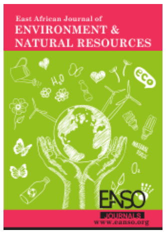

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Original Article

VULNERABILITY ASSESSMENT OF SUSTAINABLE DRINKING WATER SUPPLY AND DEVELOPMENT IN A CHANGING CLIMATE IN NAKURU TOWN, KENYA

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ABSTRACT

The close connection between the climate and the hydrological cycle makes climate change to have a significant impact on water resources with regard to variability, distribution and occurrence. Research wise, climate change has assumed increasing importance from the perspective of development compared to the water environment. In Kenya, key water-related issues facing the country are the effects of climate variability and the steady degradation of the nation's water resources. Limited research has focused on alleviating the problem as the effects of the water crisis remain wider, deeper and more uncertain requiring immediate attention. Major indicators of existing problems are manifested in lack of information and knowledge on climate-induced changes under natural variability conditions in drinking water regimes, quality, quantity, human health and likely future changes. The study uses a scientific approach based on hydrological analysis focusing on the link between changing climate conditions and drinking water quality and supply issues in Nakuru Municipality. Primary data collection employed measurement and analysis of selected inorganic drinking water quality variables with significant risk to health in the area's local natural conditions. To explore short and long-term trends of climatic change indicators and their effect on the area's hydrology, statistical trend analysis of rainfall for a period of 45 years was used. Temperature data used covered a period of 36 years. Water samples were taken to represent important water source points for public supply for ten months (June 2014 to March 2015) and analysed in accordance with standard methods. Data were analysed by trend analysis, descriptive and correlation techniques. Strong, weak and negative trends were observed between water quality variables and rainfall variability. Results show that temporal and spatial variability of rainfall patterns and temperature in the area of study affect surface and groundwater recharge processes, water table, quality, quantity and supply issues. According to the study, the effects of drinking water crisis linked to climate variability and change in terms of prediction methods, frequency, and rate of change, quality and quantity are wider, deeper and more uncertain requiring immediate attention. The existing challenges limit sustainable development, effective long-term planning and management of the areas drinking water resources. The results can be valuable in characterizing and addressing the study area's water quality conditions and trends.

INTRODUCTION

Climate change has become one of the greatest environmental threat across the world characterized by increasing global greenhouse gases, oceanic temperatures, widespread melting of snow and ice and rising sea levels (IPCC, 2007). The long-term climatic change related to changes in precipitation patterns, rainfall variability, and the temperature is attributed to increasing the frequency of droughts and floods. The combination of these factors commonly results in increased water use, competition and pollution in addition to highly inefficient water supply practices. As global climate change continues to have a significant or even profound impact on regional water supplies and demands, an assessment of the impact on groundwater and surface water resources will require basic monitoring systems capable of providing quality data over time. According to Vaux (1991), current understanding of global climate patterns makes it very difficult to assess and predict the impacts of such change. Despite the existing problems, research on the projections of the impacts of climate change on water resources variability and sustainable development is limited resulting to lack of reliable and availability of data that can be used to identify the potential gaps at present and future date. This has undermined the capacity of understanding, estimating and predicting the current and future impact of climate change on water resources at local and regional scales. Therefore, to eliminate the gap, measures and actions of climate change and variability on water resources management must be identified to strengthen local, regional and global scientific knowledge and capacity to develop feasible solutions.

McCarthy et al. (2001) acknowledge that climate change will have a significant impact on water availability and quality in most African countries. In Kenya, this phenomenon is already evident and ever-intensifying at an alarming rate depicted by the countrywide temperature raise and erratic as well as intense rainfall patterns (UNFCCC, 2011). In the early 1960s, Kenya generally experienced increasing temperatures in many regions across the country hence a general warning. Annual rainfall events indicated that 24-hour rainfall amount experienced today is lower than those of the 1960s (NCCRS, 2010). The changing temperatures and rainfall patterns have a profound impact on water resources which are manifested in the form of erratic rainfall.

The UN's World Water Development Report 2015 puts water at the core of sustainable development. Water is an essential and invaluable element of services for poverty reduction, economic growth and environmental sustainability. The question of climatic impact on the hydrological domain is a widespread concern requiring investigation and proper documentation both at the local and global scale (Bates et al., 2008; Kabat & Van Schaik (2003); Eisenreich ,(2005); WMO (2009).

According to Mogaka et al. (2006), the most important water-related issues facing Kenya as a country are the effects of climate variability and the steady degradation of the nation's water resources. In Nakuru County, the causes of climate change have been attributed to natural and anthropogenic factors. The impacts have led to changes in the hydrological cycle and circulation by the destruction of water catchment areas, changes in balances of normal temperature and rainfall leading to irregular rainfall patterns, shifting precipitation patterns affecting quality, availability and supply of drinking water resources among other socio-economic sectors which are climate-sensitive.

In Nakuru area, little research has been done on the consequences of climate variability and change on the hydrological system, drinking water supplies in terms of natural environmental conditions, distribution, availability, demand and quality. The existing challenges include understanding and predicting the connections between the current and future status of the area's water resources under the changing climate. Understanding these impacts is essential for the area's drinking water supplies; therefore this study attempted to fill that gap. Appropriate research methods and tools were employed to assess and predict the impacts of climate change on drinking water supply sources and sustainability in Nakuru Town water basin using available data on temperature and precipitation. The objectives were to assess the impact of climate change on temperature and precipitation variability in Nakuru Town and to determine the impact of rainfall and temperature variability on drinking water quality trends, availability, supply and sustainability in Nakuru Town.

Study area

Nakuru Municipality is located within the East African Rift Valley. The area is geographically located in an environmentally fragile ecosystem that has been described by researchers as exceptionally vulnerable to environmental changes due to its unstable geological zones experiencing frequent local geological faulting characteristics (Daniel et al., 2009). This state has been reported to have great potential to pose a risk to the regional groundwater variably depending on its elemental composition due to its persistent interaction with the water. The geology of an area is a significant factor in the overall quality of its water resources. Thus, geogenic factors become as important as anthropogenic factors on the overall quality of water resources. In this regard, water–rock interactions in altered zones of geological units are now considered to be key topics influencing the quality of water resources.

Nakuru Town is known for its water scarcity, but reasons for- and effects of the water problem have not yet been well documented. Water scarcity is manifested in alterations of supply, streams becoming intermittent or permanently dry, over mining of groundwater, degradation of land resources, and unpredictable precipitation timing among other factors.

Climate

Nakuru County has predictable weather patterns with annual temperature ranging approximately from 8ºC to 30ºC. February, July and December are the driest months of the year. The lowest temperatures are experienced in July and August while the highest temperatures occur in January to March. The potential evaporation is about twice the annual rainfall (Farah, 2001; Muller, 2007; CDN, 2009). Nakuru has two rainy seasons; April, May, August (long rains) and October, December (short rains). Rainfall has a tri-modal distribution with peaks centered around April, August and November. April peak being highest followed by August and November. The county receives between 700 mm and 1200 mm of rainfall annually with average annual rainfall of 960 mm (Nakuru County, 2019; KIG, 2019).

Nakuru Town water supply system

The water provider to the town and its peri-urban areas is NAWASSCO which the municipality has given the role to provide clean and reliable safe drinking water supply to all users but findings from the study indicate that piped water is limited to urban areas of Nakuru Municipality. It sources its water from rivers and boreholes where the ratio surface water/groundwater fluctuates depending on the weather (during rainy season, more surface water is available for abstraction) adding uncertainty to its operations (Akollo, 2014). This makes the area more susceptible to the effects of climate variability. NAWASSCO produces approximately 45,000 cubic meters of water per day against a water demand of 70,000 cubic meters (Kahenda, 2018).

RESEARCH METHODOLOGY

To assess the impact and understand how climate variability affect the quality and reliability of the areas drinking water supply, long-term meteorological data for temperature and rainfall (1980–2018) from Nakuru meteorological stations, which is located in the study area was used. The data period was used to identify existence of any trend for the two variables that is temperature and rainfall by calculating the means on annual and mean monthly basis and determine their effect on the quality and availability of drinking water resources of the area.

Standard analytical techniques and instruments were employed in water sampling and analysis to establish quality characteristics of drinking water sources and their spatial and temporal extend. Water samples were taken at sites that represent the sources of the areas drinking water supply. Parameters considered include; pH, fluoride, electrical conductivity, selenium, chloride and cadmium. Their selection was based on the fact that water quality is not determined by a single parameter, being important elements that are of a high importance in determination and evaluation of drinking water and being widely used as important indicators of inorganic constituents of significant health risk that occur in drinking water. The parameters are also used to note variation or changes in natural waters quickly (WHO, 1993; Abbasi, 2012). The parameters were also chosen on the possibility of their relative influences on drinking water quality at spatial and temporal scales and tracing their origin in relation to the area's natural and environmental conditions such as climate and geographical variations.

Water samples were collected from thirty eight sampling points for a period of one year (June 2014 to May 2015) where the sampling periods were put in three groups; (transition, short rain and dry period). Descriptive and correlation analysis was applied to establish the existence of any trends between precipitation patterns and drinking water chemical characteristics of selected water parameters in the area.

RESULTS AND DISCUSSION

Influences of Climate Changes on water resources quality and availability

Analytical water quality results

Range values of measured water parameters covering the three sampling periods at different sampling points of the water supply system against set standards by WHO and NEMA for drinking water are given in Table 1.

Table 1: Analytical results

Parameter	Range	WHO (2006)	NEMA (2006)
pH	7.10 – 9.03	6.5 – 8.5	6.5 – 8.5
Electrical conductivity	146.84 - 866.27 µS/cm	1500 µS/cm	300 µS/cm
Fluoride	0.84 – 8.07 mg/l	1.5 mg/l	1.5 mg/l
Cadmium	0.05 – 0.42 mg/l	0.003 mg/l	0.01 mg/l
Chloride	13.95 mg/l – 27.61 mg/l	250 mg/l	200 mg/l
Selenium	0.64 - 9.98 mg/l	0.01 mg/l	0.01 mg/l

Source: Authors.

Results of measured water quality parameters indicated elevated levels confirming an existing problem in water quality conditions, variation at spatial and temporal scales and possible contaminant factors of the town's drinking water supply system which is cumulatively changing the water and posing a risk to individuals who consume the water on a regular basis.

Trend analysis of river and groundwater quality characteristics at spatial and temporal scales shows a relationship with temperature and precipitation variation over the study period (*Table 2* and *Table 3*).

Table 2: Relationship between mean monthly rainfall, temperature variation and quality of drinking water measured parameters (groundwater sources)

Date	Electrical conductivity (µS/cm)	pH	Cadmium (mg/l)	Selenium (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Mean monthly precipitation (mm) (Jun, 2014 to Mar, 2015)	Maximum temperature (ºC) (Jun, 2014 to Mar, 2015)	Minimum temperature (ºC) (Jun, 2014 to Mar, 2015)
Jun, 2014	937	10.54	0.21	6.75	28.4	3.28	79	28	21.0
Jul, 2014	898	8.54	0.10	6.40	28.4	10.6	63.8	28.0	22.4
Aug, 2014	897	8.82	0.00	6.55	28.4	8.90	92	27.2	22.7
Sep, 2014	922	9.26	0.15	5.04	28.4	4.0	57.6	30	22.3
Oct, 2014	890	9.98	0.20	6.12	28.4	4.51	98.2	29	23.5
Nov, 2014	934	9.83	0.29	8.20	28.4	14.5	82.2	27.7	21.9
Dec, 2014	978	9.76	0.32	5.09	28.4	7.0	67.8	28.3	21.7
Jan, 2015	924	9.90	0.35	3.12	28.4	8.5	0	29.8	27.2
Feb, 2015	939	9.65	0.30	9.20	28.4	12.3	3.8	31.4	25.6
Mar, 2015	854	10.53	0.21	6.85	28.4	14.0	15.6	31.5	25.7

Source: Authors.

Table 3: Relationship between mean monthly rainfall, temperature variation and quality of drinking water measured parameters (river water)

Date	Electrical conductivity (µS/cm)	pH	Cadmium (mg/l)	Selenium (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Mean monthly precipitation (mm) (Jun, 2014 to Mar, 2015)	Maximum temperature (ºC) (Jun, 2014 to Mar, 2015)	Minimum temperature (ºC) (Jun, 2014 to Mar, 2015)
Jun, 2014	158.50	8.50	0.54	3.33	14.2	4.25	79	28	21.0
Jul, 2014	234.25	7.85	0.51	2.29	14.2	4.58	63.8	28.0	22.4
Aug, 2014	129.75	7.68	0.10	0.93	14.2	2.14	92	27.2	22.7
Sep, 2014	173.00	7.08	0.13	2.83	14.2	0.98	57.6	30	22.3
Oct, 2014	187.25	8.18	0.20	3.67	14.2	1.63	98.2	29	23.5
Nov, 2014	165.50	8.96	0.18	3.94	14.2	1.30	82.2	27.7	21.9
Dec, 2014	160.50	8.44	0.40	0.74	14.2	1.26	67.8	28.3	21.7
Jan, 2015	285.50	7.86	0.60	0.98	14.2	2.18	0	29.8	27.2
Feb, 2015	280.50	8.60	0.73	3.38	14.2	1.86	3.8	31.4	25.6
Mar, 2015	336.75	9.50	0.39	4.37	14.2	1.89	15.6	31.5	25.7

Source: Authors

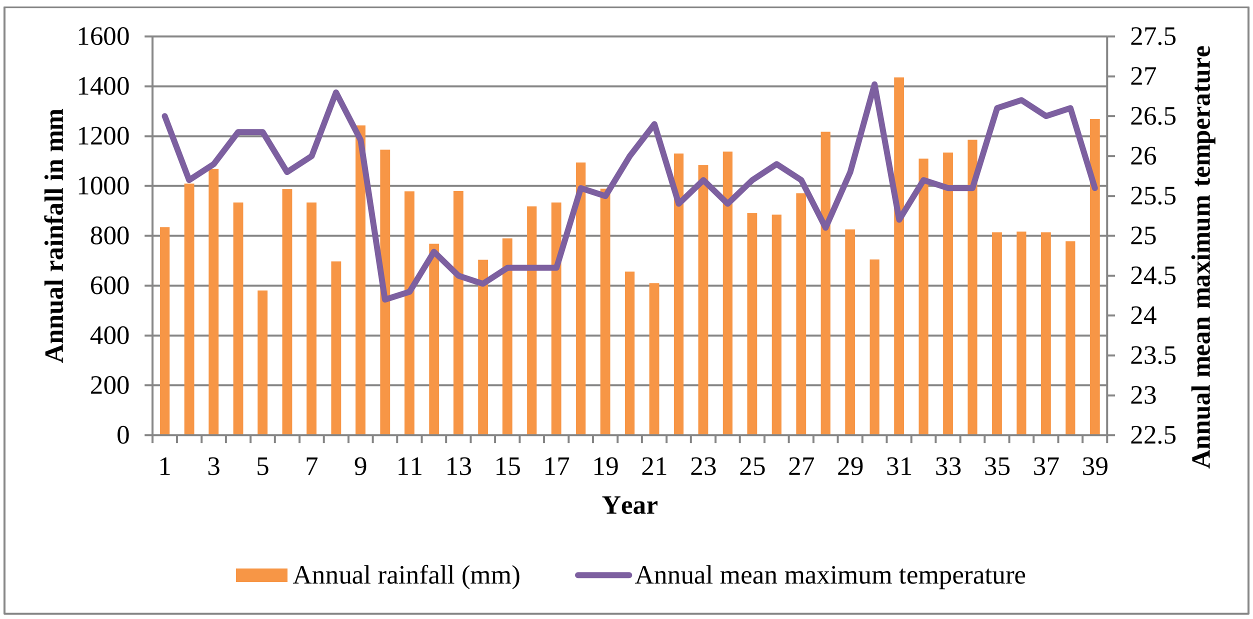
Results show trends existed in concentration levels of electrical conductivity, fluoride, selenium and cadmium over the sampling period at different sampling points in relation to recorded mean monthly rainfall and minimum and maximum temperatures in both river and groundwater. Chloride and pH levels had little variation within the sampling period. From field data collection it was also observed that there was high reticulation of water by the areas water provider during the months with little or no rainfall that affected the water users. According to Akolo, 2014, ratio of surface water/groundwater fluctuates depending on the weather (during rainy season, more surface water is available for abstraction). The results were attributed to the areas local environmental conditions with relative influencing factors of climate change and variability conditions. Current drinking water quality status together with climate change and variability was confirmed to have a significant negative impact on the area's economy, ecosystems, and public and human health sectors. Heavy precipitation events cause problems in water quality and infrastructure, as sewer systems and water treatment plants are overwhelmed by the increased volumes of water causing floods and outbreak of water-related diseases as reported by the areas drinking water provider. The combined pressures were attributed to the area's existing challenges in the water crisis that affect sustainable development.

Mogaka et al. (2006); Chebet (2010); Ghaleni and Ebrahimi (2015) observed the same trends in related studies on effects of human activities and climate variability on water resources and socio-economic activities at local and global scales. The findings support prior observations by Georgakakos et al., 2014 concerning the effect of water quality and increases in rainfall on public health.

Precipitation and Temperature Trend Analysis

Results of trend analysis on monthly and annual basis using meteorological and hydrological time series data period of 1980 to 2018 for temperature and rainfall, show significant variation in precipitation and temperature year after another and within the year (Figure 1).

Figure 1: Long term total annual rainfall and annual mean maximum temperature for the study area



Source: Nakuru Meteorological Station; Rainfall Station Number 9036261; WMO No.63714

Given that the areas annual temperature ranges from 8 ºC to 30ºC with an average annual rainfall of 960 mm (Nakuru County, 2019; KIG, 2019) deviation from the normal conditions are observed from the annual maximum temperature where highest recorded value was 26.9 ºC in the year 1989 and annual average rainfall of 1268.5 mm in the year 2018. According to the Republic of Kenya (2010), Kenya has generally experienced increasing temperature trends in many areas. However, the increase in minimum temperature is higher than the increase in maximum temperature.

Results as presented in Table 4 show increasing and decreasing trends of mean monthly minimum and maximum precipitation and temperature, as well as annual mean minimum and maximum temperature and precipitation from the 38 year period, indicating a significant influence on local rainfall patterns which can affect water sources storages such as rivers and boreholes in regard to their discharge, recharge and flow capacities, water quality and supply.

Table 4: Variation in long term mean monthly rainfall data, maximum and minimum temperatures and mean monthly precipitation within the study period

Month	Mean monthly precipitation for 38 years (mm) (1980 and 2018)	Mean monthly precipitation (mm) (June 2014 to March 2015	Mean monthly maximum temperature (ºC) (1980 and 2018)	Mean monthly minimum temperature (ºC) (1980 and 2018)	Sampling periods (for the study (June 2014 to March 2015).
June	82.1	79	24.6	12	Transitional period
July	89.0	63.8	24.0	11.8	
August	104.6	92	24.5	11.8	
September	80.4	57.6	25.8	10.5	
October	83.1	98.2	25.4	11	Short rain period
November	83.8	82.2	24.4	11.5	
December	50.4	67.8	25.8	11	
January	27.7	0	27.4	10.5	Dry period
February	29.4	3.8	28.5	11	
March	63.7	15.6	28.3	12	

Source: Nakuru Meteorological Station; Rainfall Station Number 9036261; WMO No.63714

The results confirm that climatic factors such as temperature, quantity and distribution of precipitation in combination with the areas geology and other environmental factors affect the quality of drinking water sources, availability, distribution and supply demands. Many previous studies in Nakuru County had similar findings to the present study (Vandas *et al*., 2002*;* Gicheru *et al*., 2006; Chebet, 2010).

The results show an existing water crisis where the major indicator is water scarcity manifested in form of challenges in the timing of rainfall, changing temperature patterns, ineffective institutional arrangement and capacity, deteriorating drinking water quality, availability, reliability, recharge processes and declining water storages. The observations were attributed to the consequences of climate change and variability. The findings indicate that development and management of the areas drinking water resources are unsustainable as an estimate on reliability is uncertain at present and in the future due to inadequate hydrological information. Many previous studies concerning the contribution of climate variability on water resources in Kenya had similar findings (Mogaka *et al*., 2006).

CONCLUSION

The main climate change consequences related to water resources at the area of study are increases in temperature, shifts in precipitation patterns that affect the timing of rainfall and stream discharge, surface and groundwater recharge, pollution of water resources, quantity and supply issues. The effects have been noted to contribute to the water crisis in terms of scarcity in the area. Important sectors and overall sustainable water resources management and development have been adversely affected. Existing challenges include the capacity to establish immediate and long-term impacts of climate change and variability on the areas hydrological conditions, understanding and characterizing water quality conditions and trends. Further research is therefore essential to understand and to predict the connections. This will contribute to better understanding the impact of changing weather patterns on the areas drinking water supplies and sustainable development where the information can be used to guide the areas hydrological forecast and water demand projections for better management strategies that adapt to changing conditions as they occur.

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REFERENCES

Abbasi T., Abbasi S.A. Water Quality Indices. Elsevier; Oxford, UK: 2012. pp. 15–55.

Akolo, D. (2014). Personal communication.

Bates, B., Kundzewicz, Z., & Wu, S. (2008). *Climate change and water*. Geneva, Switzerland; Intergovernmental Panel on Climate Change Secretariat.

Chebet, N. K. (2013). *Assessing women domestic chores and vulnerability to climate variability in Chepseon Sub location, Nakuru County, Kenya*. Thesis. Kenyatta University.

Daniel, O., Alfred, O. and Justus, B. (2009). Holocene palaeohydrology, groundwater and climate change in the lake basins of the Central Kenya Rift, Hydrological Sciences Journal, 54:4, 765-780, DOI: 10.1623/hysj.54.4.765.

Eisenreich, S. J. (Ed.). (2005). *Climate change and the European water dimension: A report to the European Water Directors* (EU Report No. 21553). Ispra, Italy: European Commission-Joint Research Centre.

Georgakakos, A., Fleming, P., Dettinger, M., Peters-Lidard, C., Richmond, T. C., Reckhow, K.,... & Yates, D. (2013). Chapter 3: water resources. *National Climate Assessment*, 107-164. U.S. Global Change Research Program.

Ghaleni, M. M., & Ebrahimi, K. (2015). Effects of human activities and climate variability on water resources in the Saveh plain, Iran. Environmental monitoring and assessment, 187(2), 35.

Gicheru, E., Gachene, C. K., & Claessen, L. (2006). *Anticipated Climate Change and Impact on Kenyan Agriculture*. Nairobi: UNEP COP 2006.

IPCC. (2007). *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC. Geneva: Intergovernmental Panel on Climate Change (IPCC).

Kabat, P., & Van Schaik, H. (2003). *Climate changes the water rules: how water managers can cope with today's climate variability and tomorrow's climate change*. Delft, the Netherlands: Dialogue on Water and Climate.

Kahenda, M. (2018, February 24). *Nakuru town residents court diseases as water scarcity rages*. Retrieved from https://www.standardmedia.co.ke/article/2001270950/nakuru-town-residents-court-diseases-as-water-scarcity-rages

KIG (2019, December 24). *Nakuru County - Kenya*. Retrieved from http://www.kenya-information-guide.com/nakuru-county.html

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J, & White, K. S. (2001*) Climate Change 2001: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Mogaka, H., Gichere, S., Davis, R., & Hirji, R. (2005). *Climate variability and water resources degradation in Kenya: improving water resources development and management*. The World Bank.

Nakuru County (2019, December 24). *About Nakuru County*. Retrieved from http://www.nakuru.go.ke/about/

NEMA, (2006). Environmental Management and Co-ordination (Water Quality) Regulations. Arrangement of Regulations, Kenya Gazette supplement No. 68, Republic of Kenya.

Republic of Kenya. (2010). *National Climate Change Response Strategy*. Nairobi: Government Printers.

UNFCCC. (2011). *Climate Change and Freshwater Resources: a Synthesis of Adaptation Actions Undertaken by Nairobi Work Programme Partner Organization*. Nairobi, KE. United Nations Framework Convention on Climate Change (UNFCCC)

Vandas, S. J., Winter, T. C., & Battaglin, W. A. (2002). *Water and the Environment* (p. 28-29).

American Geosciences Institute Environmental Awareness Series.

Vaux, H. J., Jr. (1991). California's water resources. In Knox, J. B. and Scheuring A. F. (eds), *Global Climate Change and California: Potential Impacts and Responses* (p. 69-96). Berkeley, CA: University of California Press.

WHO (World Health Organization) (1993) Guidelines for drinking water quality; Vol. 1. Recommendations (2nd Ed.), WHO, Geneva.

WHO (World Health Organization), 2006: Guidelines for drinking water quality.3rd Edn.WHO, Geneva. Available at: www.who.int/water_sanitation_health/dwq/gdwq3rev/en.

WMO. (2009). *Challenges and opportunities in research to enable improved products and new services in weather, climate and environment*. Report of the Executive Council Task Team on research aspects of enhanced climate, weather, water and environmental prediction framework. Geneva, Switzerland: World Meteorological Organization Research Department (WMO).