We would like to thank the reviewers for the constructive comments. Please find our replies and modifications below.

Comments by Ref#2 in Rep#1

General comments

Rep1.1: There is one point where my original request may have been misunderstood. When I referred to a "conceptual model," I did appreciate the flow chart added in response. However, what I primarily had in mind was a **concise conceptual description of the hydrological situation at each of the three locations along the river stretch — including land use, surface elevation, groundwater conditions (e.g., confined vs. unconfined), and the degree of connection to the river**. It is somewhat unusual to characterize this using rectangular areas rather than sub-catchments, although I recognize the constraints posed by limited data availability. In that sense, the authors appear to have extracted what is feasible from the existing data.

AC: Thank you for your comment and for clarifying your original suggestion. We have revised and restructured parts of section 2.1 to include a more explicit conceptual description of the conditions for each of the three locations, addressing land use, surface elevation, groundwater characteristics, and stream connectivity. Furthermore, we have moved the Section "Conceptual Model of Drought Propagation" to follow directly after Section 2.1 to create a more coherent structure.
The decision to characterise the sites using rectangular areas stems from the NDVI data format. We acknowledge that this is a pragmatic simplification driven by data availability rather than a reflection of natural sub-catchment boundaries, but this choice only affects the NDVI assessment and does not influence our broader conclusions.

Specific comments

Rep1.2: L117: I appreciate that you acknowledge the missing crop-type metadata as a source of uncertainty. However, this point does not need such strong emphasis in the main text. It would be more appropriate to state it concisely and address the implications in the discussion section. For example, a sentence like the following would be sufficient: "Agricultural crops in Berlin-Brandenburg are commonly cereals and fodder grasses. Detailed crop-type metadata for the study area and period were not available from our data sources."

AC: Thank you for your comment. We added the detailed information on crops as a response to a previous review comment, so we can not take it out completely. But we highly appreciate your suggestions and have therefore restructured parts of section 2.1 (also see previous comment) and removed the discussion points originally included in order to address them separately in the Discussion Section 4.2. We have also taken your suggested wording and rephrased it to better fit the flow of the text as follows:

"At Luebars (surface elevation: 42.1 m a.s.l.), the surrounding land use is dominated by open agricultural fields and shrubland with only sparse tree cover. Detailed crop-type metadata for the study area and period were not available from our data sources, but the landscape suggests seasonal crops, which are common in Brandenburg, likely cereals and fodder grasses."

Rep1.3: L28ff: Can you add information on the filter depths of the other groundwater wells?

AC: Thank you for the suggestion. Based on the groundwater well metadata from https://wasserportal.berlin.de/stationen_start.php and https://apw.brandenburg.de/,the filter depths are estimated to be 9 m in Schildow (31.7 m a.s.l.), 18.2 m in Luebars (24 m a.s.l.), and 16.5 m in Tegel (21 m a.s.l.). We have also added this information to section 2.1 of our revised manuscript.

Rep1.4: L136: This is explaining the data, but the reader has not seen it until here. Try to integrate this comment when describing the time series.

AC: Thank you for pointing this out. While restructuring section 2.1, we decided to remove this sentence because it did not fit well in that paragraph. When revisiting the well information from all sites in response to another comment, we were unable to confirm the previously assumed differences between the wells. Available records indicate all wells have relatively high sand content. Measurements which would allow more precise conclusions about storage capacity, could not be conducted within the scope of our study. Moreover, such measurements would also only represent point observations several years after our study period and would therefore provide only limited insight into potential changes in retention capacity over time. Therefore, to avoid confusion, we decided not to relocate the statement elsewhere in the manuscript, as the information could no longer be meaningfully linked to this specific site and remained rather superficial.

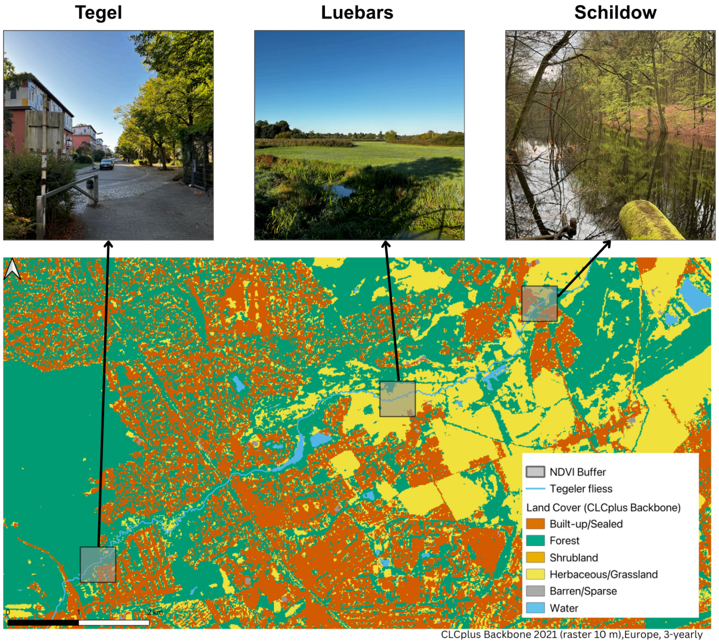
Figure 2: Is it possible to use a different map projection so that the NDVI pixels appear rectangular? I am not convinced that the current representation is very informative. From visual inspection, it seems that the NDVI buffer around Schildow includes a higher fraction of urban area than the one around Tegel, which may be a projection artifact. While I agree that Tegel is more strongly influenced by urban surroundings—also supported by the surface water and groundwater responses—this may not be evident from the NDVI buffer alone but rather from the characteristics of the sub-catchment and the upstream area of the groundwater well. You might consider combining the (very helpful) site photographs with the information currently shown in Figure 7. In fact, Figure 1 already provides an impression of the land use within the NDVI buffer pixels; therefore, increasing the opacity of the rectangles or giving them a clearer outline there could help to emphasize the relevant areas more effectively and making the land use provided here obsolete. If you decide to keep the map, I would recommend adjusting the land-use color coding: the red–green combination is not color-vision friendly, and approximately 8 % of male readers will have difficulty interpreting it.

AC: We agree that this map projection created an artifact that was visually distorting the urban fractions within NDVI pixels. We have solved the projection issue; the NDVI pixels now appear as squares (500 x 500 m) without the tilt that we introduced previously to make pixels look more level. Furthermore, we have also updated the projection in Figure 1 (please see the revised manuscript for the updated Fig. 1).

We appreciate you bringing up the accessibility issue with the red-green color coding. We have completely revised the land cover color palette to make it more color-vision friendly, ensuring that all readers can readily comprehend the land cover classes.

Regarding your suggestion to integrate site images with Figure 7 while removing the land cover map, we have opted to leave Figures 2 and 7 distinct. The land-cover map, which appears with the site pictures (Fig. 2), was prepared to address a previous reviewer's comment. That reviewer requested a more thorough and visual representation of the land cover distribution inside the MODIS pixels to help justify our interpretation of the NDVI signals across the various vegetation types. Because this figure is necessary to satisfy that prior feedback, we have decided to retain Figure 2 with the updated projection and color-blind friendly palette, distinguishing it from the groundwater distance data provided in Figure 7.

We feel that these updates considerably improve the clarity and accessibility of our visual data, and we thank you for helping us refine the manuscript.



Rep1.5: L286: remove s

AC: Thank you for pointing this out. We deleted the typo.

Rep1.6: L463: My comment again relates to the hydrological setting, which remains insufficiently clarified. If the aquifer indeed has a "limited recharge connection to the atmosphere," and this has been known beforehand, why would hydrological droughts be expected to affect groundwater levels? Furthermore, the distribution of groundwater depths shown in Figure 7 indicates a substantial proportion of shallow water tables, which suggests that the aquifer may only be partially confined?

AC: Due to the geological evolution of the landscapes in the region, especially the erosion processes of the Ice Ages, the confining layers are never uninterrupted. One can always expect some limited connection to the recharge processes (Tsypin et al., 2024; Pohle et al., 2025). While the geological log from the used borehole shows an extensive confining layer above the aquifer, the geological maps of Berlin indicate its limited extent (SenStadt, 2026). For this reason, we believe it makes sense to evaluate the potential impact of hydrological droughts at this location as well.
In the revised manuscript, we have rephrased the site introduction in section 2.1 as follows:

"The subsurface profile consists of a sand layer partially compacted with construction debris, followed by sandy glacial till up to approximately 16 m deep. This is underlain by fine, medium, and coarse sand, as well as gravel and coal-bearing material. The groundwater well filter is located at 18.2 m below surface (24 m a.s.l.) within a locally confined aquifer. This aquifer is at least partially isolated from above and was formed by regional geological processes (Tsypin et al., 2024; Pohle et al., 2025), which limit its recharge connectivity and distinguish Luebars hydrologically from the other two sites ."

Figure 7: Which extent is shown? The area of the NDVI buffer? (add scale information)

AC: Thank you for pointing out this ambiguity. We have adjusted the image and caption as follows:

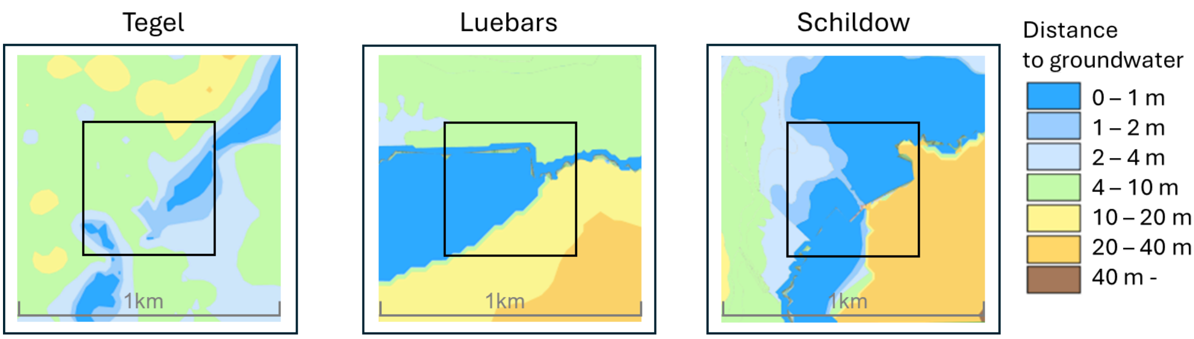


Figure 7. Average groundwater distances at Tegel, Luebars, and Schildow. Black rectangles indicate the NDVI buffer areas as shown in Figures 1 and 2. Data source: Geoportal Berlin (SenStadt, 2026)

Rep1.7: L495: The statement should be revised. In German lowland agricultural landscapes, trench networks are primarily designed for drainage and accelerate runoff rather than provide more efficient water redistribution. Without specific retention or control measures, such structures do not increase resilience to hydrological extremes.

AC: Thank you for this correction, and we absolutely agree. Our previous statement misinterpreted the hydrological purpose of these small trench networks.
As you pointed out, these structures in German lowland agricultural landscapes were originally constructed for drainage and accelerating runoff, not for holding or dispersing water. We have eliminated the premise that this network provides drought resistance. In the updated text, we now stress that without proper retention measures, such drainage systems do not strengthen resistance to hydrological extremes. Rather, the shallow groundwater table, which permits deep-rooted plants to immediately utilize water as a buffer, has become the sole focus of our explanation for the observed vegetative resilience at Luebars.

Rep1.8: L522: Please move the limitations to the Discussion or the Data section (with reference to the Supplement). The temporal interpolation of groundwater levels (e.g., from weekly to daily) introduces minimal uncertainty in this lowland setting and should not be combined with the study period limitation. The 13-year study period remains a key limitation for capturing longer-term climate cycles, and each issue should be addressed separately.

AC: Thank you for this comment and for pointing this out. We agree with your suggestion to separate these aspects and address them in the Discussion section. The explanation of the interpolation methods in the Data section was expanded also in response to another reviewer's comment. The corresponding paragraphs now read as follows:

In 2.3 Data Collection and Processing Tools:
"Daily surface water and groundwater level measurements were obtained from two regional water management authorities (see Table 1) depending on the station's location. Groundwater level data for Luebars and Tegel are available at daily resolution and contain only minor gaps, whereas groundwater level measurements at Schildow are provided at weekly resolution. At Schildow, groundwater levels were typically recorded four to five times per month (115 out of 150 months), with three measurements available in 31 months, most likely due to temporary technical issues. The only larger gap of missing records occurs between November 2008 and February 2009 at the beginning of the study period. To harmonize all groundwater level time series to the same daily temporal resolution, the datasets with missing values were linearly interpolated (see Supplementary Fig. S1)."

In 4.2 Impact of Drought on Vegetation:

“The vegetation resilience observed across the stations suggests that the natural ecosystems in the Tegeler Fliess area remained relatively robust during periods of water scarcity. The study period ending in April 2021 may not have been long enough to capture the delayed vegetation responses to the prolonged drought conditions of 2018-2020. The time frame of our study was limited by the availability of complete data sets. Even though some measurements date as far back as 1945, the surface water level station at Luebars began recording in 2008 and precipitation measurements were discontinued at the site in 2021. This is a key limitation, as the study period of 13 years may not fully capture longer-term climate cycles that influence drought patterns.”

[...]

“The linear interpolation applied to harmonize groundwater level time series introduced a potential source of uncertainty, particularly at Schildow, where measurements were recorded at weekly and not daily resolution. However, because drought indices were calculated on a monthly basis, the influence of short-term interpolation on index values is expected to be minimal. The only substantial gap at the beginning of the study period (November 2008 to February 2009) falls outside the main drought events discussed and does not affect their interpretation.”

Rep1.9: L527 to 534: I suggest moving the detailed discussion, especially the previously unmentioned citation, to the discussion section, and keeping only a concise summary of the main points in the conclusions.

AC: Thank you for your comment and constructive suggestion. The study you refer to by De La Iglesia Martinez and Labib (2023) is first mentioned in Section 2.4.4 when the NDVI classes are introduced. However, we agree that points for discussion should not be discussed in the conclusion. This was an oversight on our part. Based on your comments and those of another reviewer, we have revised the conclusion for language and structure and moved the discussion points to their appropriate places in the discussion section. Since many paragraphs in the Discussions and Conclusions have been modified, we will not present them all here. Please refer to the revised manuscript for clear tracking of the changes.

References

De La Iglesia Martinez, A., and Labib, S. M. (2023). Demystifying normalized difference vegetation index (NDVI) for greenness exposure assessments and policy interventions in urban greening. Environmental Research, 220, 115155. https://doi.org/10.1016/j.envres.2022.115155

Pohle, I., Creutzfeldt, B., Lüdtke, S., Merz, B. (2025). The 2018–2023 drought in Berlin – hydrogeological conditions and groundwater response in a glacially formed aquifer system. *Natural Hazards and Earth System Sciences*, 25, 1293–1315.

SenStadt (Senatsverwaltung für Stadtentwicklung, Bauen und Wohnen Berlin) (Eds.) 2026: Umweltatlas Berlin, 2014, Karte Geologische Schnitte, Berlin. Online: https://gdi.berlin.de/viewer/main/

Tsypin, M., Cacace, M., Guse, B., Güntner, A., Scheck-Wenderoth, M. (2024). Modeling the influence of climate on groundwater flow and heat regime in Brandenburg (Germany). *Frontiers in Water*, *6*, 1353394.

Comments by Ref#3 in Rep#2

General comments

Rep2.1: 1. The study only uses the precipitation data from a single site, Berlin-Tegel, to represent the precipitation conditions of the entire basin. Although it mentions that the distances between the stations within the basin are relatively close, it does not **quantify the spatial heterogeneity of precipitation among the stations (such as the differences in precipitation that may be caused by terrain and land use)**. Directly substituting regional data with single-point data may introduce systematic errors, affecting the accuracy of SPI calculation and the reliability of subsequent drought propagation analysis.

AC: Thank you for this comment. We checked the spatial distribution across the study sites using CER v2 gridded precipitation dataset and found low spatial variability, as expected for this lowland setting and the close proximity of the study sites. For the sake of transparency, we have added the following figure and explanations to the Supplementary Material as well as this short note to the revised manuscript:
"Spatial distribution in precipitation across the study sites was assessed using the gridded CER v2 dataset (Bart et al, 2024), confirming low spatial variability and suggesting negligible heterogeneity in this lowland setting (see Supplementary Fig. S7)."

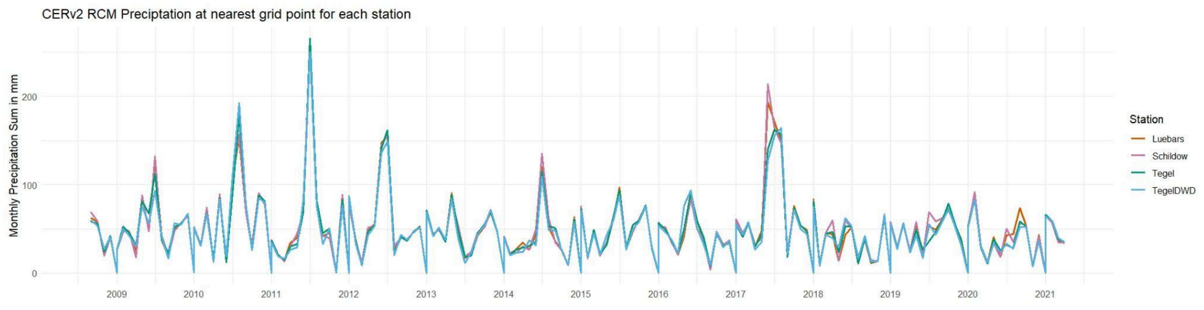


Figure S7: Spatial distribution of precipitation data based on the gridded CER v2 dataset. The time series at the different stations taken from the gridded climate dataset shows small variations in precipitation between the stations used in the study. Data source: Bart et al. (2024)

Rep2.2: 2. Linear interpolation is used to fill in the missing values of groundwater level data, but the **impact of this method on the calculation of drought indices is not explained, nor is a sensitivity analysis conducted**. Linear interpolation may distort the true response pattern of groundwater to drought; at the same time, the **error assessment method for the interpolated data is not described**, making it impossible to judge the credibility of the interpolation results.

AC: Thank you for this comment. As can be seen in Figure S1 in the Supplementary Material, data imputation was only relevant for the Schildow site, while the other stations contain only very minor gaps. This is related to the different temporal resolutions of the datasets. Groundwater level data for Luebars and Tegel are available at daily resolution, whereas measurements at Schildow were recorded only weekly during the study period. The interpolation was therefore mainly applied to harmonize all groundwater level time series, rather than reconstruct missing long-term patterns.
The drought indices used in this study were calculated on a monthly basis. Because the indices are evaluated at this coarser temporal resolution, the influence of short-term interpolation on the resulting drought indices is expected to be minimal.
At the Schildow site, groundwater levels were typically measured at least weekly, resulting in four to five measurements per month. In some months, only three measurements were available, most likely

due to temporary technical issues. The only larger gap occurs between November 2008 and February 2009 (four months) at the beginning of the study period. For this interval, the October 2008 measurements were used as the basis for linear interpolation. While bridging such a longer gap with linear interpolation is admittedly a simplified approach, this period is not further analyzed in detail and does not affect the interpretation of the main drought events discussed in the manuscript. Considering the generally high measurement frequency and the monthly aggregation used for the drought indices, we expect the uncertainty introduced by the temporal interpolation to be minimal. Therefore, we consider an additional sensitivity analysis unnecessary in this case.
For transparency, we have included information on missing data at the Schildow site in the Data section as follows:

"Groundwater level data for Luebars and Tegel are available at daily resolution and contain only minor gaps, whereas groundwater level measurements at Schildow are provided at weekly resolution. At Schildow, groundwater levels were typically recorded four to five times per month (115 out of 150 months), with three measurements available in 31 months, most likely due to temporary technical issues. The only larger gap of missing records occurs between November 2008 and February 2009 at the beginning of the study period. To harmonize all groundwater level time series to the same daily temporal resolution, the datasets with missing values were linearly interpolated (see Supplementary Fig. S1)."

Furthermore, we included this paragraph to the Discussion:
"The linear interpolation applied to harmonize groundwater level time series introduced a potential source of uncertainty, particularly at Schildow, where measurements were recorded at weekly and not daily resolution. However, because drought indices were calculated on a monthly basis, the influence of short-term interpolation on index values is expected to be minimal. The only substantial gap at the beginning of the study period (November 2008 to February 2009) falls outside the main drought events discussed and does not affect their interpretation. "

Rep2.3: 3. Only the cumulative precipitation over **three months is used to calculate SPI**, without considering the lagged effects of longer time scales on groundwater and vegetation, which may underestimate the cumulative effects of drought. Some latest research work related with this topic can be referred. Study on the energy evolution mechanism and fractal characteristics of coal failure under dynamic loading. Nonlinear evolution characteristics and seepage mechanical model of fluids in broken rock mass based on the **bifurcation theory**.

AC: Thank you for this comment. We would like to note that the catchment is located in a lowland plain area with porous aquifer systems. In a previous study, Somogyvári et al. (2025) showed that in the larger region, the aquifer response times (the times required for the groundwater levels to increase after precipitation) are around 1 month. Therefore, we are convinced that any larger cumulative groundwater drought effects are not expected.

We have revised the text as:
"Later in time, a reduction in recharge can lead to drought in the groundwater. This is a slow process, as the average response times of the groundwater table in the region are around 1 month (see Somogyvári et al. (2024) and Somogyvári et al. (2025)). The reduced available soil moisture (and in the case of deep-rooted plants reduced groundwater table) can also lead to a drought in vegetation."

Rep2.4: 4. The **conclusion should explicitly highlight the study's contributions**. It should provide a comprehensive summary of the main findings to give readers a clear understanding of the research achievements.

AC: Thank you for your suggestion. We agree that the conclusion benefits from a more explicit statement of our study's contributions. Therefore, we have revised the conclusion to more clearly summarize the main findings and added two sentences that highlight the contribution of the study as follows:
"This study demonstrated that standardized drought indices, derived from routinely available meteorological, hydrological, and remote sensing data, can effectively characterize drought propagation across multiple hydrological compartments at the local scale. The methodology is transferable to comparable peri-urban catchments, bridging the gap between large-scale drought assessment frameworks and site-specific hydrological contexts."

Rep2.5: 5. There are several grammar mistakes in the paper, please revise and double-check throughout the whole manuscript. The **language could benefit from further editing and polishing**.

AC: Thank you for pointing out this issue. We agree that repeated editing has negatively impacted the text. Therefore, we revised several paragraphs in the Introduction, Methods, Results, Discussion, and Conclusion sections. We made linguistic adjustments and corrected grammatical errors to the best of our knowledge. Since many paragraphs have been modified, we will not present them all here. Please refer to the revised manuscript for clear tracking of the changes.

References

Bart, F.; Schmidt, B.; Wang, X.; Holtmann, A.; Meier, F.; Otto, M.; Scherer, D. (2024). The Central Europe Refined analysis version 2 (CER v2): evaluating three decades of high-resolution precipitation data for the Berlin-Brandenburg metropolitan region. Meteorologische Zeitschrift, 33 (5):339-363. http://dx.doi.org/10.1127/metz/2024/1233

Somogyvári, M., Scherer, D., Bart, F., Fehrenbach, U., Okujeni, A., Krueger, T. (2024). A hybrid data-driven approach to analyze the drivers of lake level dynamics. *Hydrology and Earth System Sciences*, *28*(18), 4331-4348. https://doi.org/10.5194/hess-28-4331-2024

Somogyvári, M., Brill, F., Tsypin, M., Rihm, L., Krueger, T. (2025). Regional-scale groundwater analysis with dimensionality reduction. *Natural Hazards and Earth System Sciences*, *25*(11), 4613-4628. https://doi.org/10.5194/nhess-25-4613-2025