Evaluation of climate change using statistical methods & the potential impacts on asphalt roads in New Providence

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ABSTRACT

Temperature increases has become a major concern globally. Increases in temperature can have a detrimental impact on many environmental resources and anthropogenic sectors. This study assesses temperature changes based on historical data with the intent to review potential impacts of climate change on asphalt roadways in New Providence. Climate data for this study was monitored by National Oceanic and Atmospheric Administration from the Nassau Airport station in New Providence, Bahamas. The data was evaluated using two statistical methods to determine trends and differences for the 15 year period: 1998-2013. For the t-test statistic the data was separated into three five year blocks: T1 (1998-2002), T2 (2003-2007), T3 (2008-2012). Analysis shows evidence of significant differences between temperatures of T1 vs. T2 and T1 vs. T3 blocks with p-values less than 0.05 in both cases. The t-test statistic of T2 vs. T3 shows no significant difference between temperatures for the time block with a p-value greater than 0.05. The Mann-Kendall statistic was also performed for the T1-T2 (1998-2007) and T1-T3 (1998-2012) blocks. T1-T2 block

showed an increasing trend while T2-T3 block exhibited no trend in the data. Overall temperature difference for T1 vs. T2 and T2 vs. T3 was found to be a 0.69^{o}C and a 0.03^{o}C increase respectively. This overall temperature increase has potential to reduce the life span of asphalt roadways since increased temperatures have potential to induce an increase in oxidation of the bitumen. It is likely in the future that more complex and modified bitumen material be used in order to maintain the design life span of asphalt roads under the combined effects of shearing stress and temperature increases.

1. INTRODUCTION

Global warming has become a major concern for many sectors globally. Climate change has the potential to impact the amount of overland flow consequently impacting the amount of runoff to and from roadways (Kalantari, 2011). Increase drainage then becomes an issue. In addition, both temperature and rainfall increases can act in parallel to cause cracking of the paved surface (Norwell, 2004). Higher temperature can affect the durability of seal binders and consequently impact maintenance costs. AASTO 1993 indicates that bitumen behavior is impacted by the temperature and Taha et al., (2013) finds that increased temperature decreases the modulus of elasticity and therefore roadways will be more susceptible to deformation. While studies suggest negative impacts of climate changes on road construction, there is a potential positive affect of temperature increases, according to Anfosso-Ledee & Pichaud (2007) temperature increases has potential to reduction in noise emissions. TRB, (2008) indicates that climate change will be beneficial to the marine

transportation sector since it allows more open seas, thus creating shorter shipping route.

There is a need for climate adaptation and planning in relation to road maintenance and construction (Walters, 2009). For instance, increase rainfall requires increased drainage measures, and in the case of this study, increased temperatures may require more durable material for roadways. Although this study focuses on the direct impact of temperature change on road construction (materials, methods) for The Bahamas, it should be noted that with the increase of temperature it is anticipated that there is potential for increase storm events (CARIBSAVE, 2012) which can further impact the road durability. Likewise Bueno et al., (2008) indicate that roadways (among other structures) in the Caribbean are susceptible to damage by coastal erosion due to climate changes. TRB (2008) finds that temperature increases may impact coefficients of expansion thereby causing movement and pavement integrity then becomes an issue. Modifications to bitumen in some cases were found to adapt to changes in temperature (Pareek, et al., 2012). In Europe up to 50% of the cost of road maintenance is due to weather stresses on roadways (Nembry & Demiral, 2012). The long term impacts of temperature increases should encourage new materials for road designs and improved maintenance strategies (TRB, 2008).

2. STUDY SITE

New Providence Island (Figure 1) is located at latitude 25° 02’ N and longitude 77° 21’ W. The island is approximately 21 miles in length and 7 miles wide with a population of 246,329 (Bahamas Census, 2010). Temperature observations for this study were collected at the Nassau Airport station in New Providence, Bahamas and

monitored by National Oceanic and Atmospheric AFdministration. The average daytime temperature of approximately 30ºC (86ºF) during the summer months (June-August) and 25ºC (75ºF) during winter months (December-February).

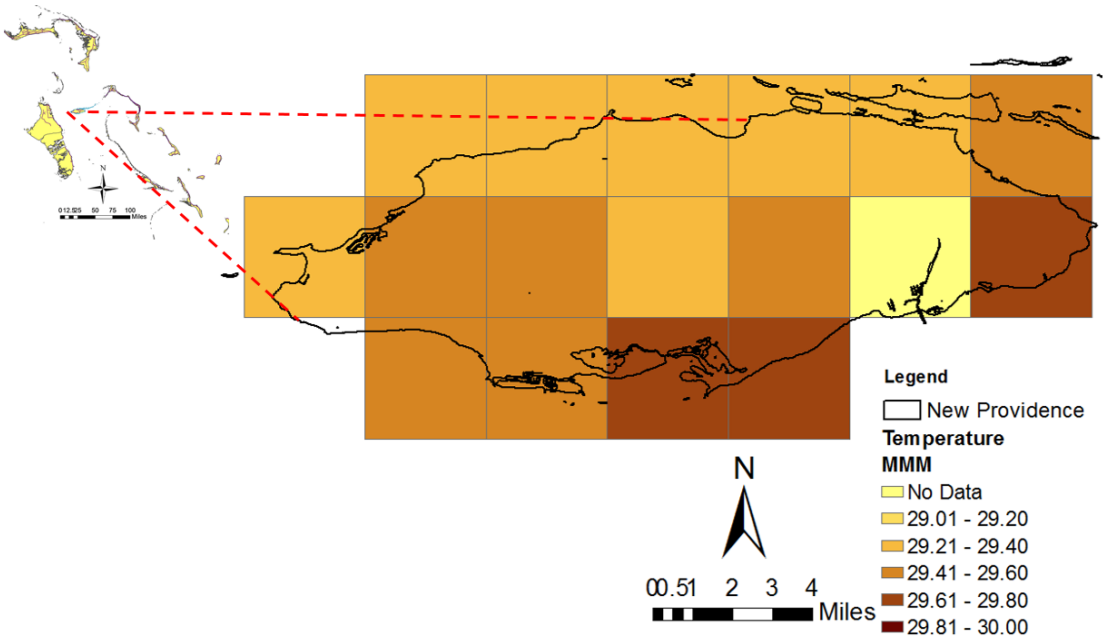

Figure 1 New Providence Island. Average surface temperatures for the island based on satellite remote sensing for the period 1996-2005. NOAA GIS shapefile.

3. METHODOLOGY

Average daily temperatures were observed at the Nassau Airport station in New Providence, Bahamas and were used to calculate the monthly averages for this region. This study will assess changes in average monthly temperatures evaluating the time blocks. The blocks were selected with the intent to focus on more recent years, and to include the time period of the recent road works but also giving sufficient years for proper analysis. The three time blocks will consists of average monthly temperatures for 1998-2002 (T1), 2003-2007 (T2) and 2008-2012 (T3). A comparison of the data will be made to determine if there is a significant difference between temperatures during each time period using the statistical methods. A two sample t-test will be used

to determine if there is a difference and how much of a difference there is. Daily and monthly averages of temperature to be compared will cover each case: T1 vs. T2; T1 vs. T3; T2 vs. T3.

3.1. Trend Testing & Statistical Analysis

Mann Kendall test is used in this study to identify trends of temperature changes over the time period as did previous studies (Karmeshu, 2012; Deka et al.; Kahya & Kalayc, 2004). To assess changes, two evaluations will be made using Man Kendall: 1) for the T1 to T2 period; 2) for the T1 to T3 period. Mann Kendall statistic (Mann, 1945) is found by calculating the incremental difference between the data values to find S (Equation 1), calculating the variance of S (Equation 2) and then determining the Z test statistic (Equation 3). For negative Z values less than zero with probability (Equation 4) greater than 95% (for this study), the trend is said to be decreasing. For Z values greater than zero with probability less that 95% the trend is said to be increasing. In this study, automated results of the Mann Kendall test were obtained through the Microsoft excel add-in 2012 XLSTAT.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_f - x_k) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$***Sign(x_j - x_k) = \begin{cases} 1, if\ \ x_j - x_k > 0 \\ 0, if\ x_j - x_k = 0 \\ -1, if\ x_j - x_k < 0 \end{cases}$$

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} tp(tp-1)(2t_p+5)\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Z = \begin{cases} \frac{S-1}{[VAR(S)]^{\frac{1}{2}}} \; if \; S > 0 \\ \frac{S+1}{[VAR(S)]^{\frac{1}{2}}} \; if \; S < 0 \end{cases} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Statistical methods is also used to determine any differences between the data. T-Test for the means determines if any of the data shows significant differences between each other. Any P-value less than 0.05 imply that the difference between the two data is not significantly different with a 95% confidence. An overall view of the difference in monthly averages for the temperature will be used to illustrate any changes over the period to show increases or decreases.

4. RESULTS & DISCUSSION

Onoz & Bayazit (2003) found that both the t-test and the Mann Kendall statistic methods are equally useful for determining trends of TSS. Results of the statistical methods will determine changes in temperature over a 15 year period.

4.1. Trend Testing & Statistical Analysis

Mann-Kendall test used for this analysis showed a trend between the data of the first time block of T1-T2 (Figure 2) but no trend between the T2-T3 (Figure 3).

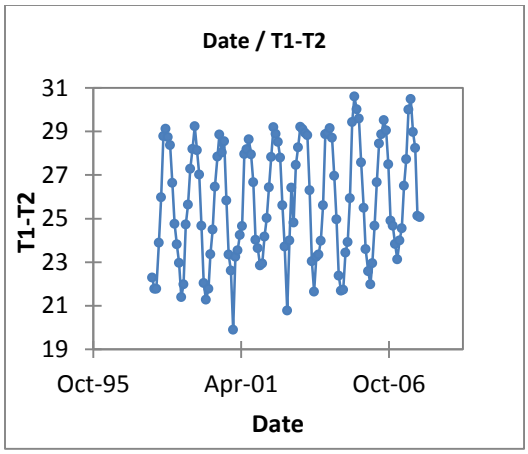

Figure 2 Mann-Kendall results of two time blocks T1-T2 (1998-2007) illustrating an increasing trend

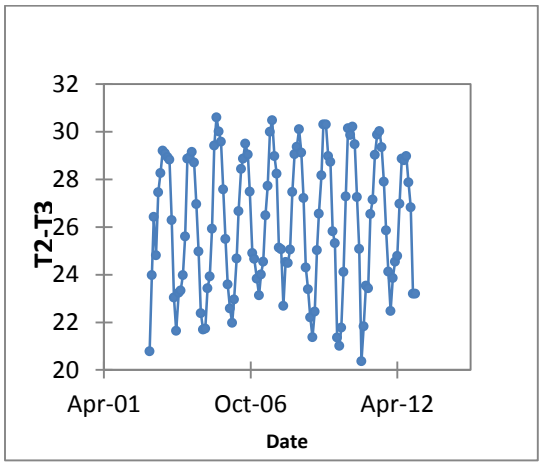

Figure 3 Mann-Kendall results of two time blocks T1-T3 (1998-2012) illustrating no trend for the period

For the average monthly temperature difference, in the case of T1-T2, an increase of 0.67°C (1.2°F) was observed for this 10 year period. Yearly averages show annual temperature increases of 0.6°C (1.1°F) between T1-T2 and 0.12°C (0.21°F) between T2-T3. A similar trend for Alaska is observed with yearly expected increases of more than 0.6°C (1.1°F) per decade (TRB, 2008). Deka et al. found a 1°C per 100 years increase in average and maximum temperature to be significant changes and it has been found that a 1-2°F global change can have a dramatic effect on the earth according to NASA. Moreover, an average monthly temperature difference of 0.05°C was observed for the T2-T3 period indicating very little change over this period. The

overall trend tends to fluctuate during the period for this study. It appears that there is a significant increase in overall temperature from T1-T2, conversely there is no major increase in temperature during the T2-T3 period.

The significance testing shows a similar relationship. P-values for T1-T2 period illustrate a significant difference between the data, while no such relationship is indicated between T2-T3 with p-values of 0.63. This is suggestive of the significant changes in temperature occurring during the T2 period as compared to T1. Greater temperature increases is observed during summer months (Figure 4). There is a 1.1^{o}C temperature increase in the average summer temperature from 1998 to 2012.

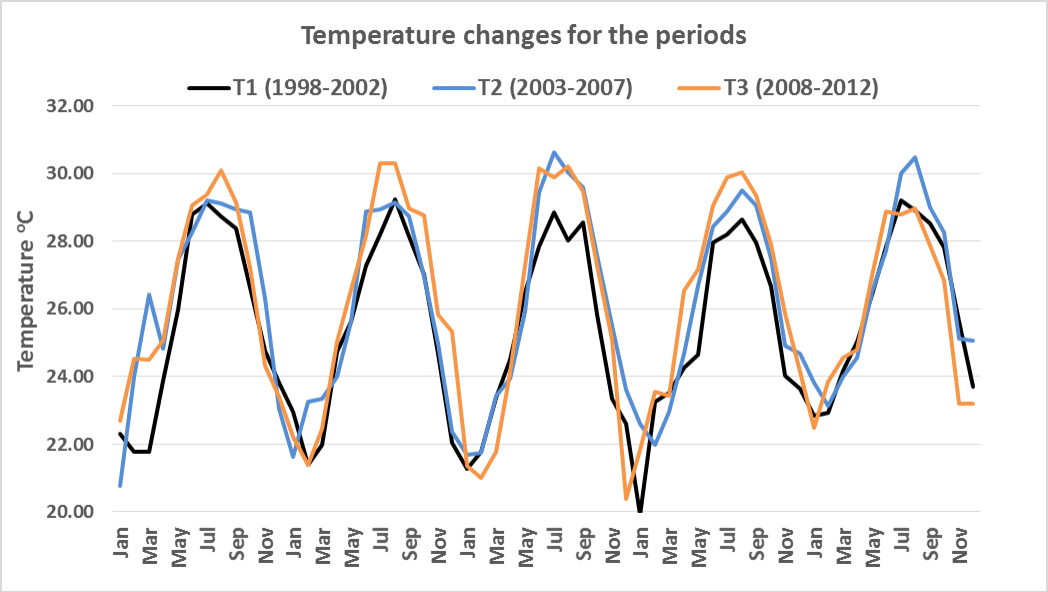

Figure 4 Temperature changes for the three time blocks showing increases in temperature over 15 years

4.2. Analysis of Possible Impacts on New Providence Roadways

Typical roadways have a design life of approximately 20 years in the Bahamas. As early as three years after road construction, maintenance to repair cracks and potholes will be necessary (Salt et. al., 2012). Standards for road construction in the Bahamas is based on Florida Department of Transportation (FDOT, 1999) standard

specifications for road and bridge construction. The bitumen type is AC-30 and Type S-I or S-III is used for pavement. (MOW&U, 2004).

Aschuri et al. (2003) determine that the modulus of elasticity for asphalt varies with the cumulative effects of temperature increases and loading, the authors also illustrated the reduction in design life based on incremental increases in temperature and loading as also concluded by several authors (TFHRC, 2003; Hamed, 2010) .

TFHRC (2003) suggests that there is a need for methods to incorporate the asphalt and other pavement response to temperature in road design. An increase in temperature from 25-37.5^{o}C decreased the asphalt stiffness by 71% as found in Aschuri et al. (2003). Temperature also affects the life of bitumen surface treatments (Norwell, 2004). For areas with higher temperatures, like New Providence, heavy loading coupled with high temperatures increases potential for deformations over time consequently reducing the hysteresis effect.

In an effort to adapt to the changing climates Nemry & Demiral (2012) estimate that changing asphalt binder can reduce pavement cracking to maintain a typical maintenance life cycle of 7-10 years. Cracking of the bitumen binder can lead to water seeping below causing damage to the structure of the roads, Salt et al. (2012), suggest that proper maintenance and timely treatment be implemented to avoid costly remediation of the structure. Thicker binders (TFHRC, 2003) or introducing additives to the mix (Hamed, 2010) may be used to avoid deformations as a result of heat and heavy loading design.

5. STUDY LIMITATIONS & WAY FORWARD

This study looks specifically at temperature changes excluding all other climatic conditions. Trends of storm patterns and precipitation have not been included in this study. Work for this study is limited because there is no account for vehicular impacts due to mechanical issues (oil leaks etc.). The vehicular impacts due to mechanical issues are very problematic as it relates to premature roadway deterioration in the Bahamas. It has been observed over the past decade that relatively newly constructed roadways are starting to ravel considerably and potholes appear as quickly as 5 years after construction. Coupled with temperature changes and storm patterns vehicle mechanical problems has become a major issue that requires further studies to direct policies governing vehicle inspections and road worthiness. Future work will include analysis of storm trends versus temperature increases and the impact of flooding and the capacity of drainage systems since flooding is a major concern of global warming. Further works will also look at the multi variance of precipitation and temperature change impacts on road construction.

6. CONCLUSION

This research intended to provide some insight to the changing temperature in the Bahamas and how it may impact roadways. The significant temperature increasing trend which was observed for the 10 year span should be considered. Although the current temperature increase does not warrant immediate changes to the current mix design regimen, it is important to predict future outcomes in order to employ preventative measures that will save cost and, in some instances, lives in the long run. The decision to be made is whether adaptation to climate changes should be managed

as a gradual incremental process or in preparation for what is to come in the long term.

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