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Full Length Research Paper

Preference for water boreholes to odor stream harnessing at Amaopkara

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The paper focuses on provision of sustainable portable water to Amaopkara community in Orumba Local Government Area of Anambra State, using “Decision Tree Analysis” which involves two options of water boreholes and odor stream harnessing. This is to achieve one of the key targets of millennium development goals by 2015, which is aimed at the proportion of people without sustainable access to safe drinking water and to ascertain the majority of premature deaths which is accounted by water related disease, in many cases could be alleviated by the provision of an adequate supply of water for both drinking and washing with full participation of the community.

Key words: Decision-tree, water supply, boreholes, stream, construction, production, maintenance, sustainability.

INTRODUCTION

Water is a source of life and fresh water resources are not unlimited, therefore communities need to use the scarce resources with care so that future generation will be able to benefit from good quality water (Kalulu and Hoko, 2010). Also, correct utilization of water means taking care of waste water in order to avoid pollution and alleviate the spread of dangerous diseases.

The (JMP) report from 2012, stated that provision of safe water supply in the rural areas is a means of defeating water borne disease and promotion of other health benefits and greatly reduce burden of water collection for women and children, especially during the dry season.

The provision of adequate supply of safe drinking water, sanitation and hygiene education is stimulating a

reduction in the incidence of diseases in developing nations even without medical intervention. UNICEF and WHO (2012) report on progress on drinking water and sanitation emphasizes that the provision of water and sanitation is greatly influencing a reduction in the transmission of many diseases and also enhances efficiency of other non-healthy living condition.

In some cases women have more time to do other rewarding activities more often (WHO, 2011) in places where water supply and sanitation coverage are in most of African countries, resulting to an extra burden placed on women to provide the facilities and service. It then becomes difficult for women to engage in rewarding activities like trading, unskilled labour and child care will be affected.

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Bhagwan et al. (2009) observed that provision of portable water for communities is at the discretion of the government without involvement of the beneficiary communities, reason is more political than socio-economical and the anomaly is leading many communities to be without access to the essential commodity.

The access to water by rural dwellers focuses on their primary source of drinking water which was recently published in Guardian Newspaper (2016), showing that about 85% of rural household rely directly on water from streams and local vendors. Observation reveals how poor rural dwellers rely on a diverse range of water source of differing quality and price for different uses, drinking, cooking and washing. Also, few of these dwellers have access to shallow boreholes and surface water for some of their needs (Mwanza, 2005).

Ndokosho et al. (2007) observes that, water is increasingly seen as one of the most critically stressed resources and yet, it plays a major role in poverty alleviation in developing countries. Moreover, Schwartz (2008) clearly explains that efficient allocation of water is a key international concern, and it demands the attention of policy makers, resource managers and government. An access to, and reliability of water sources have such large influence on promoting sustainable livelihood, and where environmental impact associated with inadequate resources management are significant as ever.

UNICEF and WHO (2011), report emphasizes on the need to consider water supply and sanitation as human right and they are basic priorities in making comparison between the two options of safe stream water supply and boreholes construction for Amaokpara community. Therefore, to achieve a proper good improved quality of life, there should be provision of education and training programme for the beneficiary community.

Sudhakar and Mamallia (2004), provided an overview that where alternate water is better quality, cheaper to develop, easier to obtain or less risk, it should be given priority. Along with checking the sequence of priorities, the planner must also consider the alternative source of water and must be compared with water harvesting in cost and risk involved (Cullivan et al., 1988). The comparison with "Decision Tree Analysis" must take into account the water quality required, operation and maintenance considered as well as the initial cost (Taha, 2011). A clear example is the two options, odor stream and water boreholes for domestic uses at Amaokpara. The water harvesting scheme will only be sustainable if it fits into the socio-economic context of the community and also fulfills a number technical criteria (UNICEF and WHO, 2012).

The establishment of Rural Water Supply and Sanitation Programme (RWSS) is one strategy to improve the living standard of rural communities, which are out of the mainstream of development. Rural water supply and sanitation programme creates and improves

the prevailing socio-economic conditions through livelihood development in the rural communities (FMWR, 2010). The programme adopts a novel and innovative approach by placing the beneficiary communities in the centre of the process and provides opportunities for them in decision making at all stages of project implementation, such as planning, design and management of the facilities created.

The provision of water supply shall have a greater impact on health and wellbeing of Amaokpara community and the prevailing issues involved in poverty, as unavailability of basic services such as water supply which is the key indicator of poverty will be alleviated.

Amaokpara community uses her limited water supply for lucrative activities such as production of palm oil, etc., as well as domestic needs. The productive use of water by the community will really thrive when the required quantity of water is available and will often generate numerous benefits.

Moreover, the basic needs approach in provision of portable water in Amaokpara requires intervention of State Government and the provision of water by the State Government depends on the resource and economic policies of the government. In the sustainability of any government sponsored water project, there must be community participation and the new approach will surely facilitate sustainability of service in the water sector, (Kalulu and Hako, 2010).

It also aims at empowering the Amaokpara community to take responsibility of her own development with the aid of government. Meanwhile the support to be provided by government shall be limited to construction phase with the assistance to training planning, technical and managerial advice, monitoring and evaluation (Mwanza, 2005). The new proposal approach will satisfy the fundamental drinking water need of Amaokpara community with demand-driven approach (WEDC, 2004).

In the year 2000, about 191 United Nation members adopted the United Nation millennium declaration of eight international development goals for the year 2015 tagged "millennium Development Goals which Nigeria is a member. One of the eight targeted goals is sustainable access to safe drinking water and basic sanitation.

Consequently, this paper focuses on provision of sustainable potable water to Amaokpara community in Orumer North Local Government Area, of Anambra State using Decision Tree Analysis which involves two project options of "water boreholes and Odor stream harnessing.

The study is to achieve a sustainable potable water supply and maintenance of good sanitation as one of the key targets of millennium development goals by 2015 but has been shifted to 2025.

The state government deemed it very important to integrate in the rural development programme, water supply and sanitation to alleviate the problem of rural dweller. Amaokpara is one of the beneficiaries of the



Figure 1. Google map image of Amaokpara and environs.

programme, because water is an essential commodity that must be given to the people for the dividend of democracy.

The purpose of the study is to select the optimum decision criterion for the benefit of Amaokpara as a community using Decision Tree method of operation research. The criterion is based on economy, quality and quantity.

The decision theory is an analytical and systematic approach of comparing decision alternatives in terms of expected out comes, examples, water boreholes and stream harnessing. The decision theory provides a frame work and methodology for rational decision-making when the outcomes are uncertain.

Aim and objective

The aim of the paper is to identify the more promising and viable choice among the two options of safe stream water supply and water borehole construction.

The objective of the study is to assess the main factors influencing economic sustainability of water supply management in the rural areas, like Amaokpara and it is expected to:

- (1) Provide safe water for the community
- (2) Increase coverage of safe water supply to the entire community.
- (3) Develop a sustainable service for provision of water supplies.
- (4) Improve public health and sanitation

(5) Promote community participation

(6) Develop private sector to actively support water supply and sanitation

(7) Develop and strengthen institutional structure for sustainable effective village level operation and maintenance of water points.

(8) Facilitate the sustained application of decision tree technology options, in making choice between water boreholes and odor stream harnessing.

(9) Give the community a voice to make choice from options, and demand accountability from service providers.

Study area

Amaokpala town is one of the communities in Orumba North Local Government Area of Anambra State of Nigeria. It is geographically located between latitude $6^{\circ} 3' - 6^{\circ} 2' 30''$ of North and South equator and longitude of $7^{\circ} 6' 00'' - 7^{\circ} 5' 25''$ East and West of Greenwich Meridian. The people are mostly farmers and the town is partly surrounded by Odor stream a non-perennial which is badly destroyed by commercial sand dredging activity. Amaokpala is found in Ameki formation which is predominantly argillaceous rock and shell. The climate is hot equatoria with average maximum and minimum at 31 and 19°C, respectively and has an average temperature of 25°C. Because of the conducive atmosphere, the herdsmen and their cattle found the town habitable, eventually contaminated the water at the upstream (Figures 1 and 2).

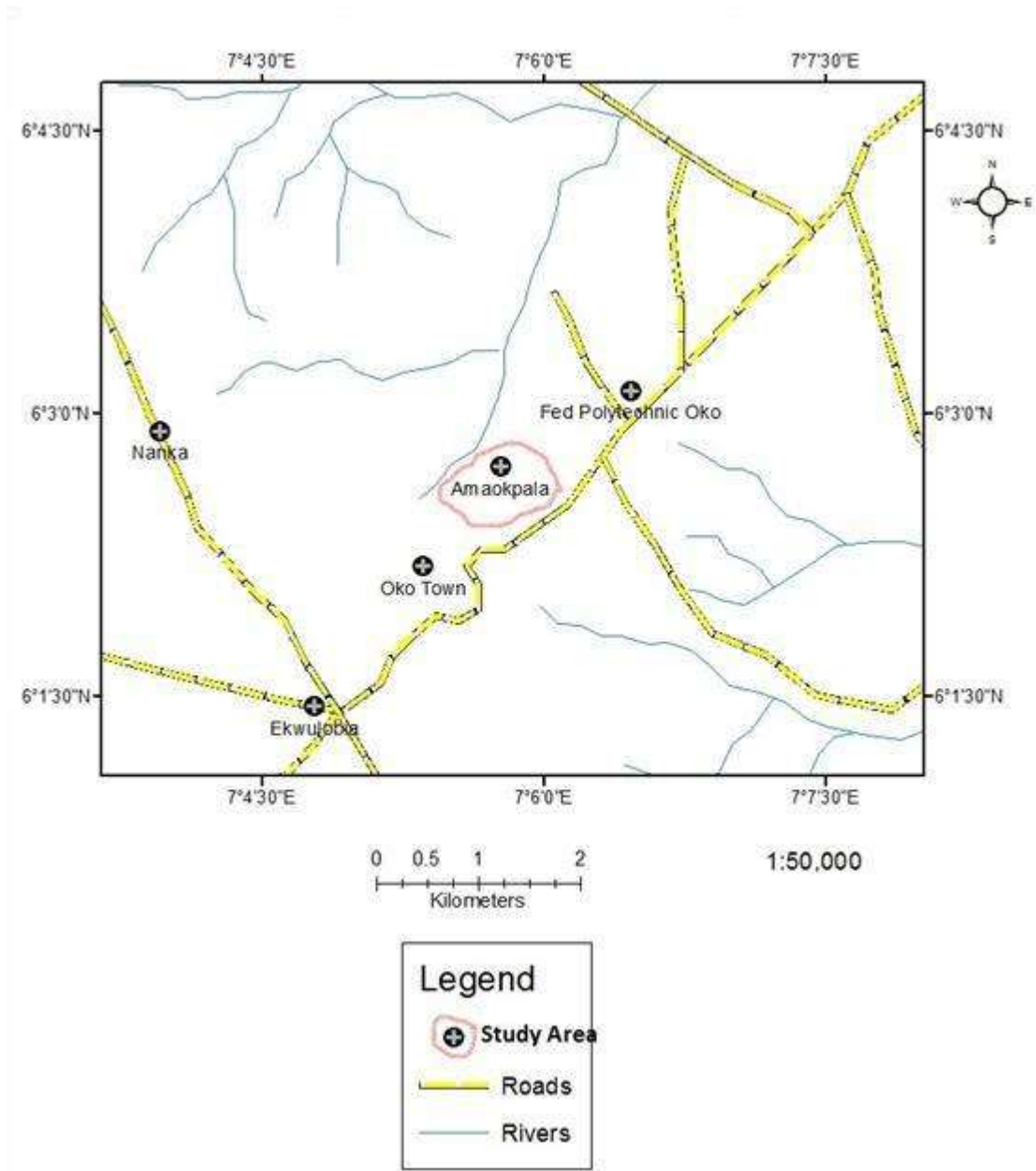


Figure 2. Amaokpara community and the surrounding rivers.

METHODOLOGY

WHO (2012) clearly defined that in order to carry out the assessment of two options, odor stream harnessing or water boreholes, for the implementation of the water scheme, Decision Tree Analysis is to be used to evaluate the cost-effectiveness, water quality and quantity. Sharma (2010) explains the reason; overall decision is based on construction, production and maintenance programme against prior probability and posterior probability being expensive or non-expensive in Table 1 and Figure 3.

Stream water harnessing is building a dam across the stream to capture and store water which would otherwise drain away during period of heavy rainfall (JMP, 2012). The dam, a concrete barrier

that stretches across the stream, allows water to pool behind it while excess spills over the top and continues downstream. Pipes installed in the pool behind the weir tap, the water and carry it underground to storage tanks. The idea is to tap the little water that flows through the stream course, but also prepare to harness bigger volume from the season flood (WEDC, 2004).

Meanwhile, boreholes construction is time taken to undertake the activities, affecting the basic drilling cost as follows:

- (1) The basic drilling cost, as mobilization drilling installation and well development.
- (2) Additional cost; includes value added tax, overhead and risk involvement.
- (3) Siting and supervision cost bore by state government.

Table 1. Data for both options and condition of projects.

Project	Prior probability	Condition	Proposal	Posterior probability
A	0.6	Expensive	₦95M	0.3
			₦70M	0.4
			₦30M	0.3
	0.4	Non Expensive	₦65M	0.3
			₦35M	0.4
			₦15M	0.3
B	0.6	Expensive	₦75M	0.3
			₦45M	0.4
			₦20M	0.3
	0.4	Non Expensive	₦35M	0.3
			₦20M	0.4
			₦10M	0.3

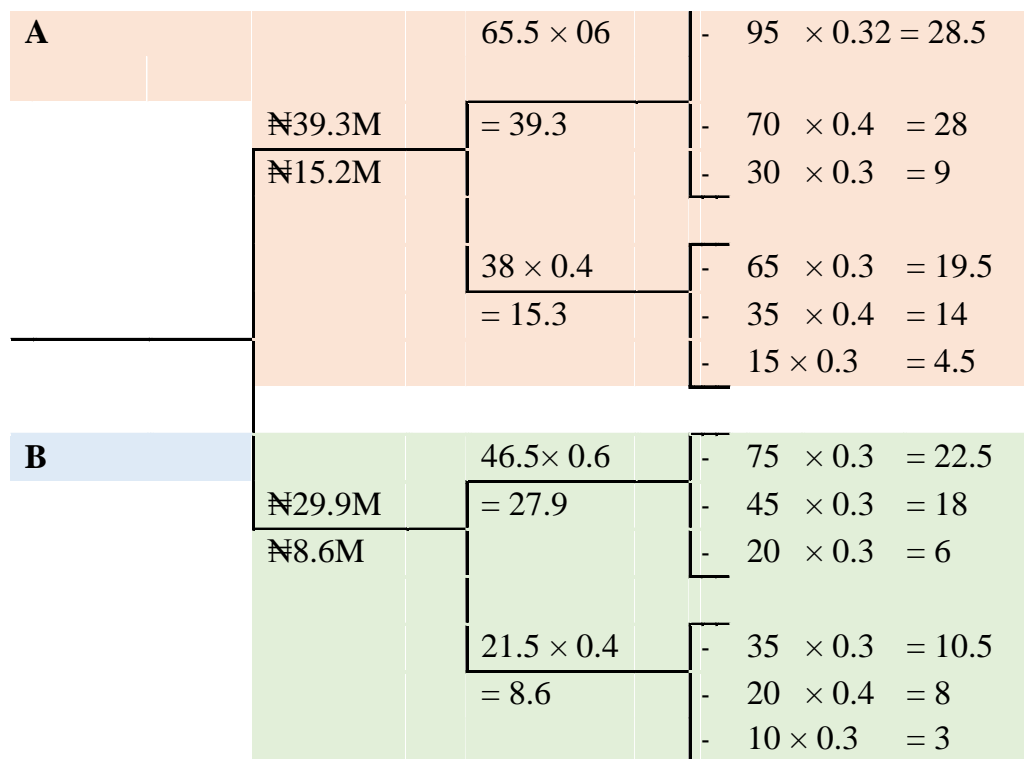


Figure 3. Decision tree for both options.

(4) Cost of social infrastructure, mobilizing and training community members.

(5) Construction quality and post construction failure increase actual borehole cost significantly.

In confirmation, ReVelle et al. (2004) justified the application of Bayesian decision tree theory in the paper. They used the example

of a contractor who was faced with the decision of whether or not to bid on one of two construction project, dam and highway. The contractor was limited to choosing, at most, only man power and equipment available to time and the highest expected profit.

Most decision made on large civil engineering and environmental projects involve element of risk and uncertainty. Risk is defined as the situation where objective data exist upon which to estimate the

probability event. The probabilities would be based upon the result of experimental test and historical data.

The study has "Alternatives of "A" or "B" projects stream harnessing or water boreholes. Each alternative has finite number probability which may depend on the previous decision made and on what happened sequent to previous decision.

Each project has some "states of nature" under the condition the condition of being expensive on non-expensive (market price "inflation" Natural disaster "erosion" Borehole - failure "lost in circulation, weather condition, political development "Defection" "Youth restiveness" nature of the soil for foundation.

States of nature are not-determined by neither contractor (individual) nor consultant (decision maker).

Payoff is the numerical values (out comes) resulting from each possible combination of alternatives and states of nature. Pay off values are large conditional values because of its unknown states of nature.

With the states of nature which are conditional, inserting the probabilities depending upon expensive or non-expensive, this leads to winning or losing by some percentages.

Project Cost

A = stream water harnessing
B = water boreholes construction

A - Expensive

- (i) Cost of construction = ₦95M
- (ii) Cost of Production = ₦70M
- (iii) Cost maintenance = ₦30M

A - Non Expensive

- (i) Cost of construction = ₦65M
- (ii) Cost of production = ₦35M
- (iii) Cost maintenance = ₦15M

B - Expensive

- (i) Cost of construction = ₦75M
- (ii) Cost of production = ₦45M
- (iii) Cost maintenance = ₦20M

B - Non Expensive

- (i) Cost of construction = ₦35M
- (ii) Cost of production = ₦20M
- (iii) Cost maintenance = ₦10M

A – Expensive

$$\left. \begin{array}{l} (i) \quad 95 \times 0.3 = 28.5 \\ (ii) \quad 70 \times 0.4 = 28 \\ (iii) \quad 30 \times 0.3 = \frac{9}{65.5} \end{array} \right\} 65.5 \times 0.6 = \text{N}39.3M$$

A – Non Expensive

$$\left. \begin{array}{l} (i) \quad 65 \times 0.3 = 19.5 \\ (ii) \quad 35 \times 0.4 = 14 \\ (iii) \quad 15 \times 0.3 = \frac{4.5}{38} \end{array} \right\} 38 \times 0.4 = \text{N}15.3M$$

B – Expensive

$$\left. \begin{array}{l} (i) \quad 75 \times 0.3 = 22.5 \\ (ii) \quad 45 \times 0.4 = 18 \\ (iii) \quad 20 \times 0.3 = \frac{6}{46.5} \end{array} \right\} 46.5 \times 0.6 = \text{N}27.9M$$

B – Non Expensive

$$\left. \begin{array}{l} (i) \quad 35 \times 0.3 = 10.5 \\ (ii) \quad 20 \times 0.4 = 8 \\ (iii) \quad 10 \times 0.3 = \frac{3}{21.5} \end{array} \right\} 21.5 \times 0.4 = \text{N}8.6M$$

RESULTS AND DISCUSSION

Surely before selecting a specific technology between stream harnessing and water boreholes, due consideration must be given to the social and cultural aspects of Amaokpara as it is paramount and will affect the success or failure of the technique to be implemented. Most of the rural water projects fail because the community's priorities are not normally taken into cognisance. Therefore, decision theory analysis as system engineering, mathematical model assisted in the choice making between the two aforementioned options. The prescriptive model gave the best strategy in choice making, considering cost effectiveness of the projects.

In the course of selection, due consideration must be taken, regarding the following issue, that may arise in the community involved.

- (1) Social and cultural
- (2) Politics of winners take all
- (3) Soil texture
- (4) Prices of materials.

All these are paramount and affect the success or failure of the technique being implemented. The success or failure of the study also depends on giving priorities to community's views and needs. Moreover, the technique of Decision Tree Analysis is totally a programme based on:

- (1) Construction
- (2) Production
- (3) Maintenance

All against prior-probability and posterior-probability being expensive and non-expensive to arrive at optimum decision.

The prior-probability is the probability made before any experimentation taking place while the posterior-probability is the probability estimated or calculated after having seen an experimental result.

Through the institution in control of bidding in the state, the prior probability is prominently considered. The probability of not being selected will be 60% or 0.6 in expensive condition and 40% or 0.4 to non-expensive for project A (Harnessing Odor stream).

Similarly, the probability not being selected will be 60% or 0.6 in expensive condition and 40% or 0.4 for non-expensive, for project B (water boreholes). Obviously, one of the projects will be identified as the best alternative through optimum decision with regard to cost-effectiveness of boreholes construction.

Consequently, the decision-making process of safe water supply project compares two different options namely water boreholes and stream supply using Decision Tree Analysis, based on construction, production and maintenance programme against prior

probability and posterior probability being expensive or non-expensive could solve the problem of water scarcity in the community.

Based on the result formed by cost-effectiveness of Decision Tree, the analysis shows that the economic sustainability of water schemes management is reviewed through a comparison of the two schemes, through cost construction, production and maintenance.

Taha (2011) research proves to be effective in the methodology adopted and relevant for the findings achieved which highlights issues seriously affecting the sustainability of water schemes and their functionality, so ultimately affecting people ability to access water service. Therefore, emerging response to need for rapid and effective provision of safe and water supply in Amaokpara community is informed by the decision makers and the prioritization of intervention need to be made within limited time and resource available.

Conclusion

The study provides strength for the proposed index prescription of an "Answer to water Scarcity" to Amaokpara community (UNICEF and WHO, 2011). Moreso, shows economic sustainability of water scheme management which is reviewed through a comparison of the two proposal, with cost of construction, production and maintenance.

Consequently, in the past the community suffered some setbacks because of inappropriate technology of choice, supply-driven approach to project design and failure to involve Amaokpara community in decision making processes at project preparation stage, retard her growth in water supply coverage.

In comparing and contrasting of the two options regarding the cost-effectiveness, water boreholes scheme is more sustainable than odor stream harnessing in Amaokpara community, mainly boreholes management is more economical and easier to maintain than that of odor stream harnessing.

Investigation shows that odor stream harnessing is non-perennial and faces seasonal changes in quantity and quality and could result in water pollution which is considered as a side effect of economic growth of the community development and environmental pollution problems.

Finally, based on the result found by cost-effectiveness of "Decision Tree Analysis" (Taha, 2011; Sharma, 2010), odor stream harnessing (₦39.3M/ ₦15.2) and water boreholes (₦27.9M/ ₦8.6) both in expensive and non-expensive criteria, water boreholes is more economically sustainable than odor stream harnessing. Therefore, the water boreholes are preferred to odor stream harnessing.

RECOMMENDATIONS

Water as a key resource for sustainable development

and its economic-good value hence requires proper management (WEDC, 2004). However, efficient management of water remains a challenge in the developing nations leading to unsustainability of institutions that are mandated to provide water services.

Therefore, in recommendations, the planner project must prepare and introduce materials as well as supply innovative and important methods aimed at sustainability in all phases and activity, policies and guidelines, organisational structure consisting a stake holder project cycle including targets, training and outcomes, available technical options, terms of reference for community base organisation (CBO), awareness and technical options for water supply and maintenance system for pipe borne-water supply.

Consequently, there must be provision for safe water and liable water supply and sanitation facilities for the entire community, confirmed by WHO (2011) in evaluating household water treatment option. Moreover, it is an important goal to make a particular strong commitment to improve water and sanitation in the plan for accelerating and sustainable development to poverty alleviation which targets an increase in access to sufficient water of acceptable quality to satisfy basic human needs (Dach, 2007).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Bhagwan V, Grandison T, Gruhl D (2009). Sound index: charts for the people, by the people. *Communications of the ACM* 52(9):64-70.
- Cullivan D, Tippet B, Edwards DB, Resenswing F, Mccafery (1988). *Guidelines for institutional assessment: water and wastewater institutions* Washington DC 20523 US, WASH technical Report No. 37.
- Dach S (2007). *Water sector reform in Kenya*, Infor Resource Berne, Autuinn.
- Federal Ministry of Water Resources (FMWR) (2005). *Rural Water Supply and sanitation Initial, Programme Implementation Manual*.
- Guardian Newspaper (2016). *Provision of portable water to the rural households for the eradication of water-borne diseases*, Oct 2015 editorial column.
- Joint Monitoring programme (JMP) (2012). *Progress on sanitation and drinking water 2012 update: World Health Organisation and UNICEF: Geneva*.
- Kalulu K, Hako Z (2010). *Assessment of the performance of public water utility 10th water Net/ 35:806-816*.
- Mwanza DD (2005). *Promoting good governance through regulatory framework in Africa Water Utilities* 51(8):71-76.
- Ndokosho J, Hoko Z, Makurira H (2007). *Assessment approach in a public water utility*. Elsevier Ltd. *Physics and Chemistry of the Earth* 32:1300-1309.
- ReVelle CS, Whitlatch Jr EC, Wright JR (2004). *Civil and Environmental System Engineering*; Pearson Prentce Hall, Upper Saddle River New Jersey 0758.
- Schwartz K (2008). *The new public management, the future for reforms in the African Water supply and sanitation Sector: UNESCO IHE institute for water Education: Elsevier Ltd Utility Policy*, 1b:49-58.
- Sharma JK (2010). *Operation Research, Theory and Application*:

- MacMillan publishers, India Ltd.
- Sudhakar MR, Mamatha P (2004). Water quality in sustainable management. *Current Science* 87(7):942-947.
- Taha HA (2011). *Operation Research: An introduction* 9th Edition, University of Arkansas, Fayetteville.
- UNICEF and WHO (2011). *Drinking water, Equity, safety and sustainability. Thematic report on drinking water 2011.*
- UNICEF and WHO (2012). *Progress on drinking water and sanitation 2012 update* New York and Geneva.
- WEDC (2004). *Integrated water resource management postgraduate module* WEDC Loughborough University, UK. Providing safe water, sanitation and hygiene promotion facilities to the rural communities, 2004 annual report.
- World Health Organization (WHO) (2011). *Evaluating Household water treatment option-health-based target and microbiological performance specification*, Geneva Switzerland.
- World Health Organization (WHO) (2012). *UN-water global annual assessment of sanitation and drinking water (GIAAS) 2012 report.*

Full Length Research Paper

Assessment of water resources management and past works on water points development in Borana Rangelands, Southern Oromia, Ethiopia

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Water is the principal resource for all living to prosper but a major limiting factor when mismanaged. The wide spread clearing of trees has caused soil erosion that is resulting silt accumulation in the reservoirs 40 to 50% /year. Purposive selection techniques have deployed for this study to gather information. Borana community has been managing water and pasture using its customary institutions called 'Abbaa Gadaa' which formulates and enforces general laws. Open surface water are the major water sources for study area. Accordingly the respondents (80%) runoff water, during wet season while ponds, boreholes and micro-dams during the dry season. More than 81% respondents explain that community near the water point involved in almost all stages of water work activities. The mobility of herd from village is determined by water and/or pastures availability and seasonal variation; travel short distance in wet and normal dry season but long distance during drought season as per 79% of respondents. This long distance mobility is termed as the 'Furaa' herd movement. The water point development conducted in the past has negative impact on traditional systems in managing and usage of the resources. This is because of lack that proper land use planning and insufficient resource to effectively maintain and manage water points by local government. This paper also reveals that policy makers should oversee any interventions in water case as per integration of science and indigenous knowledge in order to sustain the solution to scarcity of water in the area

Key words: Water resources, community, indigenous knowledge, water points.

INTRODUCTION

Water is the principal resource that has helped agriculture and society to prosper, and it has been a major limiting factor when mismanaged. Several steps environmental problems are related to the countries rapid loss of natural forests. Commercial logging, slash- and – burn agriculture, fuel wood gathering, and population growth have contributed to the deforestation. The wide

should be taken to develop drought-resistant farming systems even in normal years including both policy and management action (Alemayehu, 1998). Many spread clearing of trees has caused soil erosion and the resulting silt accumulation in waterways and irrigation channels which may pollute the water resources. It estimated that around 40 to 50% of the water ponds are

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underused due to siltation severs. Recurrent drought combined with mismanagement of the existing water sources has aggravated the pastorals livelihood in the current years (Coppock, 1994). The seasonal occurrence of rainfall in most of the study area often results in highly variable river flows. A river may have virtually no discharge in the late dry season followed by severe flooding in the rainy season or early dry season which may cause soil erosion which may result siltation. Coppock (1994) reported that, the Borana plateau is characterized by general scarcity of surface. About 95 ponds were constructed and some of these ponds are inefficient because water is lost either due to high infiltration (seepage) or siltation. Water is lost from deep wells during the process of livestock watering. Many environmental changes like drought, soil degradation and other contributed partly to the changes of water management and utilization systems in the region.

Pastoral and agro pastoral areas in general are known to be deficit in water. In southern Oromia this condition is clearly visible needs careful research and development priorities. In Borana area individuals own a cistern which was uncommon in the past. This situation justifies that the traditional system is gradually changed. Water resource managed by Gada system but now a day exists in principles and very weak in practice. Because wells require large input of labor to lift water to the surface, there is a fear that these pastoralists can get enough labor through out of the year these days.

This concern is due to recurrent drought, loss of key grazing land and water resources, and inadequate infrastructural developmental investment as well as massive death of cattle followed by restocking and destocking are the major ones (Hurst et al., 2012). In southern Ethiopia drought has recurred more frequently and for longer periods of time than documented previously. This changing climate in the region has resulted in diminished both quality and quantity of local water and forage resources, thereby its negative impact and severity is provoked the problem of livestock production system and the livelihood of nomadic pastoralists' such as Borana, who depend on the animals for livelihood and subsistence. Development works over water point has been practiced by SORDU and CARE Ethiopia as well as other and non- Governments for long time. But part of these works is not effective and water points fail to function. The study has been conducted to assess the current status of traditional as well as modern water sources in the area.

MATERIALS AND METHODS

Study area

The study has been carried out in five districts of Borana rangelands so-called Yabello, Duda Dawa, Miyo, Dire and Moyale. There are four seasons in the area: *Ganna*—long rainy season, *Adolessa*—cool dry season, *Hagayyaa*—the short rainy season and

Bona—the warm dry season. The climate is, generally, semi-arid with annual rainfall averaging 500 mm in the south to 700 mm in the north and the altitude ranges from 1000 m above sea level in the south to 1500 m above sea level in the North West (Desta, 2000). Purposive selection techniques have deployed to choose the kebeles /peasant association within the districts. Accordingly more than fifteen peasant associations were included for gathering relevant information (Figure 1). Customary institutions are also contacted to gather the required information.

Data collection, sampling procedures and data management

Participatory rural appraisal and semi-structured interview has been employed to gather information. Besides, discussion was held with key informant and different water management bodies at local and district level. The major issues contained in the questionnaires includes traditional knowledge of water use, watering frequency, length of water available time for use, critical periods of water shortage and proximity and fairness of watering points. The amount of water lost due to watering efficiencies also considered. Labor availability at different seasons and pastoralists' perceptions over water resources depletion were also captured. GPS and GIS software were used to collect and mapping watering points, respectively. Totally, 143 households were interviewed whereas statistical package (SPSS version 21) was used for final analysis.

RESULTS AND DISCUSSION

Types of water source and their trends

Borana zone ephemeral drainage system is located within the Genale-Dawa river basin. Generally ground waters levels of the study area are deep and there is no perennial river in the zone. Major types of water source for pastoralist in the study area are open surface water which includes runoff/flood water, ponds and micro dams and ground water such as boreholes, shallow wells/ "adadi", motor pumps and Tula wells. These water sources had been serving for both domestic use and livestock consumption depending up on the season. According to the respondents (greater than 80%) runoff/flood water sources are utilized during wet season while ponds, boreholes and micro-dams are used during dry season. The remaining types of water sources had been used mostly during drought season. Runoff/flood water and small family ponds are temporary water sources collected around the village during rainy season and are generally called 'Hara' by the Borana community. On the other hand 'Haro' is the term used to represent medium ponds and micro-dams which are used during the normal dry period. More than half of the respondents agreed that, ground water sources such as boreholes, shallow wells/ "adadi" and Tula wells are preferred water sources for livestock watering due to the salinity content that improve livestock body condition. Majority of water sources in the region are communal except some small family ponds. More than 81% respondents explain that during water source development process the community near the water development point are involved at almost all stages of the activities with their labor and material

contribution.

Watering livestock and its frequency

Availability of water, pasture and season are the most determinant in movement distance of herd from home village. During wet and normal dry seasons, water is available at a distance of less than 1 km and at around 9 to 12 km, respectively, whereas during drought season, 'oolaa', the distance of watering point increases from 25 km to hundreds of kilometers as per 79% of the respondents. This long distance mobility to fetch water and pasture during drought season is termed as the 'Furaa' herd movement where movement from village is done based on information on weather, availability of water and pasture, livestock diseases and safety or security situation following traditional tracts of communal grazing land (Tujuba et al., 2017).

Travel hours for livestock watering are also dependent on the season. In wet season the travel hour may be less than an hour (62% of the respondent), at normal dry season it ranges from 1 to 3 h (78% of respondent) and during drought season the watering distance take 6 to 12 h or possibly more time (according to 65% of the respondents). The same is true for quench hours at watering points that 70% of the respondents agreed during wet season it may not take more than an hour; for normal dry season, 1 to 5 h (63% of respondents) and during the drought season 9 to 12 h used for watering livestock at one watering point (67% of the respondents). But, according to more than 82% of the respondents' confirmation, watering of calves, weak animals and lactating cows, during both normal dry and drought season, are at home by fetch using human back or animals like donkey and camel from long distance.

Livestock watering frequency in the past 20 years ago also depended on season. For example, during wet season, livestock watering was made daily due to less livestock number and availability of water at short distance as per 71% of the respondents. During normal dry season, one to two days was the frequency of livestock watering (64% of the respondents) while, at drought season, the watering frequency ranges between two to three days, according to 70% of the respondents. In current time for wet season, because of less water availability, one day (67% of respondents); in normal dry season, two to three days interval and, during drought season at three days interval, livestock is to be watered due to long distance between the water points and the villages (greater than 80% of the respondents).

The frequency of livestock watering is also affected by the availability of pasture in the area, according to 89% of the respondent. The more the available pasture the more will be the resistant for delayed watering frequency (Table 1). Accordingly, resistance difference to watering frequency between the past and current livestock is that the past livestock had more or less enough pasture which

makes them more resistance than the current livestock. According to 72% of the respondents, Borana breeds are resistant to long interval watering frequency than other breeds. Water point distance, quantity of water in its source, feed availability, number of livestock on water points and body condition of livestock are the determinant factors of watering frequency in Borana rangeland. In the Borana community, watering frequency is supervised by an officer, known as 'abba Heregaa', appointed by the well council (cora eelaa) which is composed of the users of the water points.

Traditional water point management system

For centuries, Borana community has been managing water resource and pasture using its customary institutions. The governing Body, the 'Abba Gada', formulates and enforces general laws-which are known as the 'Aada seera' - that govern access to and use of communal water and forage. Each newly elected governing Body revises existing tenure; arrangements and rangeland management in Borana are a social and political affair. The households reported to be abided by the traditional bylaws on how to keep ones turn in watering animals as ordered by the traditional water resource administrators or 'abba Herregaa', assigned by the Gada council as routine practice. Rote cycle for each user is determined by the managers which depend on the amount of available water and the existing demand (Figure 2).

Each water sources is subject to a complex set of restrictions, rules and regulation that are administered and enforced by selected agents like 'Aba Herega' under the surveillance of the traditional elders. Failure to supply labor to the well and failure to participate in the politics of well council will lead to rapid exclusion. Depending on the degree of problem punishment by money, desilting and fencing to water source are among the simple punishment. The major sanction under the Borana system of water control is exclusion. The development of organization in the past has negative impact on organization in the past has negative impact on water points by different organization in the past has negative impact on traditional systems in managing and usage of the resource. This is due to the fact that lack of proper land uses planning practice by planners and that of sufficient resource to effectively maintain and manage water points by local government. Even if they agree that management of water points developed by external bodies (more than 90% of the respondents) had to be by the whole community, those problems resulted in discrimination of watering point management by the community. Lack of proper land using a head resulted in overgrazing around the water points, aggravation of soil and incidence of human and livestock diseases. Moreover, due to the absence of rules and regulation,

Table 1. Water utilization for livestock.

Livestock types	Past watering frequency 20 years ago (days)						Current watering frequency (days)					
	Dry seasons	Respondents (%)	Wet seasons	Respondents (%)	Drought year	Respondents (%)	Dry seasons	Respondents (%)	Wet seasons	Respondents (%)	Drought year	Respondents (%)
Cattle	Daily	71	2	75	2-3	70	Daily	78	2	60	3	76
Sheep and Goats	After 1day	55	4-5	60	4-6	73	Daily	60	3-5	71	3-5	78
Camel	None	70	>8	60	8-10	70	None	77	3-6	65	3-6	69
Donkey	Daily	66	1	78	1-2	75	Daily	79	Daily	83	Daily	79

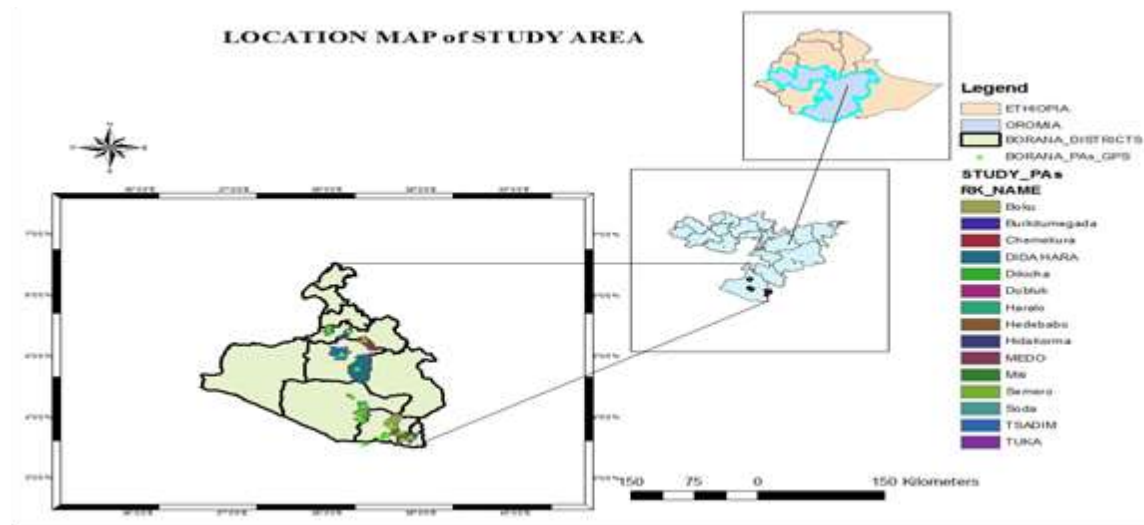


Figure 1. Location map of the study area with respect to Borana.

free access of both water and grazing resource created a room for conflict. Large ponds, constructed in dry season grazing area, lead to shift the dry season grazing land to wet season which resulted in shortage of feed at dry season. The traditional wells are known as the 'Tulas' which are the 'singing wells' used during the

drought time. Among 9 *Tulas*, scattered in Borana traditional grazing horizons, at least five of them are now reported not to be accessible for Borana. This is due to recent re-demarcation of the area out of the traditional range land administration legacy of the Borana *Gada* system without moderating the contending societies on mutual

access to the common water and grazing natural resource (Tujuba et al., 2017). Watering right in any particular water source is gained and maintained through participation in the water resource council. Upkeep, control, utilization and maintenance of the traditional water sources

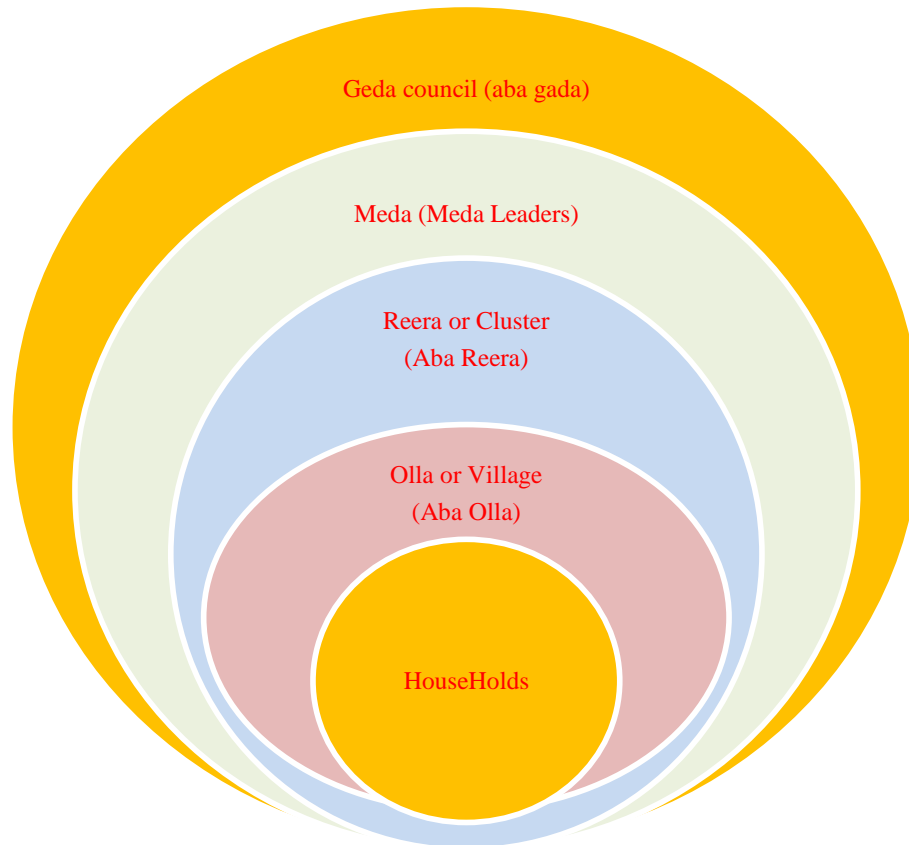


Figure 2. Traditional water point management set up in the study area.

are constant concern of all Borana`s. The continuous and coordinated supply of labor is essential for the operation of traditional or community water points. Even though the decision on tenure arrangements and rangeland management primarily involve male-dominated governing councils headed by elders, women are participating to erase it (greater than 93% of the respondents). The trend of surface water points in Borana rangeland, in terms of quality, has been declined, siltation increases through time due to loss of vegetation cover, land degradation by erosion and expansion of cultivated land (71%of the respondents). De-silting micro-dams and small ponds are the common practices to increase the volume of water harvested and the quality of water during the dry periods. However, lack of materials/tools and high labor consumption nature of the activities was the major problems of de-silting surface water points, according to 97% of the respondent confirmation.

Kota system water harvesting policy of 2003/2004

The Kota system of water harvesting technology introduced in 2003/2004 has been reached by the pastoral community. According to the respondents (85%),

the purpose of construction was for both small scale irrigation and livestock watering, however, when compared to traditional water harvesting technologies it has been found below or not suitable at all due to small volume of water harvested, seepage loss and lack of awareness as well as difficulty of watering for livestock. So, by now there is a demand for the improved water harvesting technology by the community due to high scarcity of water in the area and lack of technology that tackle existing water harvesting problem.

Mobility for water resources

Generally, the Borana rangeland is characterized with no Perennial River, recurrent drought and erratic rainfall pattern. Respondents of this assessment pointed out that most of them did not have enough water for both domestic and livestock watering. In order to cope with this critical shortage of water, mobility is the only solution especially for livestock watering during dry and drought periods in the region (greater than 80% of the respondents). As cattle is more sensitive to watering frequency, mobility for water accounts at first degree but if the situation is barbed all of livestock migrate to the

place where water and pasture are relatively available. The right to use water with local people is relatively equal because access to water and pasture depends up on equal participation in management. But it is important to notify and gather information about the resource in the area because it is mandatory to participate with labor and sometimes in cash at mobility sites.

Conclusions

Even if much effort has been made to develop water resource, Borana rangeland is an area with chronic water shortage. The major water sources in the area are surface water like runoff/flood water, ponds and micro dams and ground–water source which are boreholes, shallow wells/ "adadi", motor pumps and Tula wells. Distance, traveling hours towards water points and for quench hours at watering points are dependent on the season, which is high and very high in dry and drought season, respectively. The frequency of watering livestock, generally, has been increased because of recurrent drought which results in diminishing the grazing and water resource in the region about three days of interval for cattle watering.

Customary institution of Borana pastoralist has very sophisticated means of crucial resource management such as water and pasture for more than millennia. Those institutions build bylaws, rules and regulations that are overseen and revised by the governing councils headed by elders. The weakening of those customary institutions over time is a result of many factors. Among the factors population growth, massive immigration, political marginalization, land privatization and land conversion to cultivation, ignorance of indigenous knowledge by planners during development activities and lack of sufficient resource to effectively maintain and manage water points by local government are some of the evident. This problem contribute to the further filer for the water and pasture proper management even lead to cause for rangeland degradation and conflict over limited resource. So any intervention measures should be consider local knowledge in integration with the scientific ones and policy makers need to intervene for its implementation.

RECOMMENDATION

- (i) Supporting local customary institution, proper planning of developmental activities incorporating local knowledge, combining technical, science and customary knowledge systems for water and pastoral development.
- (ii) Proper water harvesting technologies which are easily adaptable by the community must revel in such a way

that it accommodate the local indigenous institution and create ownership by the pastoralists and agro-pastoralists of the region not 'Kota' system.

(iii) Introduction of participatory natural resource management as an approach for water development is important.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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REFERENCES

- Alemayehu M (1998). The Borana and the 1991-92 droughts. A rangeland and livestock resource study. Institute for Sustainable Development and French Catholic Committee against Hunger and for Development, Addis Ababa, Ethiopia. P 90.
- Coppock DL (1994). The Borana Plateau of Southern Ethiopia: Synthesis of Pastoral research, development and change, 1980-91. ILCA (International Livestock Center for Africa), Addis Ababa, Ethiopia 418 p.
- Desta S (2000). Pastoralism and Natural Resources Management: the case of the Borana in southern Ethiopia, Proceedings of 8th annual conference of the Ethiopian Society of Animal Production (ESAP) held in Addis Ababa pp. 17-25.
- Hurst M, Jensen N, Pedersen S, Sharma A, Zambriski J (2012). Changing Climate Adaptation Strategies of Boran Pastoralists in Southern Ethiopia. Working Paper No. 15 Cali, Colombia; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org
- Tujuba J, Harpal S, Merga B, Tefera Y, Abraham A, Belay W, Getachew G (2017). Borana Cattle Breed Production, Their Economic Role for Pastoralists under Drought, Diseases and Policy Constraints in Borana Zone, Oromia Sate, Southern Ethiopia, The International Journal of Science and Technology (ISSN 2321 – 919X). <http://www.thejst.com>

Full Length Research Paper

Detection of hydrological impacts of climate change in Benin by a multifractal approach

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This study analyzed the hydrological impacts of climate change over Bénin synoptic stations from 1951 to 2010 using multifractal approach. This method is based on the study of temporal evolution of fractal dimension (D_f), multifractality index (α), co-dimension (C_1) and probable maximum singularity (γ_s). The comparison of the average values of yearly fractal dimension ($\overline{D_f}$) obtained over the sub-period [1951-1970], [1971-1990] and [1991-2010] has shown and confirmed that [1971-1990] is a drought period in the region. However, the sub-period [1991-2010] is not the end of the drought over all the synoptic stations as known before, in West Africa. During the period from 1951 to 2010 over all synoptic stations, except Natitingou, there is a slight increase in γ_s exponent, controlling the extremes values of rainfall. Thus, the evolution of the extremes rainfall over this period has a slight increasing tendency. These results confirm those obtained by some studies over the Ouémé River Basin (Benin) using the climate index method. Thus, the multifractal approach is an excellent tool to evaluate the hydrological impacts of climate change using only three parameters.

Key words: Climate change, multifractal, hydrological impacts, extreme rainfall, Bénin.

INTRODUCTION

West African zone has experienced a sharp drop in annual rainfall since 1970 (Bigot et al., 2005; Goula et al., 2006). However, this climatic context has coincided with an increase in flood damage, both in urban and rural areas (Panthou, 2013). According to Panthou (2013), extreme rainfall is an indicator of climate change and particularly of the potential for intensifying the hydrological cycle. According to Hoang et al. (2014),

extreme rainfall study is very useful for the management of water resources. Generally, in the literature, the evolution of the extremes rainfalls is made through the study of annual climate indices (Zhang et al., 2011) and especially by the standardized index of rainfall anomaly (Lamb, 1982). Based on these climate indices in sub-Saharan of Africa, Ozer and Ozer (2005) found an increase in extreme rainfall events, in western Niger

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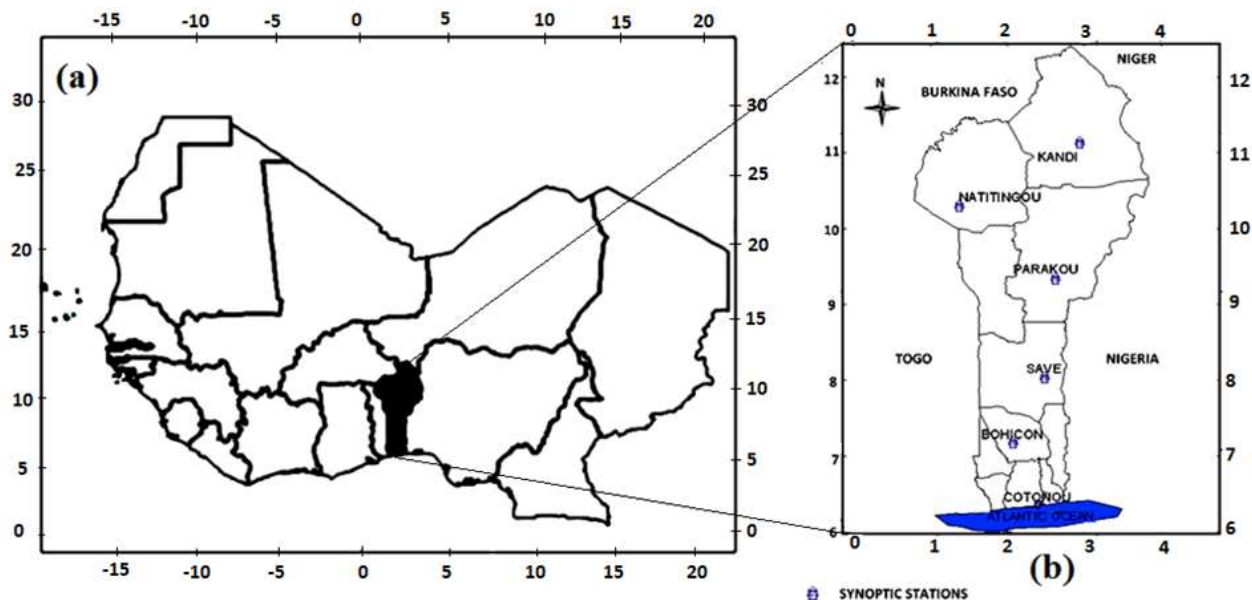


Figure 1. Study sites location: (a) Bénin location in West Africa, (b) Synoptic stations location in Benin Republic.

Republic. But, others studies, for example (Oguntundé et al., 2011; Easterling et al., 2000), (Aguilar et al., 2009; Ozer et al., 2009; Soro et al., 2016; Mason et al., 1999) have indicated a decrease in respectively Nigeria, Guinea Conakry, in eastern Niger, Ivory-Coast and South Africa in the last few decades, using climate indices.

In Benin Republic, Hountondji et al. (2011) have shown significant decreasing trends for the total precipitation, for the annual total rainfall and for the maximum rainfall in the period 1960-2000 from 21 rainfall stations. Hounkpè et al. (2016) have shown an increase in heavy historical precipitation for the period 1960-2012 over the Ouémé River Basin (Benin). Recently, N'Tcha M'Po et al. (2017) analyzed the trends of extreme daily rainfall indices over the Ouémé basin using the observed data from 1950 to 2014. They detected significant decline in the number of heavy and very heavy rainfall days, heavy and extremely heavy rainfall, consecutive wet days and annual wet-day rainfall total using climate indices method. All these methods are not a 'physical-based method'. They are based on the annual climate indices using a lot of parameters (for example RX_n day, Maximum n -days precipitation, PRCPTOT: Annual total wet-day precipitation). Their great weakness is that they do not consider the characteristics of rainfall (Variability, intermittence, scaling regimes etc).

However, multifractal approach could be a prospect to characterize the impact of climate change. For example, Hoang et al. (2012) have shown that this approach is the most appropriate for analyzing and characterizing the strong spatio-temporal variability observable over a wide

range of rainfall fields. In addition, Hoang et al. (2014) suggested the possibility of detecting the hydrological impacts of climate change from the evolution of multifractal parameters. The strength of these methods is that they use less parameters with physical interpretation. In West Africa and especially in Benin, no study has analyzed the impacts of climate change through a multifractal approach. This paper aims to study, for the first time in Benin, the hydrological impacts of climate change through a multifractal approach.

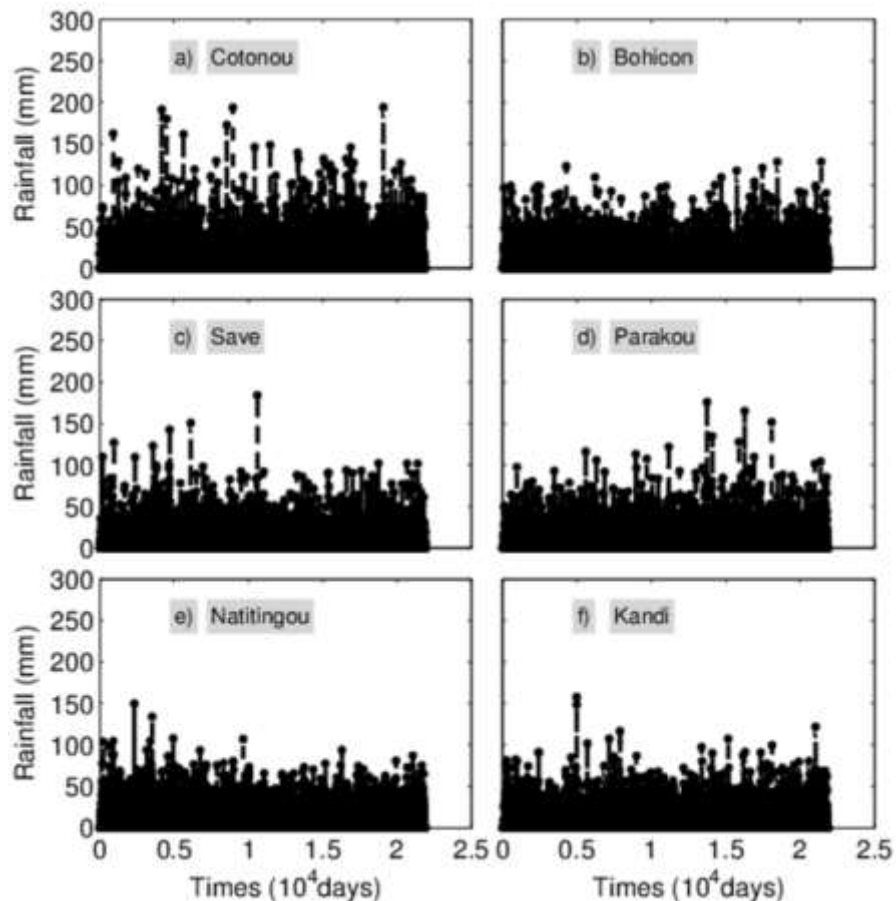
MATERIALS AND METHODS

Site description

The study covers all the synoptic stations of Benin Republic (Figure 1) whose geographical positions are presented in Table 1. Benin Republic is characterized from the South to North by three climatic zones in which the synoptic stations are located (Boko, 1988): (1) Cotonou and Bohicon are located in sub-equatorial region where March is the hottest month ($\sim 26^\circ\text{C}$), while August is the coldest month ($\sim 24^\circ\text{C}$). The daily and annual thermal amplitudes are respectively ~ 10 and $\sim 5^\circ\text{C}$. The relative humidity ranges between 70 and 95% because of the proximity to the Atlantic Ocean. The sub-equatorial climate has four seasons: a long rainy season (April to July) followed by a short dry season (August-September) and a short rainy season (October-November) followed by long dry season (December to March) in the year. However, (2) the stations of Kandi and Natitingou are located in Sudanian region in the northern part of the country. The daily mean of air temperatures in Natitingou and Kandi are respectively ~ 25 and $\sim 35^\circ\text{C}$. (3) Savè and Parakou are located in the transition area between the two kinds of climatic zone. The daily mean of air temperatures in Savè and

Table 1. Benin's synoptic stations geographical coordinates.

Synoptic stations	Latitude °N	Longitude °E	Altitude (m)
Cotonou	6.21	2.23	3.9
Bohicon	7.10	2.03	166.00
Save	8.02	2.26	198.51
Parakou	9.21	2.37	392.00
Natitingou	10.19	2.52	289.75
Kandi	11.08	1.23	460

**Figure 2.** Temporal variations of rainfall time series collected from 1951 to 2010: (a) Cotonou station, (b) Bohicon station, (c) Savè station, (d) Parakou station, (e) Natitingou station and (f) Kandi station.

Parakou is $\sim 27^{\circ}\text{C}$ (Table 1).

Data records

Data were provided by the Agency for the Aerial Navigation's Security in Africa and in Madagascar (ASECNA). Daily rainfall data from Bénin synoptic stations are used from 1951 to 2010. Rainfall variation during the study period is presented in Figure 2 for each synoptic station. Figure 2 shows the daily rainfall strong variability

throughout all the synoptic stations.

Approach

This part of the paper describes respectively the different methods applied to study the hydrological impacts of climate change through a multifractal approach. To achieve our goals, the following methods are applied: (i) The yearly intermittency degree of rainfall is characterised through the yearly fractal dimension (D_f) computed

with the method of box counting. (ii) The character of the rain processes is studied by the spectral analysis method. (iii) The universal multifractal parameters α and C_1 are directly determined by Trace Moment method (TM). (iv) Finally, the probable maximum singularity (γ_s) is deduced from the universal multifractal parameters α and C_1 . The details of these methods are presented as follows.

Fractal dimension

The fractal dimension is computed by using the method of box counting (Mandelbrot, 1982; Lovejoy et al., 1987; Hubert and Carbonnel, 1989). The total observation time T is divided into n contiguous intervals of length λ taken as successive powers of 2. The total number of occupied intervals $N(\lambda)$, in which at least one rainy day has been observed, is then counted. To be more precise $N(\lambda)$ if the number of boxes where it rains on the scale λ ; if the data forms a one-dimension fractal, then:

$$N(\lambda) \propto \lambda^{-D_f} \quad (1)$$

$$\log(N(\lambda)) = -D_f \log(\lambda) + K \quad (2)$$

Where, K is a constant, D_f is defined as the fractal dimension. When plotting $\log N(\lambda)$ as a function of $\log(\lambda)$, a straight line with slope ($-D_f$) is obtained. The maximum value of the fractal dimension will be equal to 1 (Hubert and Carbonnel, 1989; Biauou, 2004) ($0 < D_f < 1$).

Spectrum analysis

Spectrum analysis on Fourier transform translates the time domain characteristics of data into frequency domain. The scaling regime of rainfall time series can be estimated from their power spectrum $S(f)$ (Lovejoy et al 2010). If a time series spectrum obeys a power law, the relation between $S(f)$ and the frequency f is given by Equation 3:

$$S(f) = f^{-\beta} \quad (3)$$

The spectral exponent β is identified as a slope of the spectrum straight-lined zone, plotted in a double logarithmic diagram (Fraedrich and Larnder, 1993; Olsson et al., 1993; Cheng et al., 2013). The value of β is often calculated by linear regression. According to Schertzer and Lovejoy (1987); Calif et al. (2014), if $\beta > 1$ in the power spectrum then the process is non- conservative. Otherwise if $\beta < 1$, the process is conservative.

Trace moment method (TM)

According to Schertzer and Lovejoy (1987), the fundamental equation of the multifractal formalism in terms of statistical moments is written as:

$$\langle \phi_\lambda^q \rangle \approx \lambda^{K(q)} \quad (4)$$

where ϕ_λ is the rainfall field seen at resolution λ , and $\langle \cdot \rangle$ is the averaging operator, q is the order of the statistical moment. $\lambda = T/d$ (where T is the largest time scale of the scaling regime, d is the observation duration). $K(q)$ is a function characterizing the scale invariance of the statistical moments of order q . $K(q)$ is deduced as the slope of the diagram obtained when plotting $\log(\langle \phi_\lambda^q \rangle)$ as a function of $\log(\lambda)$, (Schertzer and Lovejoy, 1987a, 1991b; Hoang et al., 2011). In this study, q ranges from 0.1 to 3.5 with step equal to

0.1. According to Schertzer and Lovejoy (1987), in the context of universal multifractals, when the study field is conservative (that is, when $\beta < 1$), $K(q)$ is expressed as:

$$K(q) = \frac{C_1}{\alpha-1} (q^\alpha - q) \quad (5)$$

Where the parameter α is the multifractality index ($0 \leq \alpha \leq 2$), which measures the variability of the rain intermittency ($\alpha = 0$ if it rains always, rain the same way or if it does not rain). C_1 is the co-dimension of the average rainfall, which measures the average intermittency of the rain ($C_1 = 0$ if the rain is homogeneous or if it rains all the time). According to Hoang et al. (2011) in the Trace Moment method (TM) universal multifractal parameters α and C_1 are directly determined by the first two derivatives of the function $K(q)$ when $q = 1$ as :

$$C_1 = \left. \frac{dK(q)}{dq} \right|_{q=1} \quad (6)$$

$$\alpha = \left(\left. \frac{d^2K(q)}{dq^2} \right|_{q=1} \right) / C_1 \quad (7)$$

If C_1 and α increase, then the extremes (or the extreme intensities of the rain) increase and conversely if they decrease both. When C_1 and α vary in opposite directions, the response of the extremes will depend on which of the two variations dominates. In this case, the probable maximum singularity method is more appropriate to analyse extreme fluctuations (Royer et al., 2008; Hoang et al., 2014).

Probable maximum singularity method

According to Schertzer and Lovejoy (1987), the probable maximum singularity (γ_s) is defined as:

$$\gamma_s = C_1 \frac{\alpha}{\alpha-1} \left(C_1^{\frac{1-\alpha}{\alpha}} - \frac{1}{\alpha} \right) \quad (8)$$

The slope of the linear regression of (γ_s) with respect to time allows one to deduce the (linear) trend of the temporal evolution of (γ_s). A positive value of this slope will represent a tendency towards increasing extremes, and conversely to a tendency to decrease them for a negative slope.

From the literature, some studies in West Africa (Balme, 2004; Balme et al., 2006; Ozer et al., 2003) have divided the period of [1951-2010] as follows: [1951-1970] is considered as the wet period, (1971-1990) is the drought period and (1991-2010) is the end of the drought. In order to verify this division of [1951-2010] period and to assess the risk of hydrological impacts of climate change by multifractal approach, the following computations are done:

1) The yearly fractal dimension for each year of the historical period from 1951 to 2010, then, the average of the yearly fractal dimension obtained over the sub-period [1951-1970], [1971-1990] and [1991-2010] are calculated and compared. The mean value of the fractal dimension in each sub-period is noted ($\overline{D_f}$). It is important to keep in mind that a low fractal dimension D_f value corresponds to a high intermittency of rainfall. In addition, high intermittency corresponds to a large percentage of zeros rainfall (the percentage of rainfall zeros is the fraction of time steps for which no rainfall has been recorded). In this study we considered as zero precipitation when the rainfall is less than 6 mm.

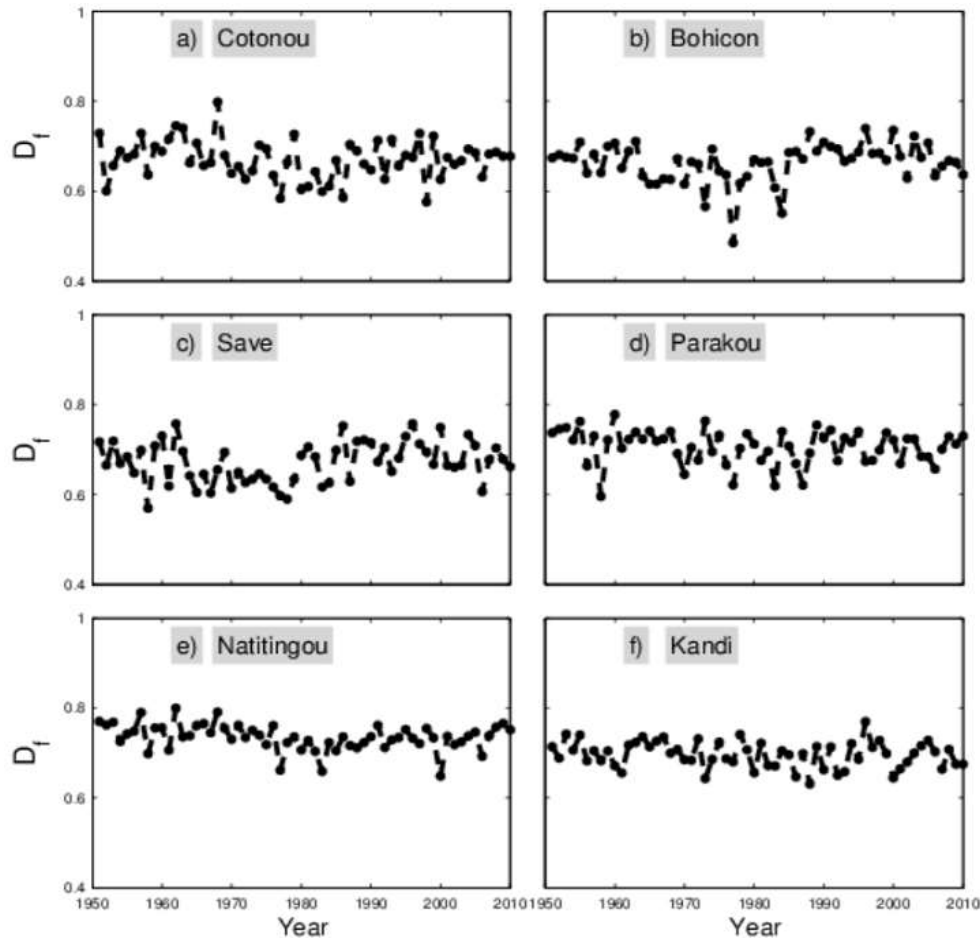


Figure 3. Temporal evolution of fractal dimension, (a) Cotonou Station, (b) Bohicon Station, (c) Savè Station, (d) Parakou Station, (e) Natitingou Station and (f) Kandi Station.

2) The multifractal parameters C_1 and α and the probable maximum singularity (γ_s) for each year of the historical period from 1951 to 2010 are calculated. Their evolution has been studied during 1951 to 2010 and during three separate sub-period: the first is [1951 - 1970]; the second is [1971-1990] and the third is [1991-2010].

3) The (linear) trend of the temporal evolution of (γ_s) over [1951-2010]; [1951 -1970]; [1971-1990] and [1991-2010] is deduced. A positive value of trend represents a tendency towards increasing extremes, and conversely to a tendency to decrease them for a negative slope.

4) The statistical significance of trend is evaluated by Mann-Kendall test. We presented all the trends obtained over period and sub-period, but only interpret those that are statistically significant.

RESULTS AND DISCUSSION

Temporal evolution of fractal dimension and spectral exponent

Figure 3 presents the fractal dimension for each year of the historical period from 1951 to 2010. This figure shows that the fractal dimension varies year to year. Thus, rainfall intermittency varies with the year and the

geographical position of the studied station.

The average of the yearly fractal dimension obtained over the sub-period [1951-1970] (black line), [1971-1990] (red line) and [1991-2010] (blue line) is presented in Figure 4. Whatever the synoptic station considered the fractal dimension mean ($\overline{D_f}$) obtained over [1971-1990] is systematically lower than those of [1951-1970] and [1991-2010]. This low value of ($\overline{D_f}$) means that in [1971-1990] rainfall times series present a high intermittency comparing to [1951-1970] and [1991-2010]. This intermittency corresponds to the large percentage of zeros in rainfall times series (Here the zeros are defined as rainfall heights less than 6 mm). This result agrees with the work which found that [1971-1990] is a drought period in West Africa (Balme, 2004; Balme et al., 2006; Ozer et al., 2003). Except for the synoptic stations of Save and Bohicon the values of ($\overline{D_f}$) obtained in the sub-period [1991-2010] are systematically smaller than those of [1951-1970]. This result means that in [1991-2010] rainfall times series present a high intermittency comparing to [1951-1970] over all synoptic station,

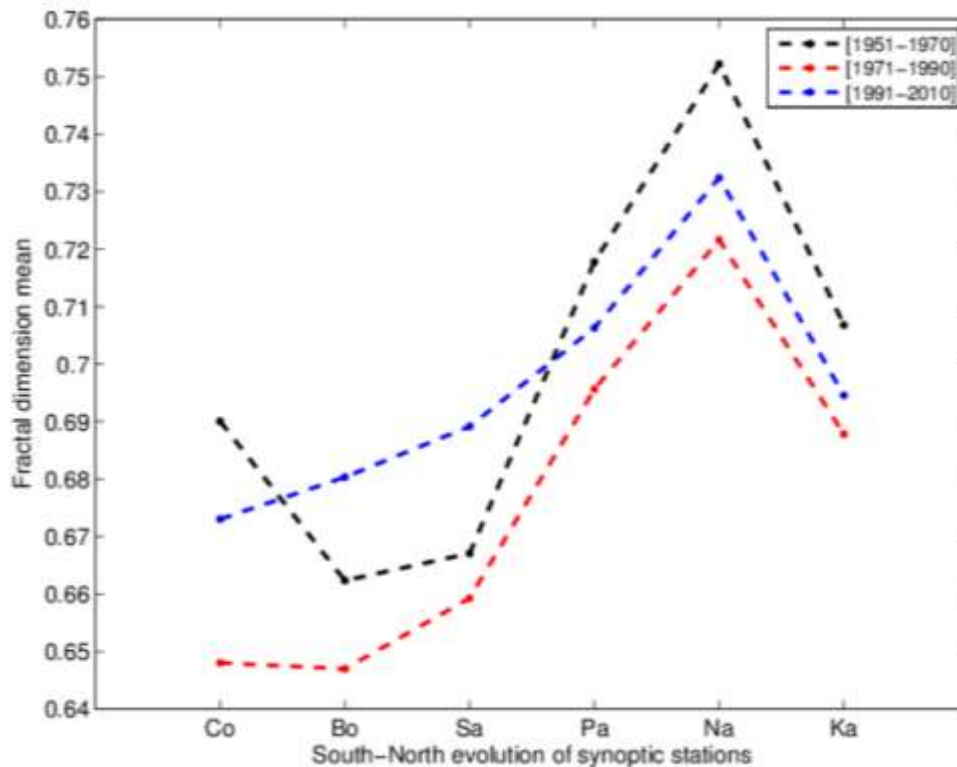


Figure 4. Spatio-temporal variation of the fractal dimension mean value, obtained over [1951-1970] (black line), [1971-1990] (red line), [1991-2010] (bleue line).

except Bohicon and Save. Thus, generally the degree of intermittency of the rainfall fields on the sub-period [1971-1990] is smaller than that of the sub-period [1991-2010], and that of [1991-2010] is lower than that of [1951-1970]. Therefore, [1991-2010] is not necessary the end of the drought over all synoptic stations. Thus, over the period [1991-2010], drought decreased slightly compared to [1971-1990] but cannot be systematically considered as a recovery period as mentioned in the literature by some studies (Balme, 2004; Balme et al., 2006; Ozer et al., 2003).

The spectral exponent β for each year of the historical period from 1951 to 2010 obtained in each Benin synoptic stations is presented in Figure 5. One can note that all the β values are systematically less than 1. Thus, whatever the year and the synoptic station, rainfall processes are conservative.

Temporal evolution of universal multifractal parameters

Figure 6 presents the temporal evolution of universal multifractal parameters α and C_1 obtained in each Benin synoptic stations. The results obtained in all the synoptic stations show that the evolutions of α are generally less stable and have larger sampling fluctuations than those

of C_1 . This means that the mean intermittency of the rainfall is rather stable whereas the multifractality of the rainfall is rather fluctuating with time. The green lines observed on each curve correspond to the trend of the temporal evolution of α and C_1 . The values of the slope which characterize the trend of period [1951-2010] are seen in Table 2. The Mann-Kendall test results show that the trends are not simultaneous statistically significance for α and C_1 over all the stations. Moreover, the signs of α and C_1 trend are generally opposite; thus, the response of the extremes depends on which of the two variations dominates. Therefore, the study of probable maximum singularity is necessary to analyse extreme fluctuations in Benin synoptic stations.

Figure 7 presents the time evolution of the (γ_s) of the rainfall time series in synoptic stations. The red lines represent the trend of the temporal evolution of (γ_s) over each of the sub-period ([1951-1970]; [1971-1990]; [1991-2010]), whereas green line presents that of [1951-2010].

There is a tendency in the temporal evolution of the parameter γ_s . The results of the Mann-Kendall test (not shown) revealed that the trends obtained on the [1951-2010] period in all the synoptic stations are statistically significant, which is not necessarily the case for the sub-periods ([1951-1970]; [1971-1990] and [1991-2010]). This means that the probable maximum singularity method can not be rigorously used to study the hydrological

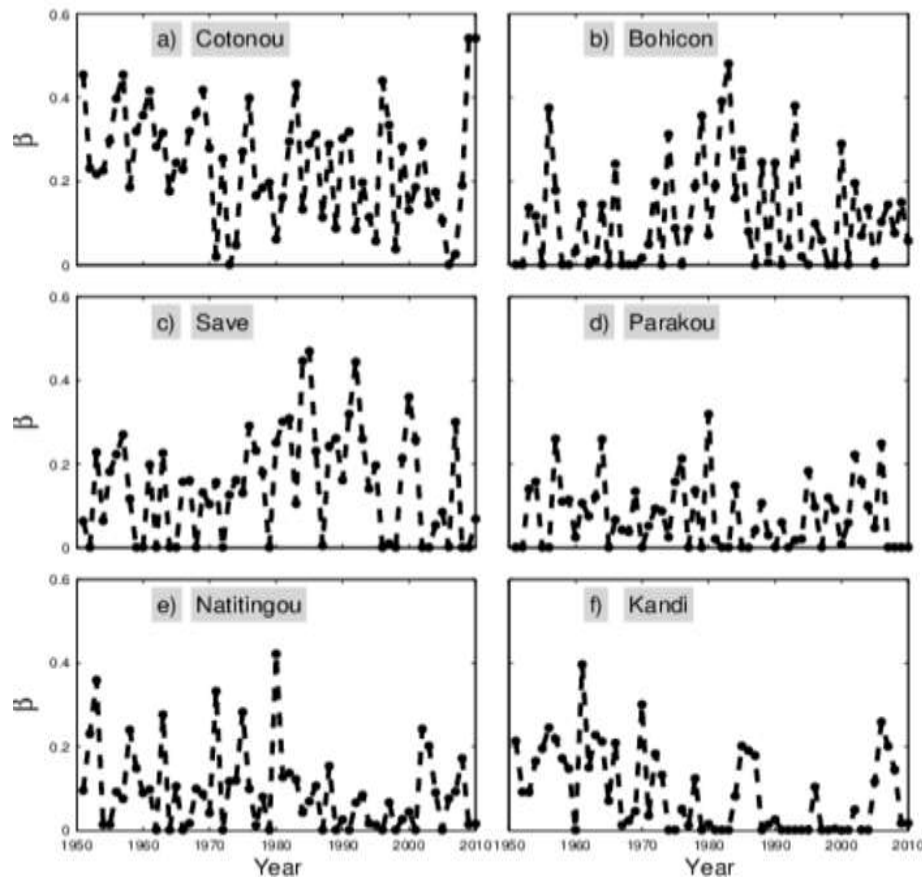


Figure 5. Temporal evolution of spectral exponent β , (a) Cotonou Station, (b) Bohicon Station, (c) Savè Station, (d) Parakou Station, (e) Natitingou Station and (f) Kandi Station.

Table 2. Trend of the temporal evolution of α and C_1 obtained on each synoptic station over [1951-2010] period.

Synoptic stations	α trend	C_1 trend
Cotonou	-0.0014	0.0007
Bohicon	-0.0028	0.0016
Save	-0.0051	0.0018
Parakou	0.0027	0.0004
Natitingou	-0.0015	0.0002
Kandi	-0.0009	0.0005

impact of climate change on these sub-periods.

The spatial evolution of the γ_s trend obtained over [1951-1970]; [1971-1990]; [1991-2010] and [1951-2010] is respectively presented by black line; red line; blue line and green line in Figure 8. Given that the tendency in the temporal evolution of the parameter γ_s on the sub-periods ([1951-1970]; [1971-1990] and [1991-2010]) is not statistically significant according to Mann-Kendall test as mentioned above, our analysis will be focused only on the curve which describes the spatial evolution of the γ_s

trend obtained over [1951-2010] (green line).

The results obtained over the period from 1951 to 2010 revealed a positive trend in all synoptic stations except Natitingou. There is a slight increase in γ_s (except Natitingou). Thus, the evolution of the extremes rainfall over this period has a slight tendency to increase. These results agree with those obtained by Hounkpè et al. (2016) and N'Tcha M'Po et al. (2017) over the Ouémé River Basin (Benin) using the climate indices method. At Natitingou Station, there is a slight decrease in (γ_s)

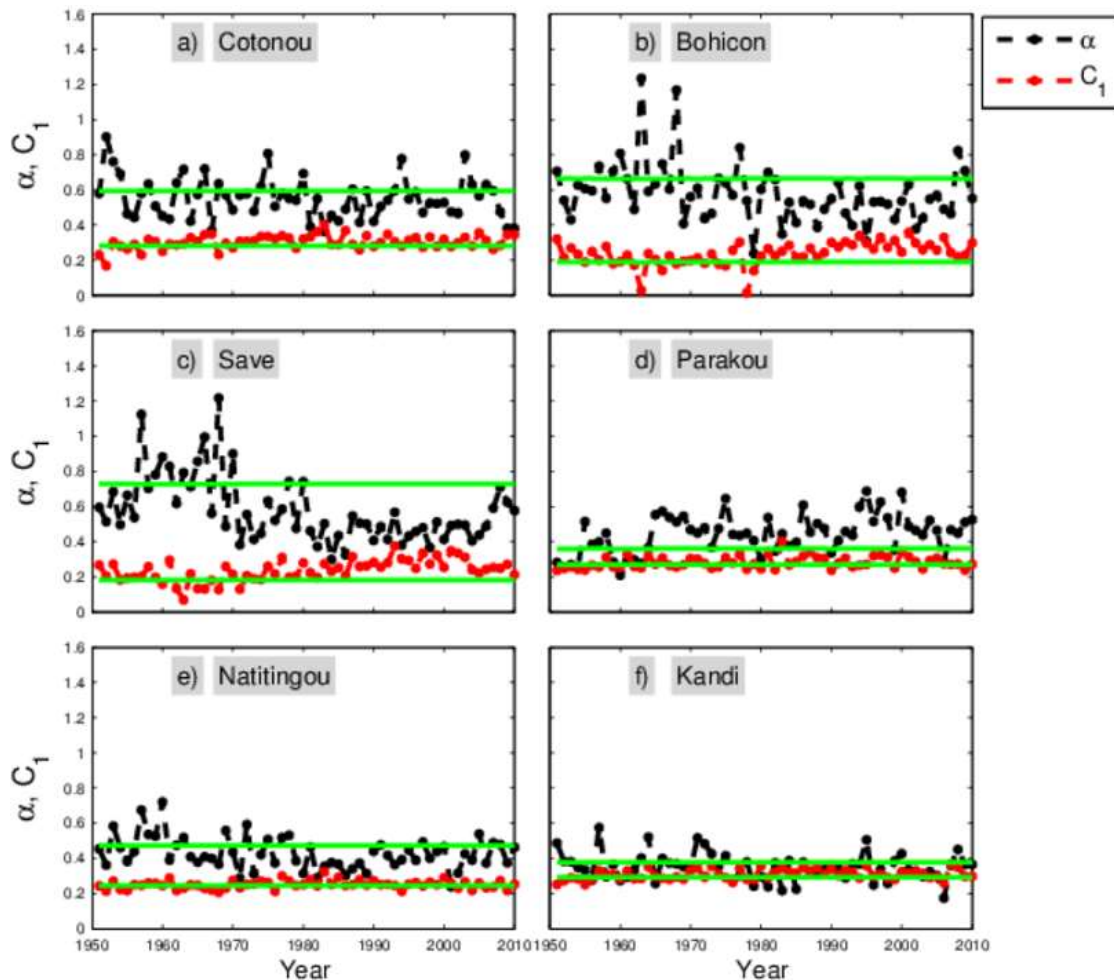


Figure 6. Temporal evolution of universal multifractal parameters α and C_1 , (a) Cotonou station, (b) Bohicon station, (c) Savè station, (d) Parakou station, (e) Natitingou station and (f) Kandi station. The green line corresponds to the linear fit of the estimated values of α and C_1 .

controlling the extreme values of rainfall, indicating a tendency to decrease extremes over the period from 1951 to 2010. This result could be explained by the fact that Natitingou is located in the mountainous region of Benin. The presence of mountains confers to this station the most watered of Benin. In summary, the reason behind the exception done at Natitingou could be linked to the fact that Natitingou is the rainiest region of Bénin because of the presence of mountains (~800 m of high). These different results show and confirm that the multifractal approach is an excellent tool to evaluate the hydrological impacts of climate change using only three parameters. Given that over the sub-period, the Mann-Kendall test revealed that trends are not statistically significant, we cannot use the results obtained to properly explain extreme rainfall evolution over these sub-periods. However, we must not neglect the consequences of a small increase in (γ_s), as it is the parameter that characterizes the extremes.

Conclusion

Generally, in the literature, the impacts of climate change are analysed through the study of annual climate indices and especially by the standardized index of rainfall anomaly. But the weakness of this method is that it does not consider the characteristics of the rains. In Benin, no study has analyzed the impacts of climate change through a multifractal approach. This paper aims to study for the first time in Benin the hydrological impacts of climate change through this approach. The main results obtained from the study are:

i) Whatever the synoptic station considered the yearly fractal dimension mean value ($\overline{D_f}$) obtained over [1971-1990] is systematically lower than those of [1951-1970] and [1991-2010]. This low value of ($\overline{D_f}$) means that in [1971-1990] rainfall times series present a high intermittency comparing to [1951-1970] and [1991-2010].

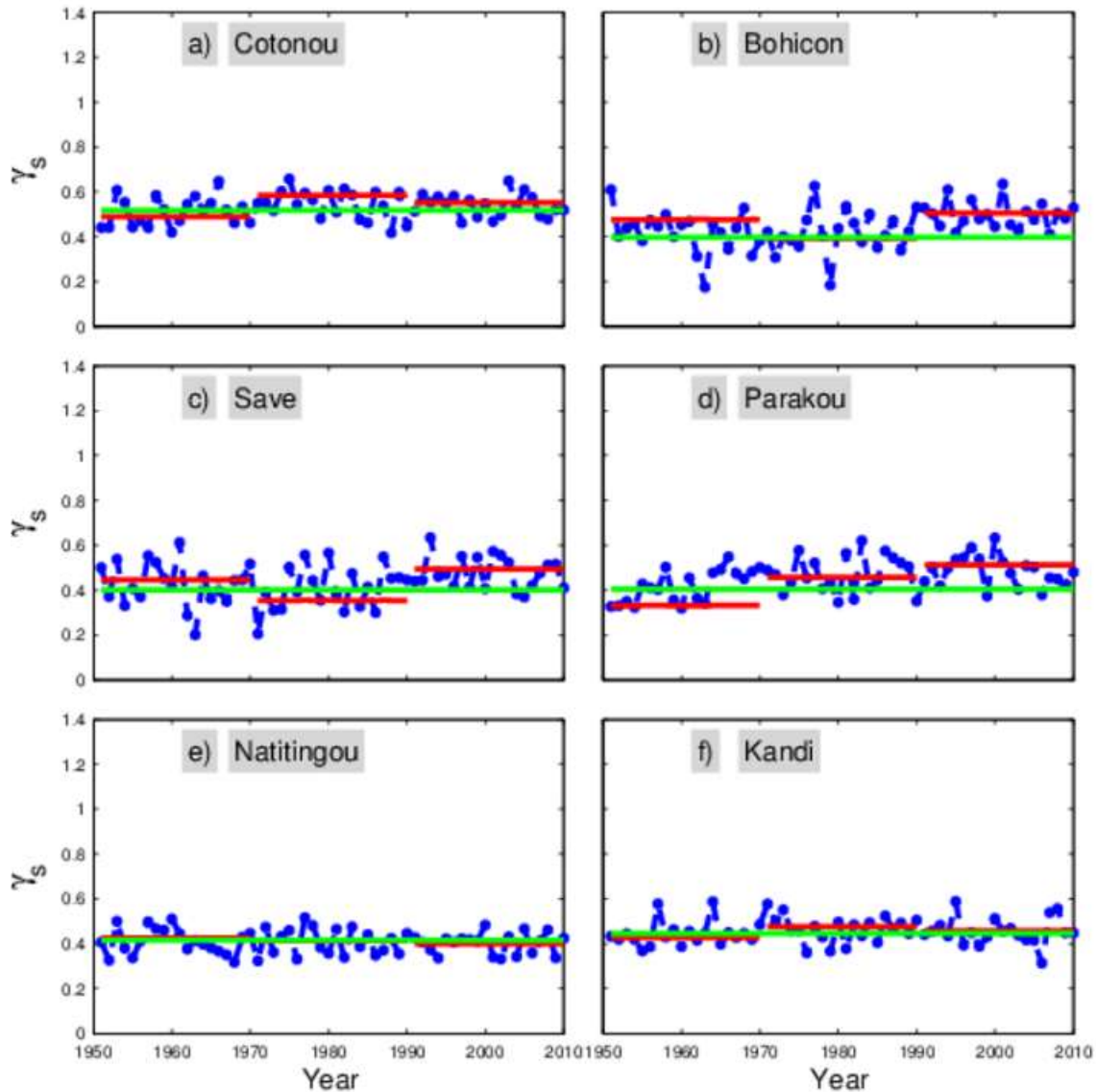


Figure 7. Time evolution of the (γ_s) of the rainfall time series in synoptic stations. The red and green line corresponds to the linear fit of the estimates of (γ_s) over respectively the sub-period ([1951-1970]; [1971-1990]; [1991-2010]) and [1951-2010].

Thus, [1971-1990] is systematically a drought period as found by some studies in literature;

ii) Except, Save and Bohicon, the values of ($\overline{D_f}$) obtained in the sub-period [1991-2010] are systematically smaller than those of [1951-1970]. This result means that in [1991-2010] rainfall times series present a high intermittency comparing to [1951-1970]. Therefore, [1991-2010] is not necessary the end of the drought over all these synoptic stations;

iii) The evolutions of α are generally less stable and have larger sampling fluctuations than those of C_1 . This means that the mean intermittency of the rainfall is rather stable whereas the multifractality of the rainfall is rather

fluctuating with time.

Therefore, the study of probable maximum singularity is necessary to analyse extreme fluctuations in Benin synoptic stations.

iv) The Mann-Kendall test revealed that γ_s trends obtained on the [1951-2010] period in all the synoptic stations are statistically significant, which is not necessarily the case for the sub-periods ([1951-1970]; [1971-1990]; [1991-2010]).

v) During the period from 1951 to 2010 over all synoptic stations except Natitingou, there is a slight increase in γ_s exponent controlling the extremes of rainfall. Thus, the evolution of the extremes rainfall over this period has a

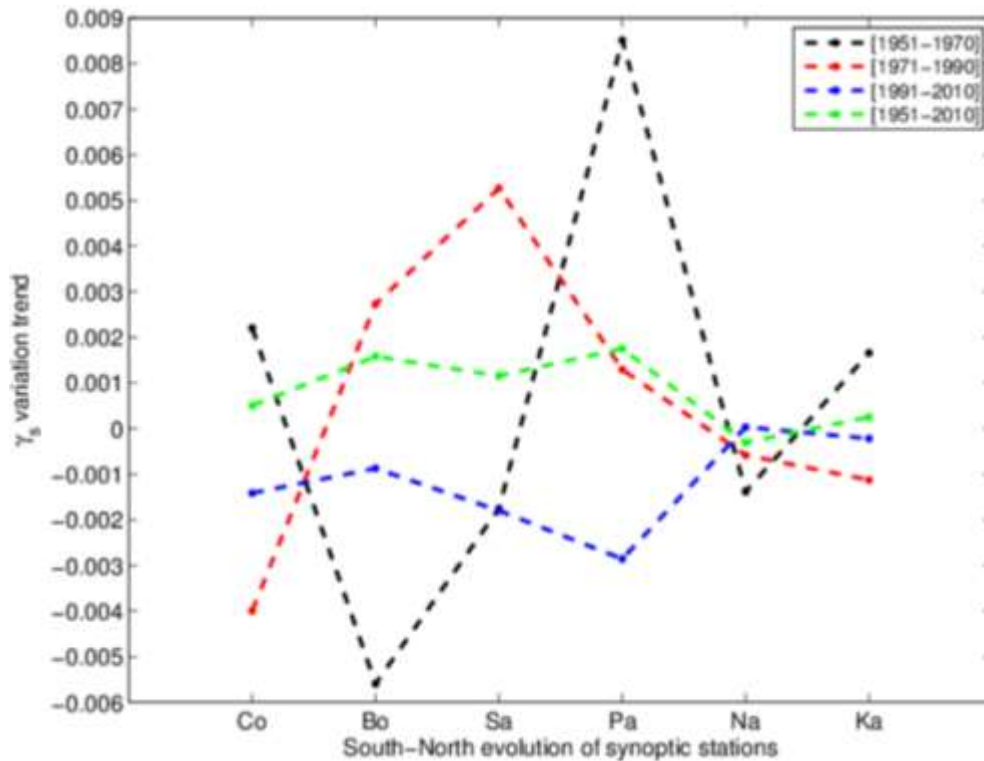


Figure 8. Spatial evolution of the γ_s trend obtained over [1951-1970] (black line); [1971-1990] (red line); [1991-2010] (blue line) and [1951-2010] (green line).

slight tendency to increase. These results agree with those obtained by some studies over the Ouémé River Basin (Benin) using the climate index method. Thus, the multifractal approach is an excellent tool to evaluate the hydrological impacts of climate change by only three parameters. We will probably, in our next works use this method to explain the future evolution of the extremes in Benin.

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CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Aguilar E, Aziz Barry A, Brunet M, Ekan L, Fernandes A, Massoukina

- M, Thamba Umba O (2009). Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006. *Journal of Geophysical Research* 114: D02115. [CrossRef].
- Balme M, Lebel T, Amani A (2006). Années sèches et années humides au sahel: Quo vadis? *Hydrological Sciences Journal* 51(2):254-271.
- Balme M (2004). Analyse du régime pluviométrique sahélien dans une perspective hydrologique et agronomique. Etude de l'impact de la variabilité sur le mil, thèse de l'Ecole de l'Institut national Polytechnique de Grenoble, France.
- Biaou A (2004). De la méso-échelle à la micro-échelle : Désagrégation spatio-temporelle multifractale des précipitations. Thèse de l'Ecole des Mines de Paris, Paris, France.
- Bigot S, Brou YT, Oszwald J, Diedhiou A (2005). Facteurs de la variabilité pluviométrique en Côte d'Ivoire et relations avec certaines modifications environnementales. *Sécheresse* 16(1): 5-13.
- Boko M (1988). Climats et communautés rurales du Bénin. Rythmes climatiques et rythmes de développement. Thèse d'Etat, Paris IV, p. 608 pp.
- Calif R, Schmitt G, Huang Y, Soubdhan T (2013). Intermittency study of high frequency global solar radiation sequences under a tropical climate. *Solar Energy* 98:349-365.
- Easterling DR, Evans JL, Groisman PY, Karl TR, Kunkel KE, Ambenje P (2000). Observed variability and trends in extreme climate events: A brief review. *Bulletin of the American Meteorological Society* 81:417-425. [CrossRef]
- Fraedrich K, Larnder C (1993). Scaling regimes of composite rainfall time series. *Tellus* 45: 289-298.
- Goula BTA, Konan B, Brou YT, Savane I, Fadika V, Srohourou B (2007). Estimation des pluies exceptionnelles journalières en zone tropicale: Cas de la Côte d'Ivoire par comparaison des lois log-normale et de Gumbel. *Hydrological Sciences Journal* 52(1):49-67.
- Hoang CT, Tchiguirinskaia I, Schertzer P, Arnaud P, Lavabre J, Lovejoy

- S (2012). Assessing the high frequency quality of long rainfall series. *Journal Hydrological* 438-439:39-51.
- Hoang CT, Tchiguirinskaia I, Schertzer D, Lovejoy S (2014). Caractéristiques multifractales et extrêmes de la précipitation à haute résolution, application à la détection du changement climatique. *Revue des sciences de l'eau / Journal of Water Science* 27(3):205-216.
- Hoang CT (2011). Prise en compte des fluctuations spatio-temporelles pluies-débits pour une meilleure gestion de la ressource en eau et une meilleure évaluation des risques. Thèse de l'Ecole des Mines de Paris, Paris, France.
- Hountondji YC, De Longueville F, Ozer P (2011). Trends in extreme rainfall events in Benin (West Africa), 19600-2000. In *Proceedings of the 1st International Conference on Energy, Environment and Climate Changes*, Ho Chi Minh City, Vietnam 26-27.
- Hounkpè J, Diekkrüger B, Badou DF, Afouda AA (2016). Change in Heavy Rainfall Characteristics over the Ouémé River Basin, Benin Republic, West Africa. *Climate* 4:15.
- Hubert P, Carbonnel JP (1989). Dimensions fractales de l'occurrence de pluie en climat soudano-sahélien. *Hydrologie Continentale* 4:3-10.
- Lovejoy S, Schertzer D, Tsonis AA (1987). Functional box-counting and multiple elliptical dimensions in rain. *Science* 235:1036-1038.
- Mandelbrot B (1983). *The fractal geometry of nature*. Freeman, San Francisco.
- Mason SJ, Waylen PR, Mimmack GM, Rajaratnam B, Harrison JM (1999). Changes in extreme rainfall events in South Africa *Climatic Change* 41:249-257. [CrossRef].
- N'Tcha M'Po Y, Lawin E, Yao B, Oyerinde G, Attogouinon A, Afouda A (2017). Decreasing Past and Mid-Century Rainfall Indices over the Ouémé River Basin, Benin (West Africa). *Climate* 5:74. 10.3390/cli5030074.
- Ozer A, Ozer P (2005). Désertification au Sahel: Crise climatique ou anthropique? *Bulletin des Séances. Académie Royale des Sciences. d'Outre-51* :395-423.
- Oguntundé PG, Abiodunb BJ, Lischeid G (2011). Rainfall trends in Nigeria, 1901-2000. *Journal of Hydrological* 411:207-218. [CrossRef].
- Ozer P, Hountondji YC, Laminou Manzo O (2009). Evolution des caractéristiques pluviométriques dans l'est du Niger de 1940 à 2007. *GEO-ECO-Tropical* 33:11-30.
- Ozer P, Erpicim M, Demarée G, Vandiepenbeeck M (2003). The Sahelian drought may have ended during the 1990s. *Hydrological Sciences Journal* 48(3):489-492.
- Olsson J, Niemczynowicz J, Berndtsson R (1993). Fractal Analysis of High-Resolution Rainfall Time Series. *Journal of Geophysical Research* 98(D12):23.265-23.274.
- Royer JF, Biaoou A, Chauvin F, Schertzer D, Lovejoy S (2008). Multifractal analysis of the evolution of simulated precipitation over France in a climate scenario. *Comptes Rendus Geoscience* 340:431-440.
- Soro GE, Noufé D, Goula Bi TA, Shorohou B (2016). Trend Analysis for Extreme Rainfall at Sub-Daily and Daily Timescales in Côte d'Ivoire. *Climate* 4:37. [CrossRef]
- Schertzer D, Lovejoy S (1987). Physical modeling and analysis of rain and clouds by anisotropic scaling multiplicative processes. *Journal of Geophysical Research* D8:9693-9714.
- Schertzer D, Lovejoy S (1992). Hard and soft multifractal processes. *Physica A: Statistical Mechanics and its Applications* 185:187-194.
- Zhang X, Alexander L, Hegerl GC, Jones P, Tank AK, Peterson TC, Trewin B, Zwiers FW (2011). Indices for monitoring changes in extremes based on daily temperature and precipitation data, *Wiley Interdisciplinary Reviews: Climate Change* 2(6):851-870.

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