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Predicting Food Crop Production in Times of Crisis: The Case of Wheat in Zambia

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1. Introduction

With the numerous challenges related to agricultural trade that many countries currently face, it is important for policymakers tasked with the duty of protecting the vulnerable to be aware of potential food production disruptions that their countries may experience. Russia and Ukraine which are currently at war, are both key exporters of many agricultural products including sunflower oil and seed, wheat, barley, rapeseed, and maize. The two countries jointly account for 27% of global wheat trade, 23% of trade in barley, as well as 16% and 14% of trade in colza and maize respectively. Furthermore, Russia and Ukraine, account for over 28% of global production of nitrogen, potassium, and phosphorous fertilizers. The Russia-Ukraine war has destabilized global food and agricultural value chains and this is expected to continue or even worsen, the longer and harder the war is fought. As net importers of both wheat and fertilizers, African countries are already experiencing increases in the prices of these commodities and their substitutes. The dynamic effects of the fertilizer and wheat price increases mean that production in the coming seasons will be negatively impacted, and many more households may need support from various sources in order to survive the food and fertilizer price hikes.

Better and timely statistics on domestic food supplies, especially on production, are critical in any attempt to protect livelihoods under these conditions. Like many other African countries, Zambia's data on wheat forecasts disaggregated per location is scanty, often of low quality and is usually made available at untimely moments, typically months after harvesting. In this brief, remote sensing data is used together with machine learning techniques to predict future wheat production in Zambia.

THE UKRAINE CRISIS AND AFRICAN ECONOMIES

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The models used for prediction are selected partly on their ability to correctly predict already existing wheat production data. While these methods are skill-intensive, their use limits the amount of time and the costs needed to calculate production levels from surveys and field visits. More broadly, the inherent precision in the techniques contributes to availability of better-quality data in Zambia.

During periods of crisis such as the one at hand, the earlier food production patterns can be predicted, the sooner policymakers can take corrective measures to avoid a full-blown food and nutritional security crisis. More accurate and timely information on food crop production therefore makes it possible for countries to design targeted interventions to protect access to food among their people including those in the most vulnerable communities. Once equipped with these forecasts, policymakers can start developing interventions that target various areas depending on their levels of production.

The data scientists at AKADEMIYA2063 used the in-house developed Africa Crop Production (AfCP) model to prepare Zambia's wheat production forecast. The model uses satellite remote sensing data as explanatory variables and machine learning techniques as a predictive modelling framework to provide production quantities at the pixel level, prior to the harvesting period. The remote sensing data makes it possible to uniquely characterize features on earth on several wavelengths without requiring a physical presence on the ground enabling production of more extensive and better-quality data within a short time-period. On the other hand, machine learning makes it possible to extract the many features hidden within vast quantities of data that can help unlock the mechanisms behind the inner workings of complex systems. In this brief, the two techniques mentioned above have been combined to forecast the quantity and spatial distribution of wheat production in Zambia in 2022, during the Ukraine-Russia crisis.

2. The Importance of Wheat in Zambia

Wheat is an important food crop in Zambia, it is the second most widely grown cereal crop after maize (Tembo, 2019). Wheat production has grown from almost zero in the early 1970s, to more than 300,000 tons in 2015. Zambia is now able to partially meet local demand and export wheat to neighboring countries, and consequently employment has been created at various levels of the value chain (Mulikelela, 2015). While the share of spending on maize exceeded that for other staple foods among relatively poor urban consumers in 2007/8, wheat is the most important staple carbohydrate in consumption value terms among urban consumers in general. Maize is no longer the dominant staple food in urban Zambia, except among the poor (Mason and Jayne, 2009). Wheat in Zambia is used mainly for human consumption where, in the milling process, it is ground into cereals, flour, and feed (FAO, 2017).

Agriculture in Zambia is generally rated as underperforming and productivity in wheat production as well as other crops can be increased significantly. The Zambian government attributes the current failures partly to the fact that the sector has not effectively utilized "research and development, farm mechanization, science and technology and information and communications technologies (ICT) to increase yields and maximize the comparative advantage of different areas of the country" (Republic of Zambia 2014, p. 8).

While maize in Zambia is mostly grown during the rainy season, wheat is planted during the dry periods from April 20 to May 10 on well-tilled land. Maize fetches about US$ 299 whereas wheat fetches an average of about US$ 550 per ton and the yield is higher per hectare compared to maize (Jere 2022). Wheat cultivation has for a long time been the preserve of commercial farmers in Zambia. However, to date, over 1,000 peasant farmers have been trained in growing high-value crops such as wheat in order to earn decent income as part of the country's poverty alleviation efforts (Tembo, 2018).

Recent trends in Zambian wheat production

In 2020, wheat production in Zambia was 235,000 tons. Although Zambian wheat production has varied significantly in recent years, it had increased through the 1991-2020 period (IndexMundi, 2022). The most recent statistics reveal that Zambia exported just under 2,000 metric tons of

[1] *UNCTAD (United Nations Conference on Trade and Development). 2022. The Impact on Trade and Development of the War in Ukraine. UNCTAD Rapid Assessment. Geneva, Switzerland.*
[2] *https://www.cnbc.com/2022/04/06/a-fertilizer-shortage-worsened-by-war-in-ukraine-is-driving-up-global-food-prices-and-scarcity.html*
[3] *Dia Khadim and Ly Racine. 2020. Predicting Food Crop Production in Times of Crisis: The Case of Sorghum in Burkina Faso. COVID-19 Brief number 012. AKADEMIYA2063*

wheat in 2013. Virtually all of the country's wheat exports are sold to Zimbabwe (Faostat, 2019). In the decade from 2004 to 2014, Zambia's harvested wheat area fluctuated, first rising by almost 209% before experiencing a 33% decline from 2013 to 2014. Production mainly occurs in the Central Province (49.5%), Lusaka (24%), the Copper Belt (14.3%), and the Southern Province (12.1%) (CSO, 2014).

Wheat production in Zambia has steadily increased even though its production levels still fall short of meeting national demand. Low production can be attributed to a number of constraints including the high cost of inputs such as fertilizers and herbicides, weeds, poor mechanization, lack of market information, lack of improved wheat seeds, plant diseases, soil infertility, adverse climatic conditions, and water and power shortages related to irrigation. Despite these constraints, Zambia has great potential to expand its wheat production. Much of the country has been identified as being suitable for growing the crop. Zambia's wheat research team has released high-yielding, disease-resistant varieties for both irrigated and rainfed cultivation. To maximize the yield potential of these varieties, recommended production packages have been developed for both small- and large-scale farmers (Mukwavi et al., 1990). Government and policymakers must continue to provide incentives to wheat growers in the form of available and affordable inputs as well as reasonable market prices to support expanded wheat production.

Zambia's wheat production has almost followed the pattern of its maize production, accelerating from 2008 when the country harvested 113,000 tons, eventually reaching an all-time high of 274,000 tons in 2013, before declining to about 190,000 tons in 2019 (FAO, 2019).

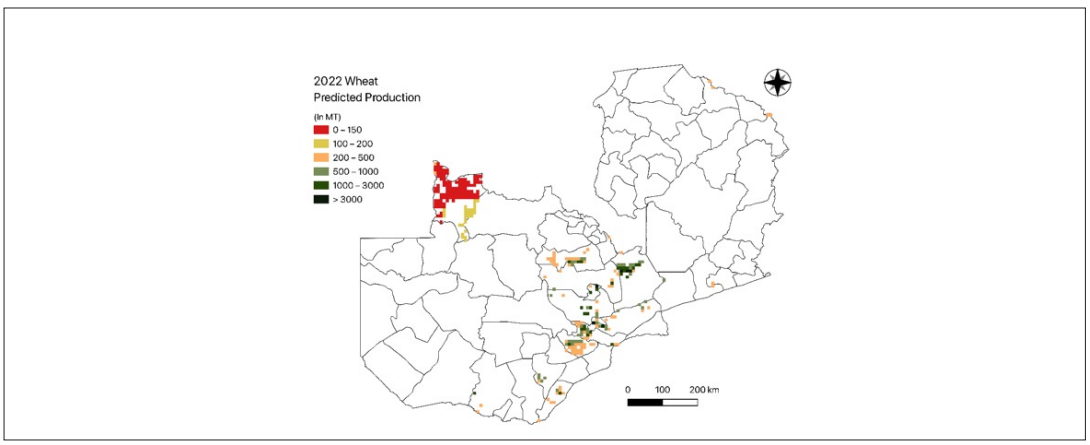
Wheat production prediction methodology

Wheat production forecasts for Zambia are generated using the AfCP model. The model uses satellite-based, bio-geophysical time-series data such as the normalized difference vegetation index (NDVI), land surface temperatures (LST), rainfall, and evapotranspiration rates as explanatory variables. An artificial neural network was built to learn the relationships between the same bio-geophysical data and historical staple food crop production data available at the pixel level. As the Russia-Ukraine crisis started several months before the wheat growing season, we implemented the prediction when in-season information about bio-geophysical data was not yet available. A random forest predictor was therefore used to forecast in-season, bio-geophysical data profiles using data from the last 20 years, and the outputs were used as inputs to the AfCP model to predict Zambian wheat production.

Zambia's 2022 wheat production forecast

Using this methodology, the AfCP model developed Zambia's 2022 wheat production forecast, which is illustrated in Figure 1. The pixels considered for this map are those where wheat is believed to be grown and have a size of ten-by-ten kilometers on the ground.

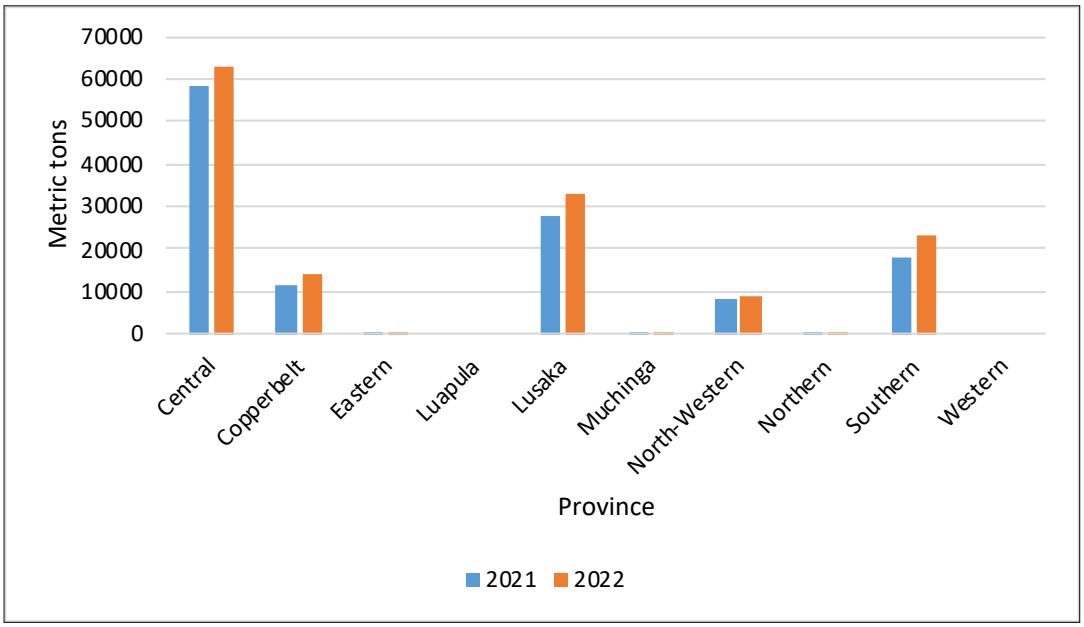
Figure 1: *Wheat production forecast in Zambia for 2022.*



Source: Africa Agriculture Watch – AAgWa, AKADEMIYA2063, 2022.
Notes: *Zambia's 2022 wheat production forecast is at a pixel level, size of ten-by-ten kilometers.*
The boundaries and names shown, and the designations used on maps do not imply any official endorsement or acceptance by AKADEMIYA2063.

Figure 1 presents Zambia's 2022 wheat production forecast. The model predicts the production of approximately 130,000 metric tons of wheat in the upcoming 2022 harvest indicating that production will slightly increase from 2021 levels of about 125,000 metric tons. In the 2022 harvesting season, it is expected that the highest level of production of wheat in Zambia will be in the Central province where production is concentrated in Mkushi, Kapiri Mposhi, Kabwe and Chibombo districts with a production of over 62,000 metric tons. Lusaka province will have a production of about 33,000 metric tons in Kafue, Chongwe and Lusaka districts while Southern province will see the production of about 23,000 metric tons in Mazabuka, Kazungula and Choma districts. Masaiti and Mpongwe districts in the Copper Belt province will have a production of approximately 14,000 metric tons and the North-Western province is forecast to produce under 10,000 metric tons in Solwezi and Mwinilunga districts. The Muchinga province (630 metric tons), Eastern (548 metric tons) and Northern (491 metric tons) provinces will produce the least quantities of wheat. When compared to the 2021 actual production levels, it is clear that there are important deviations over time which strengthens the need for advance predictions to enhance preparedness (Figure 2).

Figure 2: *Comparison of wheat production in Zambia, 2021 and 2022.*



Source: AKADEMIYA2063

The above figure shows that the predicted wheat production for 2022 is expected to be higher than that in 2021 (also see Table 1 in the Appendix, as shown by the lower ratios of 2021 wheat production as a share of 2022 production).

As annual wheat consumption is over 200,000 metric tons per annum , and since the demand for wheat is price inelastic (quantities of wheat demanded do not change much with changing prices), the rising wheat prices associated with the Russia-Ukraine war will have negative consequences on consumers unless domestic production is increased. This increase would have to occur despite the rising input prices exacerbated by the war. It is also important to ensure that steps are taken to increase consumer access to local wheat production within Zambia to limit the exposure of the low producing areas to the negative, price-related impacts of the war on international trade flows.

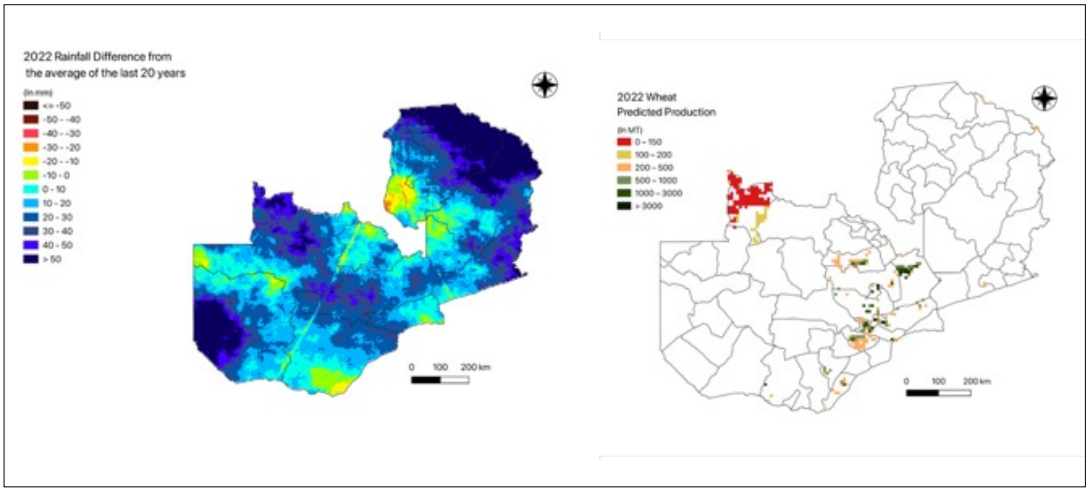
Status of crop growing conditions

This brief further examined crop growing conditions by computing anomalies in the same bio-geophysical parameters over the ongoing growing season. The parameters were aggregated from January to June for the last 20 years. The 2022 data were then compared with the aggregated trends observed over the previous 20 years.

[4] *https://www.indexmundi.com/agriculture/?country=zm&commodity=wheat&graph=domestic-consumption*
[5] *Except for the evapotranspiration data due to data availability issues.*

Figure 3 shows the spatial correlation between rainfall anomalies and wheat production forecasts for Zambia. To a large extent, areas with moderate anomalies appear to be associated with high wheat production forecasts, for instance those in the Central province, and parts of Lusaka province.

Figure 3: *Rainfall anomalies in Zambia and wheat production in 2022.*

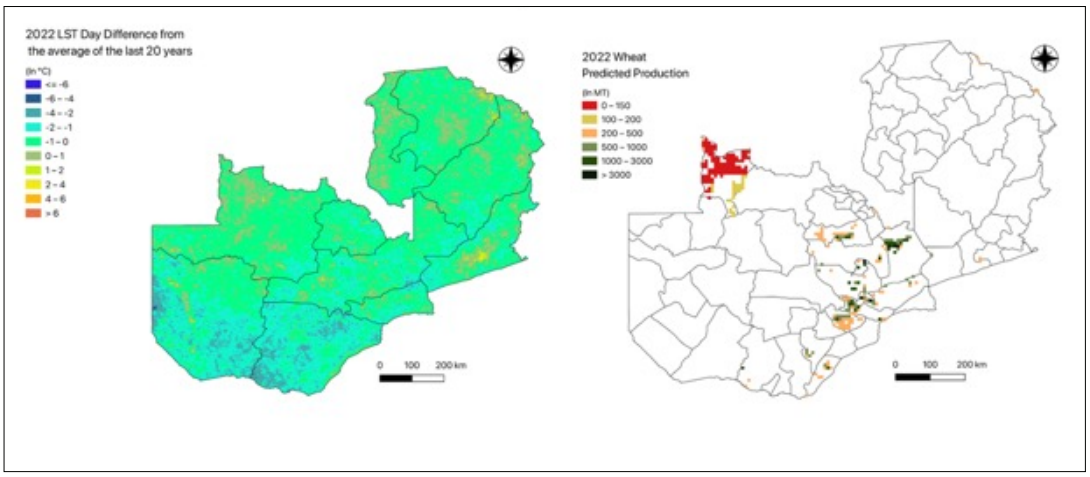


Source: AKADEMIYA2063. (Left) Zambia 2022 rainfall anomalies; (Right) Zambia 2022 wheat production forecast.

Figure 4 shows that at locations with the highest (above 4 degrees Centigrade) and lowest (below 4 degrees Centigrade) land surface temperature anomalies, predicted wheat production is at its lowest level.

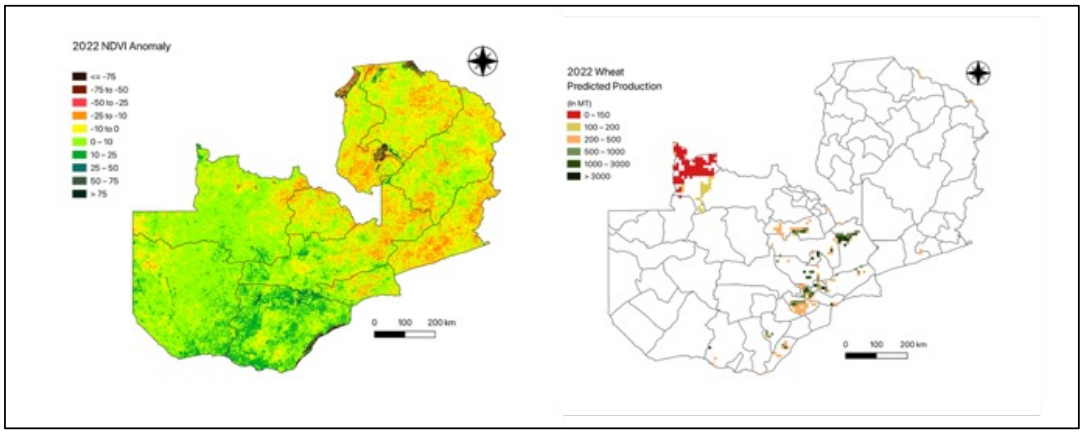
In contrast, wheat production is predicted to reach its highest level at locations with moderate land surface temperature anomalies (between -4.0 and +4.0 degrees Centigrade). Similarly, the areas with the most negative rainfall anomalies seem to show the lowest levels of forecasted wheat production compared to areas with moderate to high positive anomalies. In Zambia, the irrigated wheat cultivars are planted from mid-April to early-May while rainfed wheat is planted from October to December, depending on soil moisture and the warmer day-night temperatures during growth and reproduction. Paying attention to these temperature anomalies during planting can make production more resilient.

Figure 4: *Temperature anomalies in Zambia and wheat production forecast for 2022.*



Source: AKADEMIYA2063. (Left) Zambia 2022 land surface temperature anomalies at wheat cropland pixels; (Right) Zambia 2022 wheat production forecast.

Figure 5: NDVI anomalies in Zambia and wheat production forecast for 2022.



Source: AKADEMIYA2063. (Left) Zambia 2022 NDVI anomalies at wheat cropland pixels; (Right) Zambia 2022 wheat production forecast.

Similarly, areas with very high positive deviations in NDVI as well as those with very low NDVI anomalies did not appear to be correlated with high wheat production, but modest changes in NDVI appear to favor greater wheat production.

3. Key Messages and Recommendations

The Russia-Ukraine war presents a challenge to global food security and household resilience especially in those countries that depend on international trade for agricultural inputs and food in general. Predicting future agricultural production is critical for the development and crafting of timely interventions that will limit the negative effects emanating from the war.

This brief applied state-of-the-art innovations that combine remote sensing and artificial intelligence techniques to predict Zambia's wheat production for 2022, with the aid of information on bio-geophysical characteristics (rainfall, evapotranspiration, NDVI and land surface temperatures).

The predictions obtained are consistent with actual production ranges observed recently in Zambia, although they indicate a slight increase in wheat production in the upcoming harvest. It is important for authorities to start putting in place mechanisms that will increase consumer access to local production and limit the exposure of households in areas with declining production levels to greater threats than those already emanating from the disruption of global wheat supply chains.

Going into the next growing season, farmers should be encouraged to plant more wheat by expanding cropped areas where possible, to limit the effects of further hikes to already high global prices. Furthermore, although there is a good share of irrigated wheat production in Zambia, it is equally important to ensure that good water management practices are employed during periods of peak demand to ensure increased yields. This would address some of the water-related challenges in wheat production (see Dube et al., 2020) often reported in other countries as well as the generally observed negative correlations between rainfall anomalies and future wheat production.

Inputs such as water and fertilizers will continue to be limiting factors for wheat production in the medium- to long-term due to frequent and disruptive global crises and climate change impacts. To strengthen food system resilience, the Zambia Agricultural Research Institute (ZARI) should consider embarking on wheat yield improvement breeding programs which would look to produce wheat varieties with low input requirements (i.e., using less water, fertilizer, and pesticides per unit of wheat produced). Targeting low fertilizer and water requirements in breeding will reduce the importance of input costs in wheat production and will increase production, productivity, and profitability. Fertilizer and water abstraction costs currently present huge constraints on wheat production in Zambia.

Appendix

Table 1. Zambia level 2 (sub-county) wheat production in 2021, 2022, and 2022-2021 ratios. A ratio below one means 2021 wheat production was greater than 2022 production. A production ratio above one means 2022 wheat production is greater than 2021 production. Both 2021 and 2022 data were extracted from the Africa Agriculture Watch (AAgWa) platform (www.aagwa.org).

Province	District	2021 wheat production (MT)	2022 wheat production (MT)	Wheat production ratio (2022/2021)
Central	Chibombo	9302.00	11160.00	1.20
Central	Kabwe	7396.00	8195.00	1.11
Central	Kapiri Mposhi	4965.58	3035.98	0.61
Central	Mkushi	34671.91	38390.77	1.11
Copperbelt	Masaiti	224.94	287.80	1.28
Copperbelt	Mpongwe	10963.00	13527.00	1.23
Eastern	Katete	232.05	310.00	1.34
Eastern	Nyimba	227.72	238.75	1.05
Lusaka	Chongwe	8905.39	10465.90	1.18
Lusaka	Kafue	17741.19	21470.30	1.21
Lusaka	Lusaka	922.65	1288.28	1.40
Muchinga	Isoka	506.62	630.98	1.25
North-Western	Mwinilunga	7711.75	8258.00	1.07
North-Western	Solwezi	633.69	695.42	1.10
Northern	Mbala	399.73	491.56	1.23
Southern	Choma	2073.89	2827.10	1.36
Southern	Kazungula	1530.30	1862.00	1.22
Southern	Mazabuka	9355.00	12226.41	1.31
Southern	Sinazongwe	4953.00	5960.49	1.20

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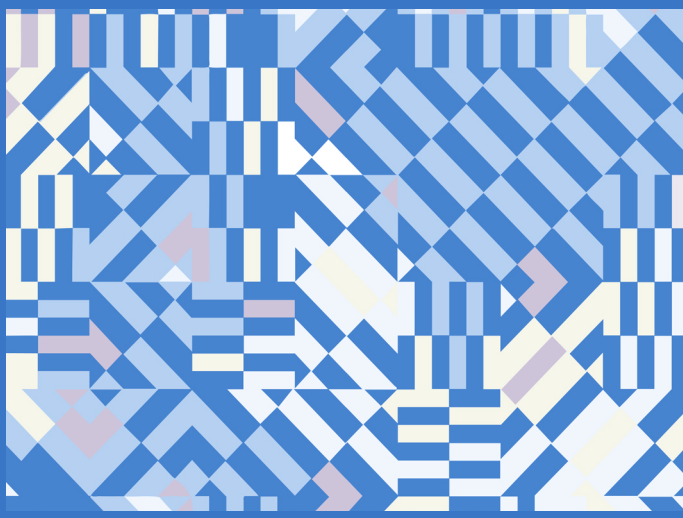

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