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Review

Water planning and management in sustainable new town building, the case of Ramshar

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The focus of this paper is on new town building in hydro drought regions. It looks at new town building from the sustainability perspective; especially it discusses the supply and distribution of water in the new towns. The aim of this paper is to resolve a dilemma in the arid regions. One side a much demand for new towns because of the population growth and other side the water anxiety is being a key reason hindering the urban development. Methodological approaches of this paper is to supply some volumes of the required water for a new town in the south of Iran called for Ramshar with the help of intense and devastating, but rare regional rains. The aim is to supply water from the rains and store it in a covered lake near Ramshar. This paper conducts a case study to find the reasons of depletion of the regional water resources, to apply the hydraulic routing method, to make the storage, and to use the water according to a hydrosocial change balance program timely. This paper suggests the practical model to supply water before every new town building. The model is a supportive and feasible tool to overcome the serious dilemma everywhere similar Ramshar

Key words: New town, water resources, sustainable development, drought, flood routing, hydro social change balance.

INTRODUCTION

Harmonious urban water supplying and building of new towns

The growing need for new towns in Iran comes from rapid increasing of the population (Mohajeri et al., 2014) and (Abdoli et al., 2014). The recent history of new town making in Iran passes a way that is very dissimilar to the way, which it should go. Now days in the dry and semi-arid climates, people need water for drinking, industrial needs, and agricultural uses to supply food, hygiene, and living requisites at least acceptable standard. This paper similar major scholars understands that new towns are necessary for Iran, but there is not enough water to build new towns (Shahraki, 2014). So, this paper is to give natural water resources beforehand the process of planning, designing, and building of new towns. The current custom is to build new towns after demanding and the pressures of the desperate people. The present style does not include pre-studies to find out suitable sites with necessary natural resources and water assets for a new town so that Klinken et al. (2012), Tsinda et al. (2015), Nhapi (2015), Broto et al. (2015), Wray and

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Cheruiyot (2015) and Davies (2015) argued that for the rapidly expanding and unplanned settlements and towns, water service provision presents a different challenge. At the present, Iran builds new towns without ensuring of the necessary water resources and with no planning of essential water supply infrastructure and distribution networks, that is Hakiminejad et al. (2015) and Yazdani et al. (2014). Therefore, people are not willing to live in the new towns, the new towns are vulnerable, and they are not sustainable.

This paper focuses on the need for provision of water resources before the process of planning, designing, and building of a new town. It highlights the need for management of likely water resources while Morris (2007) suggested to plan and to manage with respect to the local particularities:*"The issues that should be examined in a water resource management plan necessarily vary with the nature of the area and its water management problems"* (Morris et al., 2007:4).

As has been said housing and new town building projects in central and southern parts of Iran faced with the non-existing of needed water resources and so they are not sustainable. How shall Iran plan, design and built a new town to meet the needs of its inhabitants and sustainable result? After six decades of the new town buildings, the question still exists. The new towns of Iran in the southeast part of the country have more and less the condition, that Tomasella illustrated for Amazona area*:"Drought, fire and their interactions play an important role in the carbon dynamics, vegetation–atmosphere interactions, hydrology, and health of Amazon ecosystems, and in the livelihoods of Amazon residents"* (Mareng et al., 2008:1775). The regional inhabitants are damaging the built environments with ignoring the feasibility studies, natural resource analysis, and none understanding of the sites of the new towns. Worse, the municipal organizations and management bodies are unable to give the necessary knowledge and skills so that they did not meet their targets (Shahraki, 2014).

In essence, our problem now is a two facial problem. From one side the growing regional people are demanding more urban neighborhoods and from the other side the increasing population damages the natural water resources. This two facial problem has been deepened by the time passing and has reached at a serious level now. At the present, Iran must plan, design, and build new towns and supply water resources for urban consumption simultaneously. In fact, no room to lower the importance of planning water infrastructure including water supply, water distribution, and building of water reservoirs in the first step of the new urban planning, designing and building process. Therefore, the problem has a natural dimension when the region experiences drought and less precipitation so that the available water volume is short indeed (Klare, 2015; Gorelick and Zheng, 2015; Mahmoud et al., 2015). In fact, the out way is to control seasonal floods, to collect and gather the obtained water from possible catchments and use them in the new towns.

This study aims to introduce the main roots of the degrading of the water resources, which hinder the building of the new towns, and to suggest a practical model for new town planning, designing, and building. The model includes the provision of needed water. So, this paper is going to present a model for reserving the needed urban water and building of the new towns simultaneously. It encourages the urban developers to revise their current work method and to supply a part of urban water from the sudden and destructive floods before building of any new town in the region.

The hypothesis of this paper is on the fact that new towns without supplying of needed water resources will disable to settle the people successfully. It presumes that in practice a successful systematic planning, designing and building model requires simultaneous attempts to give the water resources and to build the new towns. This paper believes that the comprehensive plan of every new town should trust on realization of provision of the needed water resources, water supply infrastructures, water distribution networks, and urban water management programs. In the other word the water anxiety shall be addressed before any finalization of the new town building plan.

This research uses both theoretical and laboratory methods. It reviews the literature on the natural resources, water resources, drought that degrades the water resources, water supply and reserving, new town building and link between the constructing and needed water resources. The laboratory method of this paper is the strategy of a case study implementation. It analyzes the case of the new town of Ramshar by help of field observation and direct seeing and feeling of the problems.

To set up a real model for planning, designing and building of the new town of Ramshar this paper used practical hydraulic engineering rules to first supply urban required water for the new town of Ramshar and then to distribute the collected and stored water among the urban consumers for various needs. Ramshar has neither surface water nor ground water therefore; the method of hydraulic flood routing has been selected to predict the harmful floods with the help of the hydro graph technique aiming to calculate the volume of likely available water. It had to predict the floods and then route the flood basin aiming to gather the sudden huge volume of waters into a storage lake and to use according to a hydro social change balance program. Since the region rarely experience seasonal sharp short standing, but destructive rain falls and floods the technical methods shall be suitable for the particular features of Ramshar.

Water scarcity in the mirror of the literature

Awareness of hydrological conditions in each region can help to optimal planning for required water resources and water management (Valipour, 2013) suggested a Surface water supply index (SWSI). The index is one of the most important hydrologic parameters for study of drought and flood periods in basins. Author has used SWSI in Colorado and Oregon in United States. The study has shown that population growth is a significant indicator.

Population growth parallel to degradation of natural resources forced today's urban planners to focus on sustainable development, particularly in developing countries. Ho (2007) defines sustainable urban development as: *"Sustainable urban development improves the long-term social and ecological health of cities and towns"* (Ho, 2007:16). Many scholars and experts argue that modern lifestyles and distance from a natural life use too many natural resources. They argue that the current lifestyle causes much polluting and destroys the ecosystems. They resulted that continuation of the present trend causes climate changes. The scholars in the fields of urban and regional planning and natural sciences, that is, Barbosa and Villagra suggest changing the current wrong trend (Barbosa and Villaga, 2015). The building of new towns links with the sharp growth in population numbers and huge demands for homes. While the new town building requires adequate water resources, the world concerns with water resources as Merret (2002) wrote *"In addition to the increase in the world's population in the early years of the new millennium there is a second source of anxiety about the future availability of global water resources for people"* (Merret, 2002).

Shahraki (2014) described that during the recent six decades the demands to new towns were the result of the growth of the urban areas and metropolises. In Iran, new towns' projects were usually associated with the idea of management of population and solving of immediate urban problems like demand for homes, the need for other urban spaces, anarchical traffic regimes, and pollution. Therefore, the planning process for new towns was not integrated with the idea of sustainability and experiences prove that they did not meet the targets. Housing and town building projects are still going in wrong directions. Owing to the price of the water resources to plan, design and build a new town the developers shall understand natural and human made roots of the water depletion in the regions. The degradation of natural resources and disappearing of water resources in Iran is an important obstacle to build new towns. To react the impact of the climate change and natural hardness (Hossain et al., 2015; Ball, 2015; Beach et al. 2015; Collard et al., 2015) and many other scholars have been suggesting less water use. The recommendation of the scholars is understandable particularly when drought is the biggest problem in the way of sustainable building so the new towns shall use less water as much as possible.

Major scientists in climate studies, that is, Mullin and Rubado (2015) and Basher et al. (2015) believe that drought persists for several years; even a short intense drought can cause significant damages and harm the local people and their lives. Drought degrades the quality of existing water resources. It depletes the water resources in the drought regions, stops the new town building, and causes a dangerous water crisis. Understanding the reasons of drought suggests that the drought accelerates still the rapid growth of population. The growth undoubtedly has direct consequences for the environment.

Poverty is a significant reason of the drought. There is obvious how desperate is the national finances in poorer regions. To analyze the reasons of the drought in Sistan plain first the need for Helmand water in the two neighboring countries shall be named. Though, the rush of farm workers to big cities and bankruptcy of farms contributed to the drought. The drought remained the following impact on natural resources of the Ramshar region:

1. Erosion of lands and soils
2. Disappearing of surface water resources and falling the level of water in wells and underground resources.
3. Agricultural drought in the region as transforming of farms into sand dunes
4. Disappearing of surface vegetation and plants
5. Creation of brutal hazarding storms of sand dunes
6. Socioeconomic results poverty.

There is evidence to suggest that drought in the region is continuing to accelerate. A number of scholar uses the term of "catastrophe" as Mojtahedzadeh (2001) wrote Hamoon lake catastrophe, the most similar to Oral lake catastrophe. Generally, the drought damages natural resources. Natural resource degradation is the most dangerous enemy of the access to water for the population in these regions.

Drought is experienced as a period with rainfall below the average or on the other word with evaporation many times more than precipitation (Johnson and Sharma, 2015). Arid and semiarid environments have the special characteristics which the developers shall understand before any new town building in the regions. Rainfall in the region is not regular and it is sparse and rarely strongly pulsed (de Jode, 2015). Since regional people

Figure 1. Place of Ramshar new town in the region. Source: Google maps, Ramshar in Sistan and Baluchistan.

do not have the technologies and infrastructure to save the precipitation and use it timely such rainfalls are caustic. The task of planning, designing, and building of new towns in the regions first requires methods to hinder the ongoing degradations of water resources and to supply new water from the said floods.

The regional new towns in the mirror of practice, the case study

The new town of Ramshar has been planned two decades ago. It is one of the most obvious unsuccessful cases in sustainability. Apart managerial reason the failure has the fundamental classical planning problems. This observation introduces the problem of water depletion as a main hinder to develop the new town of Ramshar. Since Ramshar is close to border of three countries Iran, Afghanistan, and Pakistan, it has an international position. Ramshar is 40 km south of Zabol city, along the Zabol-Zahedan road in Sistan plain. Sistan is the continuation of Helmand river basin mainly in Afghanistan. Figure 1 shows red marked the position of Ramshar in Iran.

A 1000 ha land on the Sistan plain is to make the new town of Ramshar. The target was to settle 70000 people in Ramshar, but it failed. Ramshar as an arid region has not much precipitation. For climatic perspective, Ramshar is in an arid region and it has a desert climate with a hot and dry weather and no place for rains. Therefore, this study shall not count on the regular and normal precipitation. However, arid climates have the special characteristics; rainfall is sparse, rarely strongly pulsed, and unpredictable. Ramshar shall supply required technologies and infrastructure to save the precipitation and use it timely. Ministry of housing and town building has calculated the necessary water volume for supposed 70000 inhabitants per year (Table 1).

Since Ramshar's climate is arid, every person needs 200 L per day, of which 40% for household uses and 60% for other needs. Thus, Ramshar needs $200 \times 70000 = 14000000$ L water per day and 5110000 cubic meters per one year. To develop the new town of Ramshar hydraulic knowledge of the area is necessary at two stages. The first stage is planning when the general plan of Ramshar is being decided. Estimations of the discharge hydrographs on the natural watercourses and computation of possible water resources shall be done during this phase. The second stage is selection of details such as designing of the storm water channels and pipes to carry the water to consumers. The region has a gigantic, sensitive and complicated hydraulic system that includes three parts:

1. Helmand/Hirmand River as a water importing river to the plain- The name of Helmand in Iran is Hirmand. It originates from the western edge of the Hindukoosh Mountain that ranges 40 km west of Kabul. The Helmand takes the course of southwest direction and gathers several tributaries. It ends at the border of Iran and spills into the lake of Hamoon. The total length of the river is 1050 km and the catchment area is 370000 km^2.

The Helmand river system feeds mainly snow and rain falling on the mountain of the upper reaches.

2. Hamoon Lake- Hamoon Lake with its sweet and qualified water was the most important lake in the region. Satellite photos proved that the lake occupied an area of 520000 ha during the water full periods. During the dry periods, it declines considerably down to 120000 ha. During the dry times Hamoon was separated into three parts; Poozak Hamoon, Saberi Hamoon and Hirmand Hamoon. Usually the level of Hamoon water began to rise from February gradually and reached to its greatest level in the June. The changes were directly connected to the volume of Hirmand importing water. Unfortunately, at the present time the lake is dry, and it has been transferred to a source for sand dune storms and many environmental hazards.

3. Overflowing water from Hamoon Lake into the Shieh- In water full-time, floods and overflowing water come to the Hamoon and then to the Shileh Shileh locates south of Hamoon and acts as a spillway and a main drainage. This seasonal and usually dry river is 100 kilometers long and ends to Afghanistan territory. The water that passes from Shileh during a flood is significant for planning water storage and water infrastructure network in Ramshar. The overflowing water volume is between two billion up to 15 billion cubic meters (Ministry of housing and town building, 2000). Again, this study acknowledged that the first priority of new town planning, designing, and constructing is the water supplying. The field observation suggests that every new town shall think on the irregularities in regional rains. Therefore, controlling of floods and collecting of the sudden rains are essential. This case study understood that the basic water resource in the region is the rarely floods when the Helamnd flow is blocked normally. In addition, this case study is suggesting planning and building a hydraulic construction in the shape of a huge covered lake to protect future stored waters from hot sun shines and evaporations. This case study also found out the best place for the water reservoir is on the bed of Shileh in south of Ramshar and alongside of the Zabol-Zahedan road as illustrated in the following map.

Model of sustainable new town building with hydro social change balance program, MSNHP

As has been said earlier the major water resource in the region was the Helmand River traditionally. Since Helmand originates in Afghanistan and owing to an international dispute on its water Ramshar shall supply water in the place. A major technique to supply needed urban water in an arid region with none underground resources is to forecast the irregular sharp floods. A common problem facing in practice is the estimation of the rise of Shileh River at any given point in the stream during the course of a flood event. This study has resolved the problem with the help of the technique of flood routing while it pursued the behavior of a flood hydrograph from the upstream point to downstream point. Eleven stations with one kilometer distance of each other were observed. During the famous hazardous 1993's flood the water volumes were calculated at the eleven stations with the help of direct measurements. According to Figure 2, station 1 was at a point parallel to Ramshar and Station 11 with eleven kilometers distance was on the bed of Shileh. Table 2 reports the volume of water at eleven stations for upstream and downstream positions:

Using the data in Table 2 it was possible to sketch a flood hydrograph for Shileh as the flood water flowed downstream into the desert area southeast of Ramshar. In the hydrograph first, the time of the peak rate of flow occurred upstream at station 1 known as translation. Second, the size of the peak rate of flow at the downstream point went down at point 11, which was in south of Ramshar on the bed of Shileh known as attenuation there the shape of hydrograph flattened out. With the help of classic continuation equations the volume of supplied water has been calculated.

This study applied also the hydro social change balance program for Ramshar to manage the supplied water by the flood routing technique. It has been used for a five-year period. Table 3 as every generic form has both supply and use categories sides. The table reports the data for a defined interval time, 2010-2015.

Calculating of the total volume of rainwater collection item is possible by the direct engineering gauging during the flood time. Other categories of supply have been ignored owing to none existence. The calculation verified that the total net supply is approximately 6270 billion cubic meters much more than the total use side almost 462 billion cubic meters. The analysis proved that the flood routing technique and the covered lake are going to be helpful and feasible. The hydro social change balance presented by this model helps to decide the quantitative and qualitative features of the hydraulic reservoirs that Ramshar needs. By this model, Ramshar can collect the floodwater and use it in its water management program. At a time when none other resource exists investment in this model can provide Ramshar needed water.

CONCLUSION

This paper discussed a paradoxical problem that while the number of the population was growing continuously the devastation of natural resource has prevented the building of new towns. This paper proved that the dilemma originated from climate changes, natural hazards, environmental catastrophes, poor management, and failures of new town programs. The study understood the depletion of water resources as the main problem for urban developments. This paper illustrated the situation that from one side the earlier built cities concern on the

Table 1. Total average Ramshar's urban water consumption for one year per cubic meter.

Number of population	70000
Water needed for household uses per cubic meter	5600
Water needed for other needs per cubic meter	8400
Total water needed per day per cubic meter	14000
Total water needed for one year per cubic meter	5110000

Reference for data: Ministry of housing and town building, 2000.

Figure 2. Place of Shileh river near Ramshar. Source: Google maps.

Table 2. The volume of water per cubic meters during Shileh flood at eleven stations.

Station	1	2	3	4	5	6	7	8	9	10	11
Upstream volume	10000	2000000	500000000	5000000000	15000000000	12000000000	6000000000	1000000000	500000000	10	0
Downstream volume	10000	2000000000	3000000000	4000000000	2000000000	1000000000	300000000	200000000	1000000	10	0

Reference for data: Ministry of housing and town building, 2000.

needed water and experience non-sustainable and from the other side no water to build new neighborhoods and new towns. Therefore, this paper understood that the building of new towns or expanding of existing urban areas in the present condition should include provision of water resources in its job. The case study of this paper observed the new town of Ramshar in an arid climate and saw that the volume of rainfall and available water was

Table 3. Hydro social change balance for Ramshar during the five years.

Categories of supply	Per year	Categories of use	Per year
Rainwater collection	6270000000	Urban needs	5110000
Groundwater abstraction	-	Agriculture	450000000
Aquifers	-	Commercial sectors	1220000
Import of water from other regions	-	Manufacturing	--
Less; supply leakage and evaporation	-	Public services	3800000
-	-	Other uses	2000000
Total net supply	6,270,000,000	Total use	462,130,000

Reference for data: Shahraki, 2014.

much less than the new town needed. Therefore, strategies, innovative projects and investments to overcome the problem of water in the region are needed. Programs such as control of population growth and family planning, increase of environmental awareness, regulation of natural resource use and international collaborations are helpful. This paper suggested a new possibility to supply the needed water by floodwaters. The case study proved that the flood routing technique is a possible procedure to control the seasonal sharp floods and to store huge volumes of water. Then, the hydro social change balance technique manages the gathered water to use it timely. This paper presented the Model of Sustainable New town building by Hydro social change balance Program, MSNHP. The model sets the water supply in the earliest step of a new town building process. The MSNHP depends very much on the nature of the problem, the data available, local characteristics, and general necessities. The MSNHP will revise and progress the current failed trend of the regional new town buildings towards sustainable, planned and successful developments.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Classical and Bayesian Markov Chain Monte Carlo (MCMC) modeling of extreme rainfall (1979-2014) in Makurdi, Nigeria

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This study presents a probabilistic model for daily extreme rainfall. The Annual Maximum Series (AMS) data of daily rainfall in Makurdi was fitted to Generalized Extreme Value (GEV) distribution using Maximum Likelihood Estimation (MLE) and Bayesian Markov Chain Monte Carlo (Bayesian MCMC) simulations. MLE is a reliable principle to derive an efficient estimator for a model as sample size approaches infinity. Results in this study show that despite the asymptotic requirement of the MLE, its performance can be improved when adopting Bayesian MCMC. The comparison between the performance of MLE and Bayesian MCMC methods using Percent Bias (PBIAS), Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) proved Bayesian MCMC is the better method to estimate the distribution parameters of extreme daily rainfall amount in Makurdi. Based on the 36-year record of rainfall (1979-2014) in Makurdi, return levels for the next 10, 100, 500, 1000 and 10000 years were derived.

Key words: Extreme daily rainfall, generalized extreme value distribution, parameter estimation, t-year return level, Makurdi.

INTRODUCTION

Recent researches and observations of the climate system have shown that the climate system is more complex than concluded by the working group 1 of the Intergovermental Panel on Climate Change report (IPCC, 2007). According to Pielke (2011) these climate systems models do not appear to be capable of providing skillful predictions of regional, local societally and environmentally important impacts in the coming decades.

Earlier studies such as Houghton et al. (1990) reported that the Earth's climate is warming and will continue to warm in the future, as a result of changes in atmospheric carbon dioxide (CO_2) and other trace gases. This global warming will lead to changes in annual or seasonal

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precipitation. Valipour (2015) studied runoff forecasting in the United States using seasonal autoregressive integrated moving average (SARIMA) and autoregressive integrated moving average (ARIMA) for data from 1901 to 2010 (mean of all stations in each state). In this study, it was reported that the accuracy of the SARIMA model is better than that of the ARIMA model. The occurrence of many extreme events in hydrology cannot be forecasted on the basis of deterministic information with sufficient skill and lead time. In such cases, a probabilistic approach is required to incorporate the effects of such phenomena into decisions. If the occurrences can be assumed to be independent in time, that is, the timing and magnitude of an event bears no relation to preceding events, extreme hydrologic frequency analysis (HFA) can be used to describe the likelihood of any one or a combination of events over the time horizon of a decision (El Adlouni and Ouarda, 2010).

Valipour (2012) and Valipour et al. (2013) studying inflow into Dez dam reservoir in Iran used 47 years (first 42 years was used to train the model and past 5 years was used to forecast). In these studies they reported that the Auto Regressive Integrated Moving Average (ARIMA) had less error compared with the Auto Regressive Moving Average (ARMA). The superiority of ARIMA over ARMA was due to the effect output delay as an input to the network and increasing network training power.

Olofintoye et al. (2009) in studying the best–fit probability distribution model for peak daily rainfall of selected Cities in Nigeria including Makurdi, used different statistical analyses such as Gumbel, Log-Gumbel, Normal, Log-Normal, Pearson and Log-Pearson distributions and the parameters of the distributions were estimated by the methods of moments (MOM) and probability weighted moments (PWM). Isikwue et al. (2012) established an empirical model that correlates rainfall intensity-duration-frequency for Makurdi over a period of 30 years**.** The study also showed a linear relationship between the rainfall amounts and their corresponding duration. Valipour (2012) worked in Iran on number of observation data for rainfall forecasting reported that in temperate climate, due to low changes of monthly rainfall in long years, 60 observation data was enough to forecasting. Ramírez et al. (2005) used artificial neural network (ANN) technique for rainfall forecasting applied to the São Paulo region. The results showed that ANN forecasts were superior to the ones obtained by the linear regression model thus revealing a great potential for an operational suite. Han et al. (2010) forecasted drought based on the remote sensing data using Auto Regressive Integrated Moving Average (ARIMA) model successfully. Chattopadhyay and Chattopadhyay (2010) compared ARIMA and Auto-Regressive Neural Network (ARNN) models using Univariate modelling of summer monsoon rainfall time series.

Coles (2001) considered Maximum Likelihood Estimate (MLE) as the best method because of its all- round utility and adaptability to model-change. This means that, the underlying methodology is essentially unchanged even though the estimating equation is modified. One of the drawback of this method is its asymptotic requirements and a common problem in extreme value analysis is that of data scarcity. An alternative is the Bayesian approach which can be used in estimating the parameters of GEV. This approach is increasingly popular in many areas of application, a challenge when adopting this approach is the computational difficulties. This may be solved by the application of Markov chain Monte Carlo (MCMC) simulations. As noted by Eli et al. (2012) extreme data are limited in nature however, Bayesian inferences have the ability to incorporate other source of information via prior distribution. Bayesian analysis is not dependent on regularity assumptions required by asymptotic theory of MLE. Studies such as Coles and Tawn (1996), Bates and Campbell (2001), Coles et al. (2003), Smith (2005), Fawcett and Walshaw (2008) and Zin et al. (2012) have also shown the applicability of Bayesian inference using MCMC in extreme rainfall analysis.

Recent studies such as Abah (2013) show that Makurdi town is potentially susceptible to flooding in the event where there is a prolonged or intense downpour which could cause flash floods and raise the volume of the River Benue to tremendous levels making it over spill its banks. Frequent occurrences of droughts and floods in the past have severely affected the economy of Benue State, which depends primarily on agriculture. It is necessary to have a quantitative measure with high accuracy or likelihood on extreme rainfall events which can be utilized in the design and construction of hydraulic structures, planning of soil and water conservation practices and other agricultural activities**.** The main objective of extreme rainfall modeling is to estimate the values of rainfall amounts that might occur once in 10, 50 or 100 years, based on 10-year or 30-year history of rainfall. An accurate prediction of these events can significantly aid in policy making and also in designing an effective risk management system. Hence, there is a need to know the magnitudes of extreme rainfall events and their recurrence intervals over Makurdi as it continues to experience seasonal flood events induced by high rainfall magnitudes.

MATERIALS AND METHODS

Study area

Makurdi the administrative headquarter of Benue State, Nigeria lies approximately between latitude 7°44^{1}N and longitude 8° 54^{1}E. The town is located along the coast of the Benue River (Shabu and

Tyonum, 2013). The land use in and around Makurdi is agricultural and the farmers mainly produce rice since it is a low land area. The area is in the tropics and has two seasons dry (May - October) and wet (November - April). The average annual temperature is 31.5°C while the relative humidity ranges between 65 to 69% with annual rainfall varying between 1000 to 2500 mm (Isikwue et al., 2011).

Data collection

Thirty-six years (1979-2014) daily rainfall data of Makurdi was collected from the Nigeria Meteorological Agency (NIMET), which has its base station (rain gauges) at Nigeria Air force Base (NAF) Makurdi, Nigeria.

Analysis of extreme daily rainfall in Makurdi

The Generalized Extreme Value distribution (GEV) which has three parametric subsumes (Gumbel; Type I, Frechet; Type II, and Wiebul; Type III) was fitted to the Annual Maximum Series (AMS) data utilizing Maximum Likelihood and Bayes methods of parameter estimation with the intention of determining the magnitudes and return periods of extreme daily rainfall in Makurdi.

The cumulative distribution function (cdf) of GEV is given as:

$$F(x) = Pr\{X \leq x\} = exp\left\{-\left[1+\xi\left(\frac{x_i-\mu}{\sigma}\right)^{\frac{1}{\xi}}\right]\right\} \quad (1)$$

$$\text{For} -\infty < x < \infty$$

Where: $F(x)$; = the probability of an event not exceeding x, x = input variable representing the daily maximum rainfall amount (mm); X = random rainfall variable, exp; = the exponential or naperian logarithm, μ; = the location or relief parameter, σ; = scale parameter, is a function of the drainage and rain gauges network, and ξ; = shape parameter which controls the tail behavior of the probability distribution. It has a value of $\xi = 0$ for Type I, $\xi > 0$ for Type II and $\xi < 0$ for Type III.

Maximum likelihood estimation (MLE)

The maximum-likelihood approach is an example of classical statistical modeling in which the parameters are assumed to have fixed values that we are trying to estimate as precisely as possible. MLE requires us to maximize the likelihood function $l(\mu,\sigma,\xi|x)$ with respect to the unknown parameters. The Generalized Extreme Value model ($\xi \neq 0$), is given by Coles (2004) as:

$$l(\mu,\sigma,\xi|x) = nlog\sigma - \left(1+\frac{1}{\xi}\right)\sum_{i=1}^{n} log\left[1+\xi\frac{(x_i-\mu)}{\sigma}\right] - \sum_{i=1}^{n}\left[1+\xi\frac{(x_i-\mu)}{\sigma}\right]^{-\frac{1}{\xi}} \quad (2)$$

Provided that $1+\xi\frac{(x_i-\mu)}{\sigma} > 0, i = 1, \ldots, n$

Bayesian method of estimation

In the Bayesian modeling technique parameters are treated as random variables, with probabilities assigned to particular values of a parameter to reflect the degree of evidence for that value. This include a posterior density of interest, $\pi(\mu,\sigma,\xi|x)$ that is proportional to a prior distribution, $\pi(\mu,\phi,\xi)$ and the likelihood function, $L(\mu,\phi,\xi|x)$that gives the most likely parameters that generated the obtained data at hand and is given by Equation (3) with σ replaced bye^{ϕ}.

$$\pi(\mu,\sigma,\xi|x) \;\alpha\; \pi(\mu,\phi,\xi)\, L(\mu,\phi,\xi|x) \quad (3)$$

This approach is based on Smith (2005) was used on Bayesian modeling of extreme rainfall data for South-West England and also by Fawcett and Walshaw (2008) on modeling environmental extremes. The results in this section were obtained following the guidelines of Stephenson and Ribatet (2015) using the *evdbayes* package in *R* statistical programming environment (*R* Studio).

In the Bayesian approach, the MLE estimates of the GEV parameters μ, σ and ξwere utilized as the initial values for the MCMC simulations which were then used to produce trace plots and marginal posterior densities. From the simulated samples in the MCMC run we obtained the posterior estimates of the parameter vector (μ,σ,ξ) which is a stationary distribution that is slightly dependent and approximate from our target distribution, $\pi(\mu,\sigma,\xi|x)$.

Comparison of the performances between MLE and Bayesian methods

The Performances of both methods of parameter estimation were analyzed based on Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Percent Bias (PBIAS) obtained from Monte Carlo simulation. PBIAS measures the average tendency of the simulated values to be larger or smaller than their observed ones. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate overestimation bias, whereas negative values indicate model underestimation bias.

After the best models for the data have been determined, the next step was to derive the return levels for rainfall. Formally, the cumulative probability of non-exceedance is given by:

$$F(x) = P(X \leq x_T) = 1 - \frac{1}{T} \quad (4)$$

Where T = return level.

Solving for x_T using the definition of the GEV distribution yields:

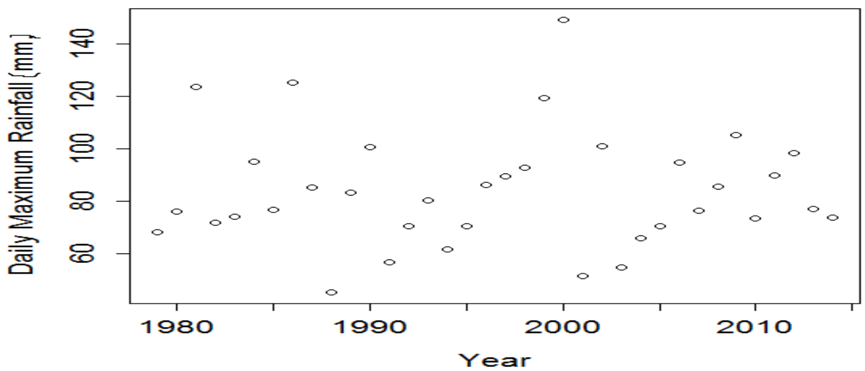

Figure 1. Scatter plot for annual maxima rainfall in Makurdi.

Table 1. Estimates of parameters using maximum likelihood estimator.

Models	$\hat{\mu}$ (se)	$\hat{\sigma}$(se)	$\hat{\xi}$(se)	$l(m)$
$Model_1$: Weibull	74.5 (3.4)	18.1(2.4)	-0.1	-159.7
$Model_2$: Gumbel	73.9 (3.1)	17.8 (2.3)	0(0.1)	-159.9

$$x_T = \begin{cases} \mu - \frac{\sigma}{\xi}\left[1 - \left\{-ln\left(1 - \frac{1}{T}\right)\right\}^{-\xi}\right], & \xi \neq 0 \\ \mu - \sigma ln\left(-ln\left(1 - \frac{1}{T}\right)\right), & \xi = 0 \end{cases} \quad (5)$$

Finally the 95% confidence intervals were also obtained using:

$$mean\ (x_T) \pm 1.96\sqrt{var(x_T)} \quad (6)$$

RESULTS

Classical and Bayesian models for extreme daily rainfall

The time series plot of annual daily maximum rainfall for Makurdi in Figure 1 shows that the highest magnitude of 149.3 mm occurred in the year 2000. While this high magnitude appears as an outlier, there is historical evidence that it did occur (according to Ologunorisa and Tor, 2006), in a year characterized by rampant flooding in rural and urban regions of Makurdi, which led to loss of lives, disruption of economic activities, destruction of agricultural lands and other properties.

The blocks n = 365 days have been chosen to be reasonably large, so we fitted our Models to the N = 36 annual maxima using maximum likelihood estimation. We obtained fitted parameter values for $Model_1$: Weibull and $Model_2$: Gumbel, standard errors in parentheses and the maximized log-likelihood values for the fitted models $l(m)$ are given in Table 1.

The Markov Chain Monte Carlo (MCMC) techniques were then applied to give the Bayesian parameter quantiles of the annual maxima rainfall data using non-informative priors. Table 2 present results for the Bayesian posterior parameter estimates of the Generalized Extreme Value (GEV) distribution ($Model_1$), the associated naive standard errors and the 95% credible intervals (CI) of the parameters μ,σ and ξ.

Test of goodness of fit of the extreme value distributions

Analysis of tail behaviour

Visualization of the goodness of fit of the Generalize Extreme Value distribution to the observed data is presented in Figure 2 (GEV: Model). This include probability, quantile, return level and density plots.

Trace plots

Convergence of the simulated distribution to the target or

Table 2. Bayesian MCMC parameter estimates of ($Model_1$).

Posterior parameter	Estimate	Naive SE	95% CI
μ	73.4	0.03	66.7, 80.1
σ	18.6	0.03	14.7, 24.9
ξ	-0.03	0.0	-0.2179,0.2

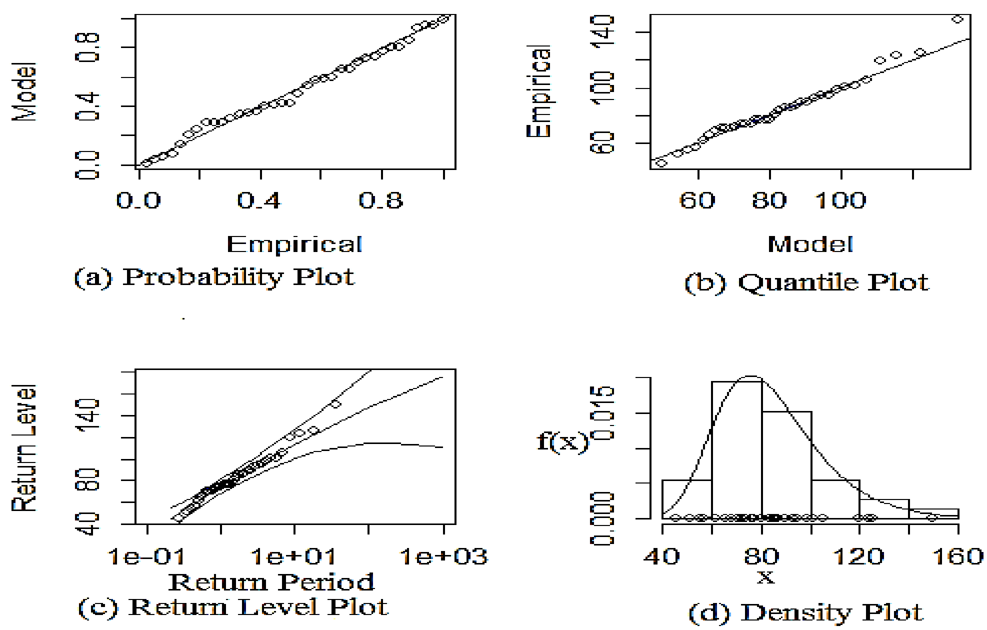

Figure 2. Diagnostic plots of the MLE approach for $Model_1$.

stationary distribution is visualized by the trace plots in Figure 3. The trace plots looks like a horizontal band, with no long upward or downward trends, the Markov chain seems to be mixing well enough and is likely to be sampling from the stationary distribution, this is evidence that the chain has converged. The Figure 3 also shows density plots for each parameter.

Table 3 presents results of the Percent Bias (PBIAS), Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) which are values computed by comparing the observed values of maximum daily rainfall in Makurdi to the simulated values from the formulated models using MLE and Bayesian MCMC approaches.

Extreme rainfall magnitudes for various return periods

The various return periods of the annual maximum rainfall are presented in Table 4. The inversion of $Model_1$ (Equation 5) yielded maximum likelihood estimates of return levels (mm) with their respective 95% confidence intervals (Equation 6) and the posterior medians defined on a 95% credible interval using non-informative prior.

The return level and return period are some of the most important quantities derived from the fitted models. The plot of x_T vs $-\log(-\log(1-p))$ is called a return level plot (Figure 4) which visualizes the return level estimates (solid line), the 95% upper and lower credible intervals (dashed lines) in the Bayesian framework.

DISCUSSION

The classical and Bayes models

The *ismev* package in R-studio yielded maximum likelihood estimates ($\hat{\mu}$,$\hat{\sigma}$, $\hat{\xi}$) of (74.5, 18.1, -0.1); with standard errors (3.4, 2.4 and 0.1) for $\hat{\mu}$, $\hat{\sigma}$, and $\hat{\xi}$

Table 3. Comparison of performance between maximum likelihood and bayesian methods.

Method of estimation	PBIAS (%)	MAE	RMSE
MLE	7.3	0.2	0.3
Bayesian MCMC	-7.5	0.2	0.3

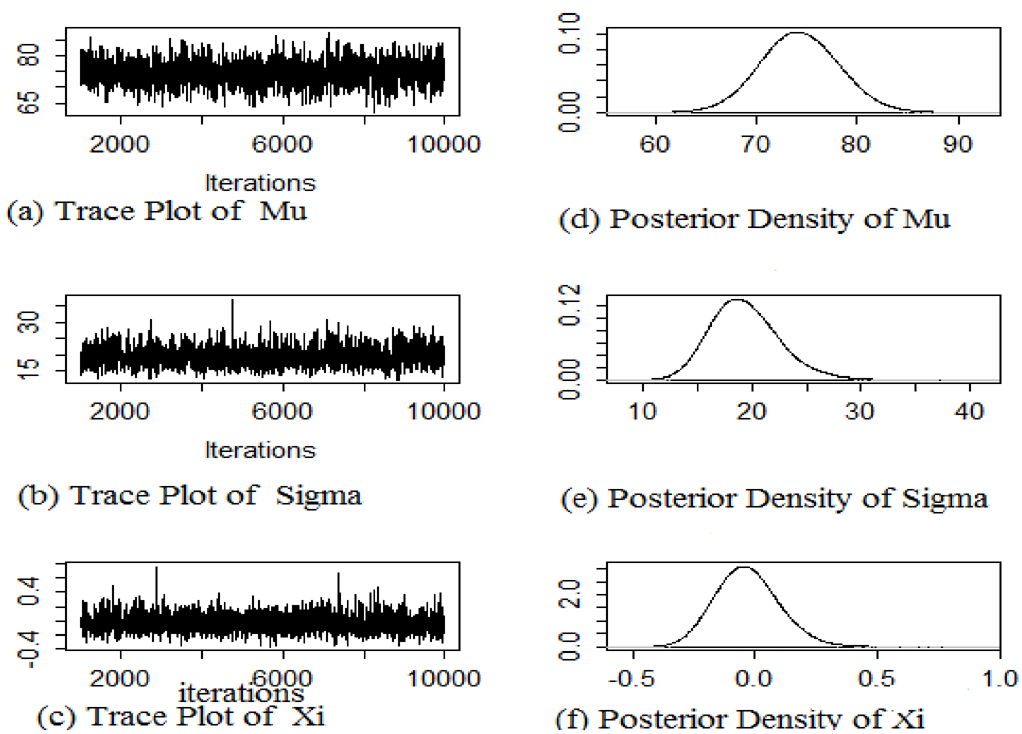

Figure 3. Trace and posterior density plots of the parameters of $Model_1$.

respectively. Resulting approximate 95% confidence intervals for each parameter are 67.9 and 81.1 for $\hat{\mu}$, 13.5, 22.7 for $\hat{\sigma}$, and -0.3, 0.2 for $\hat{\xi}$. This shows that although the estimate of the shape parameter is negative, the 95% confidence interval extends above zero, highlighting the uncertainty of estimation. The negative shape parameter and the diagnostic plots such as the probability and quantile plots (Figure 2) show each set of plotted points to be near linear, validating the use of the GEV. $Model_2$ shows only that a zero shape factor, ξ is also consistent with the data though the standard errors are smaller and the deviance statistics which is twice the difference between the absolute values of the negative log-likelihood of both models is also small. Anderson and Smith (2006) argues that even if formal tests support model reduction from GEV to Gumbel, unless there are external grounds distinguishing the value of zero for ξ, the GEV model should be preferred, as its conservatism gives increased protection. The ξ falls within the range of $-0.3 \leq \xi \leq 0$ which coincides with the most likely range in hydrological practice indicated by Martins and Stedinger (2000). Furthermore, as a cautionary principle since there are no other grounds for assuming $\xi = 0$, it seems safest not to.

The Bayesian MCMC estimates suggest that there is a finite upper endpoint to the distribution since the shape parameter is negative, again validating the use of $Model_1$ (GEV) and this supports Koutsoyiannis (2004) comment that the wide spread use of the Gumbel distribution is related to the fact that sample sizes are often small.

Performance of the MLE and Bayes MCMC parameter estimation methods

There are small differences in the parameter estimates

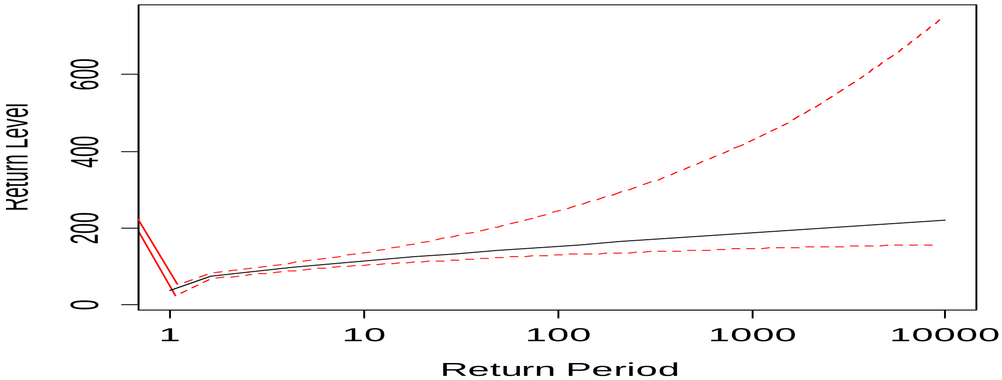

Figure 4. Return level plot of posterior distribution with 95% Bayesian credible intervals (dashed lines) in Makurdi.

Table 4. Return level estimates using MLE and Bayesian MCMC for Model$_1$.

Return period: T (Years)	MLE: x_T (mm)	Bayesian MCMC: x_T (mm)
10	112.7(102.3, 131.7)	116.3(102.4, 134.4)
100	147.2(127.9, 217.3)	157.1(133.8, 264.7)
200	156.6(132.9, 251.1)	168.6(139.5, 312.9)
500	168.3 (138.1, 304.5)	183.4(142.3, 345.9)
1000	176.8(143.0, 352.9)	194.3(146.4, 407.9)
10000	202.5 (154.6, 506.3)	228.8(155.8, 684.7)

for both methods this is expected since a near-flat prior has been used. The MCMC method seems to reduce the RMSE and MAE which is a useful property since it reduces the potential locations of the estimate or uncertainty of the estimate. The PBIAS (Table 3) is slightly higher for Bayesian MCMC probably as a result of random error in simulation, they are both close to zero indicating model appropriateness.

The expected benefit of the Bayesian analysis is the improvement in precision of the parameter estimates over the MLEs. The incorporation of prior information in Bayesian MCMC parameter estimation in line with Naakaa (2015) proved to be a marginally better method compared to the MLE; the existence of data with relatively larger values (rare events) compared to other data such as the August 3rd, 2000 extreme rainfall (149.3 mm) in Makurdi may have influenced the analysis results as the analysis is based on the mean value that is rather sensitive towards any outlier in data, this demonstrates the robustness of the Bayesian approach against outliers. One of the most important derivations of this study is that future modeling of extreme rainfall in Makurdi can utilize this results as expert opinion in prior elicitation or in specifying informative prior distribution and as more information or data is collected the model can be updated.

Prediction of rainfall magnitudes for various return periods

The sequence of simulated values (μ_i, σ_i and ξ_i) were transformed leading to a sample from the corresponding distribution of return levels, x_T. This was highlighted by De Paola et al. (2013), suppose that a flood defense scheme is to be built to protect against all levels of rainfall it is likely to experience over its engineered 100 year life span. We can estimate what rain levels might occur in the coming century, given the 36 years local data available for this study the maximum likelihood estimate for the 100-year return level, x_T = 147.2 mm, with a profile likelihood of 95% confidence interval [127, 219] mm. This show that the 149.3 mm annual daily maximum rainfall event in Makurdi of 3rd August, 2000 has a return period that is above 100 years which implies that it was indeed an extreme event as defined by Coles (2001).

Alternatively Bayesian analysis considers the problem, not as one about estimating the ultimate limit parameter, but estimates a prediction interval (quantification of uncertainty), which will give more precise information about what is likely to happen in a given year, considering the previously recorded observations (Smith, 2003). From Table 4, it can be seen that the Bayesian approach gives higher quantile estimates in the upper tails than the frequentist approach, for instance the 100-year return level gives an estimate x_T = 157.1 mm and credible interval [133.8, 264.7] mm. This means that Bayesian approach gives a shorter return period for extreme events compared to the MLE method. The return levels of the posterior distribution in Figure 4 shows the upper 95% interval to be further from the median than the lower. This is because of the heavier upper tail of the posterior distribution due to the non-negative prior on ξ.

These quantities are most useful to practitioners in extreme event modeling and engineering design. As noted by Dandy (2013) culvert design, for example, involves analysis of headwater depths, along with estimations of future extreme precipitation amounts. Severe importance lies within proper estimations of stream flow and headwater depths, demonstrating high importance of a thorough methodology towards statistical analysis of climate data. This also agrees with the comment by Wendy and Noriszura (2012) that the predictions of extreme rainfall events for several return periods provide important and valuable information for the management and the planning of water resources, especially for proper drainage systems, reservoirs and surface waters and for utilizations in agricultural sectors and socio-economic activities. The information can be used to facilitate the government and other related parties in prioritizing water resources in their efforts to reduce or control the risks of large losses.

Conclusion

Statistical model of the annual maximum of daily rainfall of Makurdi has been developed through classical and Bayesian approaches. The extreme daily rainfall was shown to follow the Generalized Extreme Value distribution which has a negative shape parameter, often appealing as it has a finite upper limit. Despite the use of non-informative prior information in the Bayesian MCMC parameter estimation method it proved to be a better method compared to the MLE, this demonstrates the robustness of the Bayesian approach against outliers (rare events) and in handling data scarcity. The model was used to compute the extreme rainfall return levels in the 95% confidence and credible intervals for the return periods of 10, 100, 200, 500, 1000 and 10,000 years. Therefore, extreme rainfall and the subsequent flooding events in Makurdi can be appropriately handled by incorporating these results in the design and assessment of dam safety level and other infrastructure, such as culverts, reservoirs, flood mitigation levees and retarding basins which can prevent flooding, pollution in watersheds, and overtopping on roadways, it is therefore necessary to make inferences on their return levels crucial for designers and engineers, to the extent that they should be built into legally binding codes of practice.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

A challenge of sustaining water supply and sanitation under growing population: A case of the Gezira State, Sudan

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The challenge of securing future water supply and sanitation services for an increasing population requires continued efforts to satisfy the future needs. This paper focuses on water availability and sanitation services under growing population taking Gezira State, Sudan, as the case. Future projection of the population was predicted based on the 2.2% growth rate. Data on water sources, quantities and sanitation was collected from Gezira State Water Corporation and various health and educational reports. The results calculated that the population is increasing by 14% from 2008 to 2014. Water stands are the main source of water in Gezira and yields 84% of the available water. The current consumption rates are 22.5 and 55 Liter per capita per day for rural and urban population, respectively. There is a gab in rural water supply and is expected to increase rapidly by 2025. Sanitation coverage in the state is 80% in schools and 88% in health facilities. The study recommended construction of new water sources to satisfy the rural consumption.

Key words: Water supply, sanitation, population growth, Gezira State, Sudan.

INTRODUCTION

Continued population growth, drought and economic development, together with the expansion of irrigation has resulted in greatly increased use and need for water resources. Consequently, added to the current decline trend of / capita availability from $5.3*10^3$ m^3 / year in 1970 to the expected $1.3*10^3$ m^3 / year in 2025 (SRFAC, 2001). Sudan must develop ways and means to cope with the increasing demand for water. It has been reported that access to water and sanitation is extremely low in rural areas in Sudan (USAID, 2009). Future access to water under pressure of the increasing population is considered a big challenge, because of the competition

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between different sectors. Increasing population and subsequent increase in food (plants and animals) need careful research to put the necessary arrangements for the near and the distant future, especially for future generations. Relationships between water and other development-related sectors such as population, energy, food, and environment, and the interactions among them require analysis, as they together will determine future food security and poverty reduction (Valipour, 2015).

Comparison between available water and future increase of population is necessary for policies formulation to ensure access to water. Any shortage of water will result in deterioration in public health, especially the spread of water associated diseases. Globally, the availability of water in both quantity and quality is highly pressurized by growing population, demographic changes, particularly urbanization, agricultural and industrial expansion following changes in consumption and production patterns. As a result, some regions are now in a low safe water availability situation. Progress report on drinking water and sanitation by UNICEF and WHO (2012) explained that over 780 million people are still without access to improved sources of drinking water and 2.5 billion lack improved sanitation. It has been estimated that by 2025, the share of the world's population living in regions subject to water stress will reach 35% (Cairncross, 2003a).

Adequate water supply and sanitation protected communities from water-borne diseases and, hence, directly contribute in poverty eradication. In low income regions, only one in two people is covered by improved sanitation. WHO/UNICEF (2010*)* reported that about 2.6 billion people or 39% of the world's population lack access to improved facilities for the disposal of human excreta*.*

The World Bank estimated that rural access to safe water is as low as 14%. More than one billion people still practice open defecation. About half the world's populations live in rural locations and are typically served by small community water supplies, which are vulnerable to breakdown and contamination (WHO, 2010). Paul et al. (2010*)* has justified the reasons for the limited progress towards universal access to an adequate water supply, by high population growth rates in developing countries, insufficient rates of capital investment, difficulties in appropriately developing local water resources, and the ineffectiveness of institutions mandated to manage water supplies. Gezira is one of the most densely populated regions in Sudan, because of location and availability of economic activities. This makes Gezira population grow by a rate more than the normal rate of 2.2%.

Studies in developing countries have shown wide variation in the impact of improved water supply and sanitation facilities on water related diseases (Aziz et al., 1990). In Gezira, more than 70% of populations in the villages are infected by water borne diseases mainly because of the use of the polluted irrigation canal water for their domestic water needs (Henri et al., 2002). In Gezira, irrigation practices are increasing. Increasing of irrigation systems have adverse impacts on soil and quality of water resources (Valipour, 2014). Inadequacies in water supply affect health adversely both directly and indirectly (Paul et al., 2010). Lack of access to water is the main factor of displacement because of insufficient amount of water resources to produce food for subsistence.

Shortage of water causes absence of basic sanitation associated with unhygienic practices. Lack of water directly influence education because no schooling especially for children involved in fetching remotely available water. Mortality among children below 5 years of age is expected because of diarrheas associated with contaminated and polluted water. Examining future water supply and sanitation under dramatic growing population is of a vital importance, particularly for rural people in low income countries.

METHODOLOGY

The Gezira State lies between the Blue Nile and the White Nile in the east-central region of the country. It lies between 13° 30´, and 15° 35´N and 32° 15´, and 34° E (Figure 1). Gezira has an area of 23.3 thousands km^2. The majority of the population depends on irrigated agriculture, animal husbandry and trade. Only fewer are urban population. The average rainfall in the region during the last 30 years is estimated between 250 to 300 mm per year. The mean monthly temperature is about 22°C in January and 34°C in May. Humidity is generally low (minimum in April and maximum in August). Humidity varies from 13% in the north to more than 60% in the southern part of the State.

Data collection and analysis

The data used in this paper was collected from the Gezira State Water Corporation (GWC) and other various sources as classified in Table 1. Water supply component includes improved and adequate domestic water supply for human consumption. The sanitation component includes improved and adequate sanitary facilities for households, schools and health facilities. Population data was collected from Sudan censuses of 2008 and 2010. Population projections from 2010 to 2025 were calculated by the authors based on the following population growth equation using 2.2 growth rate:

$$N = N_o e^{rt}$$

Where, N: final population; N_0: initial population; e: exponential; r: the rate of growth and t: time in year. The purpose of the following analysis is to demonstrate the impacts of an increase in population growth on water supply and sanitation and to highlight the efforts need to be exerted in water supply and sanitation sectors against static population growth. Population growth model was used to predict future population up to 2025 and then increasing population growth rate was determined (Figure 2). Available water was allotted against population to determine current and future per capita water consumption for both rural and urban population. Sanitation coverage in education and health facilities was estimated and compared with national and regional levels.

Figure 1. Gezira State location in Sudan.

Table 1. Data classification and sources.

Data type	Data package	Sources
Population in Gezira	Rural population Urban population Migrant population	Sudan population census (2008&2010) Gezira population statistical office
Population projection	Population growth $N = N_o e^{rt}$	Population growth equation
Water sources and quantities	Water stands Treatment plants Hand pumps Slow sand filters	Gezira Water Corporation data sets Gezira strategic plan NGOs (UNICEF, WHO, USAID) reports
Sanitation	Latrines in schools and health facilities	Gezira water corporation, UNICEF project Health and education reports NGOs (UNICEF, WHO, USAID) reports

RESULTS

Recent and projected population of the Gezira (2008-2025)

In 2008, the population was 3.57 million persons and expected to reach 5.2 million by 2025 based on the annual growth rate of 2.2% (Table 2). The majority (81%) of the State population are rural (3.3 million). Currently the population is increasing by 14% from 2008 to 2014 and expected to increase by 27% between 2008 to 2025.

Water availability and per capita consumption in Gezira

The results show that water stands constitute the main source of water for rural (88.4%) and urban (73%)

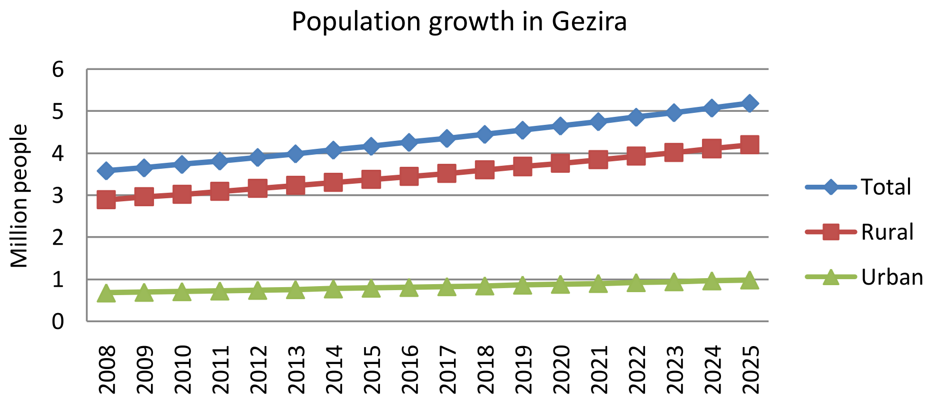

Figure 2. Gezira Urban and Rural Population for the period 2008 – 2025.

Table 2. Recent and projected percent population growth in the Gezira.

Year	Rural	Urban	Total
2008	2.90	0.68	3.58
2010	3.10	0.71	3.81
2012	3.20	0.75	3.95
2014	3.30	0.78	4.08
Growth (2014-2008)	0.40	0.1	0.5
Growth %	14	14	14
2014	3.30	0.78	4.08
2015	3.37	0.80	4.17
2020	3.77	0.88	4.65
2025	4.20	0.99	5.19
Growth (2025-2014)	0.90	0.21	1.11
Growth %	27	27	27

population (Table 3). Water stands yield 67.4 and 32.4 thousands m^3/day for rural and urban needs, respectively. The hand pumps were used only in rural areas where groundwater is scare. These pumps produce 3% of the total water production. The functioning slow sand filters exist in rural areas and produce 7% of the consumed water. The water purification plants produce the remaining 26.3% for urban areas Form Table 2, it is calculated that rural water supply consumption was estimated at 76.21 thousands m^3/day, making an average consumption rate of 22.5 L per capita per day. Water supply consumption for urban centers was estimated at 43.9 thousands m^3 per day, making an average consumption rate of 55 L per capita per day. The study estimated that the current gab in rural water supply is 92.5 m^3 per day. This gab is expected to increase to 112 m^3 per day and to 134 m^3 per day in 2020 and 2025, respectively (Figure 3).

Sanitation coverage in the Gezira

Sanitation coverage in the Gezira State has been improved from 32% in 1990s to 42% in 2010 (Figure 4). Compared to national scale, the Gezira State is faster in sanitation coverage. The results show increasing trend in sanitation coverage in the Gezira and Sudan compared to the decreasing trend in sanitation coverage in Africa. This result is in agreement with (Cairncross, 2003) who stated that Africa in sanitation coverage has actually decreased slightly during the last decade. Sanitation coverage in schools has increased from 60% in 2010 to 88% in 2014, with increasing rate of 7% (Figure 5). In heath facilities, sanitation coverage has increased from 39 to 79%, in four years, from 2010 to 2014 by 10% increasing rate. Still the coverage is insufficient to keep pace with population growth leaving a widening gap in the number of unsaved households.

DISCUSSION

The main water resources in the Gezira are the Blue Nile River, Eldinder and Elrahad rivers and their tributaries in addition to the rainfall and huge groundwater resources.

Table 3. Water availability in the Gezira.

Water source	Rural water availability			Urban water availability		
	Number	Production (m^3 per day)	% of total	Number	Production (m^3 per day)	% of total
Water stands	1835	67440	88.4	26	32353	73.6
Hand pumps	594	2376	3	0	0	0.00
Slow sand filters	111	5136	7	4	0	0.00
Water treatment plants	18	1296	1.7	4	11580	26.3
Total		76248	100		43933	100
Population (2015)		3376435			796644	
Liter per capita per day		22.5			55.1	

The average rainfall during the last 30 years is estimated within the range of 250 to 300 mm/year. Groundwater generally occurs in the Gezira Nubian and basement aquifers. Ahmed (2004) indicated that 90% of Gezira water supply from the Gezira aquifer, while about 10% is from Nubian sandstone aquifers. The groundwater is mainly recharged from the Blue Nile. Literature confirmed that groundwater quality recorded over the past indicates a good quality, except in some locations and pockets. Sudan is rich of water resources, however, greater multiple efforts are needed to make these resources available to use.

The results show that population in Gezira is expected to increase by 27% between 2008 to 2025. This indicates that the Gezira State will be one of the most densely populated states in the country. This is attributed to the availability of economic activities and natural resources, such as water resources and fertile soil, as well as health and education services. The State is characterized by an enabling and attractive environment, due to its strategic location and large scale agricultural schemes e.g. Gezira scheme (0.88 million hectare) and Rahad agricultural Corporation (0.35 million hectare).

The analysis indicates that, the gab in rural water supply in Gezira is far below what was stated by Pual et al. (2010) of at least 50 L per person per day is needed to ensure all personal hygiene, food hygiene domestic cleaning, and laundry needs. With continuing trend of population growth in the Gezira State, the gab in rural water supply will remain unacceptably high in 2025. According to these results, new water sources should be constructed to fulfill the future needs, particularly for rural community. The gab in water supply for rural people in the Gezira might lead to child mortality, diarrhoea, malaria and bilharzias, which are the most common diseases in the State. These diseases are also seriously creating socio-economic problems with adverse effects on agricultural output, school attendance etc. Some places in the State are currently facing shortage of safe water supply because of saline water like Managil region.

Public house connection and tap/stand-pipe are the main source of drinking water in urban and pre-urban areas, while protected wells are wildly used in rural areas and urban centers.

Hand pumps are very popular in areas where ground water is not enough, especially in basement complex areas in the West and East Gezira. Groundwater aquifers in these areas are not rich and communities depend mainly on surface water, which is liable to contamination. Slow sand filters are useful in improving surface water quality. Haffirs (are rectangular or semi-circular impoundments that store rainwater to be used by both human and livestock population during the dry season). Haffir is considered an important water source for livestock and, therefore, it is excluded in this Gezira case. Sustainability of these water sources in the Gezira is a problem as Paul et al. (2010) justified that it is relatively easy to increase coverage through construction of water supply systems, but it is much more difficult to ensure that such systems continue to provide service over the long-term.

In Sub-Saharan Africa (SSA) coverage is just 31%. Sanitation coverage in SSA has not kept pace with population increase, but has dropped from 60% in 1990, to 47% in 2000 (Waterkeyn and Cairncross, 2005).

The present study showed that there is a slight improvement in sanitation coverage in the Gezira State. It has been found that the per capita water rate for rural people in Gezira is around 20 L per day and this may cause poor sanitation.

Poor access to water and sanitation at the home, and at health facilities may be associated

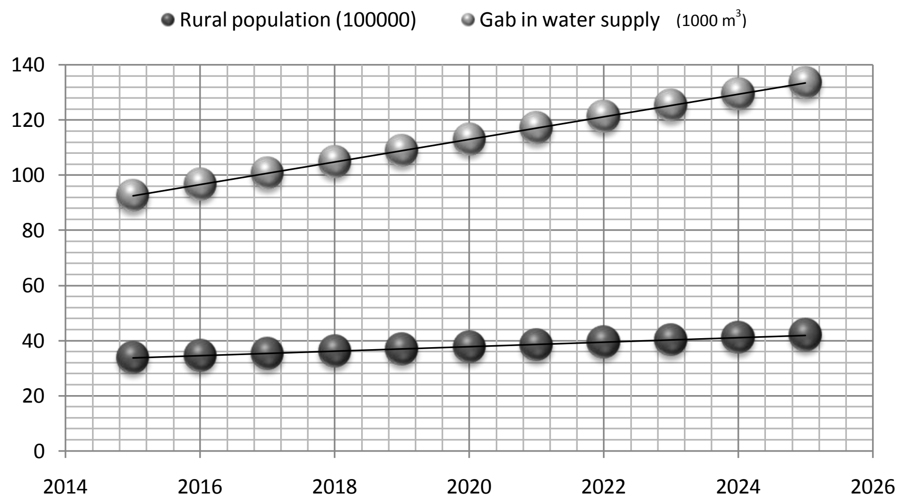

Figure 3. The gab in rural water supply.

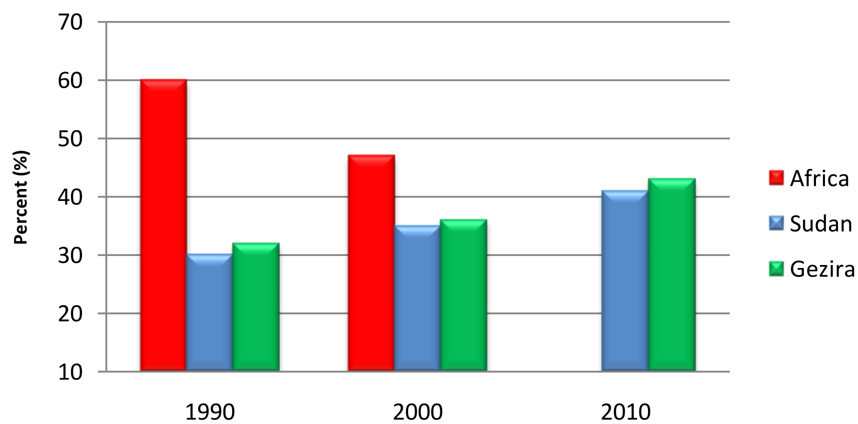

Figure 4. Change in sanitation coverage.

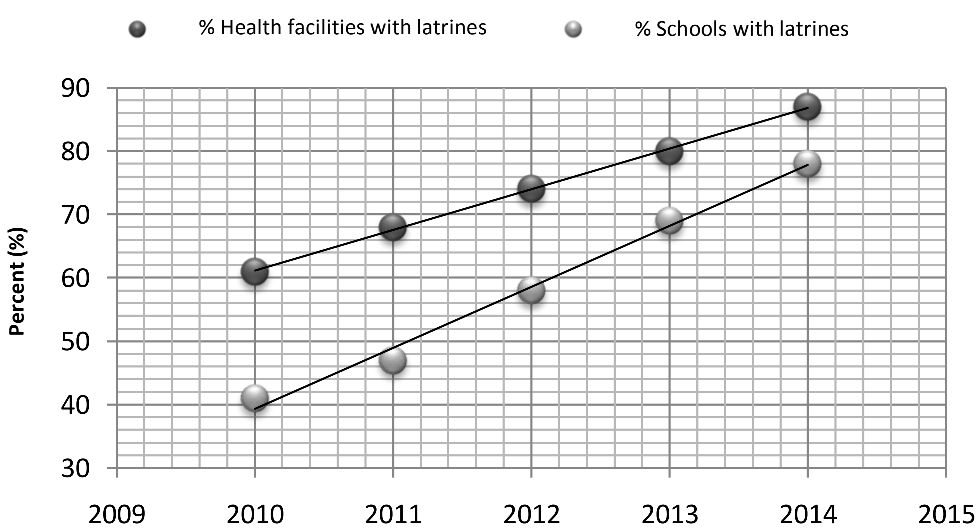

Figure 5. Primary schools and health facilities coverage.

with higher maternal mortality. It has been observed that there is an increasing number of latrines in the State. This may reduces environmental contamination and rate of disease transmission, however, Asaolu and Ofoezie (2003) stated that latrine facilities does not always imply they are used, and even where they are used, they might not be used properly. The state includes settlements around Gezira scheme canals where population from different places and ethnic groups come to work in farming at the scheme. Most of these inhabitants have neither latrines nor do they have access to safe water supply and their only source of drinking water is directly from the irrigation canals; while some of them had water hand pumps.

A slight improvement in sanitation coverage might be ascribed to the improvement of economic situation in general, which resulted from oil extraction before the secession of South Sudan. Moreover, in 2010, opportunities of gold exploration has just begun, which constituted a great wealth for rural people. These economic developments have resulted in rehabilitation and construction of houses, health and schools with good sanitation facilities. MDG target in water supply and sanitation might not have been met in Gezira, however, slight improvements have been achieved in the Gezira State.

Conclusion

Population growth is the key factor that influences water supply and sanitation. Growing population is increasingly creating gab in water supply and sanitation in both quantity and quality, particularly for rural people. Under dramatic increasing population, compared with stable or deteriorating water sources, access to water and sanitation will be decreasing with time. Associated water stress and health problems are highly expected, particularly among rural communities in the Gezira. Under scarce technical and financial resources in low income countries, development of water supply and sanitation services with a rate similar to increasing rate of population constitutes big challenge.

Conflict of Interest

The authors have not declared any conflict of interest.

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