Online ISSN : 2249-4626
Print ISSN : 0975-5896
DOI : 10.17406/GJSFR

Global Journal of Science Frontier Research: H

Environment & Earth Science

Highlights

- Potable Water Management
- Energy Transition in Unsettled Times
- Consumption Against Emission
- Investigating the Seasonal Variations

Discovering Thoughts, Inventing Future

VOLUME 23 ISSUE 6 VERSION 1.0

Global Journal of Science Frontier Research: H
Enviornment & Earth Science

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Volume 23 Issue 6 (Ver. 1.0)

Open Association of Research Society

Incorporation No.: 0423089
License No.: 42125/022010/1186
Registration No.: 430374
Import-Export Code: 1109007027
Employer Identification Number (EIN):
USA Tax ID: 98-0673427

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Framingham Massachusetts Pin: 01701,
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Pricing (Excluding Air Parcel Charges):

Yearly Subscription (Personal & Institutional)
250 USD (B/W) & 350 USD (Color)

Contents of the Issue

Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 23 Issue 6 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Investigating the Seasonal Variations of Event, Recent, and Pre-Recent Runoff Components in a Pre-Alpine Catchment using Stable Isotopes and an Iterative Hydrograph Separation Approach

By Simon Hoeg

Abstract- An analysis of the runoff generation processes in terms of event, recent, and pre-recent runoff components is demonstrated for the Swiss pre-Alpine Alp catchment (46.4 km^2) and two smaller tributaries (Erlenbach, 0.7 km^2, and Vogelbach, 1.6 km^2), whereas, recent water is understood as the contribution of the respective three prior rainfall-runoff events. A four-years time series of daily stable water isotope data in stream water and precipitation is used for the analysis of seasonal variations. In addition, high-frequency data (10 minutely intervals) are used for a detailed visualization of the rapid mobilization of recent water for single events. An iterative extension of the standard two-component hydrograph separation method is applied; this approach can be interpreted as a discretization of the catchment water and tracer mass balance along the event and pre-event time axis. Furthermore, the calculated event, recent, and pre-recent runoff components can be used to estimate time-varying backward travel time distributions.

Keywords: hydrology, runoff generation, stable isotopes, balance equations, hydrograph separation, travel time distribution, catchment hydrology, isotope tracers, water resource management, climate change adaptation.

GJSFR-H Classification: FOR Code: 0406

Strictly as per the compliance and regulations of:

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The two tributaries expose an additional peak of pre-recent water in the snowmelt season (April, 47-62%), and at this time also, the lowest event water fractions (6-8%) can be expected. For the Alp catchment, the event component (29-32%) and recent water component (56%) clearly exceeded the pre-recent component (17-21%) in August and September after the month of July, which is characterized by relatively low precipitation, high evapotranspiration, and low soil moisture. This may be an important finding regarding the expected dryer summers in middle Europe in the near future.

Keywords: hydrology, runoff generation, stable isotopes, balance equations, hydrograph separation, travel time distribution, catchment hydrology, isotope tracers, water resource management, climate change adaptation.

I. Introduction

In recent years, there has been a noticeable increase in the severity of droughts in central Europe and various other regions around the world (Balting et al. (2021), Satoh et al. (2022)). These prolonged periods of water scarcity have had significant impacts on the natural water cycle and the ecosystems that rely on it (Trumbore et al. (2015), Neumann et al. (2017), Senf et al. (2020)). As a result, addressing this issue requires a comprehensive reevaluation of our approach to forest and landscape design (Liu et al. (2022), Gvein et al. (2023)), along with the implementation of appropriate hydrological methods. Isotope-based hydrograph separations can be particularly helpful in this regard, as they can provide insights into the travel times of water within the catchment.

Over the past few decades, the separation of storm hydrographs using stable isotope tracers has become a standard method for investigating runoff generation processes in catchment hydrology. The early pioneering work was accomplished in the late 1960s and 1970s (Pinder and Jones (1969), Dincer et al. (1970), Martinec et al. (1974), and Fritz et al. (1976), Sklash and

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Farvolden (1979)), and over the years, the methodology has been progressively expanded and adapted to address the challenges and tasks found in the feld (Klaus and McDonnell (2013), Jasechko (2019)). Hoeg (2019) recently proposed a method that iteratively extends the standard two-component separation, such that n time components are separated by using a single stable isotope tracer. This approach can be used to trace the event water over a much longer period after the initial event, hence expanding the space of addressable use cases for catchment hydrologists. Hoeg (2019) applied the new method to an experimental data set of the mountainous Zastler catchment (18.4 km^2, Southern Black Forest, Germany) and compared the outcome with previous investigations in that area, showing the influence of antecedent moisture conditions on the event water contributions of subsequent events. This iterative extension uncovered the temporal structure of the pre-event component, and enabled a closer look at the temporal composition of the pre-event water, hence determining the extent to which recent events were involved.

A catchment response pattern related to antecedent moisture conditions similar to that of the Zastler catchment was found by Iorgulescu et al. (2007); they used a hydrochemical model based on a parameterization of three runoff components (direct precipitation, acid soil water, and deep groundwater) to predict conservative tracer data in the Haute-Mentue catchment (12.5 km^2, Swiss Plateau). The authors concluded that the soil water component that corresponds to recent water stored in the upper soil horizons dominates catchment outflow in wet conditions but is virtually absent in dry conditions. James and Roulet (2009) formulated antecedent moisture conditions and catchment morphology as controls on the spatial patterns of runoff generation. Based on stable isotopes, they examined the spatial patterns of storm runoff generation from eight small nested forest catchments ranging in size from 0.07 to 1.5 km^2 (formerly the glaciated terrain of Mont Saint-Hilaire, Quebec), here as a function of antecedent moisture conditions and catchment morphology. For the storms observed under dry conditions, larger magnitudes of new water were generated from the three largest catchments attributable to basin morphology, while the storms observed under wet conditions exhibited no consistent pattern, with larger variability among the smaller catchments. The results illustrated the complexity of the influences of antecedent moisture conditions. For the pre-Alpine Erlenbach tributary (0.7 km^2) Von Freyberg et al. (2018) showed that pre-event water as a fraction of precipitation was strongly correlated with all measures of antecedent wetness but not with storm characteristics, implying that wet conditions primarily facilitate the mobilization of old (pre-event) water rather than the fast transmission of new (event) water to streamflow, even at a catchment where runoff coefficients can be large.

Time series of the natural isotopic composition (2H, 18O) of precipitation and streamwater can provide important insights into ecohydrological phenomena at the catchment scale. However, multi-year, high-frequency isotope datasets are generally scarce, limiting our ability to study highly dynamic short-term ecohydrological processes. Von Freyberg et al. (2022) recently presented a four years of daily isotope measurements in streamwater and precipitation at the Alp catchment in Switzerland and two of its tributaries. Therefore, the current study contributes here in three ways:

1. The classic hydrograph separation is embedded in a discretization of the catchment water and tracer mass balance along the event and pre-event time axis.
2. A characteristic seasonal variation of event, recent, and pre-recent runoff components is shown for the pre-Alpine Alp catchment (46.4 km^2) and two smaller tributaries (Erlenbach, 0.7 km^2, and Vogelbach, 1.6 km^2).
3. Single rain-runoff events of the Erlenbach catchment are analyzed in more detail to visualize and quantify the rapid mobilization of recent water.

II. Methods

a) Separation of n Time Components

Consider a control volume, for instance, a catchment in a river basin, with the following bulk water balance:

$$\frac{\mathrm{d}S(t)}{\mathrm{d}t} = J(t) - ET(t) - Q(t) \tag{1}$$

where S is the time evolution of the water storage, J is the precipitation, ET is the evapotranspiration, and Q is the total stream discharge. Let C be a conservative isotope tracer with the following bulk mass balance:

$$\frac{\mathrm{d}(C_\mathrm{S}(t)S(t))}{\mathrm{d}t} = C_\mathrm{J}(t)J(t) - C_\mathrm{ET}(t)ET(t) - C_\mathrm{Q}(t)Q(t) \tag{2}$$

where C_S, C_J, C_ET, and C_Q are tracer concentrations of the water storage S, and the volumetric flow rates J, ET, and Q. In addition, there are the time points $t_0, t_1, \ldots, t_n$ and time intervals $[t_0, t_1[, [t_1, t_2[, \ldots, [t_{n-1}, t_n[$ that describe the start and end of n rainfall-runoff events along the time axis. Furthermore, there is a semantic time measure with the intervals e (event) and p (pre-event) that can be moved across the rainfall-runoff events, whereas the interval p is the range of all intervals just before interval e. For instance, the stream discharge Q during event e is composed of water from the current rainfall-runoff event and the prior rainfall-runoff events, such that

$$\begin{aligned} Q(t) &= Q^e(t) + Q^p(t) \\ C_\mathrm{Q}(t)Q(t) &= C_\mathrm{Q}^e(t)Q^e(t) + C_\mathrm{Q}^p(t)Q^p(t) \end{aligned} \tag{3}$$

where C_Q^e and C_Q^p are bulk tracer concentrations in the event and pre-event components, respectively. The same relations can be applied to the physical variables $\mathrm{d}S(t)/\mathrm{d}t$, $J(t)$, and $ET(t)$. Therefore, we can write generally for each volumetric flow rate $\dot{V}$ that

$$\begin{aligned} \dot{V}(t) &= \dot{V}^e(t) + \dot{V}^p(t) \\ C_{\dot{V}}(t)\dot{V}(t) &= C^e_{\dot{V}}(t)\dot{V}^e(t) + C^p_{\dot{V}}(t)\dot{V}^p(t) \end{aligned} \tag{4}$$

Furthermore, an iterative balance of the catchment event and pre-event mass and volume flows can be formulated along the time axis; that is, the pre-event water fraction of each rainfall-runoff event is entirely composed of the event water and pre-event water of the previous event. Therefore, for a first backward iteration, we have the following equations:

$$\begin{aligned} \dot{V}^p(t) &= \dot{V}^{e-1}(t) + \dot{V}^{p-1}(t) \\ C^p_{\dot{V}}(t)\dot{V}^p(t) &= C^{e-1}_{\dot{V}}(t)\dot{V}^{e-1}(t) + C^{p-1}_{\dot{V}}(t)\dot{V}^{p-1}(t) \end{aligned} \tag{5}$$

and for τ backward iterations, the whole system of the balance equations can be defined as follows:

$$\begin{aligned} \dot{V}(t) &= \dot{V}^e(t) + \dot{V}^p(t) \\ C_{\dot{V}}(t)\dot{V}(t) &= C^e_{\dot{V}}(t)\dot{V}^e(t) + C^p_{\dot{V}}(t)\dot{V}^p(t) \\[1em] \dot{V}^p(t) &= \dot{V}^{e-1}(t) + \dot{V}^{p-1}(t) \\ C^p_{\dot{V}}(t)\dot{V}^p(t) &= C^{e-1}_{\dot{V}}(t)\dot{V}^{e-1}(t) + C^{p-1}_{\dot{V}}(t)\dot{V}^{p-1}(t) \\[1em] \dot{V}^{p-1}(t) &= \dot{V}^{e-2}(t) + \dot{V}^{p-2}(t) \\ C^{p-1}_{\dot{V}}(t)\dot{V}^{p-1}(t) &= C^{e-2}_{\dot{V}}(t)\dot{V}^{e-2}(t) + C^{p-2}_{\dot{V}}(t)\dot{V}^{p-2}(t) \\ \vdots \quad &= \quad \vdots \\ \dot{V}^{p-\tau+1}(t) &= \dot{V}^{e-\tau}(t) + \dot{V}^{p-\tau}(t) \\ C^{p-\tau+1}_{\dot{V}}(t)\dot{V}^{p-\tau+1}(t) &= C^{e-\tau}_{\dot{V}}(t)\dot{V}^{e-\tau}(t) + C^{p-\tau}_{\dot{V}}(t)\dot{V}^{p-\tau}(t) \end{aligned} \tag{6}$$

Here, the event components $\dot{V}^e$, $\dot{V}^{e-1}\ldots\dot{V}^{e-\tau}$ and pre-event components $\dot{V}^p$, $\dot{V}^{p-1}\ldots\dot{V}^{p-\tau}$ are usually unknowns, whereas the volumetric flow rate $\dot{V}$ and its tracer concentration $C_{\dot{V}}$ are usually measured physical quantities. The tracer concentrations of the event components $C^e_{\dot{V}}, C^{e-1}_{\dot{V}}, \ldots, C^{e-\tau}_{\dot{V}}$ and pre-event components $C^p_{\dot{V}}, C^{p-1}_{\dot{V}}, \ldots, C^{p-\tau}_{\dot{V}}$ are usually the estimated physical quantities.

When being applied to all physical variables $\mathrm{d}S(t)/\mathrm{d}t$, $J(t)$, $ET(t)$, and $Q(t)$, the linear equation system (6) can be regarded as a discretization of the ordinary differential equation system (1) and (2) along $\tau+1$ rainfall events. In the literature, equation (3) is the standard two-component separation model and has been used in many hydrological investigations (Klaus and McDonnell (2013)). Sklash and Farvolden (1979) and Buttle (1994) mentioned the following criteria, which also apply to the iterative separation model (6):

1. The isotopic composition of the event component is significantly different from that of the pre-event component.
2. The event component maintains a constant isotopic signature in space and time, and if not, any variations can be accounted for.

3. The pre-event component maintains a constant isotopic signature in space and time, and if not, any variations can be accounted for.

I would like to add another criterion (Criterion 4) that is usually implicitly considered and demands that both the event water $\dot{V}^e$ and pre-event water $\dot{V}^p$ cannot be less than zero or larger than the total runoff $\dot{V}$ (Liu et al. (2004)). Given the equations above, this is the case if the tracer concentration in the volumetric flow $C_{\dot{V}}$ is always between that of the event water $C^e_{\dot{V}}$ and pre-event water $C^p_{\dot{V}}$. In the context of separation model (6), it is required for all the backward iterations τ that

$$C^e_{\dot{V}} < C_{\dot{V}} < C^p_{\dot{V}} \quad \vee \quad C^p_{\dot{V}} < C_{\dot{V}} < C^e_{\dot{V}} \tag{7}$$

Based on the measured knowns $\dot{V}$ and $C_{\dot{V}}$ and the estimated tracer concentrations $C^e_{\dot{V}}$, $C^{e-1}_{\dot{V}}, \ldots, C^{e-\tau}_{\dot{V}}$ and $C^p_{\dot{V}}, C^{p-1}_{\dot{V}}, \ldots, C^{p-\tau}_{\dot{V}}$, we can iteratively derive for $\tau \in \mathbb{N}$ backward iterations for the following solutions:

$$\dot{V}^e(t) = \dot{V}(t)\frac{C_{\dot{V}}(t) - C^p_{\dot{V}}(t)}{C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t)} \tag{8}$$

$$\dot{V}^p(t) = \dot{V}(t)\frac{C^e_{\dot{V}}(t) - C_{\dot{V}}(t)}{C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t)} \tag{9}$$

$$\dot{V}^{e-\tau}(t) = \dot{V}^{p-\tau+1}(t)\frac{C^{p-\tau+1}_{\dot{V}}(t) - C^{p-\tau}_{\dot{V}}(t)}{C^{e-\tau}_{\dot{V}}(t) - C^{p-\tau}_{\dot{V}}(t)} \quad , \tau \geqslant 1 \tag{10}$$

$$\dot{V}^{p-\tau}(t) = \dot{V}^{p-\tau+1}(t)\frac{C^{e-\tau}_{\dot{V}}(t) - C^{p-\tau+1}_{\dot{V}}(t)}{C^{e-\tau}_{\dot{V}}(t) - C^{p-\tau}_{\dot{V}}(t)} \quad , \tau \geqslant 1 \tag{11}$$

In addition, from linear equation system (6), we obtain the following total mass balance for each volumetric flow rate $\dot{V}$:

$$\dot{V}(t) = \sum_{i=0}^{\tau} \dot{V}^{e-i}(t) + \dot{V}^{p-\tau}(t) \tag{12}$$

b) *Determination of End Member Concentrations and Error Estimation*

Resolving the system of balance equations being introduced in section 2.1 for the mentioned unknowns ($\dot{V}^e$, $\dot{V}^{e-1} \ldots \dot{V}^{e-\tau}$ and $\dot{V}^p$, $\dot{V}^{p-1} \ldots \dot{V}^{p-\tau}$), also called end members, requires appropriate estimators for the end member concentrations ($C^e_{\dot{V}}, C^{e-1}_{\dot{V}}, \ldots, C^{e-\tau}_{\dot{V}}$ and $C^p_{\dot{V}}, C^{p-1}_{\dot{V}}, \ldots, C^{p-\tau}_{\dot{V}}$). For instance, when referring to the use case of hydrograph separations, which is addressed by the volumetric flow rate variable Q, the isotope signature C^e_{J} of precipitation J can be taken as an estimator for the tracer concentration C^e_{Q} regarding end member Q^e, whereby changes in the isotope composition of precipitation as a result of evapotranspiration ET or changes in the water storage S (e.g. snow pack with sublimation and re-sublimation processes) must be considered. This context becomes visible if balance equations (1) and (2) are restricted to the event water fraction, such that

$$\begin{aligned} Q^e(t) &= J^e(t) - ET^e(t) - \mathrm{d}S^e(t)/\mathrm{d}t \\ C^e_{\mathrm{Q}}(t)Q^e(t) &= C^e_{\mathrm{J}}(t)J^e(t) - C^e_{\mathrm{ET}}(t)ET^e(t) - \mathrm{d}(C^e_{\mathrm{S}}(t)S^e(t))/\mathrm{d}t \end{aligned} \quad (13)$$

In a similar way, the isotope composition C_{Q} in the discharge Q, which occurs right before a rainfall-runoff event, can be taken as an estimator for the tracer concentration C^p_{Q} of the end member Q^p, whereby changes in the isotope composition of the bulk pre-event isotope composition because of interception J, evapotranspiration ET, or changes in the water storage S (rapid mobilization of pre-event water) must be considered, which becomes obvious, if balance equations (1) and (2) are restricted to the pre-event water fraction, such that

$$\begin{aligned} Q^p(t) &= J^p(t) - ET^p(t) - \mathrm{d}S^p(t)/\mathrm{d}t \\ C^p_{\mathrm{Q}}(t)Q^p(t) &= C^p_{\mathrm{J}}(t)J^p(t) - C^p_{\mathrm{ET}}(t)ET^p(t) - \mathrm{d}(C^p_{\mathrm{S}}(t)S^p(t))/\mathrm{d}t \end{aligned} \quad (14)$$

The above equations show that the quality of the estimators $C^e_{\mathrm{Q}}, C^{e-1}_{\mathrm{Q}}, \ldots, C^{e-\tau}_{\mathrm{Q}}$ and $C^p_{\mathrm{Q}}, C^{p-1}_{\mathrm{Q}}, \ldots, C^{p-\tau}_{\mathrm{Q}}$ can be improved by increasing the observation rate in all volume flow rates $\mathrm{d}S(t)/\mathrm{d}t$, $J(t)$, $ET(t)$, and $Q(t)$, and in fact, there are various approaches in the literature that have directly or indirectly addressed the time variant transformation of tracer mass precipitation via evapotranspiration losses or water storage changes. For instance, by solving the above set of ordinary differential equations (Laudon et al. (2002)), by using transfer functions (Weiler et al. (2003), Iorgulescu et al. (2007), and Segura et al. (2012)), age functions (Botter et al. (2011)) or storage selection functions (Harman (2015), Benettin et al. (2017)), or by applying the correlations between tracer fluctuations in precipitation, evapotranspiration and discharge regarding longer observation periods (Kirchner (2019), Kirchner and Allen (2020))).

In a natural hydrological system, the accurate determination of tracer concentrations $C^e_{\mathrm{Q}}, C^{e-1}_{\mathrm{Q}}, \ldots, C^{e-\tau}_{\mathrm{Q}}$ and $C^p_{\mathrm{Q}}, C^{p-1}_{\mathrm{Q}}, \ldots, C^{p-\tau}_{\mathrm{Q}}$ remains a difficult task, and this is where the error estimators come into play. For the analysis of the field data, the sensitivity of the model plus the input errors of the known variables are usually included in one measure. For instance, Genereux (1998) and Uhlenbrook and Hoeg (2003) have demonstrated this based on analytic expressions for the case of uncorrelated known variables and assumed uncertainties, that is, a classical Gaussian error propagation. Others, for example, Kuczera and Parent (1998), Joerin et al. (2002), Weiler et al. (2003), Iorgulescu et al. (2007), Segura et al. (2012), and Borriero et al. (2023), approximated the expected values based on designed field scenarios and the law of large numbers, which is better known as the Monte Carlo method.

Gaussian error propagation means that the uncertainty u_j of the unknown variable $y_j (j = 1..n)$ is related to the uncertainties $u_i (i = 1..m)$ of the known

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variables $x_i (i = 1..m)$ (assumed to be independent from each other) in the following way:

$$u_j = \sqrt{\left(\frac{\partial y_j}{\partial x_1} u_1\right)^2 + \left(\frac{\partial y_j}{\partial x_2} u_2\right)^2 + .. + \left(\frac{\partial y_j}{\partial x_m} u_m\right)^2} \tag{15}$$

The first-order partial derivatives $\frac{\partial y_j}{\partial x_i}$ can be collected in the following Jacobian $n \times m$ matrix:

$$J(y_1..y_n) = \begin{bmatrix} \frac{\partial y_1}{\partial x_1} & \cdots & \frac{\partial y_1}{\partial x_m} \\ \vdots & \ddots & \vdots \\ \frac{\partial y_n}{\partial x_1} & \cdots & \frac{\partial y_n}{\partial x_m} \end{bmatrix} \tag{16}$$

For instance, in case of $\tau = 0$ for the linear equation system (6) with the unknown variables $\dot{V}^e$ and $\dot{V}^p$ and known (respectively estimated) variables $\dot{V}, C_{\dot{V}}, C^e_{\dot{V}}$, and $C^p_{\dot{V}}$, we get the following:

$$J(\dot{V}^e, \dot{V}^p, t) = \begin{bmatrix} \frac{C_{\dot{V}}(t) - C^p_{\dot{V}}(t)}{C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t)} & \frac{\dot{V}(t)}{C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t)} & \frac{\dot{V}(t)(C^p_{\dot{V}}(t) - C_{\dot{V}}(t))}{(C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t))^2} & \frac{\dot{V}(t)(C_{\dot{V}}(t) - C^e_{\dot{V}}(t))}{(C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t))^2} \\ \frac{C^e_{\dot{V}}(t) - C_{\dot{V}}(t)}{C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t)} & \frac{-\dot{V}(t)}{C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t)} & \frac{\dot{V}(t)(C_{\dot{V}}(t) - C^p_{\dot{V}}(t))}{(C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t))^2} & \frac{\dot{V}(t)(C^e_{\dot{V}}(t) - C_{\dot{V}}(t))}{(C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t))^2} \end{bmatrix} \tag{17}$$

When looking at the denominators of the single Jacobian entries, we can consider the uncertainties $u^e_{\dot{V}}(t)$ and $u^p_{\dot{V}}(t)$ as functions of $1/(C^e_{\dot{V}}(t) - C^p_{\dot{V}}(t))^2$. Beyond the uncertainties of the known variables, a high model-driven uncertainty is expected for event water isotope concentrations that are close to the corresponding pre-event water isotope concentration.

c) *Separated Event Water Response as an Estimator for the Time-Varying Backward Travel Time Distribution*

An iterative separation model (6) can be used to trace event water over a much longer period after the initial event being studied. For the obtained result, I use the term *separated event water response* to emphasize the fact that the traced response relates to the water of exactly one rainfall event. Conceptually, it can be related to the more commonly used term *travel time distribution*. Basically, it can be a time-varying approximation for this.

The travel time distribution is the response or breakthrough of an instantaneous, conservative tracer addition over the entire catchment area. It is the probability distribution that can be derived analytically based on the physical assumptions of the system under investigation. By applying a convolution integral, it can balance the tracer inputs and outputs of equation (2), as follows (Niemi (1977)):

$$C_{\mathrm{Q}}(t) = \int_{-\infty}^{t} C_{\mathrm{J}}(t_{\mathrm{in}})\, h(t - t_{\mathrm{in}}) \mathrm{d}t_{\mathrm{in}}, \tag{18}$$

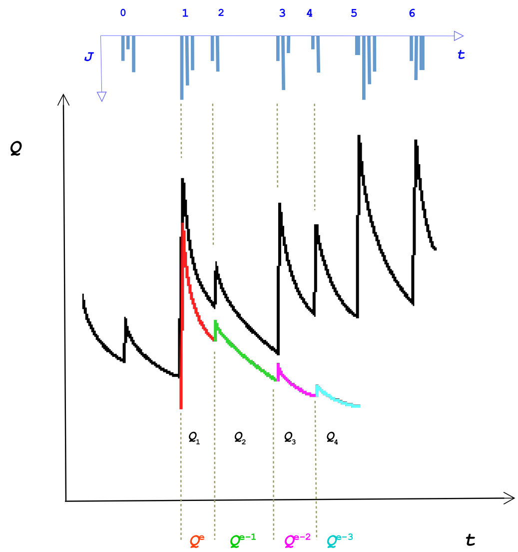

Figure 1: Basic procedure to reconstruct the event water response, here showing the event water contribution of event 1 during events 2, 3, and 4. It is arranged one after the other: the contribution of event water Q^e (t) during event 1, the contribution of the last event water Q^{e-1}(t) during event 2, the contribution of the second-to-last event water Q^{e-2}(t) during event 3, and the contribution of the third-to-last event water Q^{e-3}(t) during event 4

where $h(\varphi)$ is the probability distribution of the travel time φ and t_{in} is the injection time of the tracer. The residence time, travel time, and life expectancy of water particles, along with the associated constituents flowing through watersheds, are three related quantities whose meaning has been well defined (see Rigon et al. (2016)). For instance, Maloszewski and Zuber (1982) introduced a similar convolution integral, as shown in equation (18), but they used the quantity *exit age* instead of *injection time.* On the catchment scale, travel time distributions can serve as fundamental catchment descriptors, revealing information about storage, flow pathways, and sources of water in a single characteristic (McGuire and McDonnell (2006)). Assuming steady-state conditions, travel time distributions are often interpreted and applied as time invariant, for example, as a mean over the period under investigation. In addition, travel time distributions are usually inferred by using lumped parameter models that simplify the description of a spatially distributed catchment behavior. Of course, there is evidence and knowledge to the contrary (Hrachowitz et al. (2010), McDonnell et al. (2010), Botter (2012), Heidbüchel et al. (2013)).

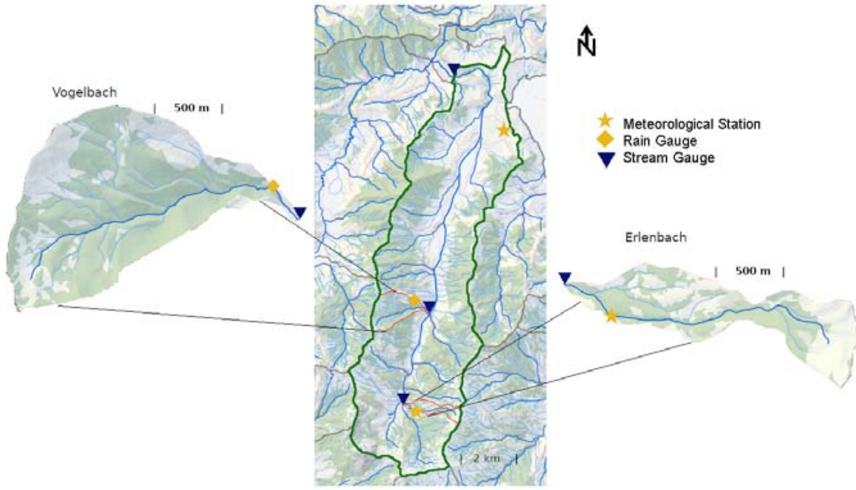

Figure 2: The Alp Catchment (46.4 km^2) with its Two Tributaries Erlenbach (0.7 km^2) and Vogelbach (1.6 km^2)(Bernese Institute for Geography (2018), Von Freyberg et al. (2022))

For non-stationary systems, it makes sense to distinguish between two types of probability density functions: the *forward travel time distribution* and *backward travel time distribution* (Niemi (1977)). The forward travel time distribution, $\overrightarrow{h}(\varphi, t_{\text{in}})$, is the probability distribution of the travel times φ conditional on the injection time t_{in} of a volume flow (e.g., precipitation). The backward travel time distribution, $\overleftarrow{h}(\varphi, t)$, is the probability distribution of the travel times φ conditional on the exit time t of a volume flow (e.g., discharge). When the system is in a steady state (constant input/output fluxes), then the forward and backward travel time distributions collapse into a single probability density function (Niemi (1977), Botter et al. (2011), Rinaldo et al. (2011)); otherwise, the following relation (*Niemi's theorem*) applies:

$$\overleftarrow{h}(t - t_{\text{in}}, t)Q(t) = J(t_{\text{in}})\theta(t_{\text{in}})\overrightarrow{h}(t - t_{\text{in}}, t_{\text{in}}) \tag{19}$$

where $\theta(t_{\text{in}})$ is a partition function describing the fraction of rainfall $J(t_{\text{in}})$ that ends up as runoff Q. In addition, an age function ω_{Q} can be defined that describes the ratio between the number of water particles with an age in the interval $[\varphi, \varphi + \mathrm{d}\varphi]$ sampled by Q at time t and the amount of particles with the same age stored in the control volume at that time:

$$\omega_{\text{Q}}(\varphi, t) = \frac{\overleftarrow{h}(\varphi, t)}{\widehat{h}(\varphi, t)} \tag{20}$$

where $\widehat{h}(\varrho, t)$ is the probability distribution of the residence times ϱ of the water particles stored within the control volume at time t.

The age function $\omega_{\text{Q}}(\varphi, t)$ is an interesting quantity in the sense that the tracer concentrations $C_{\text{Q}}^{e}, C_{\text{Q}}^{e-1}, \ldots, C_{\text{Q}}^{e-\tau}$ and $C_{\text{Q}}^{p}, C_{\text{Q}}^{p-1}, \ldots, C_{\text{Q}}^{p-\tau}$ from equation system (6) can be represented as a function of the same. For instance, the pre-event concentration C_{Q}^{p} for the event e can be calculated as follows:

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$$C^p_{\mathrm{Q}}(e) = \int_{-\infty}^{e-1} C_{\mathrm{J}}(t_{\mathrm{in}})\omega_{\mathrm{Q}}(t - t_{\mathrm{in}}, t)\widehat{h}(t - t_{\mathrm{in}}, t)\mathrm{d}t_{\mathrm{in}} \tag{21}$$

The basic procedure to reconstruct the event water response has already been demonstrated in Hoeg (2019), where the single components Q^e, $Q^{e-1} \ldots Q^{e-\tau}$ were arranged in the following way: Assume we are interested in the event water contribution of event 1 during events 2, 3, and 4. In this case, I can arrange one after the other, in which we have the event water Q^e of event 1, the last event water Q^{e-1} of event 2, the second-to-last event water Q^{e-2} of event 3, and the third-to-last event water Q^{e-3} of event 4, as illustrated in Figure 1.

When referring to the rainfall events $J_1, J_2, \ldots, J_{\tau+1}$ and the related catchment responses $Q_1, Q_2, \ldots, Q_{\tau+1}$, I can define the *separated event water response* as follows:

$$H_{[t_1,t_2[} := \sum_{\mathrm{k}=1}^{\tau+1} Q^{e-k+1}(Q_k) \tag{22}$$

This is the volume flow of the water that entered the catchment at interval $[t_1, t_2[$ with rainfall J_1, which appears in the stream discharge Q during interval $[t_1, t_{1+\tau+1}[$, here as a result of the rainfall events $J_1, J_2, \ldots, J_{\tau+1}$ and the related catchment responses $Q_1, Q_2, \ldots, Q_{\tau+1}$.

Furthermore, I postulate that the volume-weighted function of the time-varying separated event water response $H_{[t_i,t_{i+1}[}$ can be considered an approximation of the time-varying backward travel time distribution, $\overleftarrow{h}(\varphi, t)$, on the time interval $t \in [t_i, t_{i+\tau+1}[$ when it comes to all water molecules that entered the catchment (the control volume of system (1)) at $t_{\mathrm{in}} \in [t_i, t_{i+1}[$:

$$\overleftarrow{h}(\varphi, t) \approx \frac{H_{[t_i,t_{i+1}[}}{\int_{t_i}^{t_{i+\tau}} H_{[t_i,t_{i+1}[}(t)\mathrm{d}t} \tag{23}$$

, respectively

$$\overleftarrow{h}(\varphi, t) \approx \frac{H_{\mathrm{e}}}{\int_{e}^{\mathrm{e}+\tau} H_{\mathrm{e}}(t)\mathrm{d}t} \tag{24}$$

regarding the semantic time intervals $e, e+1, \ldots, e+\tau$ on τ backward iterations.

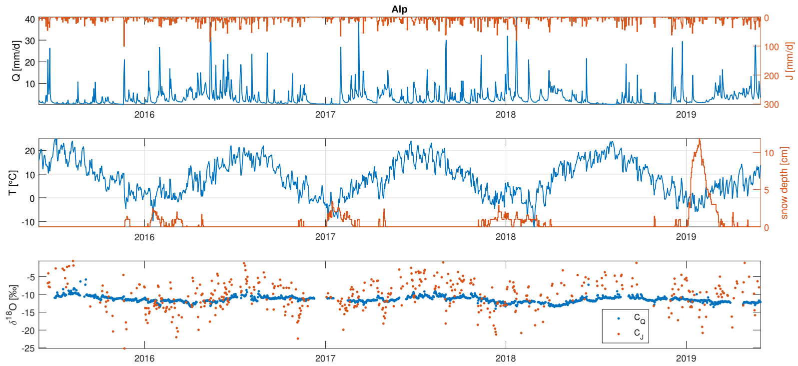

Figure 3: Alp catchment: Four years time series (June 2015–May 2019) of daily stream discharge [mm/d] and precipitation [mm/d], temperature [°C], and snow depth [cm], as well as $\delta^{18}O$ composition in discharge and precipitation [‰] (Von Freyberg et al. (2022)). Tracer concentrations in precipitation are area weighted according to the hypsometric curve. The snow depths are retrieved from ERA5 as part of the Copernicus Climate Change Services (Hersbach et al. (2019)

III. Study Site and Data

According to Von Freyberg et al. (2022) the 46.4 km^2 Alp catchment is located near the city of Einsiedeln in central Switzerland (Figure 2). The

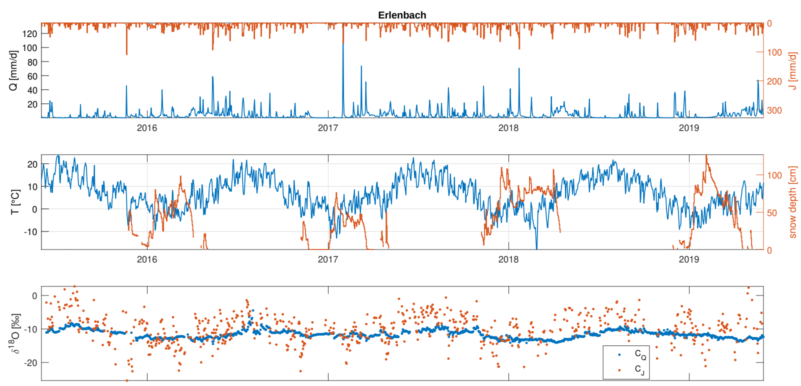

Figure 4: Erlenbach catchment: Four years time series (June 2015–May 2019) of daily stream discharge [mm/d] and precipitation [mm/d], temperature [°C], and snow depth [cm], as well as $\delta^{18}O$ composition in discharge and precipitation [‰] (Von Freyberg et al. (2022)). Tracer concentrations in precipitation are area weighted according to the hypso- metric curve

catchment spans an elevation range of 1058 m, with the outlet at 840 m above sea level and highest summit (Grosser Mythen) at 1898 m above sea level. The average slope of the Alp catchment is 16° with a flat valley bottom and very steep slopes of up to 75° at the south-western catchment boundary. The 0.7 km^2 Erlenbach catchment is located on the eastern side of the Alp valley (elevation range from 1080 to 1520 m above sea level), whereas the 1.6 km^2 Vogelbach catchment is located on the western side (elevation range from 940 to 1480 m above sea level).

The bedrock geology of the Alp catchment consists of tertiary flysch (sandstone, limestone, clays, and marls) and subalpine molasse (conglomerates, sandstone, and marls); the valley bottoms are overlain by gravel and landslide material from the adjacent hillslopes. Soils are generally shallow, with low permeability. The flanks of the Alp catchment are dominated by forests, grasslands, and wetlands, and the valley bottom is dominated by summer pastures and settlements. Van Meerveld et al. (2018) mention that the Alp tributaries are wet throughout most of the year. This is due to the high clay content, the low drainable porosity and shallow soils. The water table is generally close to the soil surface, especially in hollows and flatter areas, where the hydraulic gradient is low or at the bottom of hillslopes because of the large amount of water coming from upslope areas. Surface soil

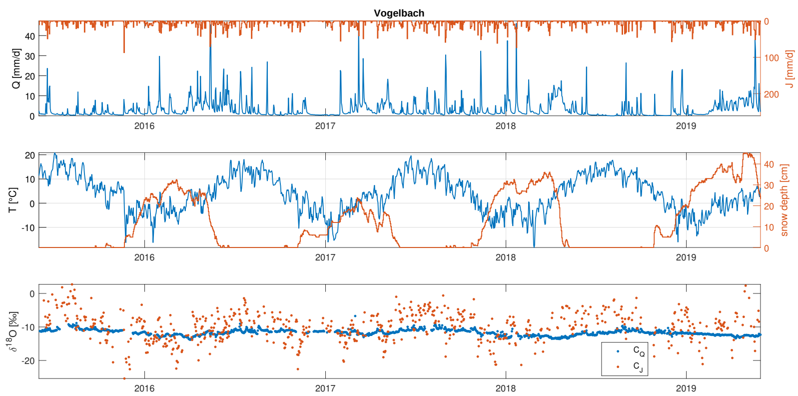

Figure 5: Vogelbach catchment: Four years time series (June 2015–May 2019) of daily stream discharge [mm/d] and precipitation [mm/d], temperature [°C], and snow depth [cm], as well as δ^{18}O composition in discharge and precipitation [‰] (Von Freyberg et al. (2022)). Tracer concentrations in precipitation are area weighted according to the hypso- metric curve

moisture measurements show that soil moisture is lowest in the forested ridge sites and highest in the flatter meadow and wetland sites.

Total annual precipitation in the Alp valley is strongly controlled by elevation, averaging 1791 mm/year in the flat northern part near the outlet, and roughly 30% more in the mountainous headwaters of the catchment (2300 mm/year). Snowfall comprises up to one-third of the total precipitation in the headwaters of the Alp, although snowfall is frequently interrupted by rainfall during mild periods in winter, with a corresponding occurrence of rain-on-snow events (Rücker et al. (2019)).

The ratio of current to potential evapotranspiration (ETa/ETp ratio) serves as a valuable indicator of water availability for plants. When this ratio falls below 0.8, it suggests an increased likelihood of drought-related impairments (Allgaier Leuch et al. (2017)). In the Alp catchment, we can expect ETa/ETp values to range from 0.61 to 0.9 in the valley bottoms, and from 0.81 to 1.00 in the upslope areas. These figures are based on the long-term average spanning from 1981 to 2010.

In the present study, a four-years time series (June 2015–May 2019) of daily stable water isotope data in stream water and precipitation is used for the analysis of seasonal variations. The data set is described by Von Freyberg et al. (2022), who provided detailed information on the precipitation and

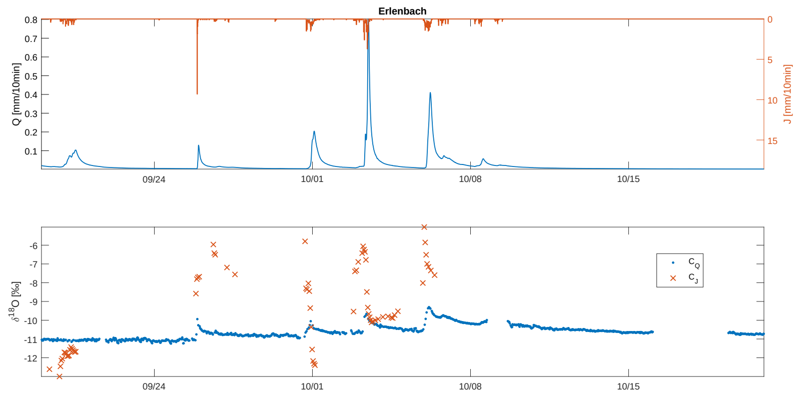

Figure 6: Erlenbach catchment: High-frequency measurements of stream discharge [mm/10 minutes], and precipitation [mm/10 minutes], as well as $\delta^{18}O$ composition in discharge and precipitation [‰] between September 19, 2017 and October 21, 2017 (Von Freyberg et al. (2018))

streamwater sampling, sample handling and isotope analysis. Streamwater isotopes were measured in the Alp main stream and in two of its tributaries (Erlenbach and Vogelbach). Precipitation isotopes were measured at two grassland locations in the Alp catchment: in the headwaters at 1228 m a.s.l. and near the outlet at 910 m a.s.l. The data set also includes the daily time series of key hydrologic and meteorologic variables, such as daily streamwater and precipitation fluxes, air temperature, relative humidity, and snow depth.

To better classify single rainfall runoff events and seasonal relationships, the hydrological data were supplemented with meteorological data (e.g., amount of snowfall, evapotranspiration, soil moisture) from ERA5. The re-analysis product ERA5 has recently been released by European Centre for Medium-Range Weather Forecasts (ECMWF) as part of Copernicus Climate Change Services (Hersbach et al. (2019)). This product covers the period from 1979 to present.

Figures 3, 4, and 5 show excerpts of the data set published via Von Freyberg et al. (2022) regarding the Alp main stream and Erlenbach and Vogelbach tributaries. In addition, Figure 6 shows an excerpt of a data set with high frequency measurements (10-minute time interval) published by Von Freyberg et al. (2018) for the Erlenbach tributary.

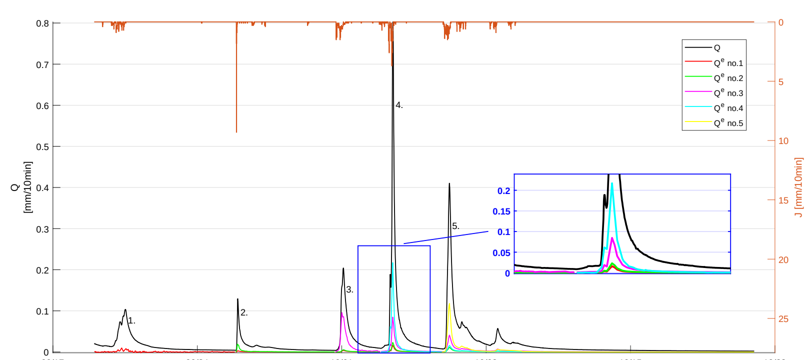

Figure 7: Erlenbach Catchment: Precipitation [mm/10 minutes], Stream Discharge [mm/10 minutes], and Separated Event Water Response [mm/10 minutes] for Five Rainfall Runoff Events Between September 19, 2017 – October 21, 2017

IV. Results and Discussion

a) *Estimating the Time-Varying Backward Travel Time Distribution for Single Events*

The calculated event, recent, and pre-recent runoff components can be used to estimate time-varying backward travel time distributions. In the following, I demonstrate this on the basis of a simple example. Five rainfall runoff events, taken from a field study in the Erlenbach catchment between September 2016 and October 2017 (Von Freyberg et al. (2018)), serve as the examples. The analysis is based on the separation model (6) applying three backward iterations ($\tau = 3$). To determine the end member concentrations $C_Q^e, C_Q^{e-1}, \ldots, C_Q^{e-3}$ and $C_Q^p, C_Q^{p-1}, \ldots, C_Q^{p-3}$, differential equations (13) and (14) are not explicitly solved; instead, the pre-event water concentrations are taken directly from the measured isotope compositions in the discharge right before the hydrograph rises. The event water concentrations refer to the volume-weighted isotope composition in the respective precipitation event. For calculating the Gaussian standard errors, an uncertainty at the scale of the discharge measurements in the field, $u(Q) = 0.001$ [m^3/s], and of the isotope analysis in the laboratory is adopted, that is, $u(C_Q) = 0.09$ [‰], $u(C_Q^e) = 0.09$ [‰], $u(C_Q^p) = 0.09$ [‰], and continuously added for each backward iteration: $u(C_Q^{e-1}) = 0.18$ [‰], $u(C_Q^{p-1}) = 0.18$ [‰], $u(C_Q^{e-2}) = 0.27$ [‰], $u(C_Q^{p-2}) = 0.27$ [‰], $u(C_Q^{e-3}) = 0.36$ [‰], and $u(C_Q^{p-3}) = 0.36$ [‰].

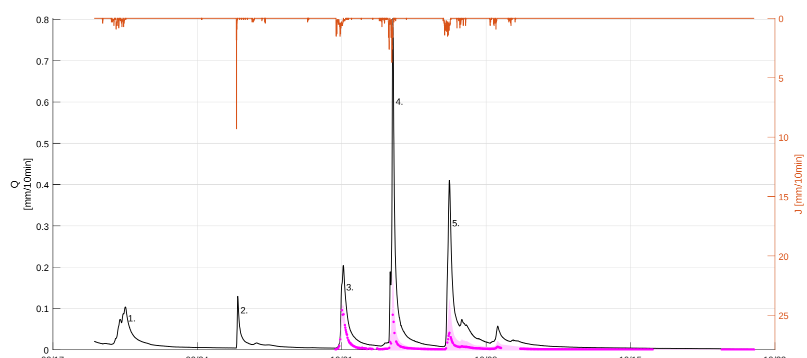

Figure 8: Erlenbach catchment: Precipitation [mm/10 minutes], stream discharge [mm/10 minutes], and separated event water response [mm/10 minutes] (inclusive Gaussian standard error bounds) for rainfall runoff event number 3 between September 19, 2017 – October 21, 2017

Figure 7 shows the separated event water response according to equation (22) and Figure 1 for five rainfall runoff events between September 19, 2017 and October 21, 2017. The volume-weighted version of this time-varying response can be considered an approximation of the time-varying backward travel time distribution, as shown in equation (23). In addition, the so-called rapid mobilization of pre-event water can be detected. For instance, in the magnified section of event no. 4, event water from the previous events 1–3 still occur at the catchment outlet. Von Freyberg et al. (2018) reported that pre-event water is more efficiently mobilized under wetter conditions, showing that the rapid activation of the pre-event water at Erlenbach (even during small storms) can be explained by generally shallow perched groundwater tables in the aquifer overlying the low permeability bedrock.

The median Gaussian standard error for the calculated event, recent, and pre-recent runoff components are $u(Q^e) = 81.9\% \ / \ 0.01 \ \frac{\text{mm}}{10\text{min}}$, $u(Q^{e-1}) = 123.4\% \ / \ 0.10 \ \frac{\text{mm}}{10\text{min}}$, $u(Q^{e-2}) = 205.2\% \ / \ 0.18 \ \frac{\text{mm}}{10\text{min}}$, $u(Q^{e-3}) = 231.6\% \ / \ 0.07 \ \frac{\text{mm}}{10\text{min}}$, and $u(Q^{p-3}) = 32.3\% \ / \ 0.18 \ \frac{\text{mm}}{10\text{min}}$. For better illustration, Figure 8 shows the separated event water response for a single rainfall runoff event (number 3) together with the Gaussian standard error bounds according to equation (15).

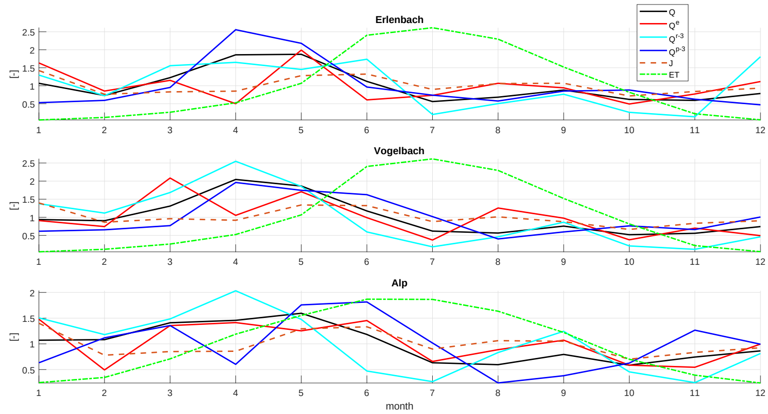

Figure 9: Monthly Pardé coefficients (1: January – 12: December) of stream discharge Q, event water Q^e, recent water Q^{r-3}, pre-recent water Q^{p-3}, precipitation (J), and evapotranspiration (ET) for the Erlenbach, Vogelbach, and Alp catchments, based on the four-year investigation between June 2015 and May 2019, and an iterative extension of the standard two-component hydrograph separation method. Evapotranspiration data are taken from the reanalysis product ERA5

b) *Seasonal Variations of Event, Recent and Pre-Recent Runoff Components*

In the following, an analysis of the runoff generation processes in terms of event Q^e, recent Q^{r-3}, and pre-recent Q^{p-3} runoff components is demonstrated for the pre-Alpine Alp catchment (46.4 km^2) and two smaller tributaries (Erlenbach, 0.7 km^2, and Vogelbach, 1.6 km^2), whereas recent water is understood as the contribution of the respective three prior rainfall-runoff events, that is

$$Q^{r-3} = Q^{e-1} + Q^{e-2} + Q^{e-3} \tag{25}$$

To compensate for altitude effects on the catchment scale, the daily isotope concentrations in precipitation considers the available isotopic samples of the two measuring stations and are area weighted based on to the hypsometric curve of the Alp catchment. The analysis is based on the separation model (6) that applies three backward iterations ($\tau = 3$), whereas the entire data set is being processed; that is, 147 rainfall runoff events are being investigated for the Alp catchment, 113 rainfall runoff events for the Erlenbach catchment, and 120 rainfall runoff events for the Vogelbach catchment. Again, the end member concentrations $C_Q^e, C_Q^{e-1}, \ldots, C_Q^{e-3}$ and $C_Q^p, C_Q^{p-1}, \ldots, C_Q^{p-3}$ are taken directly from the concentrations in the stream

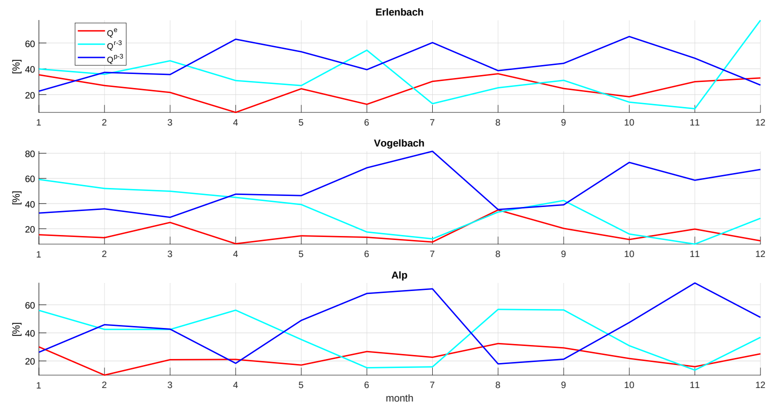

Figure 10: Monthly Pardé coefficients (1: January – 12: December) of event water Q^{e}, recent water Q^{r-3}, and pre-recent water Q^{p-3} for the Erlenbach, Vogelbach, and Alp catchments in relation to the monthly Pardé coefficients of stream discharge (Q) in %, based on the four-year investigation between June 2015 and May 2019, and an iterative extension of the standard two-component hydrograph separation method

discharge and precipitation. In addition, where necessary, the end member concentrations are partially adjusted to ensure that Criterion 4 (equation (7)) is continuously fulfilled. This approach does not reduce or increase the size of the relative error, but it does stabilize the solution overall (Hoeg (2021)). Although the absolute Gaussian standard error bounds are moderately low with values between 0.09 mm/d and 0.61 mm/d (see Table 1), the relative errors associated with this hydrograph separation are relatively high, with values between 38.5% and 622.4%. Therefore, the results may not lead to accurate quantitative conclusions. Nevertheless, qualitative statements about the seasonal runoff formation in the Alpine catchment area and its tributaries Erlenbach and Vogelbach are possible, as I will show below.

To visualize the seasonal variations, I calculate the *Pardé* coefficients for each runoff component, which is the quotient of the long-term (four years) average monthly discharge and long-term (four years) average annual discharge. The precipitation and evapotranspiration regimes are added to better evaluate and classify the monthly and seasonal changes of the runoff components, which are: stream discharge Q, event water Q^e, recent water Q^{r-3}, and pre-recent water Q^{p-3}. Evapotranspiration data are taken from the reanalysis product ERA5 of the Copernicus Climate Change Service. For the Alp catchment and its tributaries, a nivale runoff and precipitation regime can

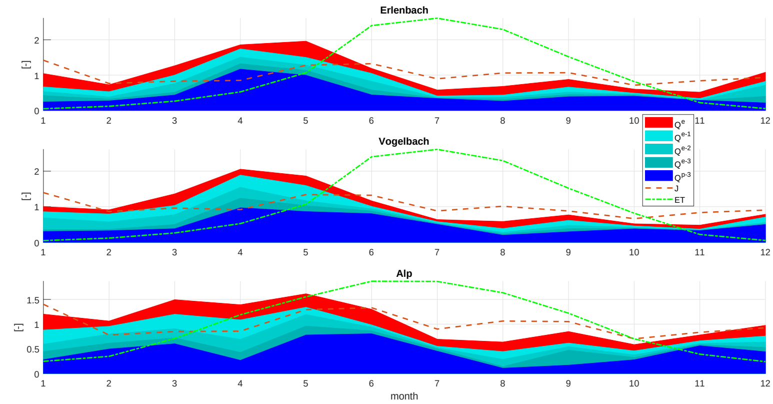

Figure 11: Added monthly Pardé coefficients (1: January – 12: December) of event water Q^e, recent water $Q^{r-3} = Q^{e-1}+Q^{e-2}+Q^{e-3}$, and pre-recent water Q^{p-3} for the Erlenbach, Vogelbach, and Alp catchments in relation to the monthly Pardé coefficients of stream discharge (Q). Monthly Pardé coefficients (1: January – 12: December) of precipitation (J), and evapotranspiration (ET), based on the four-year investigation between June 2015 and May 2019, and an iterative extension of the standard two-component hydrograph separation method. Evapotranspiration data are taken from the reanalysis product ERA5

be shown in Figure 9. In relation to the stream discharge Q, the event water component Q^e has its maximum (>32%) during August in general, as shown in Figure 10 and Figure 11. The highest recent water fractions Q^{r-3} (50-59%) can be expected at the beginning of winter (December, January), whereas the lowest fractions (7-14%) are found at the end of autumn (November). In return, higher pre-recent water fractions Q^{p-3} can be found in the summer (July, 60-82%) and in the middle of autumn (October, 64-74%). The two tributaries expose an additional peak of pre-recent water in the snowmelt season (April, 47-62%), during which the lowest event water fractions (6-8%) can be expected. For the Alp catchment, the event water component (29-32%) and recent water component (56%) clearly exceed the pre-recent component (17-21%) in August and September after the month July, which is characterized by relatively low precipitation, high evapotranspiration, and low soil moisture.

A sensitivity analysis regarding the evapotranspiration rates ET from ERA5 confirms the calculated seasonal variations of the *Pardé* coefficients both for the Alp catchment and its tributaries, Erlenbach and Vogelbach. The analysis, shown in Figure 12, indicates a shift in proportions towards

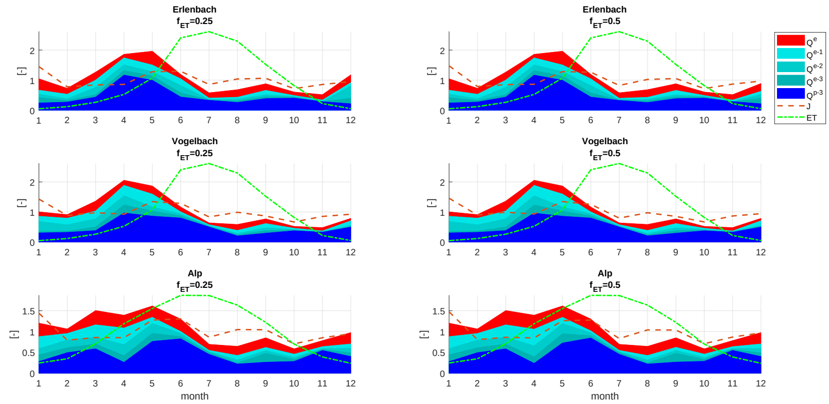

Figure 12: Added monthly *Pardé* coefficients (1: January – 12: December) of event water Q^e, recent water $Q^{r-3} = Q^{e-1}+Q^{e-2}+Q^{e-3}$, and pre-recent water Q^{p-3} for the Erlenbach, Vogelbach, and Alp catchments in relation to the monthly *Pardé* coefficients of stream discharge (Q). Monthly *Pardé* coefficients (1: January – 12: December) of precipitation (J), and evapotranspiration (ET), based on the four-year investigation between June 2015 and May 2019, and an iterative extension of the standard two-component hydrograph separation method. Sensitivity analysis to assess the impact of ET on the daily end member concentrations $(C_Q^e, C_Q^{e-1}, \ldots, C_Q^{e-3})$. This analysis involves considering a rate factor f_{ET}, which can take values of 0.25 or 0.5. To first-order approximate the daily end member concentrations, the daily precipitation rates (J) are directly reduced by 25% or 50% of the daily evapotranspiration rates, similar to equation (13). The evapotranspiration data used in this analysis are obtained from the reanalysis product ERA5.

the event water component (up to 5% in August) and pre-recent water component (up to 20% in August) when daily evapotranspiration rates are considered up to 50% when calculating daily end member concentrations $C_Q^e, C_Q^{e-1}, \ldots, C_Q^{e-3}$. However, for the Alp catchment, the event water component and recent water component still exceed the pre-recent component in August and September.

The latter result is noteworthy because, on the one hand, it confirms that considerable fractions of summer precipitation become streamflow, even though evapotranspiration fluxes are much larger in the summer (Allen et al. (2019)); on the other hand, it shows that a certain limit appears to have been reached in the Alp catchment for the months of August and September. A further increase of hydrological drought in central Europe (Balting et al. (2021), Satoh et al. (2022)) is unlikely to lead to a greater mobilization and availability of pre-recent runoff components in this area. Consequently, the

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Table 1: Median of the relative and absolute Gaussian standard errors (in % and $\frac{\text{mm}}{\text{d}}$) for event water Q^e, recent water Q^{r-3}, and pre-recent water Q^{p-3} in the Erlenbach, Vogelbach and Alp catchment between June 2015 and May 2019, here based on an iterative extension of the standard two-component hydrograph separation method with the uncertainties of stream discharge, $u(Q) = 0.001$ [m^3/s], and of the isotope analysis $u(C_Q) = 0.09$ [‰], $u(C_Q^e) = 0.09$ [‰], $u(C_Q^p) = 0.09$ [‰], $u(C_Q^{e-1}) = 0.18$ [‰], $u(C_Q^{p-1}) = 0.18$ [‰], $u(C_Q^{e-2}) = 0.27$ [‰], $u(C_Q^{p-2}) = 0.27$ [‰], $u(C_Q^{e-3}) = 0.36$ [‰], and $u(C_Q^{p-3}) = 0.36$ [‰].

Component	Erlenbach	Vogelbach	Alp
Q^e	84.1 / 0.09	622.4 / 0.09	144.4 / 0.12
Q^{r-3}	161.6 / 0.50	142.9 / 0.49	159.1 / 0.93
Q^{p-3}	50.0 / 0.26	38.5 /0.28	74.3 / 0.61

importance of event water and recent water for the catchment water balance will continue to increase, and with lower rainfall and/or higher temperatures in the summer months, the situation for vegetation, which relies on the remaining summer precipitation, might become even worse than observed in the past few years and decades, as noted by Senf et al. (2018), and Senf et al. (2020). If climate projections prove to be accurate, there will be a significant increase in drought conditions across extensive areas of the Swiss forest by the conclusion of the 21st century. Nevertheless, the duration of drought will increase the most by the year 2100 in those forest site types that are already relatively dry today. The least vulnerable are forest sites in areas with very high precipitation and cool temperatures, on deep or hydromorphic soils. (Scherler et al. (2016)).

V. Conclusions

In the present study, I have shown that the classic two-component hydrograph separation can be iteratively embedded in a discretization of the catchment water and tracer mass balance along the event and pre-event time axis. With this method, it is possible, for instance, to analyze and quantify the rapid mobilization of recent water for single (high-frequency measured) rainfall-runoff events, and to estimate time-varying backward travel time distributions. When applied to longer time series of daily stable water isotope data in stream water and precipitation, the method can be used to analyze seasonal variations of event, recent, and pre-recent runoff components.

In relation to the Alp catchment, the relatively high fractions of event water and recent water in stream discharge during August and September represents a rather unexpected result that certainly requires further investigation, but shows that fundamental assumptions, used for instance in runoff recession analysis, need to be questioned and that the sensitivity of the catchment water balance in response to drought situations could be greater than expected.

Moving forward, there are opportunities to further refine the method, apply it to new contexts, or integrate it with other techniques. For example, the method can be used to examine the event, recent, and pre-recent components in the evapotranspiration (volume flow ET) or in the groundwater recharge (volume flow $\mathrm{d}S/\mathrm{d}t$) of a catchment. In addition, there is the potential to incorporate this approach into hydrological models to improve their accuracy and predictive capabilities. Moreover, there are opportunities to apply the method in more complex and detailed ways, potentially uncovering new insights in catchment hydrology. This could include, for instance, more detailed analyses of the impacts of extreme weather events or the effects of different land use practices.

Acknowledgements

The author would like to thank Jana von Freyberg (ETH - Swiss Federal Institute of Technology Zurich, Department of Environmental Systems Science) for providing the additional excerpt of the high-frequency measurement series from the Erlenbach catchment. My special thanks goes to chief editor Marie V. Carlsen, assistant editor Marian C. Miller, and two anonymous reviewers, who contributed to this work with numerous improvement proposals.

Data and Code Availability

The data used for this study can be retrieved via Von Freyberg et al. (2018) and Von Freyberg et al. (2022). Complementary data from ERA5 (fifth generation of ECMWF reanalysis for the global climate and weather) are available at https://cds.climate.copernicus.eu/. The Matlab scripts, together with some supplementary material, will be available at https://osf.io/azrqw/.

Appendix A. Notation

Appendix A.1. Latin Symbols

$C_{\dot{V}}$	tracer concentration in volumetric flow
$C_{\dot{V}}^{e}$	tracer concentration event water in volumetric flow
$C_{\dot{V}}^{p}$	tracer concentration pre-event water in volumetric flow
ET	evapotranspiration
h	travel time distribution, impulse response function
$\overleftarrow{h}$	backward travel time distribution
$\overrightarrow{h}$	forward travel time distribution
$\widehat{h}$	residence time distribution
H	separated event water response
J	precipitation
Q	stream discharge
Q^e	event water in stream discharge
Q^p	pre-event water in stream discharge
Q^r	recent water in stream discharge
S	water storage
t	time
t_{in}	injection time
$\dot{V}$	volumetric flow rate
$\dot{V}^e$	event water in volumetric flow
$\dot{V}^p$	pre-event water in volumetric flow

Appendix A.2. Greek Symbols

θ	partition function
τ	backward iteration
φ	travel time
ω	age function

Appendix B. Linear Equation System for Three Backward Iterations

The iterative separation model (6) can be represented in the form of a linear equation system for $\tau = 3$, as follows:

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ C^e_{\dot{V}} & C^p_{\dot{V}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & -C^p_{\dot{V}} & C^{e-1}_{\dot{V}} & C^{p-1}_{\dot{V}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & -C^{p-1}_{\dot{V}} & C^{e-2}_{\dot{V}} & C^{p-2}_{\dot{V}} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & -C^{p-2}_{\dot{V}} & C^{e-3}_{\dot{V}} & C^{p-3}_{\dot{V}} \end{bmatrix} \begin{bmatrix} \dot{V}^e \\ \dot{V}^p \\ \dot{V}^{e-1} \\ \dot{V}^{p-1} \\ \dot{V}^{e-2} \\ \dot{V}^{p-2} \\ \dot{V}^{e-3} \\ \dot{V}^{p-3} \end{bmatrix} = \begin{bmatrix} \dot{V} \\ C_{\dot{V}}\dot{V} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{B.1}$$

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 23 Issue 6 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Energy Transition in Unsettled Times

By Miguel Schloss

Summary and Introduction- There are times when crises provide more eloquent warnings about unattended problems than all discourses and learned studies. The crisis detonated almost 15 years ago by the gas supply cutoff from Argentina, awakened Chile to its perilous vulnerability resulting from its growing (and excessive) dependence on a single source of energy supply. This situation also triggered the opportunity to start addressing emerging issues, particularly environmental concerns.

To this end, a simple "benchmarking" exercise was undertaken to enable Chilean power sector stakeholders to learn from what other countries have done in their energy programs in terms of their: (i) impact or results; (ii) all-in costs; and (iii) required institutional arrangements for implementation.

The results were eye-opening. Whereas countries like Germany embarked on an ambitious recasting of their energy matrix, others followed a more gradualist and organic approach to increase their share of renewables.

GJSFR-H Classification: *LCC Code: HD9502-9502.5*

Strictly as per the compliance and regulations of:

Energy Transition in Unsettled Times

Miguel Schloss

A Front Row View of What Chile Learned from the World, and the World Can Learn from Chile

I. Summary and Introduction

Seeing through the fog in front of us

There are times when crises provide more eloquent warnings about unattended problems than all discourses and learned studies. The crisis detonated almost 15 years ago by the gas supply cutoff from Argentina, awakened Chile to its perilous vulnerability resulting from its growing (and excessive) dependence on a single source of energy supply. This situation also triggered the opportunity to start addressing emerging issues, particularly environmental concerns.

To this end, a simple "benchmarking" exercise was undertaken to enable Chilean power sector stakeholders to learn from what other countries have done in their energy programs in terms of their: (i) impact or results; (ii) all-in costs; and (iii) required institutional arrangements for implementation.

The results were eye-opening. Whereas countries like Germany embarked on an ambitious recasting of their energy matrix, others followed a more gradualist and organic approach to increase their share of renewables. The former approach, required a solid top-down and disciplined investment effort, resulting in a significant change in the energy matrix, though at a major cost and increased energy risks, which became evident early on the Ukrainian war, when gas supplies were significantly curtailed, triggering an important energy crisis. There were others that acted more gradually, and hedging through some degree of diversification the risks of misjudging energy demand forecasts.

When discussing these outcomes with Chilean civil society organizations, environmental NGOs, utilities, most stakeholders particularly final consumers centered their concerns on affordability (fancy programs being OK, but "not with my money"), energy security and compatibility with the institutional capabilities in the country. In contrast with the top-down framework implied in international meetings, the approach chosen in Chile centered on "crowding in" the private sector for investments, rather than stretching an already overextended (and consequently slow) public sector for such task.

This approach in effect encouraged the Authorities to center their attention on creating business conditions through pricing, taxation and other conditions that could be instrumental in attracting financial and human resources from the private sector to finance and manage investments that otherwise would be difficult to handle, given the institutional limitations and fiscal constraints.

The progress (as described in section V, below) speaks for itself. It does not, however provide for longer-term assurance of continued enhancement, since the very success "crowds in" new players and solutions. This generates potential new sources of competition and other conditions that require further adjustment in the enabling and regulatory environment, which becomes difficult to accommodate when vested interests and inertia constrain adaptation of governance arrangements defended by incumbents.

In all, though, Chile has been ranked among the five best performing countries in terms of the increases attained of renewables in overall energy supply, leaving however a steep and more complex road ahead.

II. Taking Stock

Seeking Collaboration through Institutional Compulsion – vs. Alignment of Interests

Much of international discourse hinges on the premise that issues stemming from global warming are of such magnitude and complexity that they require collective and collaborative efforts to address them in a meaningful way.[1]

Not surprisingly:

- International debates tend to be steered by government institutions, international and multilateral organizations (UNFP, IEA, and various multilaterals), which for the most part have a public sector focus for problem solving.
- As a result, glaringly absent from the debates is an understanding of how civil society organizations, checks and balances, incentive structures including price and tax arrangements, how to hold accountable public authorities, and in what ways private sector entities work, as an integral part of the proceedings including, ultimately, ultimately in proposals for implementation.
- The focus is thus primarily public sector oriented, with predominantly supply-side concerns, such as goal settings, targets, monitoring, and associated regulatory arrangements to clear and authorize

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projects, set standards to be achieved, and resources required to be committed.

In the absence of institutions with genuine implementation experience and responsibilities, it has become almost inevitable that projections endorsed by global institutions tend to rely on aggressive assumptions and “tortured” modelling to meet desirable lower emission goals. Feasibility seems to take secondary importance.

It shouldn’t thus be surprising to see significant shortfalls from agreed targets. The tendency to seek stretch goals (with limited attention to implementation requirements or feasibility), tends to focus debates on the need for pushing harder to mobilize more financial resources, that others not present in the meetings are unable (or unwilling) to defray.

However, with considerable resource requirements for meeting identified needs, and competing claims for major pent-up adjustments requirements (like economic reactivation following Covid shut-downs) no county or entity seems to be in a position to effectively respond. Under the circumstances, pledges are easy to make, but difficult to deliver, thereby contributing to a gaping difference between goals and reality.

In all, the scale of global financing required to meet mitigation and adaptation needs is vast, and current financing availabilities fall well below desirable levels. For example, according to a November 2022 report from the Rockefeller Foundation and Boston Consulting Group (BCG), “To achieve net zero, public and private sector entities across the globe will need approximately $3.8 trillion in annual investment flows (equivalent to 3.8 percent of global GDP) through 2025. But only a fraction of this capital is currently being deployed. Even when viewed with a wider lens that considers funding such as transition finance, expected needs still outweigh flows by 66%”.[2]

Energy transition projects alone will need a substantial amount of climate finance. While estimates for this component vary as well, it has been estimated that up to several trillion dollars annually in new investments is needed for this purpose through 2030.

Given the resulting public debates stemming from implementation shortfalls, and the rather removed role of the private sector in such proceedings, attention should seriously shift towards resource mobilization and mainstreaming the private sector into the proceedings. This requires sharper attention on building the business case to attract such resources, and a consequent recasting of the approach to energy transition.

Similarly, the role of multilateral banks, particularly the World Bank and IFC to enhance their capabilities, risk mitigation arrangements, and support for policy development towards enabling conditions will be needed to achieve a major uptake of investments for energy transition.

III. Moving from Exhortation to Actions and Outcomes

Impossible Takes a Bit Longer

Aside from this, here are some broader comments beyond Chile:

- Most UN organizations and multilaterals (including much of the environmentalist community) having limited first-hand experience and responsibility in implementation, tend to focus more on exhortation and global concerns, rather than analysis and attention to issues standing in the way for effective progress. This has resulted in debates centered on processes, overall goal setting, rather than substance and focus on results, thereby rendering the proceedings largely immune to learning from empirical evidence. This enabled leaders to hide behind facile statements on the risks of global warming and exhortations, rather than the hard choices and trade-offs to be made, the experiences and results of different approaches being undertaken, and lessons to be drawn to achieve tangible results.
- As elsewhere, the evidence suggests that in the absence of adequate financial incentives, one cannot expect real action and ensuing results. Where polluters pay for the costs they generate, one can see mitigation arrangements and associated investments. This can be seen glaringly in the progress Chile has made in its energy matrix towards increased renewables though proper energy pricing. Something similar occurred in the virtual elimination of sulfur emissions through a cap-and-trade system to price sulfur emissions, which ultimately led to sharp reductions in acid rain cast by SO2 emission.[3]
- There are, of course, various market approaches to pricing externalities to reflect emissions, but the default model on environmental management in much of the world has tended to rely on regulation and top-down goal setting, which are institutionally-intensive and therefore difficult to manage, particularly in institutionally-weak countries. One shouldn't thus be surprised that the results have been at best mixed, if not downright poor, costly and overly dependent on the discretion of public officials. Almost inevitably, this has exposed investment projects to increasing and costly delays, opportunities for corruption and often changing (and contradictory or idiosyncratic) criteria for investments.
- Similarly, there are ad hoc approaches aimed at supporting specific technologies or special financial

instruments to help finance particular projects. This may be a valid, though limited, approach to circumvent constraints by earmarking resources andring-fencing projects, not much different from what the World Bank did in the early days of industrial and mining financing. Such approaches generated generally solid, but enclave initiatives that didn't sustain themselves more broadly in the absence of such special efforts, or sustained financing for further expansions to meet growing needs. Given the magnitude of resources needed to finance a meaningful program, a significantly upscaled effort will be needed to mobilize resources even in the absence of Multilateral Development Banks intervention. Focusing on enabling conditions, including carbon trading and pricing vehicles[4] should avoid having to be exposed to eternal negotiations, the whims of changing political and/or other idiosyncratic conditions, and corruption associated with excessive discretionary powers of regulatory Authorities.

- Finally, as Global Greenhouse Emissions and the attendant climate change are global factors, the current focus on county- and project-level approach has its limitations. The large increase of PV installations is, for instance, grounded on CO2 emission reductions estimates in IPCC models, rather than primary (and verified) data from actual producers. As a result, China, where according to some studies may actually generate much larger emission footprints in the manufacturing of PV facilities — more comparable to natural gas power generation, given the country's large dependence on coal-based power generation-- may serve as a better estimate for the material of its exported PV installations.[5] Conversely, the country or project focus tends to miss the emerging role of international supply chains in emission reduction of commodities like copper, lithium, graphite and nickel, whose role in emerging technologies to decarbonize productive sectors, needs to be explicitly considered as part of program evaluations of the mining as much as in the downstream power sector investments. The evaluations, and investment or policy actions must address the whole supply chain to achieve the intended goals.

IV. 'Voices with Energy' Debate in Chile

I'm not looking for those who think like me. I look for those who, like me, think

The Chilean electricity sector was the first in Latin America and one of the first in the world to deregulate (1981) and privatize (1986-88) its generation sector, forcing generators to compete with each other. As such, the sector is efficient, transparent and sophisticated, with tariffs equal to the marginal cost of production plus a market rate of return, reflecting relative scarcity and all-in costs. Chilean electricity can be sold via regulated tariffs to captive clients, and via free-market contracts with large industrial clients. In addition, generators with excess capacity can sell the electricity surplus to generators with energy deficits via spot market transactions.

The country was at the forefront of electricity de-regulation and has provided a transparent, predictable and rational means of delivering appropriate risk-adjusted returns. Chile has delivered reasonably priced electricity; capital flows have not been impeded into the sector and energy efficiency is good by international standards. The energy efficiency seems particularly good considering that Chile's main export goods are energy intensive (mining) and the topography of the country could have led to high costs. Thus, any further developments should be set within the context of building upon what has been, by and large, a successful strategy for over two decades.

The country's greatest advantage is in effect having succeeded in moving towards a streamlined regulatory system (where duplication, offsetting incentives etc. are avoided) that constitutes a solid asset to build on. The country can thus afford to minimize the rules, use pricing where at all possible, and avoid choosing energy development paths that become costly and complicated, and difficult to change when vested interests become dependent on special institutions or different forms of privileged access to resources.

As a result, Chile is in a strong position to deal with new threats to energy supply in a cost-effective manner. In many regards, Chile pioneered de-regulation in the sector, has achieved reasonable levels of energy efficiency (although more can be done) and has a strong record of bringing private finance into the sector. It has done so through a judicious mixture of solid and adaptable policy and a stable and predictable pricing framework.

With newly emerged challenges of dealing with security concerns and the environment, Chile will need to turn to the same innovation and policy adjustments, as it has done in the past. In doing so, it will be able to continue on its solid track record while integrating these new issues, embarking on a new energy chapter as it fully adjusts to its membership of the OECD. [6]

While, as noted above, the existing system has been the outgrowth of discussions with the various stakeholders of the sector, and periodic debates with various interest groups, the following summarizes the assessment of the latest (October 2023) debate on "Voices with Energy" of stakeholders on the ongoing transition that essentially:

- Reassured that the direction of Chilean energy and decarbonization policy continues to be solidly grounded, unambiguously defended, and highly performing, despite populistic inclinations and pressures of the current public administration that need to be overcome;

- Suggested that civil society organizations are becoming increasingly solid and prepared to call into account private enterprises utilities and public Authorities on their commitments;
- Reinforced a broad unease on the grasp of UN and associated organizations have to provide tangible and effective advice in support of decarbonization efforts.

On the Chilean *achievements in energy transition* (i.e., the progress/outcomes, risks and challenges), main points highlighted were:

- Power sector capacity is currently three times higher than energy demand; 63% share in renewables, and 75% if hydro and geothermal are included
- Sector has added last 10 years 14,000 MW in installed capacity, evidencing favorable investment climate to meet energy demand
- Another 7000 MW currently in execution that will enter into service in the near term
- 12000 MW projects in preparation that are currently undergoing environmental evaluation, suggesting favorable outlook and expectations for the longer term
- The country has the highest share of renewables in the region, and among the five highest internationally, and given current projections, Chile will meet, if not surpass its international pledges, suggesting a stronger policy framework compared with most at the international level.

Concerns and critiques of civil society organizations representing power sector consumers:

- The international "promise" of low cost solar and wind energy doesn't seem to be born out in Chile, where energy costs have been consistently been increasing as the share of renewables have been incorporated into the grid;
- At some point this may trigger issues of affordability, particularly for lower income population;
- There are growing risks with the current system, where most renewable sources generate power at distances ranging from 1,200 to 1,800 Kms away from main markets, which could be disrupted within such ranges.

Global approaches, particularly as seen from UNFCCC's (United Nations for Climate Change Convention) vantage point:

- The need to strengthen multilateral processes of the Paris Agreement, Kyoto Protocol and the Convention through COP proceedings for goal setting, tracking and debating emerging issues on climate change programs
- Clearer recognition of the various issues and sectors involved, indicating the actions need to be approached differently among countries
- An emerging recognition of progress that Chile has achieved with liberal policies, which are being be replicated in some European countries and US states.

The implications as seen by local power utilities have been that:

- There are no "silver bullets" to deal with the issue, and while costs have significantly decreased for renewables, they have inevitable constraints, such as being location-specific -in the case of Chile in the distant North, far away from main consuming centers, and being intermittent depending on weather conditions (i.e., when there is sunshine and wind).
- There are also major excess and shortages of energy generation in early and late parts of the day, producing excess and deficit of generation capabilities to respond to market demands for which there are no easy technological responses.
- All this requires energy storage facilities, which for the time being are costly, and major investments in transmission lines, which constitute integral parts the costs of renewables.
- On the other hand, the regulatory framework needs some updating, to reflect new services that have emerged from new players and technological developments that would permit trimming of government regulatory interventions of natural monopolies that no longer exist, and thus create conditions for growing competition and lowering costs.
- As Chile is a marginal player in terms of GHG emissions, even with the progress that has been achieved, the country could tangibly contribute at an increasing scale internationally. This could be done by reversing restrictive practices that have been instituted in recent years for new and/or expanding mining activities, by lowering barriers to investments in projects such as copper, lithium, which constitute major inputs for decarbonized energy production and storage, and where the country has major reserves and comparative advantages.
- Chilean emissions have been reduced by 28% over the last five years (partly by limited growth of economic activity), and the remaining third to achieve net zero goals will require more complex efforts, including further technical innovation, and revisiting technologies where some estimate of the footprint of solar PV suggest that they may be

higher than models being used by the IPCC, given production practices in China.

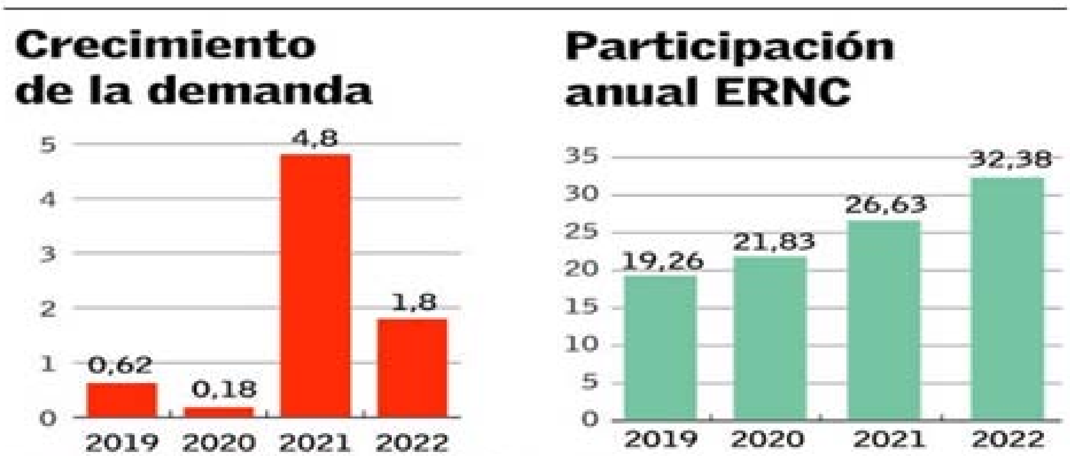
In all, it has been acknowledged that progress has been impressive, but there are challenges that need to be addressed in the steeper road ahead, and the need to take a broader view of regulatory practices if the country is to make further progress and help achieve greater impact at the global level.

V. The Record and the Lessons

To dialogue: ask, first; then... listen; then act and track

Chile's greatest advantage is having succeeded in moving towards a streamlined regulatory system (where duplication, offsetting incentives etc. are avoided) that constitutes a solid basis to build on.

The country can thus afford to minimize the rules and avoid costly public sector regulatory intervention, use pricing where at all possible, and avoid choosing energy development paths that become costly and complicated, or difficult to change when vested interests become dependent on special institutions with privileged access to resources. This enabled the country to move its energy matrix in a decisively renewable direction in an effective manner, as can be seen below:



Generación por fuente total (en TWh)

	2022	2021	Var. %
Eólica	8,8	7,2	22,4
Geotérmica	0,5	0,3	43,8
Hidráulica	20,1	16,3	23,2
Solar	14,1	10,5	33,4
Térmica	38,9	46,5	-16,3

Generación renovable no convencional (en TWh)

	2022	2021	Var. %
Biomasa	1,51	1,63	-7,4
Eólica	8,75	7,15	22,4
Pasada (minihidro)	2,23	2,05	8,8
Solar	14,03	10,53	33,2

Generación térmica (en TWh)

	2022	2021	Var. %
Biomasa	1,65	1,86	-11,3
Carbón	19,03	27,47	-30,7
Diésel	1,48	1,81	-18,2
Gas Natural	15,84	14,48	9,4

*Cifras al 28 de diciembre de 2022

Fuente Coordinador Eléctrico Nacional — EL MERCURIO

Chile is now in a strong position to cost effectively deal with many new threats to energy supply. In many regards, Chile having pioneered de-regulation in the sector, has achieved good levels of energy efficiency, and has a strong record of bringing private finance into the sector. It has done so through a judicious mixture of solid policy and a stable and predictable pricing framework.

With the newly emerged challenges of dealing with security concerns and the environment, the country will need to turn to the same innovation and introduce policy adjustments as it has done in the past. In doing so, it will be able to continue on its solid track record while integrating these new issues, embarking on a new energy chapter by integrating the requirements stemming from its membership in OECD, and further the policy and technical development for its decarbonization efforts.

While the thrust of concerns relates to growing public good externalities in the energy sector (for Chile and most other countries) of environmental impacts and security of supply concerns, addressing those concerns should still be possible within the current investment framework of the country. This can be achieved by ensuring that:

- The playing field for investment remains level (any regulations are applied across the board) while still ensuring that flexibility is built in to the system (to cope with pricing shifts and other shocks);
- Any legitimate additional costs of compliance to environmental standards can be recouped through output prices;
- Consultation between the public and private sectors would always precede any policy decisions.

VI. The Way Forward in an Uncertain World

First things first, last things later

Looking beyond the various issues mentioned above, if there is one broad lesson to be learned, it is the need to recognize that major imbalances and associated adjustment policies can be extremely disruptive. In fact, they are ultimately a sign of failure – i.e., the inability to foresee structural changes and adapt to them through deliberate changes in incentive structures and investment solutions, to adapt to emerging societal and technological requirements. Meeting the challenge of the unpredictable seldom comes from “pushing harder” or “changing faster”, but from learning to recognize the need to redesign in a timely fashion.[7]

The deeply alluring command and control ways of forcing change can just as easily produce costly and misguided investment decisions. A more open and flexible approach to constant and organic adaptation through open competition and entrepreneurship might on the whole be a more effective way of mobilizing skills, innovation, funding and technology to respond to emerging needs. If properly designed such changes could provide a framework of certainty and stability that are crucial to promote the path of growth, without prejudice to the introduction of some innovations, included much needed promotion of free competition and entrepreneurship for innovation in productive activities.

In the end, much of the complexity of policy design in relation to energy stems from a multiplicity of objectives. Ultimately, when designing policies experience suggests the following factors to merit special consideration to untangle the conflicts that tend to arise from the various objectives normally being sought:

- *Efficient resource allocation*, which requires that both producers and users of energy face prices that reflect its scarcity value—which for nonrenewable resources stems not only from direct production costs but also the opportunity cost of present consumption in terms of future consumption foregone—and any associated externalities. When externalities spill across national borders, however, they create an important distinction between global and national perspectives on efficiency: they matter for the former, but not the latter.
- *Competitiveness concerns*, with a fear of disadvantaging domestic producers in world markets, have increasingly become important in designing fiscal measures bearing on energy.
- *Terms of trade considerations* also arise in shaping fiscal policies toward energy, particularly as hydrocarbons constitutes among the largest balance of payments in most countries. Accounting for nearly 45 percent of global oil demand, for example, the G7 collectively is likely to have significant power in the world market: measures to restrict demand may bring about a reduction in world oil prices that raises their citizens’ welfare, in effect transferring to them part of the resource rent that suppliers of oil would otherwise enjoy. The converse of any such gain, however, is a corresponding loss to oil exporting countries.
- *Revenue concerns* and interactions with the wider tax system, more generally, may affect both the choice of instrument and the level at which it is set.
- *Minimizing costs of compliance and administration,* to enterprises and governments respectively, is a standard principle of public policy design, though it has received little distinct attention in relation to energy issues.

Finally, the issue of coherence across policies has become a major challenge in many countries. It is not uncommon to find an array of subsidies, grants, tax interventions, etc. that are being applied with little attention to coherence, and often producing conflicting signals. Indeed, concern over environmental effects has spawned many complex, distorting and conflicting policies. Countries should avoid such tendencies. The directness, simplicity and market orientation of Chile's approach to business and key sectors (as energy) stand it in good stead to avoid such pitfalls.

Above all, the environmental aspects need proper mainstreaming, as it is an issue that goes well beyond the energy sector.[8] Whatever the organizational set-up, a strategic framework on environmental and climate change for a country's engagement may need to be developed to:

1) Make effective climate action -- both adaptation and mitigation -- part of core development efforts (rather than reactive clearance arrangements for individual projects, which may be contentious, time-consuming and expensive);
2) Address the ensuing incremental resource requirements through up-scaling of existing innovative instruments for finance, beyond the prevailing project-by-project approach, which has had high transaction costs and consequently limited application for widespread impact programs on a larger scale;
3) Develop market friendly policies aiming at reflecting in prices and incentives externalities, and more broadly create an enabling environment for leveraging private sector investment and finance; and
4) Set up policy research, scanning international experiences, knowledge management and capacity building to facilitate development of policies and adaptation of climate-friendly technologies to local environments.

With a more structured approach to issues as suggested above, it should be possible to consider "over the horizon" issues. This should enable countries focus on emerging issues and poise themselves in a timely and systematic manner for emerging technologies, market and other disruptions to allow a coherent way of anticipating, inevitable changes in a cost effective and manageable manner.

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 23 Issue 6 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Cultural Challenges Affecting Effective Community Participation in Potable Water Management in Selected Rural Communities in the Upper West Region of Ghana

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Keywords: *challenges, community participation, cultural practices, potable water, water management.*

GJSFR-H Classification: *(LCC):TD370-388*

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Keywords: challenges, community participation, cultural practices, potable water, water management.

I. Introduction

According to Obeng, Iddrisu and Eshun (2020), "Potable water is a basic need in every community and should be made accessible and affordable to community members daily" (p. 21). It is highly believed that "Just as in many African countries, the central government and external support agencies in Ghana have been responsible for planning, constructing, and maintaining the rural water supplies with little or no involvement of the beneficiary rural communities" (Salim, 2002). Several approaches to community participation in managing resources have been in place for many years. But it seems that "After many years of failure of top-down or centralized planning and provision of such services, the emphasis has shifted to a decentralized community-oriented approach" (McCommon, Warner, & Yohalem, 1990). Subsequentseries of community participation of potable water culminated in "a review of policies on water and sanitation to keep pace with the changing conditions in Ghana and on the international scene, the National Community Water and Sanitation Programme (NCWSP) was launched in 1994. Subsequently, the Community Water and Sanitation Agency (CWSA) was established by Act 564 in 1998 with the mandate to facilitate the provision of safe drinking water and related sanitation services to rural communities and small towns in Ghana (Community Water and Sanitation Agency"[CWSA], 2007). The provisions in the very Act which recognised the CWSA also transferred rights and operation responsibilities to the communities and the district.

Nevertheless, it was understood that participation in community water programmes was restricted to the "mobilization of self-help labour or the organization of local groups to ratify decisions made by project planners outside the community" (Laryea, 1994 cited in Obeng et al., 2020). This shallowmeaning had characteristicboundaries to the effectiverural water implementation programmes. Consequently, the prominence was once moretransferred to community management. Currently, "drinking water and sanitation policies assume that the facilities can and should be best managed by local user communities. It is expected that the so-called communal management will guarantee the technical sustainability of the facilities needed to maintain access to the facilities provided" (Eguavoen, 2006). This should have always been the ideal situation. However, this culture is not what is experienced in most communities concerning

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participation in potable water management in the northern part of Ghana.

Therefore, the main objective of the study was to examine the challenges affecting effective participation in community management of potable water in the Wa West District. This research question guided the study - What are the challenges affecting effective community participation in potable water management? The research was delimited to the challenges affecting effective participation in community management of potable water in Gbaalwob, Chogsia and Gadi Townships in Wa West District in the Upper West Region of Ghana

Significantly, the outcome of this research is to help various stakeholders in promoting and developing policies for safeguarding safe drinking water sources in rural areas and the need for promoting participation and ownership of potable water by locals. It also intends to create awareness among the people of Wa West District on the benefits of effective participation in community management of potable water.It is to equally providean opportunity for residents of Wa West to determine the importance of potable water being a shared responsibility. In the sense that community members have a role to play as well as government or service providers.

II. Literature Review

This section reviews related literature on participation in community management of rural potable water supply systems. It reviews the literature on potable water management, community participation and challenges of community participation in accessing potable water.

According to Obeng et al. (2020), “safe drinking water is very important in the daily lives of human beings, and also vital for public health.”This has been the agenda for countries in the West all these years. Countries of the European Union (EU) have made high-quality tap water easily accessible to their citizens through the EU drinking water policy, which has been in force since the mid-seventies (European Commission, 2014). The policy, since its institution in the mid-1970s, has ensured high drinking water quality across the EU countries by further ensuring restrictedcompliance with the standards of the policy by member countries and state institutions. According to the European Commission (2014), about 65 million EU citizens who are predominantly dwelling in rural and remote areas rely on small drinking water supplies. This ideal situation is not the same everywhere on the planet.

Water Supply and Sustainability in Sub-Saharan Africa (SSA)has been a grappling issue all this while.It is believed that “Africa has the lowest quality water service coverage of any continent and accounts for almost one-third of the global population without access to improved water supply” (Harvey &Reed, 2007). The disparity gap in accessingsafe drinking water in Africa has been higher in rural areas as compared to urban areas. Rural water coverage in 2000 in Africa was found to be around 45% still leaving about 237 million people unservedwhile, urban water coverage was about 83% in the same yearwith only about 37 million urban dwellers unserved (WHO/UNICEF, 2000). This presents evidence that rural communities in Africa are lagging significantly behind urban areas in potable water supply.

The sustainability of potable water services in Africa has also been found to be a challenging task after the withdrawal of donors and other agencies that provide water services for communities. The reasons for this low sustainability of water services are related to environmental and technical issues, as well as social and management issues. Therefore, adequate attention should also focus on sustainability as we focus on the goal of increasing potable water service coverage through the implementation of new water systems and facilities (Harvey & Reed, 2007).

In Africa, potable water is “a scarce resource both in quantity and quality and when available it is mostly of poor quality” (Mtinda, 2006). This is particularly experienced in the rural and urban slum areas. Inadequate potable water and basic sanitation services present themselves asa major challenging health issue, not only among African countries but globally. According to the UNDP (2006), “an estimated number of 1.1 billion people in developing countries have limited access to safe drinking water while about 2.6 billion people lack access to basic sanitation.” It is estimated that “in Sub-Saharan Africa, about 250 million people in rural areas lack safe and accessible water as well andabout 81% out of an estimated 67% of the total rural population lack some sanitation facilities” (Mtinda, 2006). Unsafe water coupled with poor sanitation and hygiene in rural Africa are drivers of child mortality. For instance, “about 43% of children in Sub-Saharan Africa are reported to drink unsafe water and one in five dies before their fifth birthday”(UNICEF & WHO, 2005) Correspondingly, “lack of potable water and basic sanitation is said to account for about 1.6 million preventable child deaths each year with millions of other children suffering from waterborne diseases such as diarrhoea, typhoid and worms” (UNICEF, 2005). More so, “inadequate water supply, insufficient sanitation and unsafe hygiene are observed to have caused and reinforced poverty and deepened the disparity between rich and poor” (Nicol, 2002). As noted earlier, “the rural and urban poor communities are mostly affected by inadequate water supply and sanitation services both socially and economically” (Mtinda, 2006). This, consequently results in the vicious cycle of poverty. Hence, the community management system needs to be embraced by “stakeholders involved in water supplies and sanitation provision in rural areas" (IRC, 2003).

According to WHO (2011), some African countries particularly countries south of the Sahara and in southern Asia have less than half their population using improved facilities, thus, "the largest number of people are without access to basic sanitation." In terms of regional disparities, Africa is reported to be home to about "40% of all people without access to an improved drinking water source. The rural populations in African countries are severely vulnerable, as the number of people living without access to an improved drinking water source is estimated to be more than five times greater than that of urban populations" (WHO, 2011). There were further disparities in terms of socioeconomic levels of the people in accessingan improved drinking source of water, as well as receiving minimum water service levels and the normal rate of receiving pipe-borne water to their residences. These inequalities are projected to be exacerbated by the impact of climate change and hence present several health risks associated with poor water safety to poor people. According to Golo and Eshun (2018), "The socio-economic impact of climate change, resulting from anthropogenic activities is a major concern for the international community and governments as it has emerged as a key human rights violation, global security issue and socio-economic development threat for many countries of the world" (p.1). Ghanaians are facing the brunt of climate change in accessing potable water, especially within rural communities in the northern enclave of the country.

Recognizing the significance of water and elementary sanitation facilities and their connection to the SDGs has become very necessary. It is thus, relevant to have a clear conception of how rural communities in Africa are participating in the management of potable water systems.

There has been an increased involvement in water development which changed the traditional roles adopted by government and communities, where governments changed from "provider" to "facilitator" and the community from "receiver" to "doer" (Amerasinghe, 2009). The concept of "community participation" in water supply has since proven to be an effective way of achieving sustainability in potable water management. Potable water supply and basic sanitation services that have neglected active community participation in the planning and management of these services have lacked sustainability due to poor operation and maintenance by the beneficiary communities. There is evidence that sustainable potable water interventions in rural communities "are characterized by significant community investment of labour, other in-kind services, and user fees in the design, construction, maintenance and operation of the facilities" (United Nations, 2015). When it comes to water management services, the community should be the principal stakeholder while receiving support from "local government and other development partners such as NGOs and private sectors for proper functions of the community-managed water projects" (Mtinda, 2006). Therefore, community management of potable water services should be backed by measures that turn to strengthen local institutions in the implementation processes of community water services, as emphasized by "the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro 1992 and the World Summit on Sustainable Development (WSSD) in Dublin 2002, South" (Doe &Khan, 2004).

Community participation has great potential to ensurethe sustainability of potable water supplies. It is, however, important to note that communalinvolvement may not inevitablyresult in effective community management of potable water systems at all times in communities. There may be some aspects of the project services that may not have to be managed by the community and so should be explained during community consultations. Nonetheless, community participationis a prerequisite for achieving a sustainable potable water system that is efficient, effective, equitable and replicable in rural communities. Therefore, effective community participation is achieved through effective community consultation and participatory planning processes (Harvey & Reed, 2007). It is against this that, Thorpe (2002) suggests that participation by community members in potable water projects should start early, from problem identification to ensuring and enhancing community ownership of projects. He further noted that, if community participation is effectively done from the beginning to the end, then there will be no need for handing over projects to beneficiaries when the project is completed. He argues that, if there is a need for an agency to hand overa project to the community, then the process is already flawed since the community should already own the project. Batchelor, Mckemey and Scott (2000) also contend that "community participation at the early and simplest level of involvement greatly enhances the future sense of ownership by communities." The authors added that ongoing motivation is required for continuing participation because participating in the planning process does not necessarily mean that the community will sustain participation in ongoing service delivery.

There are "key stages of the planning process which involve community participation, among which include; the community established as a body with decision-making power, demand assessment, option identification and informed decision-making" (Harvey & Reed, 2007). Community participation at these stages is very important and must be emphasized. It is during these stages that the communities to better understand through effective participation which will eventually enhance ownership and sustainability of the project. Any community potable water project will fail if members of the community do not participate in the activities and decision-making processes involved at every stage. This illustrates how community participation-associated challenges in the management of potable water should be addressed by all stakeholders in the field.Any breakdown in the supply chain process should be tackled with all the desired effort.

In asmuch as there are benefits to community participation innatural resources, management of potable water in rural communities has its challenges. It is accepted thatthe community participation approach provides an avenue for stakeholders to play a “key role in project planning, implementation and monitoring of projects, which serves as a prerequisite for project ownership, successful implementation and sustainability” (Mwakila, 2008). The participation of beneficiaries in potable water supply project initiation, implementation, operation and maintenance is very significant because it provides “them greater opportunity to manage and decide on issues that are affecting or may affect their water supply systems” (Tadesse, Bosona, & Gebresenbet, 2013).

Low community participation in some rural development projects including rural water supply in many developing countries has resulted in projects' inability to bringprofits to rural communities over an extended perioddue to insufficient community involvement and understanding to ensure sustainability (Toyobo & Muili, 2013). According to Harvey and Reed (2007), “the low rural water supply sustainability levels throughout Sub-Saharan Africa are indicative of severe limitations of community participation and management approach.”For instance, in Western Kenya,“very few water projects out of the many projects implemented in the last 20 years lasted for more than 5 years from the date of initiation due to inadequate community participation” (Sei, 2016).

Inadequate access to financial and other resources reduces the capacity of local communities to participate in potable water management projects, as well as affects communities’ “ability to pay for water services” (Kakumba & Nsingo, 2008). The resource constraints are real and do not only affect the level of participation and management of community water projects but also, the sharing of best practices is not always easy among communities and stakeholders (European Commission, 2014).

Another challenge affecting community participation in the management of potable water has to do with the lack of adequate knowledge and skills of community members stemming from a high level of illiteracy. “This limits the scope of community participation in rural water development thus, perpetuating the continuous lack of safe and clean water among many communities” (Kakumba & Nsingo, 2008).

Again, lack of knowledge and ignorance on the part of the people in most rural communities, makes them ineffectively participate and manage their sources of potable water. A lot of people do not know that building of proper water facility is a cost-sharing between themselves, the district assembly and the service providers. Whereby the beneficiary community pays 5%, the assembly pays 5% and the service provider pays 90% of the total cost of the facility (CWSA, 2005). Cultural practices and customs whereby women and children are denied active participation in decision-makingare a cause of ineffective participation in the management of potable water. Women and children are the major users of water in a community so they should take a leading role in planning and managing the new or rehabilitated water system.

Traditionally, water is seen as a gift of nature. The view that water is a natural resource and therefore should be provided freely is still very alive today (Bacho, 2001). This lingering perception of water as a gift of nature emanated from the traditionalconcept of water that, water bodies are the natural bodies of the spirits, both evil and good. These spirits can be offended through disturbances or breaking of a taboo which would be tantamount to abusing their natural place of abode (Bacho, 2001). These cultural values and belief systems turn out to limit the participation of traditional people in discussions on the need to discard outmoded practices that serve as obstacles to potable water provision.

Apart from the universal household uses of water, economic activities and personal hygiene, water is also used for spiritual cleansing and pouring of libation. Water is also a cleansing medium of the unclean and abrogating consequences that the spirit oaths to forestall the devastating consequences that the spirit will unleash on the unfortunate victim. In everyday social interaction, water is important in fostering social relations. Among many ethnic groups in Ghana, a visitor is granted an audience only after he or she has been served water to quench his or her thirst. The worst one can do his fellow is to refuse him or her water. This would be viewed as extreme social misconduct since water is God’s gift (Bacho, 2001). Depending on the established ideas above, the people especially, traditional societies do not see the need to pay money as a counterpart fund for the building of water facilities, so they continue to utilize the streams, rivers and rainwater as the will of the gods providing it.

With this notwithstanding accessing water for domestic purposes has been a major issue in the northern parts of Ghana. According to the Wa West District Assembly Annual Progress Report (2020), “CWSA defines access to safe water to include the following elements: Ensuring that each person in a community served has access to no less than 20 litres of water per day; Ensure that walking distance to a water facility does not exceed 500 meters from the furthest house in the community; That each sprout of borehole or pipe system must serve no more than 300 persons and 150 for a hand dug well; The water system is owned and managed by the community; and Water facility must provide all year-round potable water to community members" (p. 30). However, Table 1 which spelts out the annual report on "access to safe drinking water sources and the proportion of the population with access to improved sanitation services as an indicator (Categorised by Development Dimension of Agenda for Jobs)" is not encouraging.

Table 1: "Data on Access to Safe Drinking Water Sources and the Proportion of Population with Access to Improved Sanitation Services"

1	"Indicator (Categorised by Development Dimension of Agenda for Jobs)"	Baseline (2017)	Target 2018	Actual 2018	Target 2019	Actual 2019	Target 2020	Actual 2020	Target 2021	Actual 2021
2	"Access to safe drinking water sources"	45	60	54	65		80		86	
	i. Rural ii. Urban	-	-	-	-		-			
3	"The proportion of the population with access to improved sanitation services"	39.5	54	54.7	70		75		80	
	i. District ii. Urban	39.5	54	54.7	70		75		80	
	iii. Rural	N.A								

Source: Wa West District Assembly Annual Progress Report, 2018-2021

Table 1 indicates that the Wa West District is grappling with issues in helping with provisions of accessible and safe drinking water sources and improved sanitation for all. This calls for the proper involvement of the various catchment communities within the district in realizing Sustainable Development Goal (SDG) six which is to "Ensure access to water and sanitation for all."

The lack or failure of many facility providers to involve the beneficiary community is one of the causes of ineffective participation in potable water management in communities. The deliberate non-involvement or low involvement of community members in water projects by project implementers is a concern to worry about. Involvement of the communities "is an important component of water projects as it maximizes the potential benefits of improving water supply. It also helps users appreciate the need for their proper operation and maintenance and creates a willingness to contribute to their costs. It is not sufficient to construct an improved water supply. New facilities must be used continuously by everybody and in a safe way" (CWSA, 2005).

The rapid breakdown of systems, low sense of ownership and growing proportion of unserved population generated concerns about how existing systems could be maintained and new demand met, and service sustainability became a focal concern. The realization is that "where there is no local participation in planning and local decision making and no local commitment to operation and maintenance including financing, the system has a short life span (Obeng et al., 2020). The need for access to safe water, sanitation and hygiene has become a clarion call for all humans because they are seen as one of the basic criteria for hale and hearty human health and wellbeing. Hinging on these calls for the methodological processes to realise the focus of the research.

III. Methodology and Research Setting

The study was carried out in Gbaalwob, Chogsia, and Gadicommunities in the Wa West District in the Upper West Region. The district was carved out of the then Wa District in 2004 by legislative instrument (LI. 1751) under the Local Government Act 463, 1993. "Wechiau is the capital of the district. The district is located in the western part of the Upper West Region, approximately between longitudes 9º 40' N and 10º 10' N and also between latitudes 2º 20' W and 2º 50' W. It shares borders to the south with the Northern Region, northwest by Nadowli District, east by Wa Municipal and to the west by Burkina Faso" (Ghana Statistical Service

[GSS], 2015). The population of the district, according to the 2010 Population and Housing Census, is 81,348 representing 11.6 percent of the region's total population. According to GSS (2015), "agriculture accounts for 86.0% of the district's economy. The predominant agricultural activity is farming. Most farmers undertake a combination of crops and animal production. The main crops grown are maize, millet, cowpea and groundnut. The district has a comparative advantage in groundnut and cowpea production." "The district is blessed with several water bodies including the Black Volta. Inland fishing is practised as an economic activity in the district.With regards to sources of water resources, the use of boreholes/pump/tube, wellsis the commonest, accounting for more than three-quarters (79.3%) of households in the district. A small percentage (8.8%) of households also userivers/streams as a source of drinking water. The use of pipe-borne water inside dwellings and rainwater are common and are 0.2 percentof each household" (GSS, 2015).

The study adopted a qualitative approach to research with a case study designfor the study. The core objective of the study was to examine the cultural challenges affecting effective community participation in potable water management in the Gbaalwob, Chogsia, and Gadi, communities in the Wa West District in the Upper West Region of Ghana. The population for the study included twenty residents each from the three communities, namely; Gbaalwob, Chogsia, and Gadi. Also, three key officials from the District Assembly and three opinion leaders each from the Gbaalwob, Chogsia, and Gadi communities were sampled for the study. In all the seventy-two (72) participants for the study were made up of sixty (60) residents, nine (9) opinion leaders, and three (3) officials from the district assembly.The sample size of the study was seventy-two participants. A purposive sampling technique was employed in selecting the participants for the study. "Purposive sampling therefore allows for the picking of interview objects that fit the focus of the study based on the judgement of the investigator" (Sarantakos, 2005). As a result, the participants were selected based on the fact that they had the desired knowledge to be able to contribute to the findings to achieve the objective of the study. A semi-structured interview guide and a focus group discussion checklist were employed in the data collection. Data was analysed thematically. Emerged themes from the interviews and the focus group discussion were analysed based on the themes from the data collection. Ethically, participants were assured of anonymity and free will to either leave or continue with the research process after the purpose of the study was made known to them.

IV. Findings and Discussion

This section presents the demographic characteristics of participants, and challenges affecting effective community participation in the management of potable water in the Wa West District of Ghana.

a) *Demographic Characteristics*

The demographic characteristics comprised the education, occupation, and the number of years the participant had lived in the community. The level of education of participants is relevant in assessing the level of participation of community members in the management of rural water services and systems. The educational level of participantsis presented and discussed as follows. With the total number of sixty residents selected, the study revealed that the majority, thus, 23 participants did not go to school or had formal education, while 18 participants had primary school education. The results further show that 16 participants had Junior High School (JHS) education and three participants had Senior High School (SHS) education. No respondent had a tertiary education. The above findings show that there is a low level of education among participants and for that matter confirms that educational levels are low in rural communities in the Upper West Region. Also, with the occupation of participants, 24 of the participants were farmers, 15 were dressmakers, 12 were traders, and 9 were students.

The majority of the participants being farmers reflects the rural nature of the study communities. Also, 15 of the participants were found to be dressmakers, 12 were traders and nine were students. The results reveal that the setting was typical rural and farming communities but with other livelihood portfolios as supporting systems for household food security and income. So, being farming communities will mean that there will be a high demand for water for farming and related activities both during the rainy and dry seasons. This is particularly so becauseaccording to the Ghana National Climate Change Policy document, agriculture in Ghana is rainfall dependent and rainfall over the years has demonstrated increasingly decreasing trends in amount/quantity and is highly inconstant in terms of onset and end of the season (Ministry of Environment, Science, Technology and Innovation [MESTI], 2013). This indicates that climate change is exerting unwavering socio-economic consequences on the livelihood of people (Eshun, Golo, & Dankwa, 2019).

The last demographic characteristic considered is the number of years participants have lived in their respective communities. It was revealed from the study that, all participants have lived for more than 15 years in the communities. The results show that six participants representing 10% of the total participants have lived in the communities for 16-20 years, a majority of 36 participants representing 60% also lived for 21-25 years, while 20% and 10% of the participants were found to have lived in the communities for 26-30, and 31 and more years respectively. This shows that participants' opinions on the issues of the study reflect the real subject matter in the communities since they have extensive experience regarding the problemsassociated with the participation of water management activities in the selected communities. The presentation of the demographic characteristics provides a deeper analysis and interpretation of the other findings in the next section. The next section explains why the educational level, occupation, and years of residency are relevant to understandingcommunity participation in potable water management. The demographics will also explain how beliefs and values as concepts in culture come in handy to influence participation levels and attitudes.

b) Challenges Affecting Effective Community Participation in Potable Water Management

Even though the findings show an appreciable level of community participation in the supply of potable water and in the decision-makingprocess involved in water management in the communities, therestill exist some challenges. A major challenge in the study affecting community participation in potable water management was the issue of financial constraints confronting both providers of potable water and beneficiary communities. Providers are constrained in terms of funding for providing adequate potable water to rural communities and are also unable to monitor and evaluate the use of existing potable water facilities. The Wa West District Assembly and other providers are unable to provide facilities to adequately meet the water demand of communities in the district and hence there is pressure on existing facilities and on the assembly to provide more for the populace. Corroborating this, the District Planning Officer noted during an in-depth interview that:

"The assembly is overwhelmed with increasing requests for more boreholes to be drilled in almost all the communities in the district. There is a wider gap between the demand for boreholes and the number that we (the assembly) have provided to communities in the district. There is a need for the assembly to drill more boreholes in communities for the people to use, but we are challenged with inadequate funds to do that. Our major source of funds is the District Assembly Common Fund (DACF) which is also inadequate to cater for other needs and still provides an appreciable number of boreholes. ….so we have been engaging community members and other relevant stakeholders in the water sector on how we can meet the demands of the communities…. but it is not easy to get the people to fully understand our (assembly) situation." (Planning Officer - Wa West District Assembly).

Another opinion leader had this to say:

"Some of my people believe that all sources of water are gifts from the gods and they should not be asked to partake in its provision. To them, God gave us all these. They were there before our forefathers. They believe that the rainwater that fills the rivers, the streams and all other water sources are not man-made. This makes their participation and management of water very difficult." (Community Opinion Leader - Wa West District).

Apart from the above excerpts from the study, the findings also show that the ability of some community members to actively participate in the management of potable water systems in the communities is limited due to the inability to make contributions regularly. Members who are not able to pay their contributions were said to usually dodge community water management meetings. The inability of members to pay maintenance and repair dues makes it difficult to ensure the sustainability of potable water facilities.

Another challenge the study found was the poor attitude of some members of the communities in attending communal meetings relating to potable water supply and management. It is only when all members attend meetings that popular views can be expressed and heard on important matters such as potable water supply and management in rural communities. So,when people do not attend meetings, they are not well informed about the processes of the acquisition of water facilities and the need for proper management for sustainability. This is particularly worse when it comes to farming where every community member turns to concentrate on working on their farms since they are predominantly farmers. Also, women are equally busy on their farms coupled with the picking of sheanuts. The patriarchal nature of the communitiesalso affects decision-making as collaborated by Dankwa (2018). Meetings during this period are not effective and participation therefore turns out to be low, because only a few people attend and deliberations cannot be effective and easily accepted by the whole community. Most people lack the commitment to attend water-related meetings even though water is used by everybody in the communities.This relates to the opinion of Schonten and Moriarty (2004) that, "a lack of community cohesion, commitment and management skills, unrepresentative from water communities, technical issues and financial problems are some of the drawbacks." The deduction has been underlying cultural factors.

An officer of the Community Water and Sanitation Agency (CWSA) revealed that poor attendance to meetings before and after the facilities are provided affects effective participation and hence affects management for the sustainability of the facilities provided. He noted that:

"Duringthe engagement of community members before provision of the facilities, we have always realized that many people do not turn up for the meetings. Meanwhile, management and sustainability issues regarding the water facilities are discussed during such meetings. It is in such meetings the communities select some people to be trained on repair and maintenance of the facilities. We trained these selected people as a team known as Water and Sanitation Management Teams (WSMT) and they are responsible for ensuring that the facilities are managed well. They report to us their issues that are beyond their control" (Officer, CWSA-Wa West District Assembly).

The results also show that there was a low level of education among the community members. As seen in the demographics, the majority of the people had not been to school, followed by those with primary and junior high school education. This affects effective participation during meetings and discussions since they may not be able to appreciate certain important issues relating to water supply and management. For instance, some community members do not understand the need for them to be engaged many times before drilling a borehole. They equally do not understand why authorities would attach the construction of household latrines as an automatic activity for community members. That is, they are unable to understand the link between water and sanitation due to their low level of education. It stemmed from the fact that most of them are not ready to relegate their beliefs and values when it comes to water as a gift from the gods. This makes them believe that their participation should not be compulsory. It takes much time and resources to organise several community sensitisation fora to explain and discuss to their understanding to ensure effective management sustainability when the facilities are provided.

The study also reveals that the communities are confronted with sanitation issues such as open defecation which is making it difficult to meet the sanitary aspects of potable water provision by providing authorities. The principles in providing potable water are merged with sanitary and hygiene issues dubbed Water, Sanitation and Hygiene (WASH) and hence the provision of one automatically goes with other issues. According to WHO (2011), the provision of a safe water supply "is an important environmental determinant of health that seeks to prevent and control waterborne diseases. Therefore, potable water supply and sanitation and hygiene education are effective health interventions towards minimising morbidity and mortality related to diarrhoeal and other related diseases among children in rural communities in particular." According to the outcomes from the focus group discussion, even though discussions held with the communities on the matter of open defecation are yielding results, the results are not very encouraging. They noted that it has not been easy mobilising communities for activities to curb open defecation in the communities. The Environmental Health Officer noted that:

"The people are quick to request boreholes but they are very reluctant to attend meetings to discuss sanitary issues especially issues relating to curbing open defecation in the communities. Meeting them to discuss matters of open defecation is not easy because they think that it is not important for now, despite telling them that curbing open defecation is a prerequisite for the provision of boreholes. Meetings on open defecation are in most cases attended by few young men and old people. Meanwhile, the young people have the strength to construct the household latrines that we have advocating and promoting".

The above narration relates to the view of Harvey and Reed (2007) who noted that low sustainability of potable water services is not only related to social and management issues but also to environmental and technical issues.

Also, it was deduced from the focus group discussion that there was a clear cultural issue as most of the indigenous people think water is supposed to be a gift of nature. This makes it difficult for them to simply accept the need to participate and pay for its management. Most of them believed that there was no need to pay for the provision of water-related facilities. This echoed the outcome of research by Bacho (2001), that traditionally, water is seen as a gift of nature. The view that water is a natural resource and therefore should be provided freely is still very alive. As a result of this, traditional people normally resort to thecontinueduse of available streams, rivers and rainwater as ordained sources from the gods. These cultural values and belief systems turn out to limit the participation of traditional people in discussions on the need to discard outmoded practices that serve as obstacles to potable water provision.

The foregoing cultural and socioeconomic factors serve as barriers to effective community participation relating to potable water supply and management towards sustainable development among selected communities in the Wa West District.

V. Conclusion and Recommendations

Inadequate finance is a foremostimpedimentto effective community participation in water management in the Wa West District. Low incomes among households constrain the people's ability to make regular contributions every month towards the repairs and maintenance of borehole facilities when they break down. Inadequate finance at the district assembly also affects the assembly's ability to provide adequate boreholes for the communities. Mobilization of internally generated funds of the assembly is poor as the district has only four (4) major market centres. Therefore, the Wa West District Assembly and other providers are unable to adequately meet the water demand of the communities.

Also, some members of the communities do not attend communal meetings regularly and hence are left out of decisions that are taken in such meetings. Such people turn out to be not well informed about decisions and regulations on water facilities and proper management for the sustainability of the facilities. The farming season presents an obstacle to regular attendance at gatherings on community water supply and management. Because the communities are predominantly farmers, people turn to go to work on their farms rather than attending meetings to participate in discussions on water-related matters. Hence, meetings during this period are not effective and participation therefore turns out to be low. Many people lack commitment to attend water-related meetings even though water is used by everybody in the communities.

Endemic cultural issues and low educational backgroundsamong the members of the communities also affect community participation. It makes it difficult for them to appreciate certain important issues relating to water supply and management. As traditional societies, they do not see the need to pay money as a counterpart fund for the building of water facilities. So, they continue the utilization of available sources of water as the will of the gods providing it.For instance, community members do not understand the need for them to be engaged in sanitary issues when the main issue has to do with drilling a borehole. Thus, they do not understand why authorities would attach the construction of household latrines to drilling a borehole in a community. There is no understanding of the link between water and sanitation due to the low level of education. It will take much time and resources to organizesensitizationprogrammes to explain their understanding to ensure effective management and sustainability.

Grounded on the conclusion of the study, the following recommendations are made:

It is appropriate that boreholes are mechanized and operational processes commercialized by the communitiesat a small fee within the district.Amongstthe other water services, the provision of boreholes in each of the communities should be prioritised. The mechanization will helpsafeguardthe larger population to securewater from each of the boreholesdotted in each of the communities thereby helping everyone to be served. This will solve or reduce the pressure and demand for more boreholes to provide potable water. It is also suggested that there should be the provision of credit facilities to households who are deprived to be able to diversify their livelihood to enhance them to effectively contribute monthly towards the borehole's maintenance in their various communities. In addition, this can be done through the formation of Village Savings and Loans Associations (VSLA) in the communities to improve the income of women in particular.

Also, the District Assembly through the Information Service Department and the National Commission on Civic Education (NCCE) should intensify community sensitization programmes to explain to community members the need for them to actively participate in matters relating to water and its related matters.

It is further recommended that conscious effort should be put in place by the Ghana Education Service (GES), and the National Commission on Civic Education (NCCE) to sensitize the population on the need for access to and use of potable water. The district assembly should collaborate with the needed agencies to improve on the unhindered access to education on the inculcation of a positive attitude towards access, community participation and the sustainable management of drinking water. This in due course will increase the awareness levels among community members. Deliberate educational campaigns on the link between water and sanitation will help address endemic cultural issues and the low level of education mentioned in the findings.

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 23 Issue 6 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Aftershock Predict based on Convolution Neural Networks

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Abstract- Earthquake prediction is a difficult task. Constrained within a certain spatiotemporal range, earthquakes are only a probability event. In a large area, predicting earthquakes based on geographical events that have already occurred is reliable. Predicting the duration of aftershocks under the condition that a major earthquake has already occurred is the research content of this article. Extract 6 features from seismic phase data to predict the aftershock period. We constructed a convolutional neural network model, sorted out 855 data from 1351 data, and trained the network. The accuracy of training verification reaches 90%, and the accuracy of testing reaches 100%. After further refinement, this model can be used to predict the duration of aftershocks in earthquakes. Provide data guidance for earthquake rescue.

Keywords: convolution neural network; aftershock predict; earthquake predict.

GJSFR-H Classification: FOR Code: 0404

AFTERSHOCKPREDICTBASEDONCONVOLUTIONNEURALNETWORKS

Aftershock Predict based on Convolution Neural Networks

ZhiJunLi [α], Jiyong Hua [σ], Gege Jin [ρ], & Hongmei Yin [Ѡ]

Abstract- Earthquake prediction is a difficult task. Constrained within a certain spatiotemporal range, earthquakes are only a probability event. In a large area, predicting earthquakes based on geographical events that have already occurred is reliable. Predicting the duration of aftershocks under the condition that a major earthquake has already occurred is the research content of this article. Extract 6 features from seismic phase data to predict the aftershock period. We constructed a convolutional neural network model, sorted out 855 data from 1351 data, and trained the network. The accuracy of training verification reaches 90%, and the accuracy of testing reaches 100%. After further refinement, this model can be used to predict the duration of aftershocks in earthquakes. Provide data guidance for earthquake rescue.

Key Points:

(1)Aftershocks are predictable.
(2)In the vast space of the Earth, a single earthquake in a single region can trigger other earthquakes.
(3)Neural networks are used to describe the nonlinear relationship between input and output.

Keywords: convolution neural network; aftershock predict; earthquake predict.

I. Introduction

An earthquake is a random event. A large number of earthquake events have left behind rich observational data. With our understanding of natural laws, we may be able to identify the patterns of earthquakes from big data. Cattania et al. [Cattania, 2019] believe that earthquakes cannot be considered as an isolated event for research. To study the possibility of earthquakes occurring within a larger regional space. Chang Qing Li [Chang-Qing Li, 2018] used the LSTM model to predict the location and direction of fractures in granite fracture experiments conducted in the laboratory. Sehrish et al. believe that neural networks can express the mapping relationship between earthquake occurrence signs and probabilities. They use BAT-ANN networks to avoid the algorithm falling into local optima and missing out on global optima. Asmae Berhich et al. predicted the likelihood of earthquakes based on their time, location, and magnitude.

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We believe that the aftershock period can be predicted on the premise that the earthquake has already occurred. Obviously, neural networks are currently the best tool available. In order to prevent overfitting of the model, we chose the convolutional model. In order to make the data more comprehensive, we selected 856 data from 2351 data of an earthquake. In order to make the data features more comprehensive, we selected 7 feature data from the seismic phase data block to form the input vector.

II. Relate Works

Helene et al. [Helene, 2018] conducted research on earthquake prediction. In the early days, seismologists believed that prediction was the logical goal of earthquake research. For most of the 20th century, optimism towards predicting earthquakes persisted. As bonuses flow into seismology, it drives predictive research towards conclusions. China seems to have successfully predicted earthquakes, which makes the development of earthquake prediction methods imminent. The goal of seismological research is to predict without any problems, but it should be carried out under the premise of rational and correct use of information and understanding of inherent difficulties. The public's response to earthquake prediction shows that 60-85% of people believe that earthquakes can be predicted.

Asmae Berhich et al. [Berhich, 2020] divided the Chilean earthquake dataset into two types: large earthquakes and small earthquakes. They believe that there are four methods for predicting earthquakes, namely precursor signals, statistical algorithms, machine learning, and deep learning. They take latitude, longitude, depth, year, month, day, hour, minute, second, and magnitude as 10 characteristic parameters from the seismic dataset. Large earthquakes with magnitudes greater than 5.0 are considered major earthquakes, while earthquakes with magnitudes 0.2 to 5.0 are considered minor earthquakes. By constructing an LSTM network with 10 neurons, four prediction results are output: magnitude, latitude, longitude, and year. Normalize the input data to [0,1]. Take 80% of the dataset for training and 20% for testing. The experimental results were evaluated using MAE and MSE.

Saba Sehrish et al. [Sehrish, 2017] divided earthquake prediction into three categories. Mathematical statistics, artificial intelligence, and hybrid methods. Input time and seismic signals to the ANN network to predict earthquake magnitudes. The evaluation algorithms are MAE and MSE. They believe that different technologies can predict earthquakes. Continuous improvement can lead to more accurate results. Among all technologies, neural networks exhibit better possibilities. It can achieve complex mapping relationships between input and output. Adding the BAT algorithm to ANN can effectively avoid overfitting of the network.

Chang Qing Li et al. [Chang-Qing Li, 2018] conducted fracture tests on granite in the laboratory. Analyze using six parameters: dry density, statistical friction coefficient, Young coefficient, general force, loading rate, and shear force. Obtain digital images through a two-dimensional mapping scanner. Study the transmission characteristics of sound waves during granite fracture process. Explain the mechanism of earthquake occurrence.

Molchan et al. [Molchan, 2017] believe that there is no standard method for earthquake prediction and evaluation. It is necessary to carefully examine the theoretical analysis. One important point to emphasize is that algorithms based on early warning mechanisms are not trustworthy.

Cattania et al. [Cattania, 2019] proposed that the prediction of large earthquakes should be studied in a large spatiotemporal space. Relatively speaking, small earthquakes are caused by the slow rupture of isolated convex bodies while large earthquakes have already occurred. These fractures are periodically repeated and can be predicted. They conducted research on earthquake prediction from a temporal and spatial perspective.

Qianlong W et al. [Qianlong W, 2020] constructed a two-dimensional input LSTM to reveal the spatiotemporal relationship of historical earthquakes. Divide LSTM into small parts to reduce algorithm complexity. They noticed that most neural network algorithms use different feature inputs. Not fully considering the spatiotemporal relationship of earthquakes. In the time domain, there seems to be a reasonable pattern of seismic activity. In the spatial domain, adjacent geographical activities can trigger each other. RNN is not suitable for handling long-term time dependence. LSTM uses functions to store information, replacing memory units. The unit state is transmitted along the entire path, only undergoing some linear interaction in the middle, and the information can be well maintained to the output end. Compared with one-dimensional input, the algorithm verification accuracy has improved from 79.6% to 87.8%.

Gitis et al. [Gitis, 2021] believe that a dense network of GPS receiving stations can monitor the movement of the Earth's surface. Can these measurement data be effectively used for system earthquake prediction. The paper studied data from Japan and California. Propose the minimum alarm area method to analyze the daily time series of horizontal displacement on the Earth's surface. Clearly distinguish the spatial and temporal regions of the location before the epicenter of a strong earthquake. Reflecting abnormal changes in seismic structures and geodynamic processes can be predicted.

Rui L et al. [Rui L, 2020] divided earthquake sequences into multiple learning samples and precursor patterns. Based on these patterns and samples, eight dominant features are extracted, while implicit features are also extracted. Based on the attention mechanism, combine explicit and implicit features. A dynamic loss function was designed in the model optimization using a small batch gradient descent optimization method. Adapting to different training data and balancing different categories of algorithms by combining explicit and implicit features is an effective earthquake prediction method.

William et al. [William, 2019] wrote a collection of 20 papers. It is divided into seven parts, including historical earthquake phenomena, physical models, precursor earthquakes, surface geochemistry, seismic related atmosphere signals, ionospheric processes, and interdisciplinary earthquake prediction methods. Believing that earthquake warning can promote building standards. Build buildings and facilities that can withstand earthquakes. It can reduce the cost of future earthquakes and reduce the number of injuries and deaths.

Danijel et al. [Danijel, 2018] pointed out that CSEP is a global network infrastructure used for prospective evaluation of earthquake prediction models and algorithms. The global CSEP collaboration has been conducting predictive experiments in various tectonic environments worldwide. The experiment provides a large number of results, providing information for operable earthquake prediction systems and earthquake disaster models. New and surprising insights have been provided on the predictability of earthquakes.

Gualberto et al. [Gualberto, 2016] explored seismic indicators on the Chilean National Earthquake Service dataset. After fully adjusting these indicators, the accuracy of prediction can be improved. The results indicate that by adjusting the input appropriately, the predictive ability of the classifier is significantly exceeded. Optimize and develop adaptive systems that utilize all available information, discover new metrics to provide more information to the system.

Elshin Oleg et al. [Oleg, 2020] introduced Terra Seismic, which can predict most major earthquakes 2-5 months in advance. The geological pattern and pressure accumulation of earthquake development are usually the same. Terra Seismic currently provides earthquake prediction for 25 key earthquake prone areas. Successfully detected approximately 90% of major earthquakes in the past 50 years.

The above literature shows that aftershocks can be predicted. Neural networks are the most suitable method to establish corresponding prediction models.

III. Proposed Method

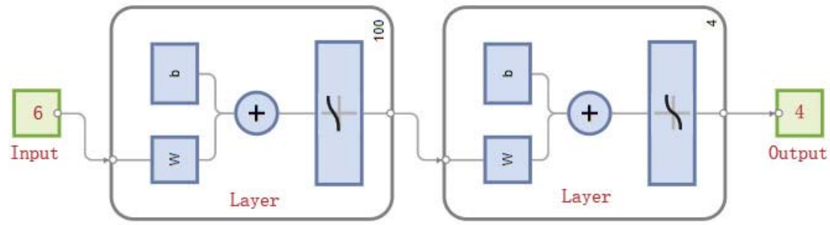

Figure 1: Network Structure

Using a forward propagation network, input the RxQ1 matrix. Q1 input vector containing R elements. The output is the SNxQ2 matrix. Q2 target vectors containing SN elements. Adopting a three-layer structure as figure 1. The hidden layer has 100 neurons, with an input layer width of 7 and an output width of 4. The transfer function takes the S-shaped transformation function Logig and the hyperbolic tangent S-shaped function transig, respectively. Try not to use linear functions. The gradient descent function adopts training dx, which is an adaptive learning rate training function. The weight of the input layer is determined by the input, and the hidden layer may come from the input layer. The weights of each layer are updated by the learning function. Training is performed by the training function. Performance is measured by a performance function.

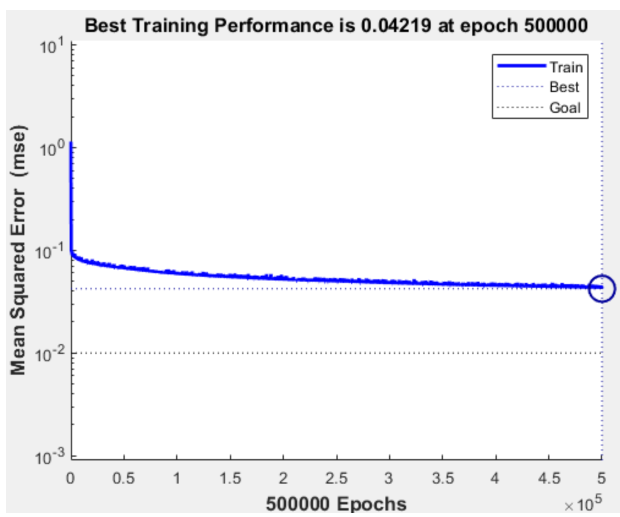

Figure 2: Training State

The learning rate is taken as 0.01. Display intermediate results every 50 rounds. The target error of neural network training is taken as 0.01. The maximum number of iterations is taken as 50000.

Training State is as figure 2.

IV. Experiment and Results

The data is from China Earthquake Networks Center and National Seismological Science Data Center （ http://data.earthquake.cn ）. We selected the seismic phase data block DPB from the Qinghai Maduo 7.9 magnitude earthquake phase dataset on May 22, 2021 at 02:04. Original data shows in figure4.There are 1351 recorders. Training performance shows as figure 3.

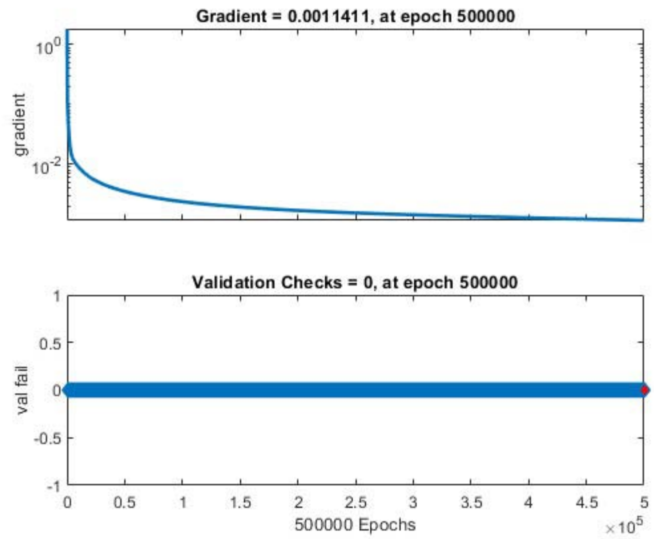

Figure 3: Training Performance

Original data format:

	A	B	C	D	E	F	G
1	02:05:46.10	2.4	6.1	341	3837	11.2	7.4
2	02:05:46.10	2.4	6.1	341	3837	11.2	7.4
3	02:05:46.10	2.4	6.1	341	2971	13.5	
4	02:05:46.10	2.4	6.1	341	2504	7.2	7.4
5	02:05:46.10	2.4	6.1	341	25	1.4	
6	02:05:46.10	2.4	6.1	341	22.3	1.6	6.4
7	02:07:30.00	4.3	6.1	341	22.3	1.6	
8	02:06:06.00	4.3	6.1	341	22.3	1.6	
9	02:06:06.00	4.3	15.1	56	8641	20.9	8
10	02:06:06.00	4.3	15.1	56	4891	19.6	
11	02:06:06.00	4.3	15.1	56	3048	19.1	7.9
12	02:10:57.80	4.7	15.1	56	3048	19.1	
13	02:10:46.40	0.6	15.1	56	3048	19.1	
14	02:10:39.30	3.5	15.1	56	3048	19.1	
15	02:07:53.60	-0.5	15.1	56	3048	19.1	
16	02:07:46.60	-1.9	15.1	56	3048	19.1	
17	02:07:46.60	-1.9	16.4	294	4294	17.1	7.8
18	02:07:46.60	-1.9	16.4	294	3972	15.8	
19	02:07:46.60	-1.9	16.4	294	1781	17.1	7.9
20	02:11:11.50	5.2	16.4	294	1781	17.1	

*Figure 4.*Original Data

Seismic phase refers to seismic wave groups with different properties or propagation paths displayed on seismic maps. Various seismic phases have different characteristics. Specifically, in terms of arrival time, waveform, amplitude, period, and particle motion mode. The seismic phase characteristics are related to the source, propagation medium, and receiving instrument. These wave groups all have a certain duration. The waveforms of different seismic phases overlap with each other, causing interference, resulting in a complex pattern in the seismic map. One of the tasks of seismology is to analyze and explain the causes and physical meanings of various seismic phases. Using various seismic phase characteristics to determine the basic parameters of earthquakes, studying the mechanical properties of seismic sources, and exploring the internal structure of the Earth.

Filter the raw data. Select 7 features. They are: Phase when the seismic phase arrives_ Time, travel time residual Resi, epicenter distance, station azimuth Azi, amplitude Amp, magnitude Mag_ Val and Period. Due to the fact that the dates are on the same day, only hours, minutes, and seconds are taken. For ease of operation, subtract the initial time from the time and take the offset as the time characteristic value. Figure 5 shows the organized data. Removed data without magnitude from the data, leaving 856 valid data. Divided into four categories based on duration. Category 4 for more than 20 seconds. Category 3 ranges from 10 seconds to 20 seconds. Category 2 ranges from 5 seconds to 10 seconds. Category 1 is defined as below 5 seconds.

Organized data format:

1	Phase_time	Resi	Distance	Azi	Amp	Mag_val	Period_val	Period
2	186.16	2.4	6.1	341	3837	7.4	3	11.2
3	186.16	2.4	6.1	341	3837	7.4	3	11.2
4	186.16	2.4	6.1	341	2504	7.4	2	7.2
5	186.16	2.4	6.1	341	22.3	6.4	1	1.6
6	246.06	4.3	15.1	56	8641	8	4	20.9
7	246.06	4.3	15.1	56	3048	7.9	3	19.1
8	386.66	-1.9	16.4	294	4294	7.8	3	17.1
9	386.66	-1.9	16.4	294	1781	7.9	3	17.1
10	751.56	5.2	16.4	294	70	7.3	2	5.4
11	751.56	5.2	16.4	294	6.3	6.9	1	1.2
12	442.56	-2.8	15.2	64	82	6	4	20.1
13	442.56	-2.8	15.2	64	728	7.2	3	14
14	393.46	-4.7	15.2	64	26.9	6.6	2	9
15	393.46	-4.7	15.2	64	0.2	5.3	1	1.7
16	386.36	-2.3	10.1	338	4333	7.6	3	13.5
17	386.36	-2.3	10.1	338	2823	7.9	3	14.7
18	386.36	-2.3	10.1	338	53.6	7	3	11.5
19	386.36	-2.3	10.1	338	0.6	6.2	1	0.9
20	278.46	-2.4	24.7	54	2558	7.9	3	14.2

Figure 5: Computed Data

We divided the dataset into two subsets.80% of the dataset is a training subset, and 20% is a testing subset.

Input data format:

input

6x856 double

	1	2	3	4	5	6	7	8	9	10	11	12
1	-0.8429	-0.8429	-0.8429	-0.8429	-0.7923	-0.7923	-0.6736	-0.6736	-0.3656	-0.3656	-0.6264	-0.6264
2	0.2043	0.2043	0.2043	0.2043	0.4086	0.4086	-0.2581	-0.2581	0.5054	0.5054	-0.3548	-0.3548
3	-0.9971	-0.9971	-0.9971	-0.9971	-0.9912	-0.9912	-0.9903	-0.9903	-0.9903	-0.9903	-0.9911	-0.9911
4	0.9044	0.9044	0.9044	0.9044	-0.6985	-0.6985	0.6400	0.6400	0.6400	0.6400	-0.6535	-0.6535
5	-0.7923	-0.7923	-0.8645	-0.9988	-0.5323	-0.8350	-0.7676	-0.9036	-0.9962	-0.9997	-0.9956	-0.9606
6	0.2222	0.2222	0.2222	-0.3333	0.5556	0.5000	0.4444	0.5000	0.1667	-0.0556	-0.5556	0.1111

Figure 6: Input Data

Train the data using BP network and CNN network respectively. Predict the duration of aftershocks from input. Figure 7 shows the input vectors.

input_matrix

856x7 double

	1	2	3	4	5	6	7
1	186.1600	2.4000	6.1000	341	3837	7.4000	3
2	186.1600	2.4000	6.1000	341	3837	7.4000	3
3	186.1600	2.4000	6.1000	341	2504	7.4000	2
4	186.1600	2.4000	6.1000	341	22.3000	6.4000	1
5	246.0600	4.3000	15.1000	56	8641	8	4
6	246.0600	4.3000	15.1000	56	3048	7.9000	3
7	386.6600	-1.9000	16.4000	294	4294	7.8000	3
8	386.6600	-1.9000	16.4000	294	1781	7.9000	3
9	751.5600	5.2000	16.4000	294	70	7.3000	2
10	751.5600	5.2000	16.4000	294	6.3000	6.9000	1
11	442.5600	-2.8000	15.2000	64	82	6	4
12	442.5600	-2.8000	15.2000	64	728	7.2000	3
13	393.4600	-4.7000	15.2000	64	26.9000	6.6000	2
14	393.4600	-4.7000	15.2000	64	0.2000	5.3000	1
15	386.3600	-2.3000	10.1000	338	4333	7.6000	3
16	386.3600	-2.3000	10.1000	338	2823	7.9000	3
17	386.3600	-2.3000	10.1000	338	53.6000	7	3
18	386.3600	-2.3000	10.1000	338	0.6000	6.2000	1
19	278.4600	-2.4000	24.7000	54	2558	7.9000	3

Figure 7: Input Vector

Figure 8 shows output result data.

output

856x4 double

	1	2	3	4
1	0	0	1	0
2	0	0	1	0
3	0	1	0	0
4	1	0	0	0
5	0	0	0	1
6	0	0	1	0
7	0	0	1	0
8	0	0	1	0
9	0	1	0	0
10	1	0	0	0
11	0	0	0	1
12	0	0	1	0
13	0	1	0	0
14	1	0	0	0
15	0	0	1	0
16	0	0	1	0
17	0	0	1	0
18	1	0	0	0
19	0	0	1	0
20	0	0	1	0

Figure 8: Output of the Neural Network Model

After training, we test the model with new dataset. Figure 9 shows the test results.

	1	2	3	4	5	6	7	8
1	657.3600	-4.3000	25.9000	58	1033	7.8000	3	3
2	1.0559e+03	2.6000	25.9000	58	34.5000	7.1000	2	2
3	1.0559e+03	2.6000	25.9000	58	0.2000	5.5000	1	1
4	588.1600	1.4000	27.6000	56	3125	7.9000	3	3
5	588.1600	1.4000	27.6000	56	1669	8.1000	3	3
6	645.0600	-4.5000	27.6000	56	9.2000	6.8000	1	1
7	645.0600	-4.5000	27.6000	56	0.2000	5.6000	1	1
8	641.8600	-0.9000	17.3000	93	5285	7.9000	3	3
9	641.8600	-0.9000	17.3000	93	5267	8.1000	3	3
10	765.8600	-0.8000	17.3000	93	45.9000	7.1000	1	2
11	765.8600	-0.8000	17.3000	93	0.7000	5.6000	1	1
12	454.6600	-1.7000	15.9000	107	5563	7.9000	3	3
13	454.6600	-1.7000	15.9000	107	4185	8	3	3
14	697.9600	3.3000	15.9000	107	36.2000	7.1000	1	2
15	697.9600	3.3000	15.9000	107	1.1000	6	1	1
16	398.1600	-0.6000	22.4000	47	5769	8.1000	3	3
17	398.1600	-0.6000	22.4000	47	2591	8.3000	3	3
18	955.5600	2.1000	22.4000	47	34.9000	7.2000	1	1
19	955.5600	2.1000	22.4000	47	1.8000	6.4000	1	1
20	553.0600	-0.2000	8.6000	159	8067	7.6000	4	4

Figure 9: Test Result

V. Evaluation

From the rendering, it can be seen that the built-in trainingdx training function has a large output value of the entire model, resulting in significant errors that make the model unusable. In addition to output constraints and setting an output upper limit, the training is good and the approximation effect is good. This indicates that the improved constrained training dx training function can handle similar situations where the model output value is too large or too small, resulting in better results.

Mean square error (MSE) is a measure that reflects the degree of difference between the estimator and the estimated quantity. Let t be the overall parameter determined based on the sample θ. An estimator of (θ- t) is mathematical expectation of 2. It is called the mean square error of the estimator t. It is equal to σ^2+b^2, where σ^2 and b are the variance and bias of t.

Consistent estimation (or consensus estimation) is the standard for evaluating estimators in large samples. When the sample size is not large, people tend to use small sample based evaluation criteria. In this case, variance is used for unbiased estimation and mean square error is used for biased estimation.

Generally, when the sample size is fixed, the criterion used to evaluate the quality of a point estimation is always a function of the distance between the point estimation and the true value of the parameter. The most commonly used function is the square of the distance. Due to the randomness of the estimation, the expectation of this function can be obtained, which is the mean square error given by the following equation:

VI. Conclusions

Predicting the duration of aftershocks is feasible on the premise that an earthquake has already occurred. In different regions, aftershock warning mechanisms can be established based on the geological conditions of the region. Expanding to larger regions and for a longer period of time, based on existing earthquakes, predicting future earthquakes should also be feasible. This is the direction that this article strives to explore.

Earthquake prediction is not the goal. The goal of this study is to provide data support for earthquake relief. In the event of an earthquake, minimize personnel and property damage as much as possible.

In future research, we will delve deeper into the use of deep learning algorithms and construct new aftershock prediction models using typical residual models. Fully utilize all parameters in seismic phase data to make detailed predictions of aftershocks.

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 23 Issue 6 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Analysis and Visualization of Fuel Consumption Against CO_2 Emission

By Shakir Adeyemi Adeyemi Tewogbade

Abstract- CO2 emission has an adverse effect on the environment and cause greenhouse effect with significant negative climatic changes. This subsequently lead global warming which hurts both human and crops. It is important for us to perform visual analysis with available dataset using Canada as a case study.

GJSFR-H Classification: *LCC Code: TD885.5.C6*

ANALYSISANDVISUALIZATIONOFFUELCONSUMPTIONAGAINSTCO2EMISSION

Strictly as per the compliance and regulations of:

Analysis and Visualization of Fuel Consumption Against CO_2 Emission

Shakir Adeyemi Adeyemi Tewogbade

Abstract- **CO2 emission has an adverse effect on the environment and cause greenhouse effect with significant negative climatic changes. This subsequently lead global warming which hurts both human and crops. It is important for us to perform visual analysis with available dataset using Canada as a case study.**

I. Introduction

The progress in technological development has led to few negative effects on the climate. Carbon Dioxide is the major compound accountable for climatic change (Nataly and Yiu, 2014). Consumption of automobile fuel produces CO2 emission globally. As claimed by USEAP 2022, a standard vehicle releases about 4.6 metric tonnes of CO2 annually. A study by Environment Canada in 2015 shown that private automobiles released 82 million tonnes of carbon dioxide in year 2013 alone. As noted by Carvaheira 2018, fuel consumption and CO2 emission of a particular vehicle is based on operating variables and design characteristics (mass, aerodynamics, tyres, auxiliary systems). Beyond vehicle operating variables and design characteristics, there are other factors mentioned by Fontara, Zacharof and Ciuffo, (2017) such as weather conditions, traffic conditions, road morphology, vehicle maintenance and driving style. The degree of causal effect of CO2 on the climate has warranted the need to study and analyze root causes based on available data that captured these variables and conditions. In this study, fuel consumption open data from 2010 to 2014 is used for visual analysis of influencing factors of CO2 emissions for new light- duty vehicles for retail sale in Canada. The data used is from an open source and it was collected from *Fuel consumption ratings - Open Government Portal (canada.ca).* Open data has consent for re-use and let researchers build on existing studies (Brandon and Weber, 2022). Our dataset includes the following variables: vehicle make, vehicle model, vehicle model year, make of vehicle, size of vehicle engine, transmission, cylinder, type of fuel, fuel consumed during movement in the city, fuel consumed in the highway, and emission values.

For appropriate visualization, we have selected Python libraries like Num Py (computation of numerical values), pandas (loading and manipulating data), matplotlib (handling plots) and seaborn to carry out our analysis in Jupyter Notebook. Various types of graphs like line graph, bar chart, heat maps were plotted to answer the questions formulated from our dataset.

II. Background

It is important to use correct visualization techniques in data analysis (Xi and Xinyu, 2021). Visualization technique selected for data analysis will be good if it is efficient, suitable and expressive (Mackinlay, 1986. Schumann and Muller, 2000). Our visual analysis is being carried out on Jupyter notebook platform. Jupyter notebook allow us to create and share files which include texts, live codes and visualizations.

Figure 1: Jupyter Web Interface

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Jupyter is interactive and web-based platform where computational activities can be executed with visualization. With the notebook, users can view their codes outcomes in-line independent of other segment of the project work. Each cell containing lines of codes are seen with their corresponding outputs. To use Jupyter notebook for our study, we divided the process into four stages:

1. Launch the platform
2. Load dataset
3. Clean & process the data
4. Analysis and Visualization

To load, clean, process and analyze data, important libraries are used with Python Jupyter such as

1. Panda-loading, reshaping, merging, slicing, sorting and aggregation of data through its special data structure and operations. With Python, panda perform efficiently with data structures (Rupal and Khushboo, 2022)
2. NumPy-It is used for mathematical and numerical computation on python coding environment with capabilities for quick array processing
3. Matplotlib-a low-level library used for plotting graphs and it is a great alternative to MATLAB
4. Seaborn-was developed by Michael Waskom in 2012 to handle statistical plots. It is a high-level source unlike matplotlib with an improvement in terms of aesthetics and readability. With seaborn, line of codes for making plots will be fewer compare to matplotlib.

III. Main Part

Jupyter notebook exist in document format with three segments which are cells for marking down, cells for coding and result parts (Park and Sekerinski, 2018). The architectural design of Jupyter notebook is based on JavaScript browser which interacts with HTTP server through WebSocket. The webserver utilize tornado embedded in Python to relate incoming message to the kernel. kernel that provides appropriate outputs after processing of the messages and these are communicated through notebook web interface. The kernel is the core actor in carrying out execution of codes in the Notebook. In this work, our target is to write codes that import fuel consumption dataset in.csv, clean it, prepare it and perform visual analysis. As stated earlier our graphs and plots are achieved with aid of libraries with Python Jupyter with appropriate codes. Important graphs and plots that put answers to the questions posed by our fuel consumption dataset are:

a) Line Graphs

Widely used visualization technique where independent variables and dependent variables are projected on X and Y axis. Various data points are joined to show appropriate line produced by selected dataset. Line graphs show quick glance of upward movement (direct proportional) and downward movement (inverse proportional).

b) Scatter Plot

This is like line graphs but data points are not joined but rather trendline are fitted. It displays clusters, trends and relationships. Scatter plots allow users to deduce how much data points are in close or spread out (SAS, 2014).

c) Bar Chart

Also known as column chart. It is used to display categorical data either vertically or horizontally where value of each category is represented by corresponding bar. Bar chart is readily modifiable most times with colours to capture significance differences. These are seen in stacked bar chart and clustered bar chart.

d) Box Plot

Box plots show extreme values, median and quartiles. While the plot is gotten from the interquartile range (length of the box) and median, the whisker moves the box to the minimum and maximum values without including the outliers.

e) Heat Map

It is used to display relationship between columns as represented in matrix view mode. Visualization analysis is achieved through selection of appropriate coloring. Heat map is an excellent plot in displaying variance through many variables while patterns are formed.

IV. Analysis

Data are raw fact based on occurrences in human daily life and its environment. One of the means of turning data into comprehensible information and knowledge is through visualization (Narra and Yashaswini, 2020). When there is huge amount of data, there will be difficulty in understanding facts in it. With existence of data visualization techniques, visual illustrations that reveal hidden insights can be readily created. Thus, this study will be answering the questions that do with fuel combustion and C02 emission considering different models of cars in Canada.

1. C02 trend in the years of study
2. What fuel type caused most emission?
3. What make of car produced most C02 emission during the period of study?
4. Which vehicle class considering fuel consumption produced most C02 emission ?

a) Data Collection

The first step was to import the needed data in .csv file format to our working environment using Panda library.

```
#load dataset
df = pd.read_csv("MY2010-2014_Fuel_consumption.csv")
```

Figure 3: Loading of Fuel Consumption Dataset

b) Data Cleaning

The dataset imported was viewed using syntax df.head () to display the first five rows for our perusal.

	MODEL	MAKE	MODEL.1	VEHICLE CLASS	ENGINE SIZE	CYLINDERS	TRANSMISSION	FUEL	FUEL CONSUMPTION*	Unnamed: 9	Unnamed: 10	Unnamed: 11	CO2 EMISSIONS
0	YEAR	NaN	# = high output engine	NaN	(L)	NaN	NaN	TYPE	CITY (L/100 km)	HWY (L/100 km)	COMB (L/100 km)	COMB (mpg)	(g/km)
1	2010	ACURA	CSX	COMPACT	2	4.0	AS5	X	10.9	7.8	9.5	30	219
2	2010	ACURA	CSX	COMPACT	2	4.0	M5	X	10	7.6	8.9	32	205
3	2010	ACURA	CSX	COMPACT	2	4.0	M6	Z	11.6	8.1	10	28	230
4	2010	ACURA	MDX AWD	SUV	3.7	6.0	AS6	Z	14.8	11.3	13.2	21	304

Figure 4: Checking the Dataset

The unnamed columns (9, 10 and 11) were given right title.

```
# renaming the columns
df.rename(columns={'MODEL':'MODEL_YEAR','MODEL.1':'MODEL','FUEL':'FUEL_TYPE',
                   'FUEL CONSUMPTION*':'FUELCONSUMPTION_CITY',
                   'Unnamed: 9':'FUELCONSUMPTION_HWY','Unnamed: 10':'FUELCONSUMPTION_COMB',
                   'Unnamed: 11':'FUELCONSUMPTION_COMBml','CO2 EMISSIONS ':'CO2_EMISSIONS' }, inplace = True)
```

Figure 5: Renaming the Unnamed Columns in the Dataset

Also, unwanted row 0 was dropped and the new data head was called to confirm if row 0 has been dropped.

```
# droping the row
df.drop(0,  inplace = True)
```

Figure 6: Dropping Unnecessary Row

```
# checking to make sure the row has been dropped
df.head()
```

	MODEL_YEAR	MAKE	MODEL	VEHICLE CLASS	ENGINE SIZE	CYLINDERS	TRANSMISSION	FUEL_TYPE	FUELCONSUMPTION_CITY	FUELCONSUMPTION_HWY
1	2010	ACURA	CSX	COMPACT	2	4.0	AS5	X	10.9	7.8
2	2010	ACURA	CSX	COMPACT	2	4.0	M5	X	10	7.6
3	2010	ACURA	CSX	COMPACT	2	4.0	M6	Z	11.6	8.1
4	2010	ACURA	MDX AWD	SUV	3.7	6.0	AS6	Z	14.8	11.3
5	2010	ACURA	RDX AWD TURBO	SUV	2.3	4.0	AS5	Z	13.2	10.3

Figure 7: Rechecking Our Dataset to Confirm the Row Has Been Updated

Codes were run to confirm the data type represented by each column and existence of null in the whole dataset.

```
df.info()

<class 'pandas.core.frame.DataFrame'>
Int64Index: 5359 entries, 1 to 5359
Data columns (total 12 columns):
 #   Column                  Non-Null Count  Dtype
---  ------                  --------------  -----
 0   MODEL_YEAR              5359 non-null   int32
 1   MAKE                    5359 non-null   object
 2   MODEL                   5359 non-null   object
 3   VEHICLE CLASS           5359 non-null   object
 4   ENGINE SIZE             5359 non-null   float64
 5   CYLINDERS               5359 non-null   float64
 6   TRANSMISSION            5359 non-null   object
 7   FUEL_TYPE               5359 non-null   object
 8   FUELCONSUMPTION_CITY    5359 non-null   float64
 9   FUELCONSUMPTION_HWY     5359 non-null   float64
 10  FUELCONSUMPTION_COMB    5359 non-null   float64
 11  CO2_EMISSIONS           5359 non-null   int64
dtypes: float64(5), int32(1), int64(1), object(5)
memory usage: 523.3+ KB
```

Figure 8: Checking Out the Data Type

The last action in our data cleaning was to confirm any missing values and none was observed in the dataset.

```
# checking for missing values
df.isnull().sum()

MODEL_YEAR              0
MAKE                    0
MODEL                   0
VEHICLE CLASS           0
ENGINE SIZE             0
CYLINDERS               0
TRANSMISSION            0
FUEL_TYPE               0
FUELCONSUMPTION_CITY    0
FUELCONSUMPTION_HWY     0
FUELCONSUMPTION_COMB    0
CO2_EMISSIONS           0
dtype: int64
```

Figure 9: Checking Out Missing Values

c) Data Preparation

We checked our dataset after all the cleaning to be sure that it is reading for visualization.

```
df.head()
```

	MODEL_YEAR	MAKE	MODEL	VEHICLE CLASS	ENGINE SIZE	CYLINDERS	TRANSMISSION	FUEL_TYPE	FUELCONSUMPTION_CITY	FUELCONSUMPTION_HWY
1	2010	ACURA	CSX	COMPACT	2	4.0	AS5	X	10.9	7.8
2	2010	ACURA	CSX	COMPACT	2	4.0	M5	X	10	7.6
3	2010	ACURA	CSX	COMPACT	2	4.0	M6	Z	11.6	8.1
4	2010	ACURA	MDX AWD	SUV	3.7	6.0	AS6	Z	14.8	11.3
5	2010	ACURA	RDX AWD TURBO	SUV	2.3	4.0	AS5	Z	13.2	10.3

Figure 10: Confirming That the Dataset is Properly Cleaned

Columns are confirmed for uniqueness.

```
len(data['Make'].unique())

45
```

Figure 11: Confirming Uniqueness of Value in "Make" Column

d) Data Analysis

The first set of plots with our dataset is to show trend in C02 emission from 2010 to 2014.

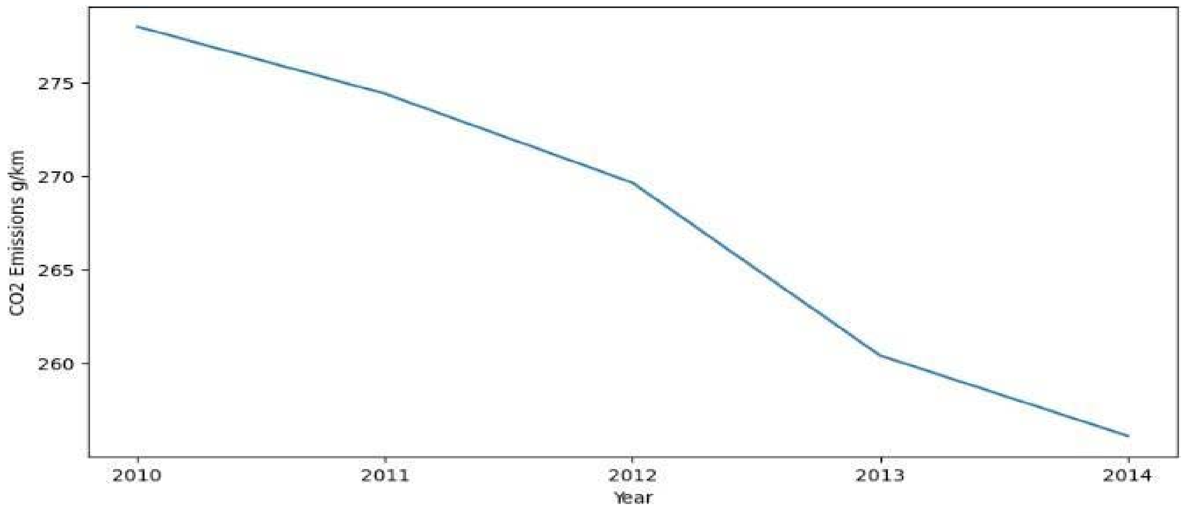

Figure 12: Line Graph to Show Trend Between Year 2020 and 2014

The plot shows downward trend which support various governmental policies in reducing emission and greenhouse effect.

The next visual analysis is setting up heat map to show interaction between our dataset attributes.

```
plt.figure(figsize=(12,8))
sns.heatmap(data.corr());
```

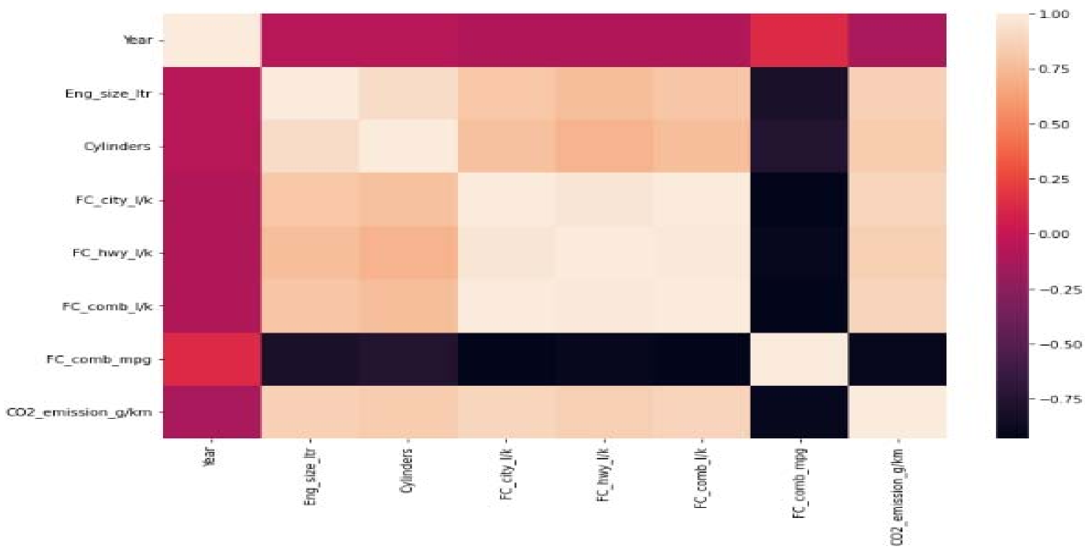

Figure 13: Heatmap Showing Correlation Among Variables

It was observed from the heat map that there is high positive correlation between fuel consumptions, engine size and cylinders with C02. Thus, we extend our visualization to plotting of fuel types with C02.

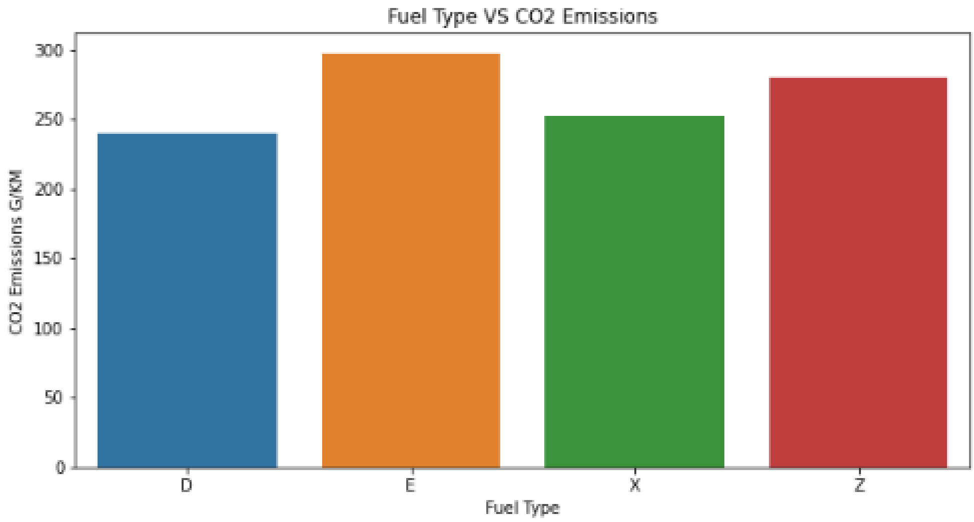

Figure 14: Bar Plot of C02 Emission Against Fuel Type

The plot showed that fuel type E and Z yields more C02 emission during the period under study. In a similar manner we plotted vehicle class based on fuel consumption against C02 emission using seaborn library. The graph showed that Van passenger and Van cargo yielded highest number of C02 emission between 2010 to 2014. We can also infer that weight of the vehicle has determining effect on C02 emission. The bigger vehicles are seen towards the right with high value of emission. This supports proposal by Pagerit et al, 2006, Wohlecker et al 2007 and Bishop et al 2014 as mentioned in our introduction.

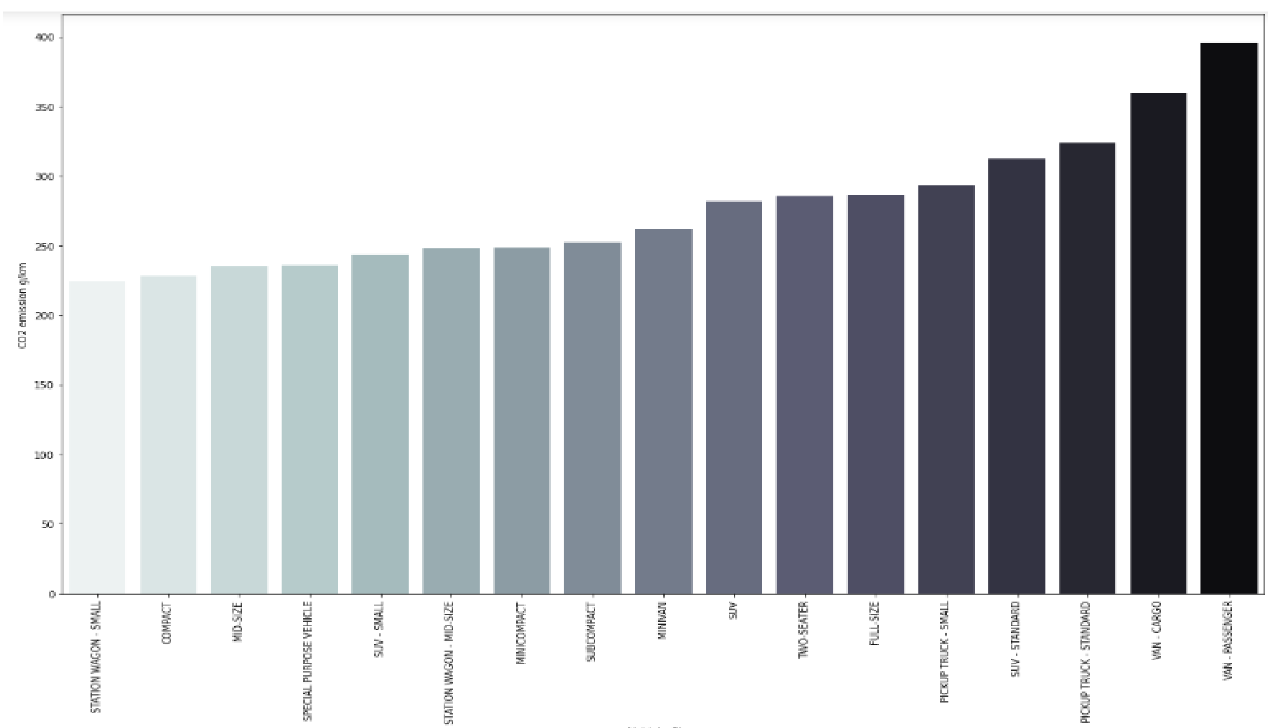

Figure 15: Bar Plot of Vehicle Class With Fuel Consumption Against C02 Emission

Moving forward, we produced another visual that display which of the vehicle make produced most emission.

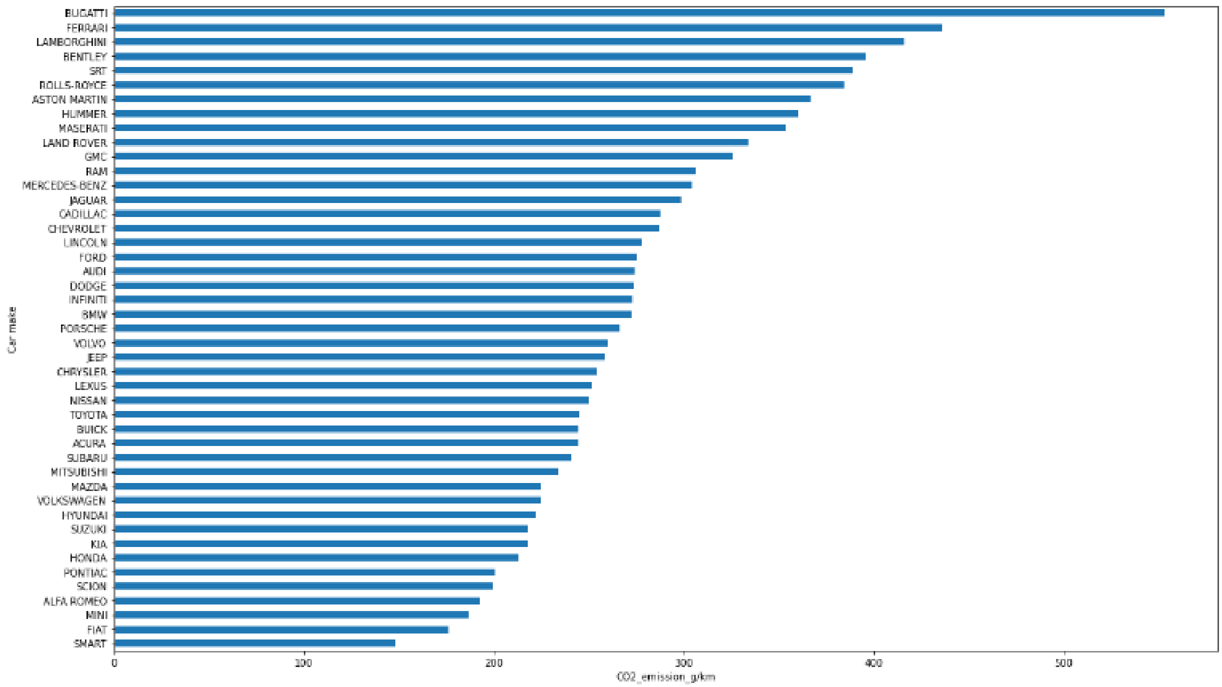

Figure 16: Bar Plot of Vehicle Make Against C02 Emission

The graph (Fig. 16) shows that Bugatti lead in term of amount of C02 emission produced into the environment. Bugatti uses fuel type Z with more controlling impact CO2 emission as shown in Fig. 14 above. As identified by our heat map, interaction between engine size C02 emission is plotted using scatter plot through seaborn.

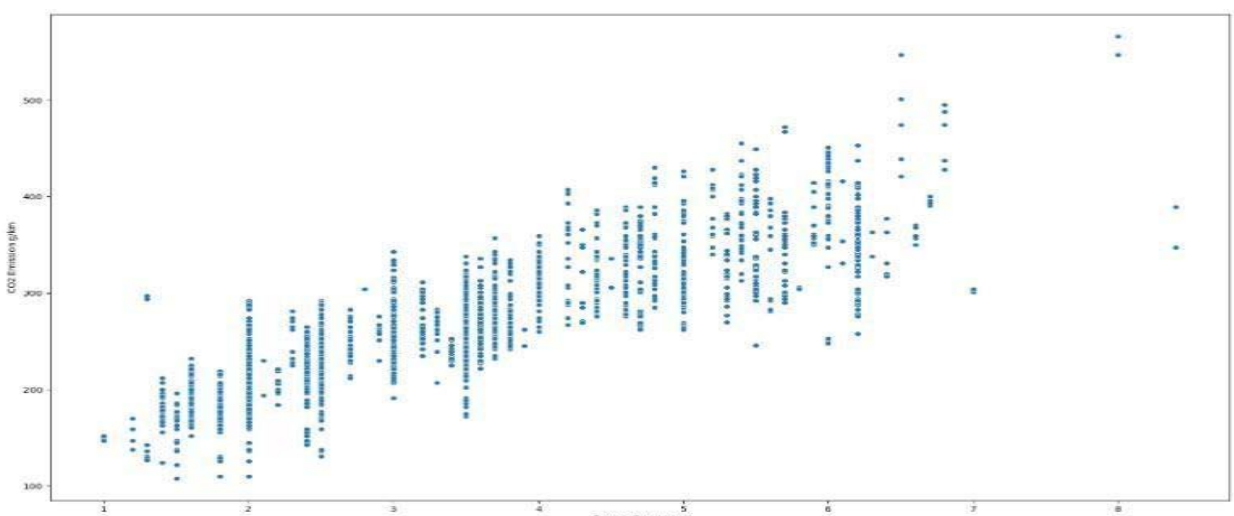

Figure 17: Scatter Plot C02 emission against Engine size

From the display, there is a strong direct proportional relationship between the two variables. The bigger the engine size the higher the C02 emission.

V. Discussion

Analysis performed on the dataset will validate emission models as generated by the various attributes. The dataset contains 5359 records with 12 attributes and as such it is hard to see information the raw figures is speaking to. Representing the data on various visual plots allow us to see hidden information at ease. Ben and Rachel 2015, used applicable visualization techniques like column chart, pie chart, line plot to analyze fuel consumption data. Similarly, Bielaczyc, Szczotka and Woodburn 2019 used column chart to represent fuel type plot against C02 emission and contour map to display emission in certain locations with vehicle load and speed.

The application of bar charts (Fig.15 & 16) in our analysis has easily been achieved because of its robustness in representing categorical data, perhaps Cleveland's dot plot would have taken fewer spaces with improved aesthetic for plot like fuel type vs C02 emission. For simplicity each dot will be represented as 40 g/km of emission. Dot plot uses minimum ink to optimum effect and still deliver excellent design (Tufte, 1983. Dave, Jaap and Ian, 2005).

Heat map has been widely used in many visualizations analysis due to its intuitive approach of colouring and ability to present interaction among variables in a single diagram. In work such as ours, we could have introduced our heat map after plotting table lens graphs. As asserted by Sinar 2015, table lens has a very high efficiency in yielding many interactions in a single plot while serving as starter in dataset visualization. Also, in addition to our heatmap, facet (Trellis) plots can be used to create additional interactions (sub-plots) for variables showing strong correlation from the map.

VI. Conclusion

Data visualization has gained great popularity with advancement of software technology and variety of platforms. One of the popular platforms to create visualization is Jupyter notebook where cells for codes and visual displays are available on the interface. We have used data visualization to investigate controlling effects of fuel consumption on C02 emission. Variety of techniques such as line chart, bar chart, heat maps and scatter plot were used to analyze the field data in order to create informative patterns on level of influence of various variables on C02 emission. Our visual analysis revealed resultant effects of important variables that need to be curtailed to minimize C02 emission in the environment. This kind of study will assist policy makers to find effective solutions to climatic changes caused by vehicle movements.

In as much as we have efficient visuals which produced graphical display of raw data., there are few exceptions. The exceptions were critically reviewed to create room for improvement. The improvement will yield visual that create more robust outcomes where concentrated interactions are revealed in our visuals and nicer aesthetic.

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We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

Alternatively, you can download our basic template from https://globaljournals.org/Template.zip

Authors should submit their complete paper/article, including text illustrations, graphics, conclusions, artwork, and tables. Authors who are not able to submit manuscript using the form above can email the manuscript department at submit@globaljournals.org or get in touch with chiefeditor@globaljournals.org if they wish to send the abstract before submission.

Before and during Submission

Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

1. Authors must go through the complete author guideline and understand and *agree to Global Journals' ethics and code of conduct,* along with author responsibilities.
2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

Declaration of Conflicts of Interest

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

Policy on Plagiarism

Plagiarism is not acceptable in Global Journals submissions at all.

Plagiarized content will not be considered for publication. We reserve the right to inform authors' institutions about plagiarism detected either before or after publication. If plagiarism is identified, we will follow COPE guidelines:

Authors are solely responsible for all the plagiarism that is found. The author must not fabricate, falsify or plagiarize existing research data. The following, if copied, will be considered plagiarism:

- Words (language)
- Ideas
- Findings
- Writings
- Diagrams
- Graphs
- Illustrations
- Lectures

- Printed material
- Graphic representations
- Computer programs
- Electronic material
- Any other original work

Authorship Policies

Global Journals follows the definition of authorship set up by the Open Association of Research Society, USA. According to its guidelines, authorship criteria must be based on:

1. Substantial contributions to the conception and acquisition of data, analysis, and interpretation of findings.
2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

Changes in Authorship

The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

Copyright

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Appealing Decisions

Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

Global Journals is in partnership with various universities, laboratories, and other institutions worldwide in the research domain. Authors are requested to disclose their source of funding during every stage of their research, such as making analysis, performing laboratory operations, computing data, and using institutional resources, from writing an article to its submission. This will also help authors to get reimbursements by requesting an open access publication letter from Global Journals and submitting to the respective funding source.

Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Science Frontier Research Paper

Techniques for writing a good quality Science Frontier Research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of science frontier then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

CRITERION FOR GRADING A RESEARCH PAPER (COMPILATION) BY GLOBAL JOURNALS

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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ISSN 9755896