan, severe drought would have a reduction aims of 20% water consumption, which means a water consumption of 113 liter/day/capita, while extreme drought would have a reduction aims of 25% that is equivalent to 106 liter/day/capita. However, according to the daily water consumption used for defining water storage trigger levels in Table 4 and for considering the reality of Hong Kong in the early 1960s, this study uses 85 (which is about 90% of the daily water consumption rate in 1962) and 65 liter/day/capita as water consumption rates for severe and extreme droughts, respectively. Then, using the water balance of water storage, rainwater collection, and water consumption, the monthly water storage curves with and without using the mitigation plan are obtained, and are given in Figure 4.

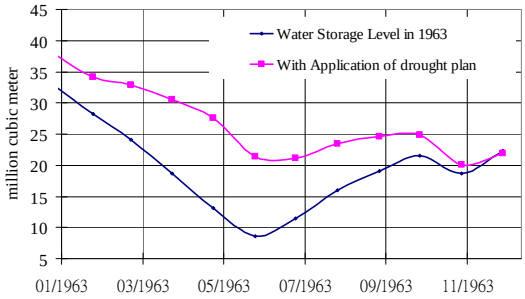

Figure 4. Monthly water storage with and without application of the drought mitigation plan

The figure, providing results of the application of the drought mitigation plan, shows a gradually decreasing trend in water storage. The reservoir storage is much higher than that without using the plan in June 1963.

6. CONCLUSION

This study investigated the drought impacts in Hong Kong in 1963. It was disclosed that the drought was the most critical in June of the year and the public suffered from four hours per four days water supply dramatically. Also, the sudden drop of water consumption from March 1963 to June 1963 might suggest that the government didn't have any suitable plans for such an extreme drought, which made the drought impacts even worse.

Subsequently, a preliminary drought mitigation plan for Hong Kong was developed in the study. Through the application of the plan, it was shown that the drought mitigation plan would be able to reduce the drought impacts effectively.

However, in this study, the trigger levels of water storage for defining drought severities were determined without including the uncertainty of precipitation prediction; therefore, further research is needed for such. Since the current water resources features in Hong Kong are mainly relying on the diverted water from the East River in southern China, a study of considering the East River water resources for revising the drought mitigation plan for Hong Kong is underway and the results will be reported later.

7. ACKNOWLEDGEMENTS

The authors thank the Water Supplies Department in the Hong Kong Special Administrative Region (HKSAR) of China for making the water historical data available at the public domain. The work described in this paper was fully supported by a grant from the Central Policy Unit of the Government of the HKSAR and the Research Grants Council of the HKSAR (Project No. HKU 7022-PPR-2).

8. REFERENCES

Chau, K.W. (1993), Management of Limited Water Resources in Hong Kong, *Water Resources Research*, 9(1), 65-73.

Chen, J. (2007), Urban Growth and Water Shortage: Experiences of Developing Hong Kong's Water Resources Security, to be submitted to Water Resources Management, 25 pp.

Chen, Y.D. (2001), Sustainable development and management of water resources for Urban Water Supply in Hong Kong, *Water International*, 26(1), 119-128.

Fessler, L. (1974), Hong Kong, population, and water, *East Asia Series*, 31(2), 1-17.

Ho, P.-Y. (2001), Water for a Barren Rock. 150 Years of Water Supply in Hong Kong. The Commercial Press (H.K.) Ltd, 250 pp, Hong Kong.

SDD (Sing Dao Daily), SCMP (South China Morning Post) and HKTS (Hong Kong Tiger Standaerd), three News Papers published and distributed in Hong Kong.

Woo, C.-K. (1992), Drought management, service interruption, and water pricing: evidence from Hong Kong, *Water Resources Research*, 28(10), 2591-2595.

WSD, 2005, 'Water Supplies Department Key Facts', available at http://www.wsd.gov.hk.