Chapter 6
The Vulnerability, Adaptation and Resilience Capabilities of Water Sector Users in Mauritius

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Abstract Mauritius is classified as a water-stressed country. This study aims at evaluating the vulnerability and resiliency levels of water users (domestic, agricultural and commercial/industrial/tourism) in the face of water scarcity, and with existing adaptation and mitigation measures. A specific zone of water supply representing the different users, namely the Northern District Water Supply System, was selected as the case study. A sample size of the target population was determined and a quota-sampling method was used to indicate the quota sample per sector. Mixed-mode surveys were conducted using the same questionnaire. The questionnaire included indicators of vulnerability, adaptation and mitigation, as well as resiliency. A scale of 1–5, 1–2 as lowest rating, 3 as moderate, 4–5 as high was generated depending on the percentage obtained through the indicators. Results were compared between users. Results show that although all sectors are vulnerable to water scarcity, the agricultural and domestic sectors face an increased risk. The sectors with a higher level of vulnerability are also those with a lower level of adaptation. On average, all users show only a basic level of resilience, but these lie within a range of importance. This paper adopts a sector-based approach to investigate the level of vulnerability and resilience of each user of water resources. It provides insightful and specific data for each sector, and proposes a comparison between the different users. Observations by experts in the water sector could provide more integrated water resource management recommendations.

Keywords Mauritius · Water stress · Vulnerability · Adaptation and mitigation · Resilience

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Short Introduction

Small Island Developing States, like Mauritius, are especially vulnerable to the effects of climate change on resources, particularly freshwater. It has become imperative not only to conduct research pertaining to water resources, but also to take appropriate conservation measures.

This paper seeks to explore to what extent the different users—domestic, agricultural, commercial, tourism and agricultural—of the water resource have the capability to adapt to water scarcity. It also investigates whether users are actually aware of water problems, which means they have to overcome these, and that further adaptation and mitigation practices need to be implemented.

Introduction

The Republic of Mauritius, located in the south-west of the Indian Ocean, east of Madagascar, is categorised as a water-stressed country by the United Nations. It faces significant water issues in the face of increasing pressure on this resource due to rapid urbanisation, and population and economic growth, a predicament intensified by the impacts of climate change.

The chief source of water in Mauritius is rainfall. Despite a rather wet climate (an average annual precipitation of more than 2,041 mm), the topography of Mauritius, the fact that a large fraction of the total amount of rainfall falls during the summer months, and cyclonic events have the consequence of a high level of surface runoff, about 53 %, of which only one third is tapped by reservoirs, lakes and rivers. The high temperatures cause 38 % of the water balance to be lost through evapotranspiration. As such, the remaining just 9 % of rainfall contributes to recharging the aquifers.

A sufficient, safe and dependable supply of water has to be mobilised to meet the various demands of all sectors: agricultural, domestic, industrial and tourism, among others. As such, Mauritius counts 11 man-made reservoirs with a total storage capacity of 90.7 mm^3, the two largest being Mare aux Vacoas and Midlands Dam. Water is also extracted from about 350 river-run offtakes, providing some annual mobilisation of 514 mm^3 of surface water (Proag 2006). Groundwater contributes 145 mm^3 of water on average yearly (Proag 2006).The Ministry of Public Utilities is the core institution responsible for the legal operational framework and management of water resources in Mauritius; authority is delegated to the Water Resources Unit in charge of assessing, managing, developing and conserving water resources. Parastatal bodies; the *Central Water Authority*, the *Irrigation Authority*, the *Waste Water Management Authority* and the *Central Electricity Board* have specific functions in managing the available water.

This study aims to evaluate the degree of vulnerability and resiliency of users of water resources—domestic, agricultural and commercial/industrial/tourism—with existing adaptation and mitigation measures in Mauritius. Along with the use of national data, the Northern region, with its highest number of users and water production among the six supply zones, was selected as the case study for conducting this survey.

Vulnerability to Water Shortage in Mauritius

Diop and Rekacewicz (2003) in their analysis of water scarcity in African countries, place Mauritius in a situation of waterstress; in 1990 1,700–2,500 m^3 of water/people/year (vulnerable category) was available but by 2025 it is projected that this amount will reach 1,000–1,700 m^3 of water/people/year (water-stress category). During recent decades, the island has witnessed an accelerated rate of development in the agricultural, industrial and tourism sectors, as well as a growing population, leading to a rise in the standard of living. This puts more pressure on existing water resources, as demand increases. Water produced by the *CWA* has increased by 20 % over the last 10 years.

Existing supply systems will not be able to sustain such an increase. Although piped water is accessible to around 99 % of the population, there are certain inequalities in distribution, particularly in the east and west of the island and to properties on higher ground (Mauritius Strategy for Implementation—National Assessment Report 2010) (Fig. 6.1).

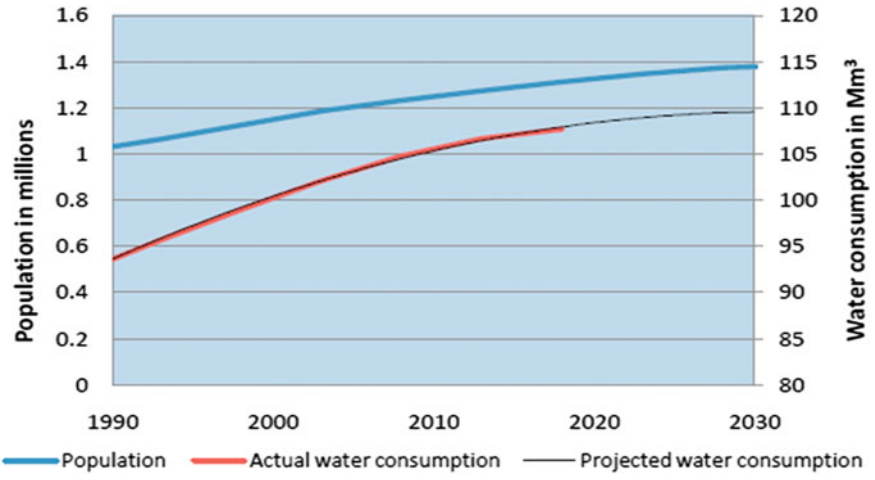

Fig. 6.1 Population and projection of water demands (Digest of Energy and Water Statistics CSO 2009)

Impacts of Climate Change

The impact of climate change on water resources will aggravate the existing situation: intense rain episodes with a high runoff capacity; an increase in droughts; salinity intrusion into coastal aquifers and higher temperatures, increasing the rate of evapotranspiration, will increase vulnerability (Mauritius Strategy for Implementation—National Assessment Report 2010).

The island depends on cyclonic and summer rainfall to replenish reservoirs and aquifers; if these were to fail, a situation of drought would arise. Between 1905 and 2007, there has been a decrease in rainfall and more frequent droughts, as the figure below shows. The temporal distribution of rain has also been modified: the number of rainy days has decreased, but the frequency of heavy rain events has increased, indicating that rainwater-harvesting capacity has to be enhanced (Meteorological Services 2009). The number of days with a daily maximum temperature of above 30 °C is increasing at a rate of 0.6 days per year, while the number of days with a minimum temperature of above 20 °C is increasing at a rate of 1.4 days annually (Meteorological Services 2010 Technical Paper).

Physical factors, like temperature change and the modification of rainfall patterns, distribution and amount, are all closely linked to climate change (Meteorological Services 2009) or topography that favours runoff (Maudarbocus et al. 2001), as well human factors like pollution, increasing pressure on water resources and significant losses through leakage or wastage, make Mauritius vulnerable to water stress (Fig. 6.2).

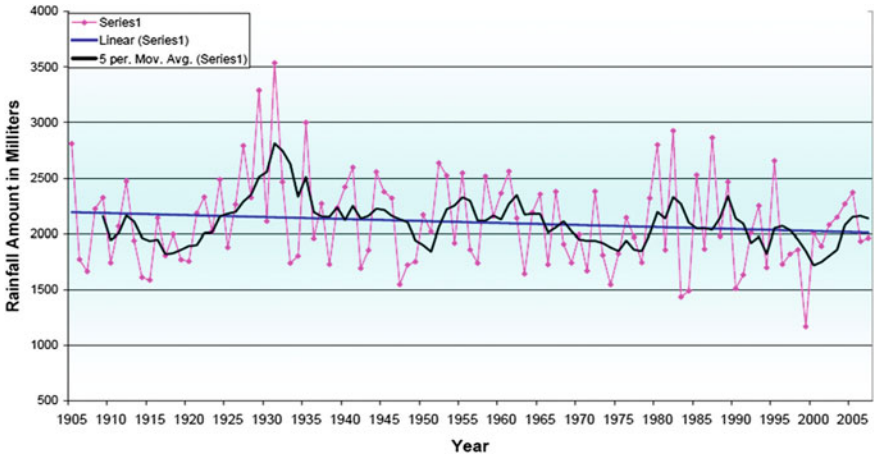

Fig. 6.2 Decreasing trend of mean annual rainfall (Meteorological Services 2009)

Users' Vulnerability Assessment

Waterstress is an indisputable issue in the island state of Mauritius. Among the six supply systems, one for each zone: Port Louis, the North, Upper Mare aux Vacoas, Lower Mare aux Vacoas, the South and the East, the largest system, namely the Northern District Water Supply System, was selected as our case study because it entails the highest percentage of the total population served, has the highest normal water production per day and has almost equal measures of surface water and groundwater utilisation.

A margin of error of 8 % was targeted for this study; as such, the sample size for the target population, considered as infinite, was determined using the following equation:

$$n = \frac{t^2 PQ}{d^2}$$

t represents abscissa of the normal curve that cuts off an area of alpha at the tails. d represents the margin of error. P represents the population proportion. Usually 0.5 is used for P and 0.5 for Q.

Therefore:

$$\therefore n = \frac{1.96^2 \times 0.5 \times 0.5}{0.08^2}$$
$$= 150.0625 \approx 150$$

The total sample size for conducting the survey was thus set at 150.

The total water requirement (raw and treated water) for 2009/2010 for the North was 133,345 m^3/d (excluding the institutional sector, which benefits from unbilled consumption). That of the domestic sector was 95,460 m^3/d, the agricultural sector 9,220 m^3/d, while, for the commercial/industrial/tourism sector it was 28,665 m^3/d, corresponding respectively to 72, 7 and 21 % of the total water requirement. The total sample size being 150, the quota sample per user, according to the percentage of total water requirements, was established as follows: 108 for domestic users, 11 for agriculture and 31 for commercial/industrial/tourism users.

Survey data was collected during the period of October to December 2011 through the use of questionnaires using mixed-mode surveys as extensively as possible throughout the Northern region. Direct, telephone and post interviews were carried out, and, depending on the literacy level of respondents, this was done using the island's native Creole language. Direct observation was also possible during field interviews. The same questionnaire, with twenty three questions, was used for all users in order to allow data comparison. The first two questions set the context of the survey. The other questions up to number six concerned the problem of water shortage, and to what extent the respondents sensed they were affected. The remaining questions involved the level of adaptation, mitigation and

awareness of causes of water scarcity, as well as their capacity for resiliency. Open-ended questions permitted respondents to answer in their own words, and gave an insight into opinions that might not otherwise have been expressed. Closed-ended questions on the other hand, necessitated the respondents to make a choice, or evaluate and rate a variable, as well as gauge their knowledge .

Respondents to the survey were asked to what extent they felt vulnerable to water scarcity. Questions pertaining to water demand, opinion on volume, pressure and frequency of water supplied and water shortage problems were asked. The three indicators for vulnerability show that most users consider themselves to be affected by water stress. A scale of 1–5 was used to evaluate the extent, with 1–2 considered as low, 3 as fairly high, 4 considered as high and 5 as critical. The majority of users from all sectors declared that their demand for water has increased, and only a very small percentage believes that it has decreased. The CWA reports an increase of 20 % of water mobilised over the years 2001–2010, confirming that the trend for water demand is on the increase. Users of the agricultural sector are, for the most part, either moderately satisfied or unsatisfied with the volume, pressure and (minimum) frequency of the water supplied. Domestic users are also moderately satisfied or unsatisfied with frequency. CIT (commercial/industrial/tourism) users are more satisfied or moderately satisfied with the volume, pressure and frequency supplied. More than 50 % of all users believe they face water scarcity, with the highest percentage in the agricultural sector.

Vulnerability indicators—water demand, water supply satisfaction and water shortage problems—demonstrated that, although all sectors are vulnerable, the domestic and agricultural sectors are most likely to endure more hardships, with a fairly high level of vulnerability, estimated at level 3 on a scale of 5 (critical). The CIT sector, with a level of 2.3, was deemed less vulnerable than the other sectors, but it is to be noted that certain disparities do exist within this sector: the most economically well-off touristic and commercial outlets and industries have lesser concerns of water shortage.

Results for the Effectiveness of Adaptation and Mitigation Measures

Another component of the survey included indicators of what extent adaptation and mitigation measures have already been adopted. These comprised alternative water sources, the need for water storage and the sources of the water stored, and have been used to measure the level of adaptation.

Alternative Water Sources

A heavy dependence purely on the CWA was considered as disadvantageous; other reliable means of obtaining water, such as rainwater harvesting, recycling wastewater or desalination, allow users to obtain water even if the CWA does not meet the totality of their demands. It must be noted that none of the respondents from any sector mentioned rain water harvesting as the most significant alternative source of water. 72 % of users of the agricultural sector use water from canals and rivers and 18 % from boreholes. Although the percentage of water available from alternative water sources is high, it does not mitigate the impact of fertilisers and pesticides pollution (leading to eutrophication in the long run) and excessive use of water sources.

29 % of CIT sector users utilise desalinated and recycled water for purposes that do not require potable water, adapting to water shortage, and, at the same time, limiting excessive consumption of treated water, a mitigation measure. However, desalination is costly, energy consuming and the release of brine into seawater can affect marine ecosystems (Mauritius Environmental Outlook Report 2010). This technique is also not available to smaller hotels, industries and commercial outlets.

Only 25 % of domestic users, particularly low-income households, use streams and springs that flow near their locality as alternative water sources. The water is used mainly for cleaning purposes, like washing clothes. Again, the pollution risk exists and, to conserve the quality of this fresh water, particular precautions are needed (Mauritius Strategy for Implementation National Assessment Report 2010).

Water Storage

The need to store water denoted a certain degree of preparedness for water scarcity. It indicates that there has been an investment and a will to remedy immediate water shortages. More than 60 % of users from all sectors store water (more than 80 % for CIT and the domestic sector), mostly in safe and durable tanks. 36 % of users in the agricultural sector, however, do not store water, presumably because a high percentage is obtained water from canals, rivers and boreholes.

Sources of Water Stored

Beyond the need to store water, the sources of the water stored also helps to define the level of adaptation. If the highest percentage of the water stored comes from the CWA, adaptation can be considered to be low. All three sectors depend heavily on the CWA for water storage, at 43 % of users from the agricultural sector, 94 %

in the domestic sector and 80 % in CIT. Rain water harvesting; a simple and effective adaptation measure (Mauritius Environmental Outlook Report, 2010) is only marginally adopted, though a higher percentage of agricultural sector has adopted this measure. Waste water recycling and desalination is available to certain users of the CIT sector for storage.

In comparison to vulnerability, the level of adaptation and mitigation methods that have been adopted per sector has been investigated and ranged on a scale of 1–5 1–2 being a basic level of adaptation, 3 a moderate level and 4–5 high. An average of adaptation and mitigation indicators showed that the domestic sector has an adaptation level of only 2, and the agricultural sector a level of 2.6: a basic level of adaptation. The CIT sector is slightly more prepared for water scarcity with a moderate level of adaptation: 3. It can be reasoned that the level of adaptation and mitigation has to be increased, more urgently for the domestic and agricultural sector, and enhanced for users in the CIT sector (including all users regardless of economic performance). Both more adaptation measures to counter balance effects of water stress and more mitigation measures to limit effects of climate change on rainfall and population pressure must be put in place.

Results for Resilience Capacity

The higher the level of adaptation and mitigation measures, the lower the vulnerability and the higher the resiliency. In addition to indicators, responses to open-ended questions have been considered in evaluating resiliency, as participation of all users is necessary to tackle the problem of water scarcity. These included awareness of causes of water scarcity and solutions proposed, acknowledgement of and attitude towards water wastage, re-use of grey water, water collection awareness and its importance for users, and the level of investment, as well as the willingness, to adopt water collection methods if facilities were to be provided. The same scale was used as for adaptation: 1–2 being a basic level of resilience, 3 a moderate level and 4–5 high.

Awareness of the Causes of Water Scarcity

A resilient population has to first acknowledge its situation of vulnerability, and then identify its spheres of weakness, so as to be more open to adaptation and mitigation, thus increasing resilience. Agricultural users have a sound knowledge of both physical/climatic and human factors that lead to water scarcity; a higher percentage believed in human induced factors, while physical/climatic factors were also mentioned, but to a lesser extent. Yet, the solutions proposed were rather simplistic: government investment for the most part, while some suggested reforestation, and some had no solutions to propose. Although agricultural users

are aware of causes of water scarcity, most believe human factors to be responsible and cannot propose far-reaching solutions. This is possibly due to a lower level of education.

About 80 % of domestic users provided more thorough reasons for water scarcity, probably because of a higher level of education (particularly middle and high income households) than agricultural users. Some even believe deviation of streams from reservoirs, pollution and the mindset of users allowing wastage to be causes. More than 60 % of respondents linked physical/climatic factors to water stress. Domestic users also proposed more drastic and extensive solutions, ranging from management issues and tighter laws to sensitisation campaigns, rainwater collection and even privatisation of the water sector. More than a quarter of respondents also advocated environmental protection measures. More mitigation and adaptation measures were proposed by the domestic sector than by the two others.

The CIT sector has the highest percentage of users who believe climatic/physical factors bring about water scarcity. Human-induced factors were mentioned to a lower extent and environmental damage, such as pollution, was not mentioned by larger hotels and industries at all, only smaller touristic and commercial resorts believe so. More than half of respondents proposed better management and more storage facilities, while others believed reforestation, desalination and water recycling would help. At the same time, some disclosed that it was more important to them to carry on their economic activities. Most of the CIT sector users, being the least vulnerable and having more adaptation measures at their disposition, were less keen to propose solutions, although most respondents had a fair level of education. More adaptation measures (like increasing storage or better management policies) than mitigation ones (for instance reforestation or protection of catchment areas) were proposed by most users from all sectors.

Most users in all sectors probably believe that an increase in supply would solve the problem. However, only an integrated approach will increase resiliency (UN World Water Development Report, 2009). Less than 50 % of agricultural respondents believe wastage occurs, as small planters consider there is not sufficient water for use in the first place, and larger plantation owners believe that some abuse can happen, particularly through irrigation methods like the overhead method. Although against wastage, most users merely informed authorities in case of leakages and passively believed not much could be done. This sector was least responsive in proposing means of avoiding wastage; counselling and economic incentives could be proposed to encourage optimised use of water resources (Proag 1995).

Acknowledgement of and Attitude Towards Water Wastage

A little more than 50 % of CIT users acknowledged water wastage through cleaning purposes, lack of appropriate technology and leisure facilities. A higher percentage agreed more should be done to avoid wastage, but most did not feel

compelled to do so. However, some did propose water saving technologies. A legal framework and user tax could be established to decrease pollution loads and grants or tax exemptions provided to encourage water saving technologies (Proag, 1995).

Among domestic users, more than 60 % acknowledged that wastage occurs through daily chores, but some also claimed wastage was inevitable and it was their right to do so. A few avoided wastage and would call the authorities in the case of a leakage. Simple water saving measures, rain water collection and education were proposed. Communities could be strengthened to allow water preservation and increase their capacity to become sustainable.

More than 70 % of agricultural users do not recycle water. Water saving techniques could be implemented to reduce consumption if reusing grey water were not possible for most of these users (Mauritius Strategy for Implementation National Assessment Report 2010). The percentage that does not reuse grey water is equally high for domestic users, at more than 70 %, and again, more education and strengthening policies are needed. A higher percentage of CIT users recycle their water compared to other sectors, but this technology should be extended to include as many users as possible.

Level of Investment and Willingness to Adopt Water Collection Methods

Agricultural users have the highest percentage of long-term water supply. CIT users have a combination of short and long term means of water supply, but the long term means are not available to users with lesser economic resources. Domestic users have the least percentage of alternative water sources, and most of those are short term. About 80 % of CIT users, the highest percentage of all sectors, have knowledge of water collection methods and believe it important to invest in those methods. Only 38 % have actually invested in those methods, indicating again, that although none of the users denied its importance, most of them cannot, or will not, invest. More than 50 % of domestic users are aware of water collection methods and more than 70 % agree on their importance, while a few do not agree it is necessary. Less than 10 % have actually invested in water collection, and none of these are users from high-income households, who content themselves with the available supply. More than 50 % of agricultural users are not aware of these methods, and more than 30 % believe it unimportant to do so, or have not thought about it, probably due to a lower level of literacy among users. More than a quarter of users have nonetheless invested in water collection.

The agricultural sector has the highest percentage of users very willing to invest if facilities were to be provided, but more than 20 % are still not willing. More than a quarter also did not know what could be done to lessen vulnerability, and others proposed more storage measures. Yet again, although having the will, users need more advice and incentives on water- collection and saving techniques.

Table 6.1 Respondents' perception of vulnerability, adaptation, mitigation and resilience

Sector	Vulnerability level	Adaptation and mitigation level	Resilience level
Agriculture	3 (Fairly high)	2.6 (Basic)	2.3 (Basic)
Domestic	3 (Fairly high)	2 (Basic)	2.5 (Basic)
CIT	2.3 (Low)	3 (Moderate)	2.8 (Basic)

The CIT sector has only 3 % of users not willing to invest; others are either very willing or willing. More adaptation measures that included all spheres of society and user responsibility were proposed. More than 50 % of domestic respondents were willing to invest and 13 % were not. Most of the users proposed both adaptation and mitigation measures, but believed that the authorities had to apply reforms to the water sector and only then would they cooperate and invest in water collection methods. A few assigned responsibility to the authorities only.

Survey data was entered into the spreadsheet application programme Excel 2007 for statistical analysis. The percentages obtained from these indicators were translated on a scale of 1–5 depending on the percentage obtained from the indicators that assess the critical issues: vulnerability (1–2 was considered as low, 3 as fairly high, 4 considered as high and 5 as critical), adaptation and mitigation (1–2 basic level of adaptation, 3 moderate level and 4–5 is high) and resilience (1–2 basic level of resilience, 3 moderate level and 4–5 high). This methodology was adapted from the *Etude de Vulnérabilité Aux Changements Climatiques,* commissioned by the *IOC* in 2011, to suit the purposes of this study. The scale system aims at facilitating the reading of results and interpretation of findings. For instance, to find the level of vulnerability of the agricultural sector, an average of the level obtained from each vulnerability indicator was calculated, and so on. The table below summarises the study's findings (Table 6.1).

Conclusion

The overall perception of users concerning vulnerability to water scarcity is fairly high within the agricultural and domestic sectors. The CIT sector is comparatively less vulnerable, with disproportions across and within this sector. The domestic and agricultural sectors have only a basic level of adaptation, while the CIT sector is slightly more prepared for water scarcity, with a moderate level of adaptation. The level of adaptation and mitigation has to be increased, more urgently for the domestic and agricultural sectors, and enhanced for users in CIT (including all users, regardless of economic performance). Both more adaptation measures to counter balance effects of water stress and more mitigation measures to limit the effects of climate change on rainfall and population pressure must be put in place.

The results demonstrated are, in order of importance, resilience level for CIT, domestic and agricultural sectors as 2.8, 2.5 and 2.3 respectively. This means that all sectors have only a basic level of resilience, with the CIT sector having the

highest level and the agricultural sector the lowest. Much more remains to be done so as to increase water users' resilience and, at the same time, ensure sustainable water management.

The example of the Americas, middle income countries, could be adopted at Small Islands Developing States Level. A series of measures have already been implemented within the framework of the Regional Policy Dialogue, which aims at an integrated approach and participation of all socio-economic actors, as well as the sharing of water-based adaptation experiences. Other countries like China, Colombia and Mexico among others, as well as the state of California, put into practice Integrated Water Resources Management, providing an enabling environment, where stakeholders with different interests team up to plan site-specific adaptation measures.

All water specialists and managers agree that sustainable water management is crucial, but a narrow and sectoral approach prevents unanimous appropriate decisions. In the face of uncontrollable changes, a precise understanding of the water sector; support for investments; the regrouping of institutions; incentives; information and capacity building necessitating the collaboration of the government; institutions responsible for managing water, the private sector and civil society are needed (UN World Water Development Report 2009).

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