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IMPACT OF CLIMATE CHANGE ON RESERVOIR RELIABILITY

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ABSTRACT

Research and observations indicate that increases in atmospheric carbon dioxide (CO_2) are raising global and regional temperatures, and producing changes in other climate variables that drive the terrestrial hydrological cycle, most notably precipitation and potential evaporation. This paper presents results of a study conducted to evaluate the possible impacts of climate change due to doubling of atmospheric carbon dioxide on the reliability of Mazowe reservoir in Zimbabwe. The reservoir supplies most of its water to citrus plantations. Thirty years (1961-1990) of hydrological data (reservoir inflows) and meteorological data were collected from the Zimbabwe National Water Authority (ZINWA) and Department of Meteorological Services, respectively. Outputs from the Canadian Climate Centre (CCC) model for the 2CO2 temperature and rainfall scenarios were used in the study. The Penman model was used to estimate potential evapotranspiration, while reservoir catchment runoff was simulated using the Pitman lumped conceptual model. Research findings revealed that doubling of CO_2 in 2050 would significantly increase mean monthly temperature by 3^oC, potential evapotranspiration (11.8%), rainfall (15%), runoff (235%) and annual reservoir yield (20.4%) at the 10% risk level. Based on the research findings, appropriate mitigation measures should be employed to minimise high rates of evaporation from the reservoir. On the other hand, the predicted high reservoir yield requires an increase in water use activities such as extension of irrigated area.

Key Words: Evapotranspiration, Mazowe reservoir, Penman model, Pitman Model

RÉSUMÉ

La recherche et les observations indiquent que l'accroissement du dioxyde de carbone atmosphérique (CO_2) élève les températures mondiale et régionale, et produit des changements dans d'autres variables climatiques qui déterminent le cycle hydrologique de la terre, notamment la précipitation et l'évaporation potentielle. Cet article présente les résultats d'une étude menée pour évaluer les impacts possibles du changement climatique dû à un doublement du dioxyde de carbone atmosphérique sur la fiabilité du réservoir Mazowe au Zimbabwe. Le réservoir alimente en eau les plantations d'agrumes. Trente ans (1961-1990) de données hydrologique (apports au réservoir) et météorologique ont été recueillies auprès de l'Autorité Nationale de l'Eau du Zimbabwe (ZINWA) et du Département des services météorologiques, respectivement. Les résultats du modèle du Centre Climatologique Canadien (CCC) pour la température 2CO2 et la pluviométrie ont été utilisés dans l'étude. Le modèle de Penman a été utilisé pour estimer l'évapotranspiration potentielle, alors que la réserve des eaux de ruissellement du bassin versant a été simulée à l'aide du modèle conceptuel de Pitman. Les résultats de recherche ont révélé que le doublement du CO_2 en 2050 augmenterait de manière significative la température moyenne mensuelle de 3^0C,l'évapotranspiration potentielle (11,8%), les précipitations (15%), le ruissellement (235%) et le rendement en réserve annuelle (20,4%) au niveau de risque de 10% .Se basant sur des résultats de la recherche, des mesures appropriées de réduction du taux d'évaporation élevé du réservoir devraient être prises. D'autre part, le haut rendement de la réserve prévu requiert une augmentation des activités de consommation d'eau telle que l'extension de la zone irriguée.

Mots Clés: L'évapotranspiration, Réservoir de Mazowe, le modèle de Penman, le modèle de Pitman

INTRODUCTION

The global warming phenomenon has sparked off vigorous research activity with the ultimate aim being to understand the effects of predicted climate change on both natural and managed ecosystems (IPCC, 2007). Research and observations indicate that increases in atmospheric carbon dioxide (CO_2) are raising global and regional temperatures, and producing changes in other climate variables that drive the terrestrial hydrological cycle, most notably precipitation and potential evaporation. At the same time, a warmer world is predicted to result in increased water use in domestic, agricultural and industrial sectors (Arnell, 1996; Fowler *et al.*, 2003).

In semi-arid countries, water resources are of considerable concern due to high water demand from users; rainfall unreliability, irregularity and high inter-annual variability compounded by unprecedented effects of climate change.Water balance relationships in most river basins are fragile (Kilsby*et al.*, 2007).The most dominant climate drivers for water availability are precipitation, temperature and evaporative demand (Mimikou *et al.*, 2000). Evaporation is a function of several climate variables (temperature, atmospheric humidity, net surface radiation and wind speed) and non-climatic factors (moisture availability, land-cover and plant physiology). Temperature is particularly important in snow-dominated basins and in coastal areas, the latter due to the impact of temperature on sea level (steric sea-level rise due to thermal expansion of water).

Water resource planning and design has conventionally assumed a stationary mean climate. Climate change invalidates this assumption, and places additional uncertainty on projections of river discharge and water supply, as well as on water demand. Stresses on water resources arising from potential climate change exacerbate water resource management problems over much of the wider southern African region (Buckle, 1996; New, 2002; van Oel *et al.*, 2008).

The objective of the study was to investigate the potential impact of global climate change on yield of Mazowe reservoir in Zimbabwe.

MATERIALS AND METHODS

Study area. Mazowe Dam (17°31’18"S, 30°59’19"E) was built across the Mazowe River in 1918, for irrigating citrus plantations and annual crops like maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.) and wheat (*Triticum aestivum* L.). It liesin agro-ecological region 2of the country,receives an average rainfall of 864 mm per *annum* and experiences a mean annual temperature of about 21^{o}C. The reservoir created by this dam has a full supply capacity of 44.6 x 10^6 m^3 with a surface area of 540 ha. Average A-pan evaporation rate of the dam catchment is the 1630 mm year^{-1} (Tererai, 2006). The dam’s catchment is 355 Km^2. Farmers abstract water from rivers, reservoirs, boreholes as well as weirs thereby affecting amount of water entering downstream dams, including Mazowe dam.

Data collection. Rainfall, temperature, sunshine, relative humidity and riverflow data spanning 30 years (1961-1990) to represent the baseline (1CO2) were obtained from Department of Meteorological Services, of the Ministry of Transport and Zimbabwe National Water Authority (ZINWA) of the Mnistry of Water Resources, respectively. Meteorological data from 5 stations were used to estimate mean areal values.

Penman Model. The Penman model was used to estimate potential evapotranspiration of the catchment and evaporation from Mazowe dam. Potential evapotranspiration of the dam catchment and open water or reservoir evaporation E_o was estimated from (Shaw, 1983).

$$E_o = \Delta/\gamma\, H + E_a/(\Delta/\gamma + 1) \quad \text{...... Equation 1}$$

Where:

γ = hydrometric constant (=0.27mm Hg temperature^{-1});
Δ = change in vapour pressure with time; and
H = is the available heat estimated from.

$$H = (1-r)\, R\, (0.24 \cos L) + 0.52n/N) - T^4\, (0.56 - 0.08e_d^{1/2})\, (0.10 + 0.9n/N) \quad \text{.................. Equation 2}$$

Where:

r = is albebo (r=0.05 for water and r=0.3 for vegetation);
n = average sunshine duration per month;
e_d = saturation vapour pressureat dew point;
N = average possible maximum sunshine duration;
T^4 = black body radiation;
L = latitude of the area;
R = total monthly radiation; and
E_a = aerodynamic term estimated from mean wind speed (µ) and vapor pressure deficit
(e_a-e_d) as:

$\mu = 0.35\ (0.5 + \mu/100)\ (e_a - e_d)$ .... Equation 3

Pitman Model. The Pitman rainfall-runoff model was used to simulate the catchment runoff.Input data comprised of monthly precipitation and potential evapotranspiration. Precipitation data were obtained from the Department of Meteorological Services in Zimbabwe, while potential evapotranspiration data were obtained as output from the Penman model (Gorgens, 1983).

During the calibration process, parameter values are automatically changed by the Rosenbrock automatic parameter optimisation routine attached to the model. This is a trialand error technique which reproduces a goodness of fit between the predicted and observed values (Gorgens, 1983).

Reservoir yield analysis. The reservoir yield analysis programme from the Zimbabwe National Water Authority (ZINWA) was used to simulate changes in the reservoir yields at 10% risk level for different temperature and rainfall scenarios. A 10% risk level implies that the reservoir will have a probability of failure of 0.1. The 10% risk level or 90% reliability level are the design criteria of Zimbabwe's dams supplying water for agriculture or irrigation purposes; while dams supplying domestic water are designed to achieve 96% reliability. The Yield Programme's input data consist of dam catchment area (355 km^2), mean annual runoff, mean annual rainfall, coefficient of variation of rainfall and runoff, open water evaporation, drawoff, upstream storage, catchment area and reservoir full volume (44.6 x $10^6 m^3$). The model was applied to Mazowe reservoir because it satisfied the condition of storage ratio (ratio of full supply capacity to the product of mean annual runoff and catchment area) of being greater than 0.5.

The Canadian Climate Centre (CCC) model (lat. 3.75^o x long: 3.75^o) was selected because it simulated the baseline precipitation rates over the Mazowe dam catchment with a small error margin (less than 15%). The outputs from the model consisted of the 1CO2 and 2CO2 runs for precipitation and surface air temperature.

RESULTS

Temperature changes. Figure 1 shows the mean monthly temperatures for the baseline (1CO2) and doubling of CO_2 (2CO2)conditions. The average monthly temperature for the baseline condition is 18 ^oC. The CCC model predicted that .the doubling of CO_2 will significantly (P=0.000) increase mean monthly temperature by 16.3% from the baseline condition of 18 ^oC to 21.17 ^oC.

Changes in potential evapotranspiration. Figure 2 shows the monthly potential evapotranspiration for the 1CO2 and 2CO2 conditions. The Penman model outputs indicate that the average monthly potential evapotranspiration in the catchment will increase by 11.8% from the baseline value of 107.75 mm. The difference between potential evapotranspiration during the 1CO2 and 2CO2 scenarios is significant (P=0.000).

Precipitation changes. The mean monthly rainfall is projected to significantly (P=0.013) increase by 15% with the doubling of carbon dioxide from 72.08 mm to 83 mm with the doubling of CO_2. Figure 3 shows the baseline and 2CO2 precipitation changes.

Runoff changes. Figure 4 shows that with the doubling of carbon dioxide the mean monthly runoff in the catchment or reservoir inflows will significantly (P=0.007) increase to 8.21 x $10^6 m^3$ from the baseline value of 2.45 x $10^6 m^3$.

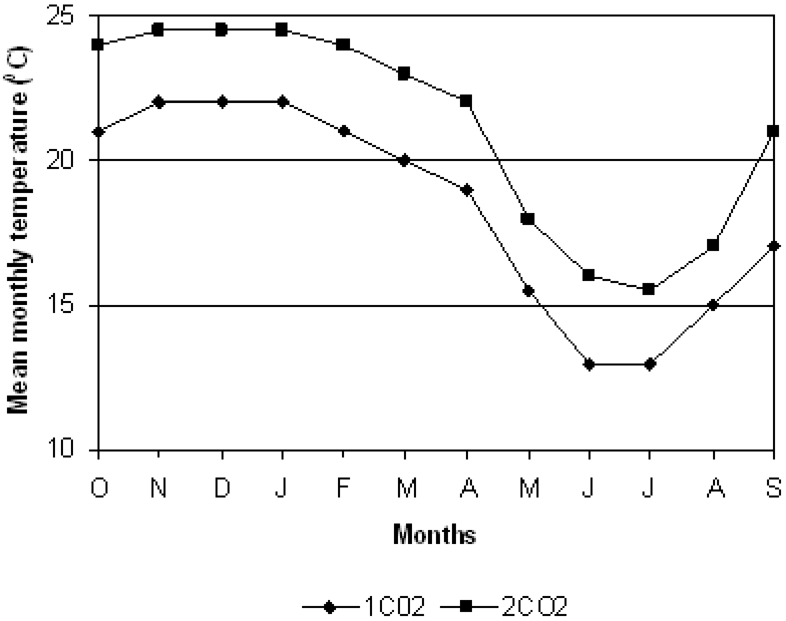

Figure1. Predicted temperature changes for the 1CO2 and 2CO2 scenarios for the Mazowe River catchment in Zimbabwe.

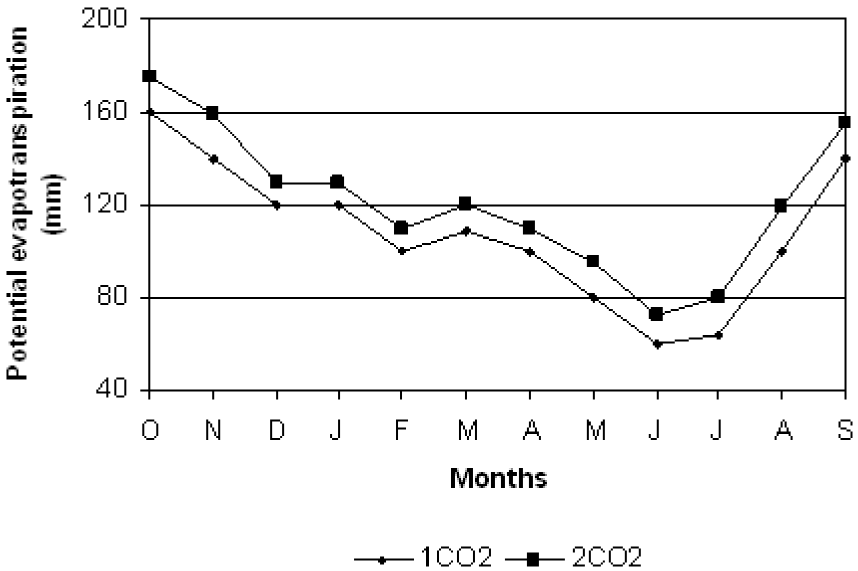

Figure 2. Predicted potential evapotranspiration rates for the 1CO2 and 2CO2 scenarios of the Mazowe River catchment in Zimbabwe.

DISCUSSION

Relatively few studies have addressed water management and adaptation measures in the face of changing water balances due to climate change. This has revealed that under the projected doubling of CO_2 in 2050, the reliability of Mazowe reservoir catchment will significantly increase from baseline (1960-1991) average condition.

The increase in mean monthly temperature by 3°C will increase potential evapotranspiration by 11% and is likely to increase catchment rainfall

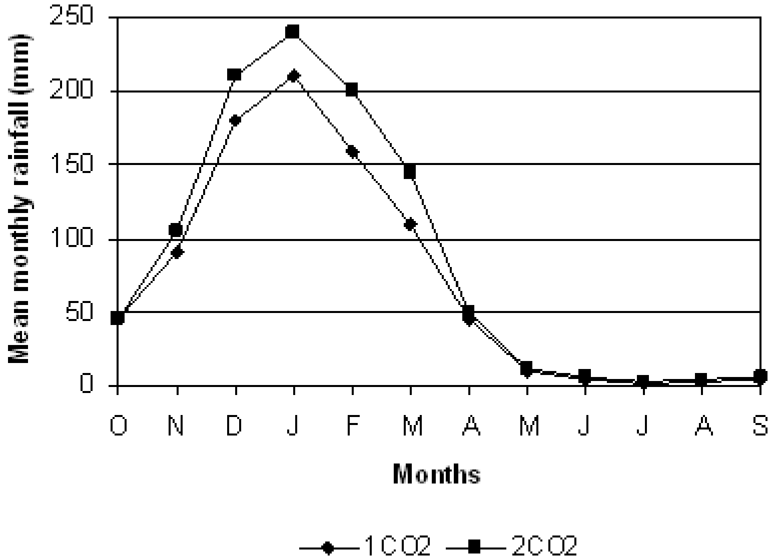

Figure 3. Predicted precipitation for the 1CO2 and 2CO2 scenarios of the Mazowe River catchment in Zimbabwe.

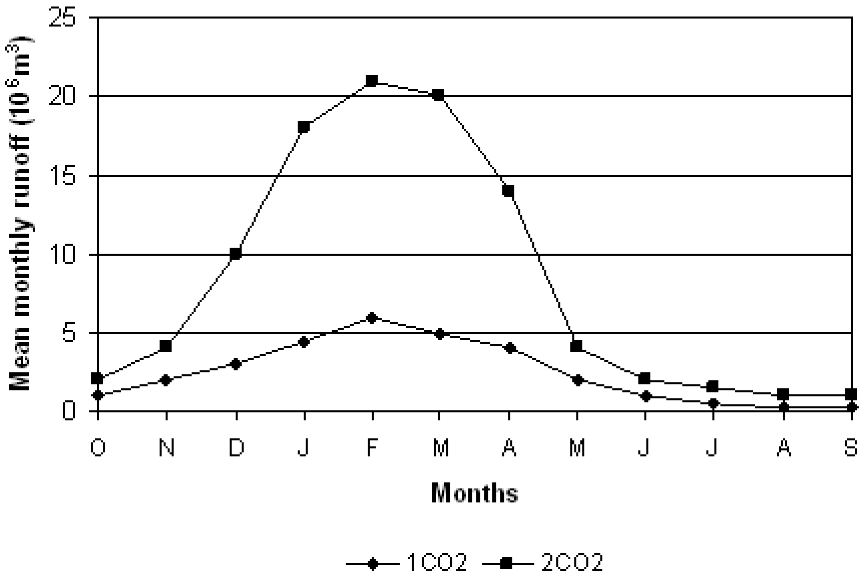

Figure 4. Predicted mean monthly runoff for the 1CO2 and 2CO2 scenarios within the Mazowe River catchment in Zimbabwe.

by 11%. Such changes increase inflows into the dam. This implies that the amount of water available in the reservoir will increase well (Fig. 5).

With the doubling of carbon dioxide, the mean annual reservoir yield will increase by 20.4% from the 1961-1990 baseline average (Fig. 5). The predicted increase in reservoir due to climate change may have a positive effect on livelihoods, especially irrigated agriculture because water will be available. Irrigated crop production may be expanded or intensified to utilise the available water.

However, the predicted hydrological changes may induce problems of flooding in times when the dam storage capacity is exceeded. Appropriate

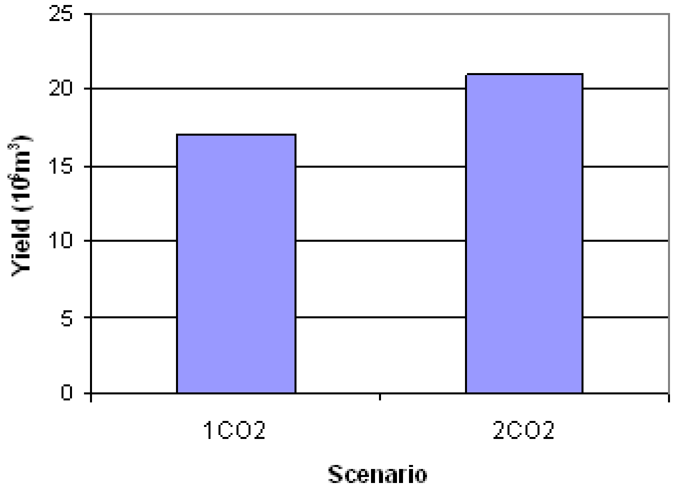

Figure 5. Predicted annual reservoir yields for the 1CO2 and 2CO2 scenarios of the Mazowe River catchment in Zimbabwe.

mitigation measures against high evaporation rates should to be employed. In such circumstances, there is need of various adaptation strategies to be taken up.The strategies may range from change in land use and land cover, cropping pattern, to water management and flood warning systems. The induction of additional stresses shall require rigorous integrated analysis before paving way into policy decisions.

CONCLUSION

This article highlights the possible impacts of climate change due to the equivalent doubling of atmospheric carbon dioxide on the reliability of Mazowe dam at 10% risk level. The Canadian Climate Centre model shows that with the doubling of CO_2, the mean annual reservoir yield will increase by about 20.4% from the 1961-1990 annual average. This rise in yield will be a result of the 15% and 235% increase in rainfall and runoff respectively. In addition, the mean monthly temperature is likely to increase by 3 ^{0}C resulting in an 15% rise in potential evapotranspiration.

The research findings may be helpful to development planners, decision makers and other stakeholders when planning and implementing catchment-wide water management strategies to adapt to climate change. The limitation of this study is that uncertainties of climate change modelling have not been taken into account and, land use and land cover in the catchment have been assumed to remain the same in future.

REFERENCES

Arnell, N. 1996. Global warming: Rivers flows and water resources, John Wiley and Sons, Chichester, UK.

Buckle, C. 1996. Weather and climate in Africa.Longman.Cambridge, England.

Fowler, H.J., Kilsby, C.G. and O'Connell, P.E. 2003. Modeling the impacts of climatic change and variability on the reliability, resilience and vulnerability of a water resource system. *Water Resources Research* 39(8):1222-1232.

Gorgens, A.H.M. 1983. Conceptual modelling of the rainfall-runoff process in semi-arid environments. Hydrological Research Unit, Grahamstown, South Africa.

IPCC. 2007. Climate change 2007. Impacts, adaptations and vulnerability. Contribution of the Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 976 pp.

Kilsby, C.G., Tellier, S.S., Fowler, H. J. and Howels, T.R. 2007. Hydrological impact of climate change in Tejo and Guadiana Rivers. *Hydrology and Earth System Science* 11(3):1175-1189.

Mimikou, M.A., Baltas, E., Varanou, E. and Pantazis, K. 2000. Regional impacts of climatechange on water resources quantity and quality indicators. *Journal of Hydrology* 234 (1-2): 95-109.

New, M. 2002. Climate change and water resources in the southwestern Cape. *South Africa Journal of Science* 98:1-4.

Shaw, E.M. 1983. Hydrology in practice, Van Nostrand Reinhold, Workinham, Zimbabwe.

Tererai, M.F. 2006. Investigating the decline of the factors associated with water level decline in Mazowe dam. MSc. Thesis, University of Zimbabwe, Harare, Zimbabwe.

van Oel, P.R., Krol, M.S., Hoekstra, A.Y. and de Araujo, J.C. 2008. The impact of upstream water abstractions on reservoir yield: the case of Oros Reservoir in Brazil. *Hydrological Sciences Journal* 53(4): 857-867.