Are rainfall intensities changing, could it be climate change and what could be the impact on Engineering hydrologic design and structures?

Joshua Kiprotich Kibii[1] and Emmanuel Chessum Kipkorir [2]

[1,2] Moi University, Department of Civil and Structural Engineering,
P.O. Box 3900-30100 Eldoret, Kenya
[1]Email: kibiiyjoshua@gmail.com

Abstract
Climate change is a contentious topic. There is evidence of climatic shifts globally. The change in climate over time is natural and expected. However, industrialization during the past century may have influenced variations exceeding natural cyclic change. This paper presents findings on research done to determine if there has been a significant change in intensity and amount of rainfall received in Eldoret town occasioned by recent flooding and to stimulate further research.
Engineers have a duty in the determination of peak storm discharge for sizing of hydrologic structures for safe conveyance of discharge. Hydrologic design use either empirical or deterministic methods based on historical data. Based on the recent weather patterns, the question is whether the historical data can still be used as a basis for providing accurate possible future events for hydrologic design.
Different analytical methods were formulated to investigate different rainfall indices for 50 years using data from Eldoret Meteorological Station. Results are indicative of decreasing but more intense rainfall events with variations exceeding natural climatic cycles previously experienced. Could this be climate change? Despite the localized nature of this research, it is indicative of the global change in rainfall trends being experienced.

Keywords: Climate change, rainfall events, intensity, hydrologic design.

1 Introduction

Climate change can be defined as the natural cycle through which the earth and its atmosphere accommodate the changing amount of energy it receives from the sun (SAWS, 2005). The world climate has been changing over the decades. However, over the past two centuries' industrialization has caused changes exceeding natural variation (Benhin, 2006), hence the climate change debate. The focus on climate change has been growing at local, regional, and global levels. However, the discourse has always been on long term-challenges without trying to understand the current local issues. Kenya is a developing country, focused on sustainable development goals and the big four agenda (food security, affordable housing, manufacturing, and affordable health care). Climate change poses a threat to the realization of these goals. This paper, therefore, aims at highlighting current engineering issues in the design of hydrologic structures because of changing rainfall trends and stimulating further research in the same field.

The global climate has been changing gradually over the past centuries. This has taken place through cold and warm periods with cycles taking hundreds of years. The changes in temperature influencing rainfall taking place over centuries has been accommodated by the biosphere through adaptation. However, recent human activities over the past two decades have caused the climate to change too fast. Plants and animals have been unable to adapt to the fast-changing climate endangering the whole ecosystem (Burger et al., 2015). This interrelation in the ecosystem makes the study of climate change complicated as it involves relationships between the atmosphere, oceans, and land surfaces beyond the scope of this study.

Scientists have developed software known as general circulation models (GCMs) to simulate and predict climate. The models use the concentration of greenhouse gases in the atmosphere and other atmospheric variables to predict climatic conditions. The prediction results are of a non-uniform change in the climate. Land areas are predicted to warm up faster than oceans while polar latitudes heat faster than temperate latitudes. From the above statements, the impact of climate change in Kenya is expected to vary from the tropical coastal region to the temperate and arid interior. The general projection of the future by these models is an increasing rainfall intensity and uncommon heavy rainfall events happening often (Burger et al., 2015). Modelling of heavy rainfall events has shown that although the number of dry days is likely to increase when it rains the maximum and average rainfall are likely to increase. The combined effect of this is little variation or increase in the total annual rainfall.

From the illustration above, increased rainfall intensities are inherent and coupled with urbanization hence more impermeable surfaces, the time of concentration is bound to decrease, runoff increase, and risk of flooding increased as noted recently in Eldoret region. The emphasis of this paper is therefore to establish, based on existing historical rainfall data if the modelled climate predictions are evident, though on a small scale. It is however not the study intention to change the hydrological design principles. The changing rainfall trends are rather highlighted and the thought of consequences on existing design principles and assumptions stimulated.

2 Materials and Methods

S**tudy Area.** Eldoret town is the headquarters of Uasin Gishu County located in western Kenya. Eldoret region is on a highland plateau with an altitude of about 1500 metres above sea level. The topography is higher at the east and gently slopes to the western border. Rainfall in the region is mainly influenced by topography and wind patterns. There are two main rainfall seasons, the ‘long rains’ occurring from March to September and ‘short rains’ occurring from October to December. The Sosiani river flows through the middle of the town and is fed by several streams from the surrounding catchments that sometimes cause flooding in the town.

Rainfall Data. The historical rainfall data for Eldoret Meteorological Station was obtained from the meteorological department and any gaps filled with rainfall data sourced from CHIRPS: rainfall estimates from rain gauge and satellite observations. Daily rainfall data for 50 years (1970-2019), although short in the context of climate change, provided the study with an opportunity for detailed investigations of rainfall trends.

Data Analysis. The rainfall data obtained from Eldoret Meteorological Stations was subjected to data quality analysis. Outliers were deleted and treated as gaps in the data to be filled using CHIRPS data set. The 50 years daily time series was divided into five decades D1 (1970-1979), D2 (1980-1989), D3 (1990-1999), D4 (2000-2009), and D5 (2010-2019). Statistical analysis, linear trend line distributions, time lag comparison and moving average plots were applied to the data. Rainfall event was defined by rainfall ≥ 1 mm (Kibii et al., 2019). Rainfall events were also subjected to a similar analysis.

3 Results

Rainfall Amounts. The amount of daily rainfall received during the period 1970-2019, (50 years) was plotted in five decades as shown in Figure 1. The plot aimed to illustrate the variation in the amount of rainfall received over the different periods as well as time lag comparison.

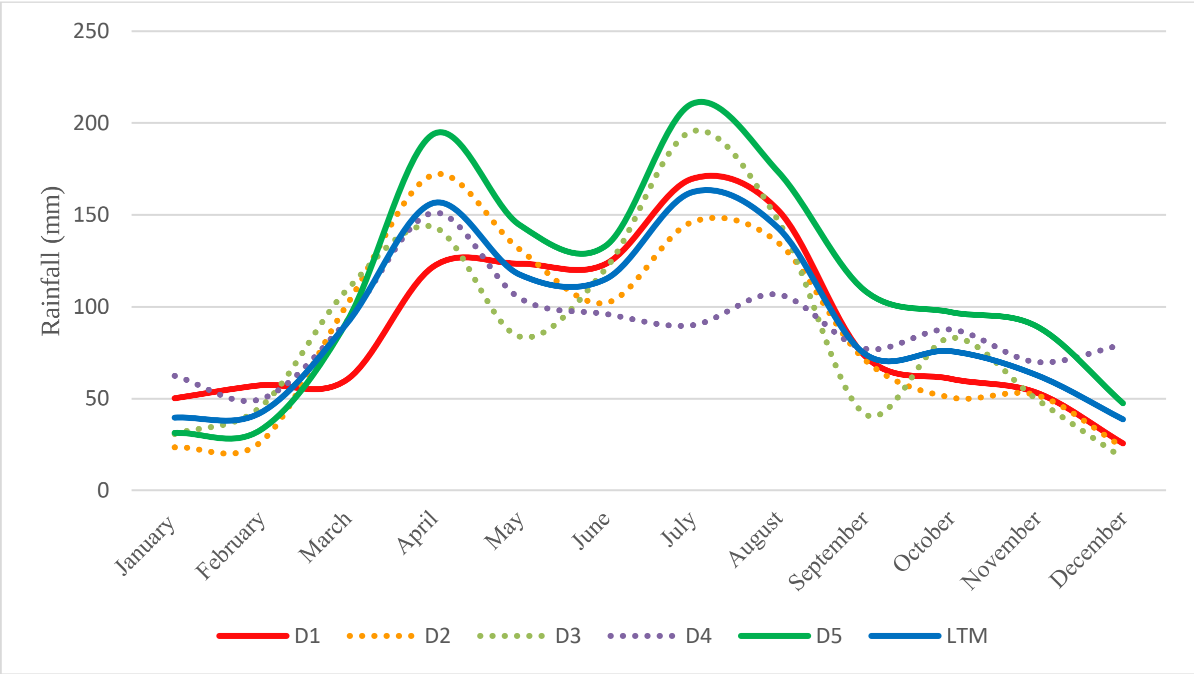

Figure 1: Graph showing amounts of daily rainfall at Eldoret Meteorological Station.

Analysed results in Figure 1 gives the distribution of daily rainfall across the five decades and also the long term mean (LTM). The results in Figure 1 supports the findings of GCMs (Dunning et al., 2018) of increasing amounts of rainfall over the recent decades with the most recent decade D5 receiving a significantly higher amount compared to the previous decades. Comparing the time-lag, the amount of rainfall received during 'short rains' (October-December) is observed to be increasing over the past three decades with the recent decade having the highest increment. During the last decade (D5) rainfall amount is observed to be comparatively more than the long term mean vis a vis the other decades. Although natural variability is expected in the amount of rainfall received from decade to decade, there is an indication of a shift towards wetter climatic conditions.

Rainfall Events. Having defined rainfall event to be rainfall of at least 1 mm, daily rainfall events were plotted for the five decades to investigate the number of rainfall events resulting in rainfall amounts presented in Figure1 and also their distribution across the rainfall seasons. Figure 2 shows the number of rainfall events recorded in Eldoret over the same period.

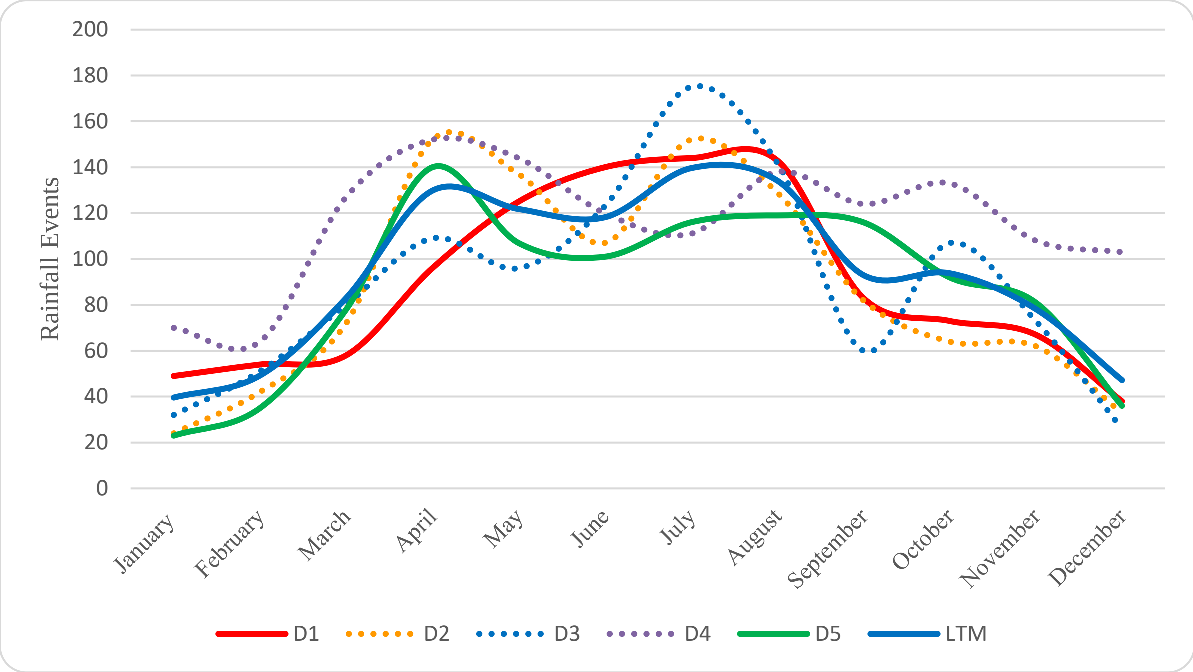

Figure 2: Graph showing daily rainfall events at Eldoret meteorological station.

From the results in Figure 2, it can be seen that the distribution of daily rainfall events has been varying across different decades. However, it is important to note that during the last decade (D5), the number of daily rainfall events decreases comparatively to the long term mean and previous decades. Despite the natural variation, the change during decade D5 is still pronounced. Further, no change in measurement method has been reported for the station. Also, despite the observed increase in the amount of rainfall received during the short rains in decade D5, the rainfall events generally decrease. As it can be seen in Figures 1 and 2, the amount and number of rainfall events vary to the LTM as the change from dry to wet periods lasting several years is expected from the natural dry-wet cycles. The question, however, is as to whether the increasing trend in amounts of rainfall in Figure 1 and decreasing trend in the number of rainfall events in Figure 2 can be attributed to natural variation or climate change.

Time Series Analysis. The annual rainfall for the period 1970 – 2019 as well as the 5 and the 10-year moving averages is shown in Figure 3. The annual rainfall has an increasing trend. The moving averages were computed with an aim at deriving periodicity arising from the natural cycles of wet and dry years and justification of the increasing rainfall intensities. Previous studies of periodicity in rainfall data have established a 21-year cycle (Alexander et al., 2005). Irrespective of a general increasing trend in annual rainfall and the moving averages, the 21-year cycles are also evident. The data indicates of an extremely wet year around 1978 and 1999 (21 years), followed by an extremely dry year around 1984 and 2005 (21 years) supporting the findings of Alexander et al., 2005. Therefore, it can be confidently observed that the year 2020 has been extremely wet after 1999 due to the natural cyclicity of rainfall (Caroline et al., 2020).

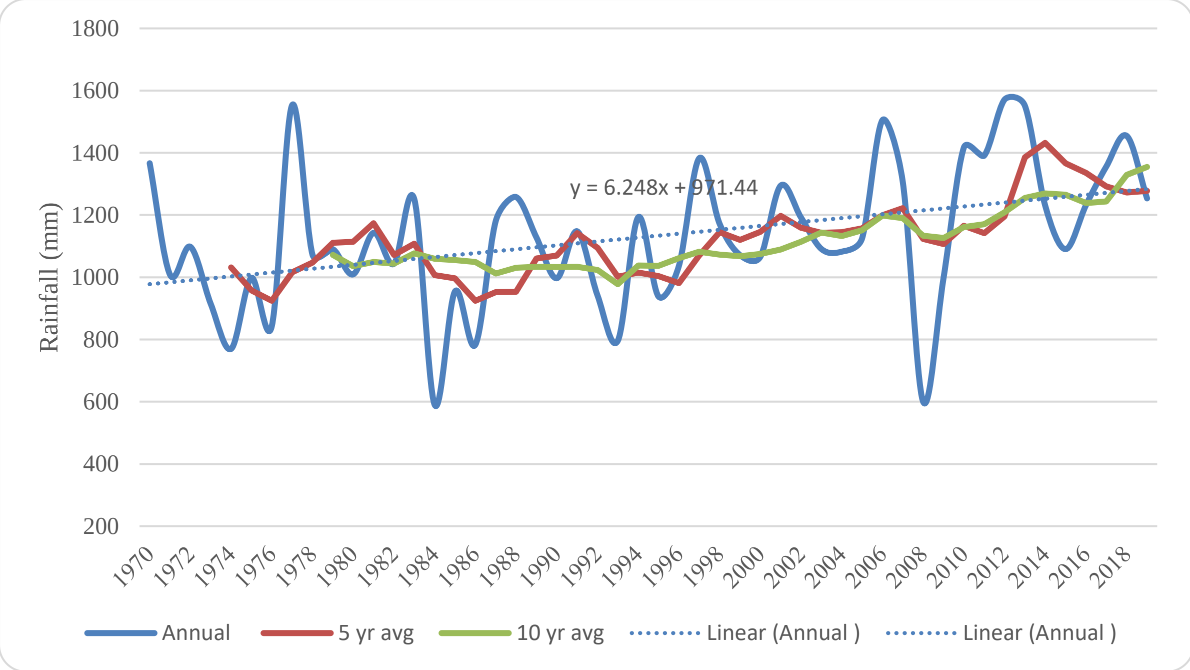

Figure 3: Graph showing total annual precipitation at Eldoret Meteorological Station.

Figure 2 shows that rainfall events recorded during the last decade have significantly decreased in comparison to the other decades. On the other hand, the daily rainfall (Figure 1) and annual rainfall (Figure 3) have recorded a significant increasing trend. With fewer rainfall events and increasing daily and annual rainfall, the conclusion of increasing intensity is inferred at supporting predictions by GCMs. The mean annual rainfall for Eldoret Meteorological station calculated from 1970-2019 is 1100 mm and the number of rainfall events responsible for this amount of rainfall was 5640 events. The average annual rainfall for the last decade (D5) is about 1300 mm, an increase of about 18% of the long term annual rainfall while the number of rainfall events responsible for the same period is 1044 events, a decrease of about 6% from the previous decade. It is therefore evident that the number of rainfall events is decreasing while the amount of rainfall is increasing hence constituting higher rainfall intensities. These findings are an indication of natural climatic cycles being exceeded which could be because of climate change.

4 Discussion

From literature, it is generally expected as indicated by GCMs that climate change will result in a decrease in the number of rainfall events and an increase in amounts of rainfall. Therefore, the objective of this study was to ascertain model predictions for Eldoret town, as with increased rainfall intensity and urbanization, runoff is expected to increase resulting in flooding. The selection of Eldoret town was objective because of the recent flooding (2020) which could have been caused by several factors. The town is experiencing increasing developments, and it can be approximated that nearly 75% of the catchment is made up of impermeable surfaces with little infiltration. Therefore, an increase in rainfall is expected to increase runoff. Over the past few years, the existing drainage systems in Eldoret town has been improved and new ones developed and sized based on historical rainfall data. The increase in rainfall intensity could therefore result in functional failure of these existing drainage structures as illustrated by an example of figures 4 (a) & (b).

Figure 4: (a) Lined drainage canal before heavy rainfall and (b) after a heavy rainfall causing flooding.

In the design of hydraulic structures, Engineers and hydrologists have always been keen on using the longest available historical rainfall data. This has been important in ensuring any short-term irregularities arising from measuring or recording errors are minimized and does not affect the design. Climate change because of human activities has resulted in a change in rainfall patterns as already observed. However, the question is the combination of pre-climate change data (natural cycles) to the climate change data to obtain long term trends to be used for design?

This may therefore mean that an engineer in future could find themselves with data of over a hundred years but only 20 years of the data to be coming from the acceptable climate change era. The historical 1:15 year recurrence interval intensity could be say 20 mm/h for a given rainfall duration. If rainfall intensity has increased due to climate change, for example, Eldoret town as observed, the climate change data with 1:15 year recurrence interval rainfall intensity might have increased to 30 mm/h. This would mean therefore that the Engineer could as well result in under-designing a hydrologic structure or even a stormwater system which is unsafe. On the other hand, should the rainfall intensities be decreasing, the combinations of pre-climate change and climate change data would result in an overdesign which is uneconomical. It is therefore imperative that Engineers and hydrologists should be keener in identifying short term trends and apply their mind in design rather than just analyzing the longest available data set for design and use of standard drawings. Figure 5 is an example of a bridge that is under construction in Eldoret, but the water level is already high, is it an under/ overdesign?

Figure 5: (a) Bridge under construction showing water levels during dry and (b) rainy seasons.

The detailed analysis of Eldoret meteorological station rainfall data yielded in increasing rainfall intensities because of decreasing rainfall events and increasing amount of rainfall. Therefore, the logical deduction is the increasing rainfall intensity coupled with urbanization has resulted in an increased runoff, straining the existing drainage structures designed using historical data, hence flooding.

5 Conclusions

Climate change is a complex system involving the interaction of many variables such as greenhouse gasses, solar radiation, topography, sea, and ocean temperatures amongst others. Trying to extrapolate the effects that change on these variables have on climate is not easy. Accepting the respect this topic deserves, we can only claim to have partial ideas on trends resulting from it.

Further studies should therefore be done to verify that the expected rainfall trends are taking place regionally and not just in one station. The natural climate variability and cyclicity should also be appreciated and adapted to while focusing on what could be the effects of climate change. This would lead to a better understanding of the effects of climate on rainfall intensities, amounts and frequency, hence proper design, and improvement in the management of engineering hydrologic structures.

Finally, it is not the intention of this study to change the existing proven engineering design principles and assumptions. It is rather to highlight the possible effects of changing rainfall trends and the consequences it has on existing hydrologic structures, design principles and assumptions theoretically.

Acknowledgement

The authors wish to thank Moi University for providing an enabling environment for research.

References

1. Alexander: Development of a multi-year climate prediction model, Water SA 31 (2), (2005)
2. Benhin, J.: Climate Change and South African Agriculture: Impacts and Adaptation Options. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa (2006).

3. Caroline, M., Declan, L., Mary, K., Emily, B. And John, H.: Extreme Rainfall in East Africa, October 2019-January 2020, and context under climate change. *Weather*. (January): 10-1002 (2020).
4. Dunning, C., Black, E. and Allan, R.: Later Wet Seasons with more intense rainfall over Africa under Future Climate Change. *J. Climate*, 31(23): 9719-9738.
5. Du Plessis and, GJ Burger: Investigation into increasing short-duration rainfall intensities in South Africa, Water SA, (2015).
6. Kibii, J. and Kipkorir, E.: Smartphone application to aid farmers on expected rainfall onset dates and associated seasonal risks of dry spells. *African Journal of Rural Development, [S.l.], v. 3, n. 2, p. 739-746, Aug. 2019. ISSN 2415-2838.*