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EFFECTS OF CLIMATE CHANGE ON FLOOD RISK AND SUSTAINABLE DEVELOPMENT IN SOUTH AFRICA

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ABSTRACT: Climate change poses a great risk to South Africa which has a dual agricultural economy. In the recent years, the country has experienced extreme weather events with floods resulting from higher than normal rainfall. The negative impacts manifest in infrastructure damage, disruption in the supply of agricultural products and damage to crops. In order to understand the dynamics involved in the effects of climate change, peak discharges for Luvuvhu River catchment were used to evaluate flood frequencies, based on flood events with a certain probability of occurrence or exceedance. Frequency distributions were used to describe historical characteristics and magnitudes of floods. Flood peaks corresponding to 2, 5, 10, 50, 100 and 200 years were estimated for flood prevention. The extreme value analysis showed that the Gumbel and Log Pearson type III distributions provided the best fit which could be used to derive the probability of occurrence of flood events. The results showed a general increase in the frequency of extreme rainfall events, accompanied by floods of higher magnitude for the small to medium floods.

Key Words: Climate Change, Distribution Models, Flood Frequency, Peak Discharges, Rainfall

1. INTRODUCTION

South Africa’s geographic location places it in the region of the world that is most vulnerable to both climate variability and climate change (IPCC 2012). The social and economic costs of climate change are a growing threat to the achievement of sustainable development. There were 539,811 deaths, 361,974 injuries and 2,821,895,005 people affected by floods between 1980 and 2009 (DEA 2011). The country is ill-prepared for the heavy summer rains that cause flooding in eight of the nine provinces. When dams overflow and rivers burst their banks, the government usually declares a state of disaster. In March 2014, the town of Bela Bela in Limpopo and surrounding areas were flooded when a dam wall gave way. Figure 1 shows flooding at the Coal mining Town of Lephalale in Limpopo Province, while Figure 2 shows flood waters and submerged houses at Port Alfred Town in October 2012.

Figure 1: Floods at the Coal mining Town of Lephalale in Limpopo Province

Figure 2: Floods in Port Alfred Town in Eastren Cape Province

1.1 THE GEOGRAPHIC LOCATION OF SOUTH AFRICA

South Africa shown in Figure 3 is located between the equator and the mid-latitudes and is bounded by the warm Indian Ocean on the east coast and the Cold Atlantic Ocean on the west coast (Alexander 2011). The relief ranges from sea-level to a plateau at about 1250 m and extends to mountains exceeding 3000 m in height.

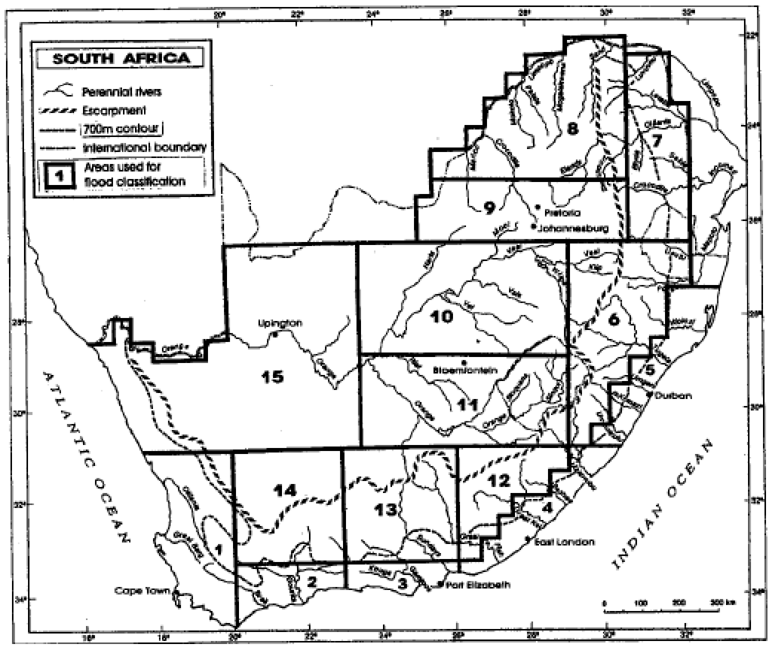

Figure 3: Map of South Africa showing 15 regions for Widespread Rainfall Analyses (Source: Alexander 2011)

1.2 RAINFALL

The measurement of rainfall and river flow in South Africa started more than 150 years ago. Figure 4 shows the rainfall districts of South Africa while Figure 5 shows the distribution of mean annual rainfall. Table 1 shows stations in four provinces that recorded more than 100 mm of rain during the first ten days of March 2014. During heavy rains, the government closely monitors the rise in water levels in four of the country's largest dams and regulates the flood gates accordingly. In March 2014, five flood gates had to be opened on the Vaal Dam, which was 99 percent full. Bloemhof Dam was 96 percent full, with an outflow of 200 cubic metres per second. The Gariep Dam was 109 percent full with the outflow at 1 200 cubic metres per second. At the Vanderkloof Dam, the capacity was at 110 percent.

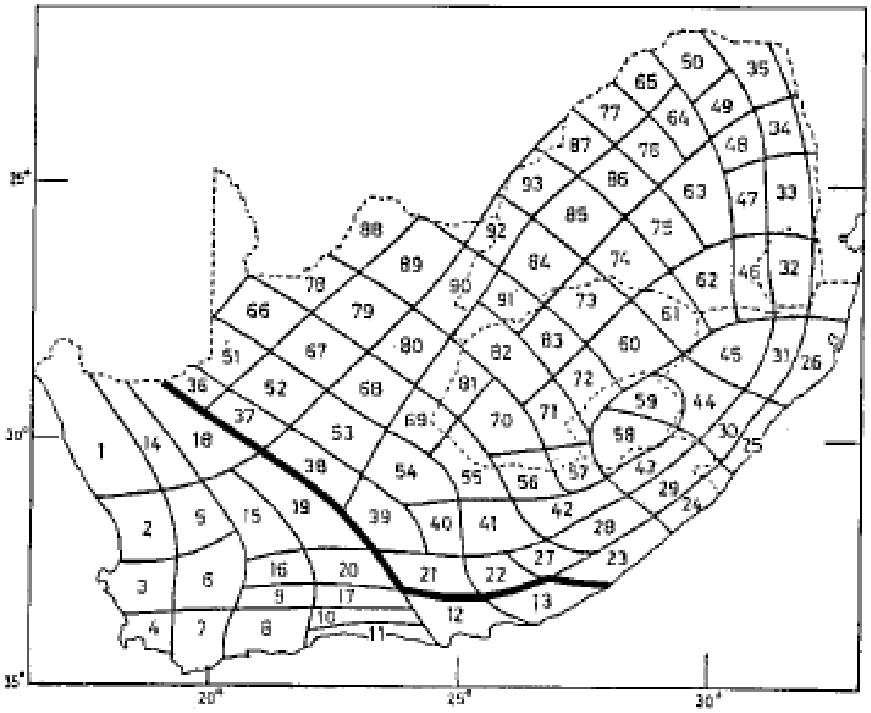

Figure 4: Rainfall Districts of South Africa (Source: Alexander 2011)

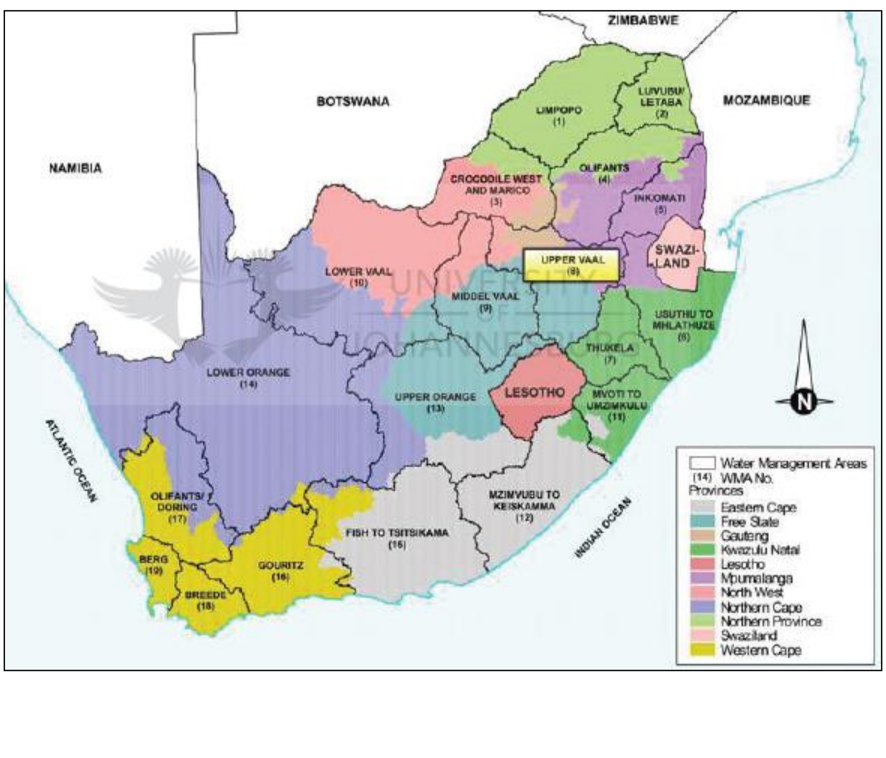

Figure 5: Distribution of mean annual rainfall in South Africa (Source: Alexander 2011)

Table 1: Stations in four provinces that recorded more than 100 mm of rain during the first ten days of March 2014

GAUTENG	RAIN (mm)	MPUMALANGA	RAIN (mm)	LIMPOPO PROVINCE	RAIN (mm)
Bronkhorstspruit AWS	138	Belfast	192	Alldays Haly ARS	117
Grand Central	129	Carolina	154	Gravelotte	222
Irene WO	190	Ermelo WO	150	Hoedspruit	134
Johannesburg INT WO	113	Komatidraai	303	Lephalale	159
Pretoria Eendracht	180	Kruger Mpumalanga	147	Marken	106
Pretoria UNISA	220	Machadodorp AWS	140	Phalaborwa Airport	120
Springs	129	Nelspruit	273	Steenborfontein ARS	306
Wonderbroom Airport	187	Skukuza	180	Thabazimbi	138
		Witbank	161	Thohoyandou WO	192
				Tom Burke S.A.P.S ARS	105
				Tzaneen-Westfalia ES	107
				Venetia mne	101
				Warmbad towoomba	177

Source: South African Weather Service (SAWS), March 2014

2. LUVUVHU RIVER CATCHMENT IN LIMPOPO PROVINCE

Luvuvhu River catchment shown in Figure 6 was selected to evaluate the effects of climate change on flood risks in South Africa. It is located between latitudes 22°17'57''S and 23°17'31''S and longitudes 29°49'16''E and 31°23'02''E. It rises as a steep mountain stream in the southeasterly slopes of the Soutpansberg Mountain range, flows through Kruger National Park, and empties into the Limpopo River at the border with Mozambique and Zimbabwe. The catchment is one of the regions where floods have caused enormous damage to property and life and impacted negatively on infrastructure and development. The catchment is also undergoing rapid land cover change, where forest and woodland is being converted to agriculture and build-up. The negative effects can be observed in Guvhebvu River sub-catchment where subsistence agriculture and build-up have eliminated the riparian zone. The river flow has been reduced to a meer trickle, and many sections of it run dry throughout the year. Prolonged rainfall over the region is associated with the ITCZ and tropical cyclones or the intense depressions of mid-latitudes.

The South African National Disaster Management Centre estimated that more than 100,000 people live in the flood plains, below water levels previously reached by floods. Therefore, flood frequency associated with higher magnitudes are of concern and require attention by water resources planners and hydraulic designers.

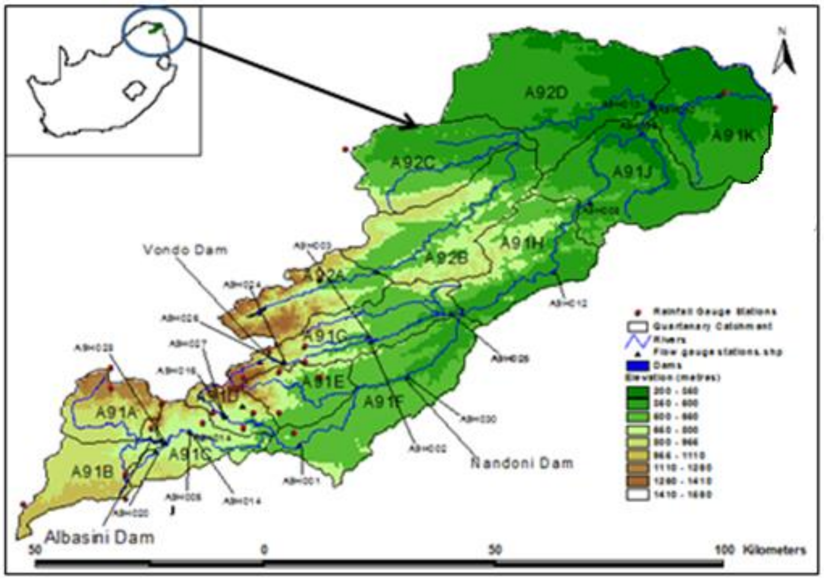

Figure 6: Luvuvhu River catchment

The mean annual rainfall for Luvuvhu River catchment was estimated by use of geostatistical tools involving interpolation and regression techniques within a GIS environment. The spatial distribution of mean annual rainfall for the rainy season was as shown in Figure 7. It showed higher amounts in the region which was undergoing rapid land cover and land use change, hence there is need for mitigation measures to control the negative impacts associated with such changes in a catchment.

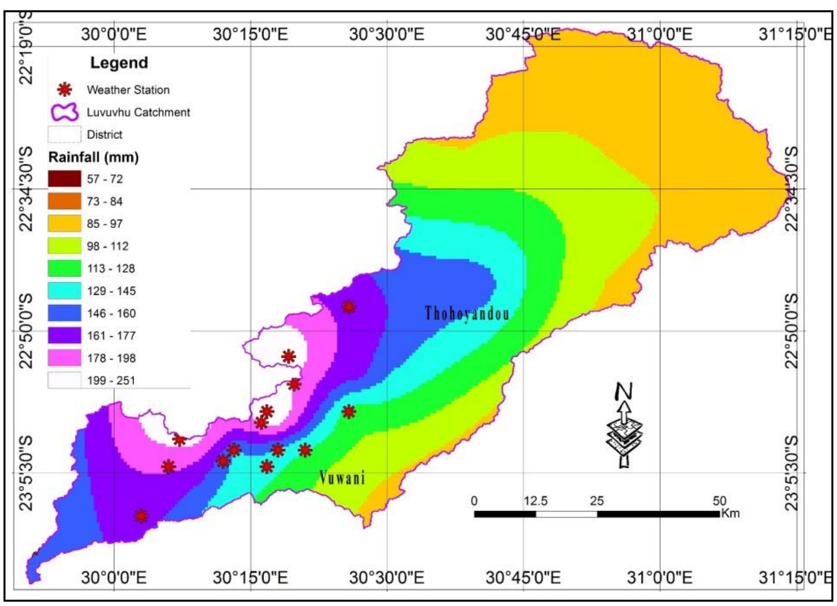

Figure 7: Mean annual Rainfall for Luvuvhu River catchment

3. FLOOD FREQUENCY AND MAGNITUDE

The severity of floods is compounded by the after effects caused by lack of housing, starvation and disease. More lives have been lost in South Africa due to structural failure of bridges than dams. Although floods typically have a sudden impact, they can also have a gradual onset resulting from an accumulation of rainfall over several days or weeks. To mitigate the effects, measurements and analysis for extreme floods are taken from 18 sites shown in Figure 8.

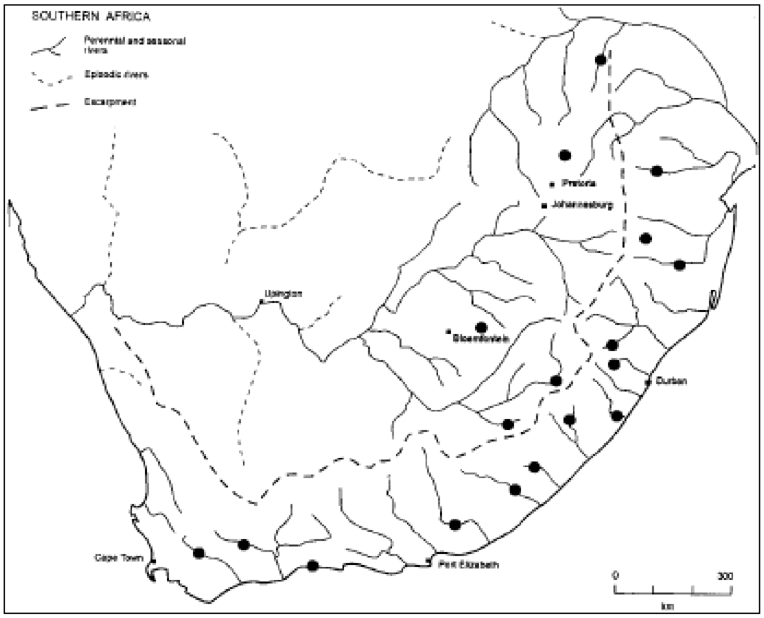

Figure 8: Location for 18 sites for Extreme Floods measurement and Analysis (Source: Alexander 2011)

When severe floods occur, people who live in flood plains close to rivers are at the risk of losing their lives; while their houses, structures and farms may be destroyed. Climate change will intensify the worst effects of poverty through losses in biodiversity, agriculture, health and industrial and commercial sectors. An early warning system for floods would be very effective in the absence of the above measures. Table 2 shows the dam safety related incidents in South Africa (DWAF 2004).

Table 2: Dam safety related incidents in South Africa

Location	Incident	Cause	Year	Number of lives lost
Lydenburg Flooding	Partial failure of Lydenburg Town Dam	High intensity rainfall (85 mm in 1.5 hours), which caused a flash flood	2001	6 lives lost
Lake Mzingazi Flooding near Richards bay	Breach of Dam wall	High intensity rainfall	2000	3 lives lost
Boomryk Dam near Levubu	Breach of Dam wall	High intensity rainfall	2000	2 lives lost

Source: Nortje JH, Dam Safety Office, DWA, (2002)

To evaluate flood frequency and magnitude for Luvuvhu River catchment, flood peaks corresponding to return periods of 2, 5, 10, 50, 100 and 200 years were estimated. Four frequency distributions including the Generalized Extreme Value distributions (GEV), the Gumbel's Extreme Value type 1 (EVI) distribution, the Log-normal (LN) distribution and the Log-Pearson type III (LP3) distribution were compared for flood estimation, using the EasyFit software from MathWave Technologies, (Drokin 2011).

3.1 GOODNESS OF FIT MEASURES

The linearity of the probability plot indicated the goodness of fit as shown in Figure 9. Given the rapid land use changes in the catchment, a significant rise in water levels would lead to an increase in potential flood damages, particularly for flood events of lower to medium extremity, reducing flood security for existing protection facilities. Figure 10 shows the probabilistic plot of return periods based on Gumbel's distribution for station A9H003 located in upstream of the catchment.

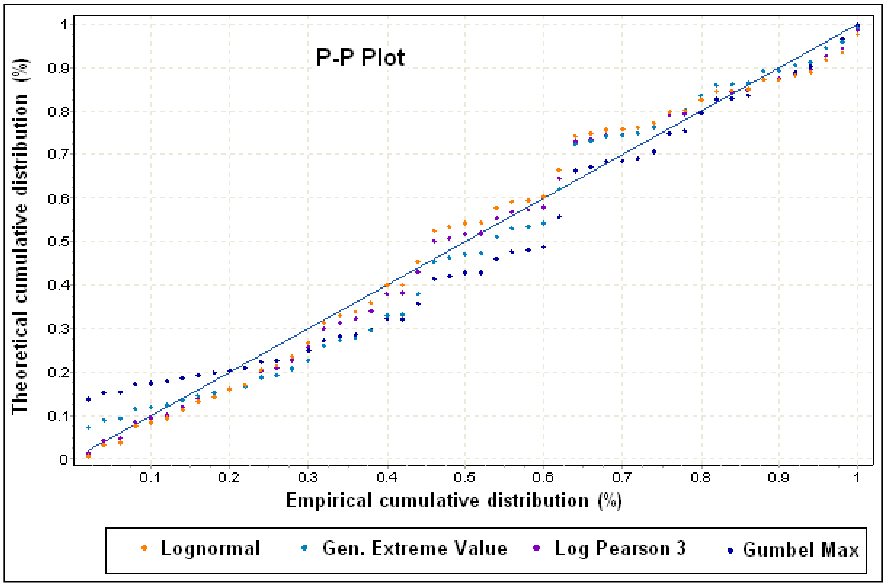

Figure 9: Probability-Probability plots

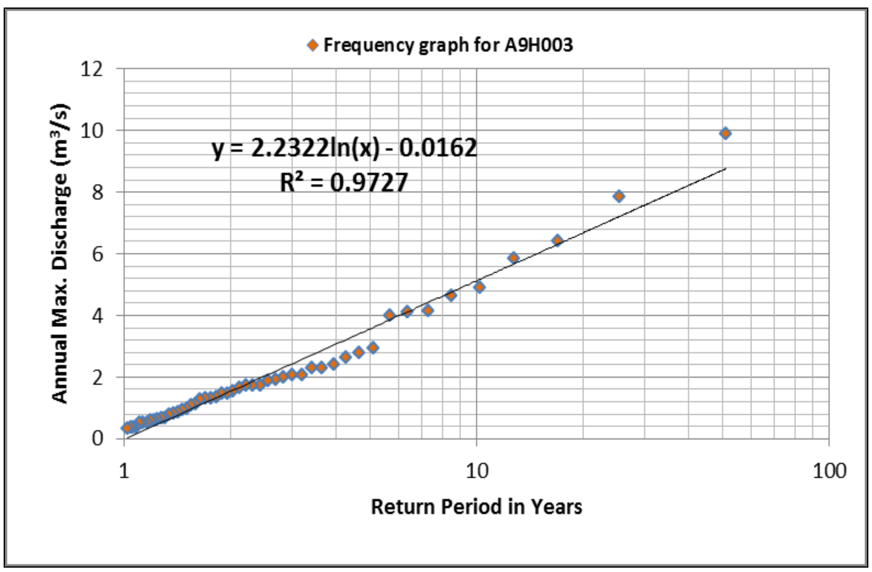

Figure 10: Probabilistic plot of return periods based on Gumbel's distribution

3.2 RECENT FLOODS AND THE ASSOCIATED DAMAGE

Heavy flood water caused damage to roads at Betty's bay and Chapman's peak as shown in Figure 11 and Figure 12 respectively. The flood water washed away part of the Sandspruit River in Zandspruit west of Hoedspruit in March 2014 and caused damage to access road to the Air Force Base at Hoedspruit as shown in Figure 13.

Figure 11: Road damaged by floods at Betty's bay

Figure 12: Road damage and debri at Chapman's

Figure 13(a): Road damage at Sandspruit River

Figure 13(b) Road damage on access road to AFB Hoedspruit in Zandspruit

4. EARLY WARNING

Attempts have been made to monitor Limpopo River flows and mitigate droughts and flood disasters with limited success. Climate change could lead to provinces such as Mapumalanga, Limpopo, the North-West, KwaZulu Natal and Gauteng becoming malaria zones. Early Warning System (FFEWS) for the

Limpopo River Basin was prepared for the World Meteorological Organisation for the benefit of Limpopo Watercourse Commission, a trans-boundary organisation established by riparian states (Botswana, Mozambique, South Africa and Zimbabwe). The use of satellite rainfall estimation techniques is emerging but challenges exist in validation of results with the actual rainfall using estimates from radar measurements or rainfall gauges. The Department of Water Affairs has a “River System Flood Management” centre that runs an in-house built flood forecasting and early warning management system for the Vaal/Orange River Basin.

5. CONCLUSION

There are attempts to monitor river flows and mitigate droughts and flood disasters in South Africa. The effects of climate change will impact more on the most vulnerable communities. The flood frequency analysis for Luvuvhu River catchment showed increasing discharges at higher probabilities of exceedence for all return periods. The results showed that an increase in the peak discharges was to be expected, especially for small and middle floods. This could be associated with the effects of land cover change and anthropogenic factors. Given the rapid land use changes in the catchment, a significant rise in water levels would lead to an increase in potential flood damages, particularly for flood events of lower to medium extremity, reducing flood security for existing protection facilities. Interpretation of flood fatality data was challenging given the occurrence of occasional extreme events, temporal trends and the completeness and accuracy of available data.

6. ACKNOWLEDGEMENTS

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