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Ministry of Equipment and Water

Quantifying and Predicting Irrigation Withdrawals in Traditional Canal Systems: A Case Study of the Tensift Basin, Morocco

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Context & Motivation

- Tensift Basin in central Morocco: strong dependence on surface irrigation.
- Agriculture relies on traditional seguias for water diversion.
- Increasing pressure on water resources due to climate change and agricultural expansion.
- Persistent issues: inefficient water allocation, upstream–downstream inequities, high conveyance losses.

Research Objectives

- Overall aim: build a data-informed, reproducible framework to quantify withdrawals and predict irrigation requirements.
- Evaluate irrigation withdrawals in Rhéraya, Ourika, R’dat and Zat sub-basins.
- Analyze upstream–downstream interactions and spatial inequities in access.
- Quantify statistical dependencies between withdrawals and river flows.

Study Area: Tensift Sub-basins & Traditional Seguias

- Central Morocco, semi-arid to arid climate.
- Four sub-basins: Rhéraya, Ourika, R’dat, Zat.
- Irrigation based on long-standing traditional canal networks (seguias).
- Downstream users often experience deficits and competition with other sectors.
- (Figure: Map with sub-basins and main seguias, upstream/downstream zones.)

Data Sources

- Hydrometric data (1971–2022): long time series of river discharge.
- Field measurements: canal cross-sections, roughness, spot discharge in representative seguias.
- Canal discharge calculations using empirical and hydraulic relationships.
- Climatic and agronomic data: temperature, radiation, wind, humidity, crop calendars and cropping patterns.

Methods (1): Assessing Irrigation Withdrawals

- Double mass curve analysis to assess homogeneity of long time series.
- Detection of breakpoints or inconsistencies between withdrawals and river flows.
- Correlation matrices and dependency analysis between withdrawals and upstream flows.
- Analysis of correlations among seguias within the same basin to detect redundancy and over-extraction.
- Geographical categorization of canals by position (upstream, midstream, downstream).

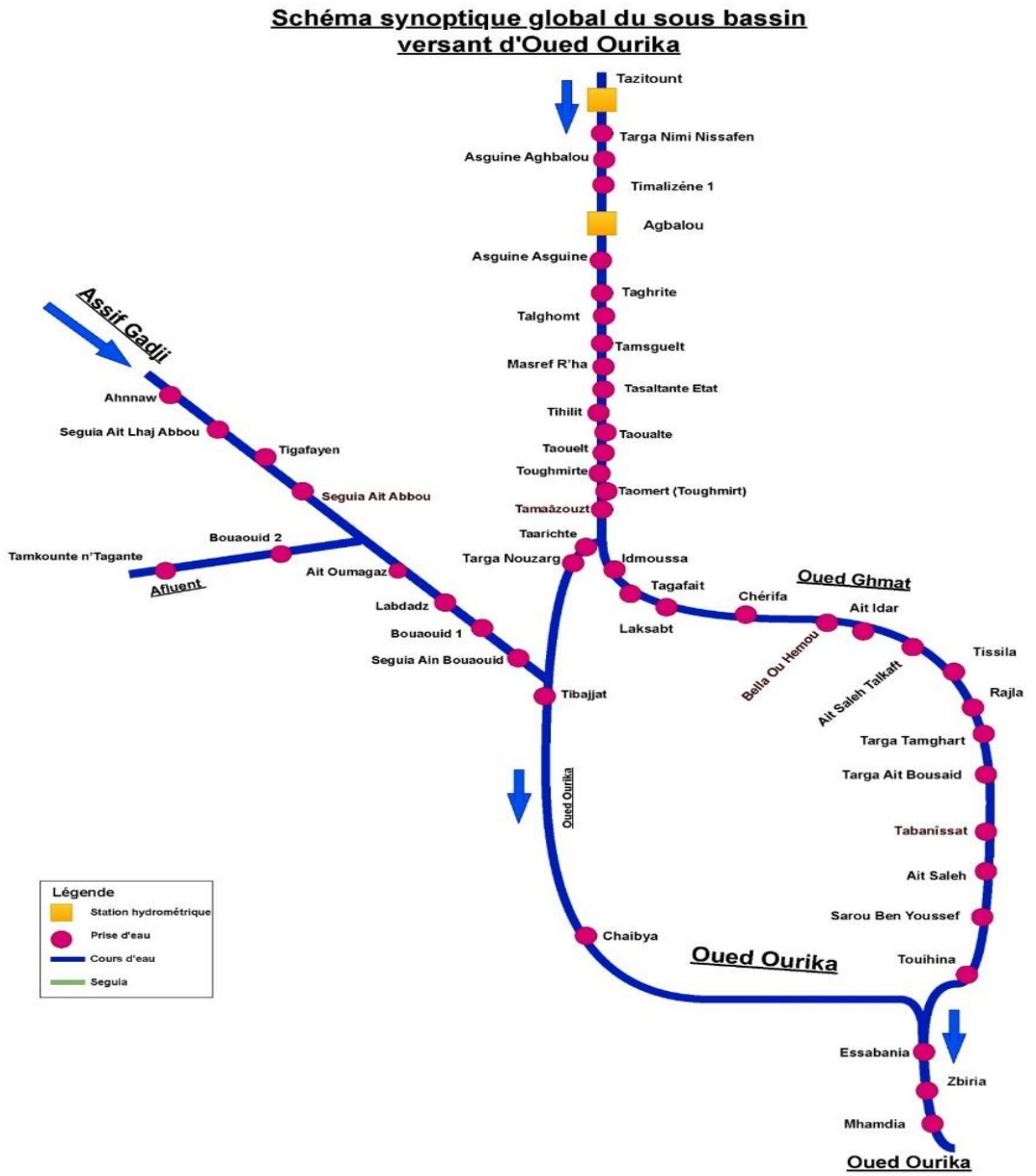
Results (1): Ourika basin

1. Quantifying Withdrawals

•Long-term irrigation withdrawals on Ourika are of the same order as the river contribution during the irrigation season (≈80 Mm^3/year).

•Recent period (2001–2022) shows a **strong decline in total withdrawals** (about 50–60% lower than in 1970–2000), reflecting droughts, infrastructure ageing, and competition for water.

•During the irrigation season, **almost all measured flow is diverted** by the seguias, leaving only a small residual flow for downstream river reaches.



Results (1): Ourika basin

2. Data Quality & Statistical Ana

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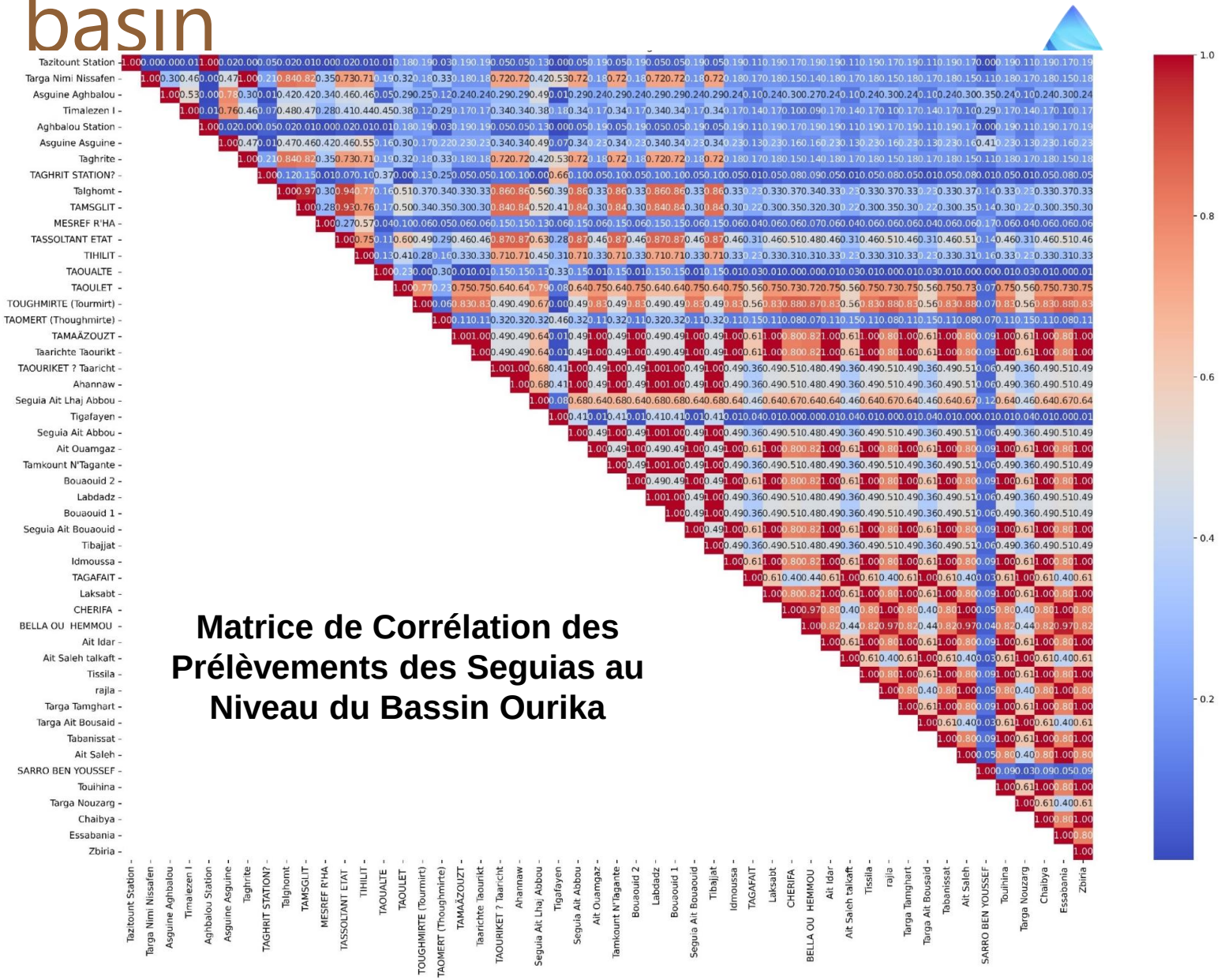

Matrice de Corrélation des Prélèvements des Seguias au Niveau du Bassin Ourika

Results (1): Ourika basin

2. Data Quality & Statistical Analysis

STATION AGHBALOU	884.62 Mm3			
Nom Station/seguia	**Volume prélevé déclaré en Mm3 (ORMVAH)**	**Volume prélevé corrigé en Mm3**	**Différence (Déc – Cor)**	**Pourcentage des débits prélevés (%)**
Asguine Aghbalou	616.8	1.74	615.06	0.20
Timalezen I	7.3	1.49	5.81	0.17
Asguine Asguine	18.7	1.72	16.98	0.19
Taghrite	35.7	15.72	19.98	1.78
Talghomt	78.2	41.02	37.18	4.64
Tamsglit	163	50.04	112.96	5.66
Mesref R'ha	313	4.2	308.8	0.47
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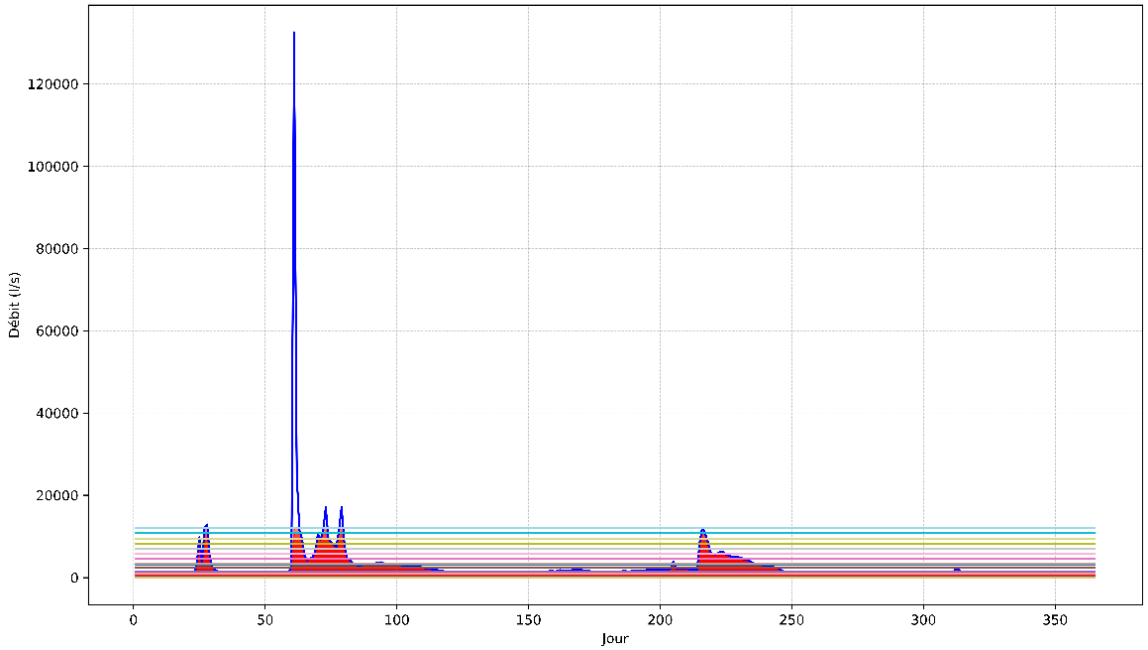
Tihilit	817.3	9.5	807.8	1.07
Taoualte	1201.5	2.46	1199.04	0.28
Toughmirte (Tourmirt)	1642.2	0.06	1642.14	0.01
Tamaâzouzt	2071.1	0.24	2070.86	0.03
Taouriket	2503.1	20.98	2482.12	2.37
Tagafait	2977.3	0.23	2977.07	0.03
Cherifa	3450	0.08	3449.92	0.01
Bella Ou Hemmou	3925.8	0.09	3925.71	0.01
SarroB Youssef	4404	0.33	4403.67	0.04
Total des débits prélevés pour l'année 2012/2013 en Mm3	24706.4	249.1	24457.3	28.12

Prélèvements vis-à-vis des potentialités de l'amont vers l'aval des seguias dépendant de l'oued Ourika sur l'année de 2012-2013



Results (1): Ourika basin

4. Implications & Link to Predictive Modeling

- The Ourika system already operates **near full capture** of surface flows; residual ecological and downstream flows are very limited.
- Under projected **higher temperatures and more intense agriculture**, crop water needs will increase, amplifying current shortages.
- Ourika therefore exemplifies the abstract's message:
- Need for **flexible and fair water governance**.
- Need for **modernisation of traditional seguias** (lining, control, measurement).
- Use of **predictive modeling with climate variables and FAO Penman–Monteith** to anticipate future irrigation demands and guide adaptation. (NEXT STEPS)

Results (1): Ourika basin

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5. Conclusion

Prélèvements mensuels (2000-2022) :

- Prélèvement mensuel moyen : 77 millions de m^3.
- Différentiel non prélevé : 5 millions de m^3 par mois.
- Homogénéité confirmée pour la majorité des données par des analyses de doubles cumuls.

Homogénéité et dépendance entre seguias :

- **Dépendance forte ($R^2 > 0.8$) :**
  - Seguias comme Talghomt, Tamsguelt, et Taourikt montrent des relations fortes avec les apports de l'oued.
- **Dépendance faible à moyenne :**
  - Certaines seguias (ex. Toughmirte, Bella Ou Hemmou) présentent une dépendance limitée aux débits de l'oued.

Prélèvements vis-à-vis des potentialités de l'oued :

Volume total prélevé (2012/2013) : 250 Mm^3 (28.15% des apports totaux de l'oued, estimés à 884.62 Mm^3).
Seguias principales :
Tassoultant Etat : plus grand volume prélevé (99.15 Mm^3, 11.21%).
Tamsguelt : 50.04 Mm^3 (5.66%).
Talghomt : 41.02 Mm^3 (4.64%).
Seguias secondaires (ex. Toughmirte, Tamaâzouzt) : volumes prélevés très faibles (<1 Mm^3).

Results (1): Ourika basin

5. Conclusion

Séries divisées en trois sous-périodes : 1971-1985, 1985-2000, 2001-2022.
Homogénéité des séries confirmée malgré des anomalies attribuées aux périodes de crues non représentées.

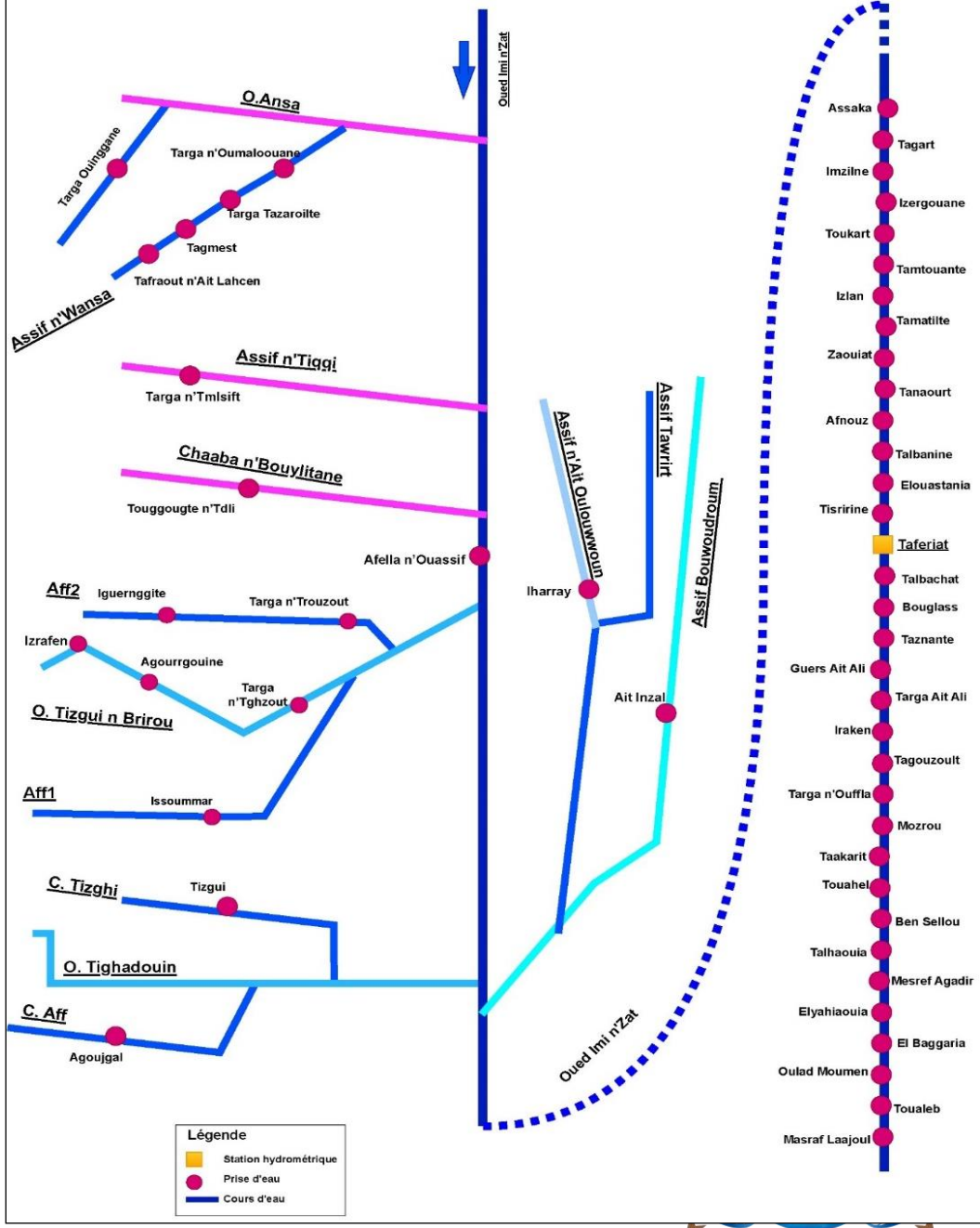
- **Réduction des prélèvements** au fil des années, en lien avec la diminution des ressources hydriques et les changements climatiques.
- Seguias principales (Tassoultant Etat, Tamsguelt, Talghomt) bien approvisionnées.

- **Problèmes de satisfaction** pour certaines seguias (ex. Toughmirte, Taoualt).
- Besoin d'améliorations dans la gestion des prélèvements et les infrastructures hydriques.

Results (1): Zat basin

1. Quantifying Withdrawals

- Historical traditional irrigation system since **1937**, with **32 intakes**, including **20 regulated seguias**.
- Average **annual withdrawals ≈ 93 Mm³** over **1985–2000**; monthly withdrawals ≤ 2.5 Mm³ in **50% of cases**.
- Comparison of three periods (1970–1985, 1985–2000, 2001–2011):
- First two periods have **similar average withdrawals**.
- The most recent period (2001–2011) shows a **19.5% reduction** in mean annual withdrawals, mainly due to drought.
- In **2011/2012**, about **58% of the discharge measured at Taferiat** was captured for irrigation, showing very strong pressure on river flows.
- For 2001–2011, total average annual withdrawals remain high (≈ **42–54 Mm³** depending on sub-period), confirming intensive use despite the recent decline.



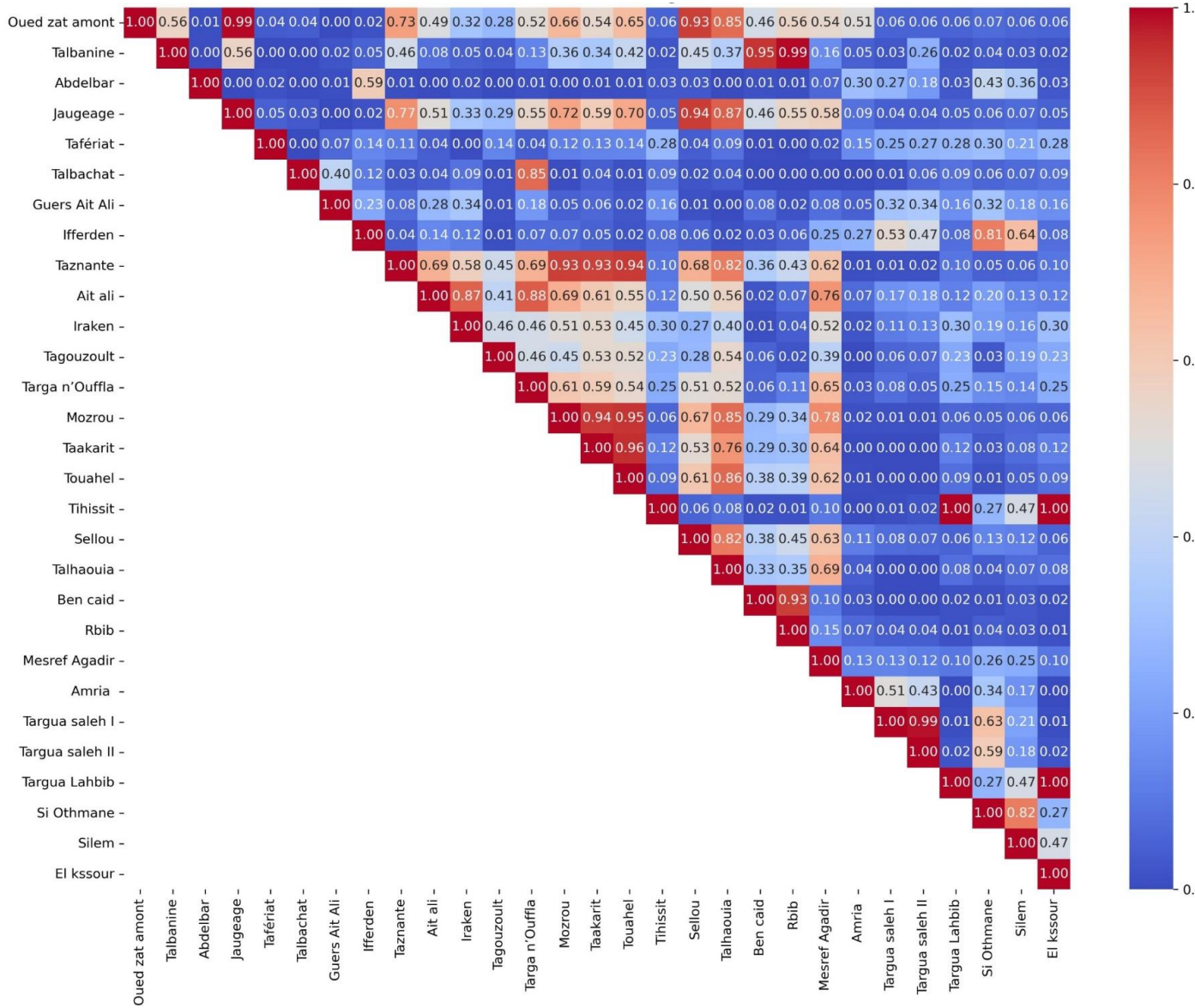
Results (1): Zat basin

2. Data Quality & Statistical Analysis

- Long, dense measurement history: ORMVAH gauging **since 1937**, in parallel with station **Taferiat**; **28 intakes** monitored, **20 regulated**.
- Double-mass curves between **river inflows and total withdrawals**:
- Show **coherent, homogeneous co-variation** of the two series.
- One abnormal value identified for **1997 at Taferiat**, inconsistent with other stations.
- Despite overall homogeneity, the study notes **important discrepancies between declared and calculated volumes**, indicating weaknesses in monitoring and control.
- Correlation matrix of seguias (annual withdrawals):
- **Very high R^2 (≥ 0.90)**: e.g. *Mozrou–Taakarit* (R^2 = 1.00), *Targua Saleh I–II* (R^2 = 0.99) → almost identical behaviour.
- **High to moderate correlations (0.50–0.90)** group several seguias into strongly interconnected subsystems.
- **Very low R^2 (< 0.20)** (e.g. *Abdelbar* vs *Taféria*t, *Tagouzoult*, *Rbib*) → largely independent behaviour.
- Correlation of **double cumulated withdrawals** confirms the same structure (very high, moderate, weak links), exactly as in the abstract's methodology (double mass + correlation matrices).

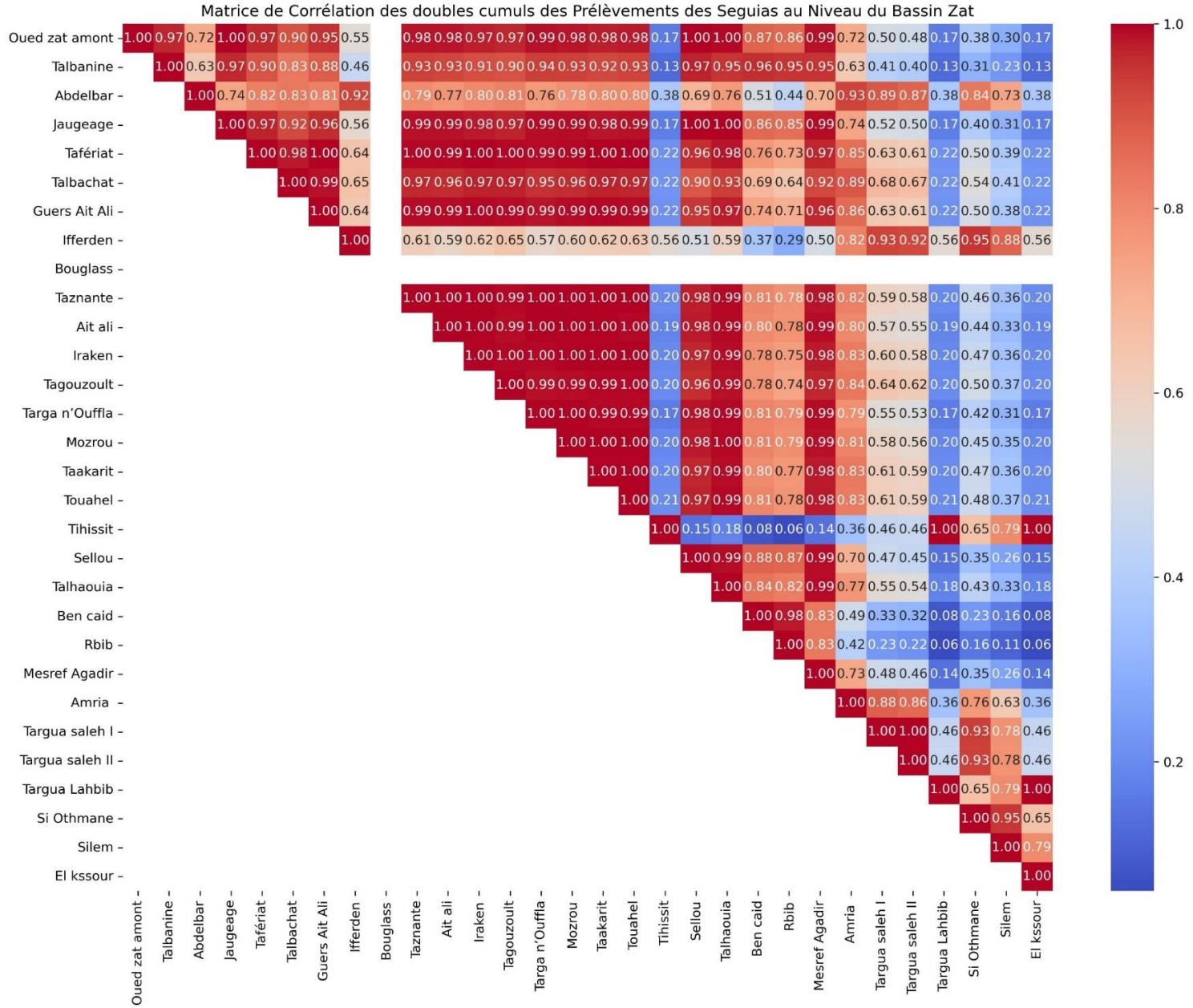
Results (1): Zat basin

2. Data Quality & Statistical Analysis



Results (1): Zat basin

2. Data Quality & Statistical Analysis



Results (1): Zat basin

3. Inequity & Canal Performance

- Four main seguias—**Taakarit, Mozrou, Touahel, Talhaouia**—divert together about **59.2% of total withdrawals** in the basin.
- Average annual withdrawals (2001–2011) show **very high volumes** for Taznent, Touahel, Mozrou, Taakarit, Talhaouia, while many other seguias have very small or zero volumes.
- This concentration of withdrawals in a few canals means **upstream–midstream segments capture most of the flow**, leaving limited water for smaller or downstream seguias.
- Analyses of "**withdrawals vs upstream potential**" (Figures 22–23) show that **cumulative withdrawals rise quickly from upstream to midstream**, so that downstream potential is much reduced in **2011/2012**.
- These results illustrate the abstract's points on **inefficient allocation, upstream–downstream inequity and strong pressure on surface water** in traditional canal systems.

Results (1): Zat basin

4. Extrapolation, Climate Stress & Predictive Modelling

To obtain long continuous series, missing data for Zat seguias were **reconstructed by correlation-based extrapolation**:

- Correlations for the reliable period **2000–2012** were used to fill gaps.
- Complete annual series of withdrawals built for **1969–2017**.

Results (1): Zat basin

5. Conclusion

Prélèvements mensuels (2001-2011) :

- Prélèvement mensuel moyen : 3,425 millions de m^3.
- Seguias les plus importantes :
  - Taznante (76.7 Mm^3, 10.24%).
  - Taakarit (53.1 Mm^3, 7.08%).
  - Touahel (52 Mm^3, 6.94%).
- Seguias secondaires :
  - Iraken (2.2 Mm^3, 0.29%), Tagouzoult (2.3 Mm^3, 0.30%).

- **Homogénéité et dépendance entre seguias :**
- **Corrélations très élevées ($R^2 \geq 0.90$) :**
  - Ex. Mozrou-Taakarit (R^2=1.00), Targua Saleh I-Targua Saleh II (R^2=0.99).
- **Corrélations modérées ($0.50 \leq R^2 < 0.80$) :**
  - Ex. Targa n'Ouffla-Tagouzoult (R^2=0.62).
- **Corrélations faibles ($R^2 < 0.50$) :**
  - Ex. Guers Ait Ali-Ifferden (R^2=0.23).

Results (1): Zat basin

5. Conclusion

Série de prélèvements annuels (1971-2011) :

- Trois sous-périodes :
  - 1971-1985, 1985-2001, et 2001-2011.
- Homogénéité confirmée via double cumul entre séries ORMVAH et station Taferiat.

Prélèvements vis-à-vis des potentialités hydriques :

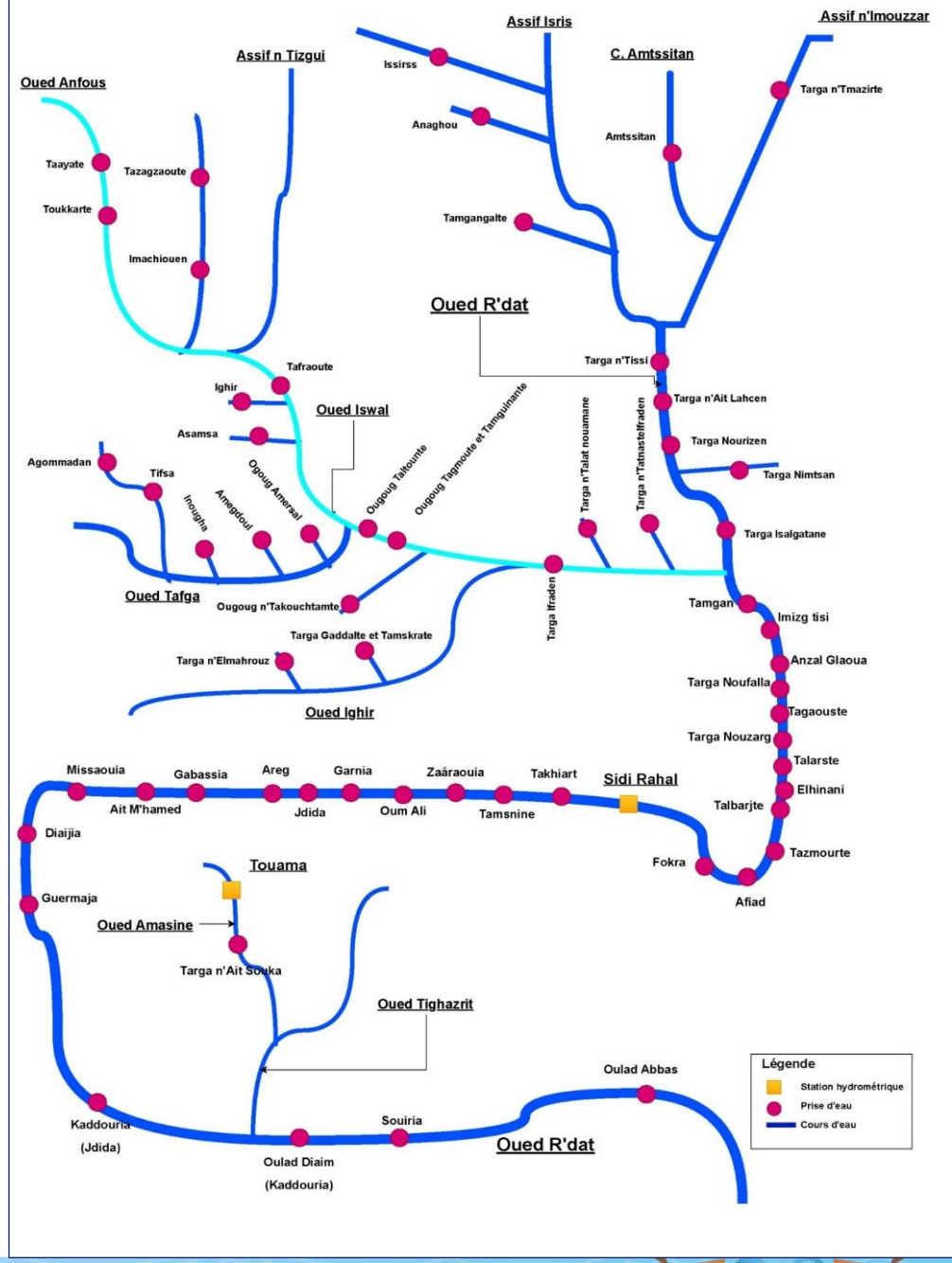
- **Année 2011/2012 :**
  - Volume total prélevé : 316 Mm^3 (42.3% des apports totaux de 749 Mm^3).
  - Seguia Taznante : plus grand prélèvement (76.7 Mm^3, 10.24%).
  - Faibles prélèvements pour seguias comme Iraken (2.2 Mm^3, 0.29%).

- **Diminution des prélèvements annuels sur les dernières décennies.**
- Forte dépendance entre certaines seguias, mais indépendance marquée pour d'autres.
- Problèmes potentiels de satisfaction des besoins hydriques avec un apport estimé à 3300 l/s contre des besoins de 3873 l/s.

Results (1): R'dat basin

1. Quantifying Withdrawals

- Oued R'Dat basin (569 km²), controlled at the **Sidi Rahal** hydrometric station since 1963.
- ORMVAH controls **19 intakes**, including **4 regulated seguias**; upstream minor seguias irrigate small terraces.
- Four main seguias – **Afiad, Tazamourte, Fokra, Takhiart** – account for about **75–80% of total withdrawals**.
- Mean annual withdrawals:
- ≈ **43 Mm³/year** over **1985–2000** (ABHT–2003).
- ≈ **99.8 Mm³/year** over **2001–2012** → withdrawals **more than doubled**.



Results (1): R'dat basin

1. Quantifying Withdrawals

•Over the full period **1971–2011**, total annual withdrawals are estimated at **≈58.3 Mm^3** (long-term average).

•In **2010/2011**, river inflows at Sidi Rahal ≈ **323.4 Mm^3**; withdrawals ≈ **227.2 Mm^3**, i.e. **70.3% of available flow**.

•The seguia **Afiad alone** diverts **≈188.7 Mm^3 (58.4% of total withdrawals)**; minor seguias such as **Mghinia** take only **0.5 Mm^3 (0.1%)**.

•For **1985–2000**, mean monthly withdrawal is **3.75 Mm^3**, with **50% of months ≤ 1.86 Mm^3**, illustrating strong intra-annual variability.

Results (1): R'dat basin

2. Data Quality & Statistical Analysis

•Long, dense observation system:

•Seguia withdrawals measured by ORMVAH **since 1946**, downstream of Sidi Rahal.

•Hydrometric records at **Sidi Rahal** used as reference for double-mass analysis.

•The study applies the same tools as in the abstract:

•**Double-mass curves** between **river inflows** and **total withdrawals**, and between inflows and **station Sidi Rahal**.

•**Pairwise correlations and correlation matrices** between seguias and upstream flow to evaluate homogeneity and dependency.

Results (1): R'dat basin

2. Data Quality & Statistical Analysis

•Results highlight **data inconsistencies**:
•Good agreement between ORMVAH withdrawals and hydrometric data up to **1992**; afterwards ORMVAH volumes become **abnormally high**.
•Overestimation is attributed to **changes in gauging personnel (aiguadiers)** and measurement practices.
•Double-mass and correlation analysis for **double cumuls** show several classes of homogeneity:
•**High R^2 (> 0.8)**: Tamesnine, Tatoulte, Oum Ali, Areg, Gabassia → strongly coupled and homogeneous behaviour.
•**Moderate R^2 (0.4–0.7)**: Takhiart, Jaugeage, Zaâraouia → partially synchronized with the system and upstream inflows.
•**Low/near-zero R^2 (< 0.4)**: Fokra, Tazamourte, Mghinia → weak linkage to other seguias and to river flow, possibly reflecting local constraints or data problems.
•This analytical framework matches the abstract's methodology: **double-mass curves, correlation matrices, and dependency analysis** to test data quality and interactions between canals and river flows.

Results (1): R'dat basin

2. Data Quality & Statistical Analysis

STATION AGHBALOU	884.62 Mm3			
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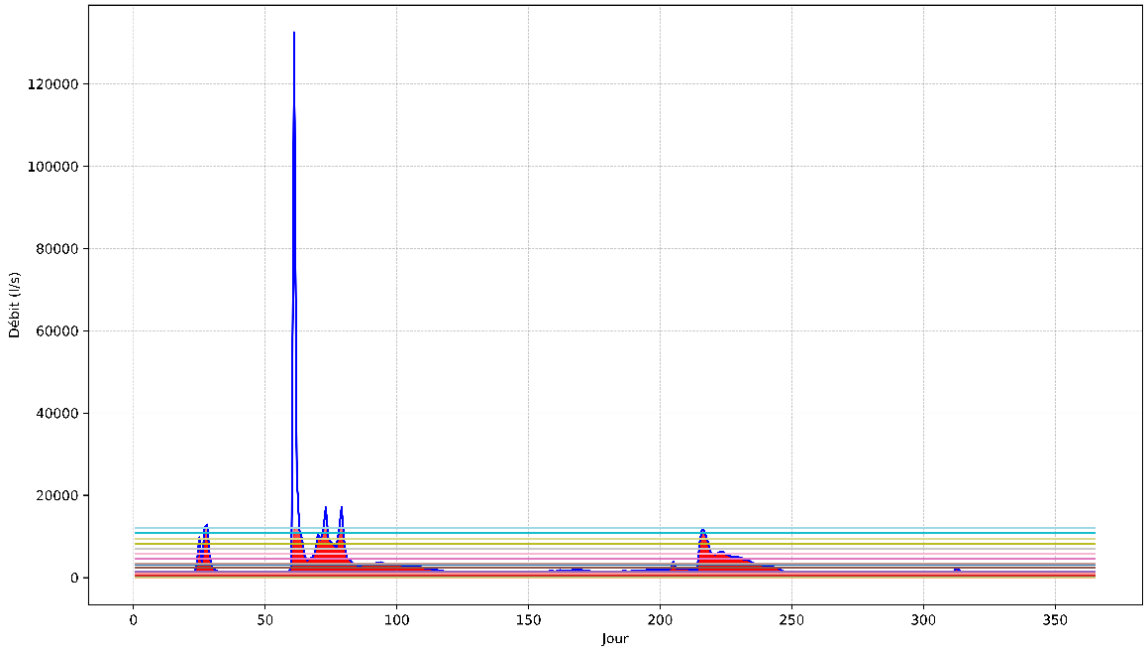


Results (1): R'dat basin

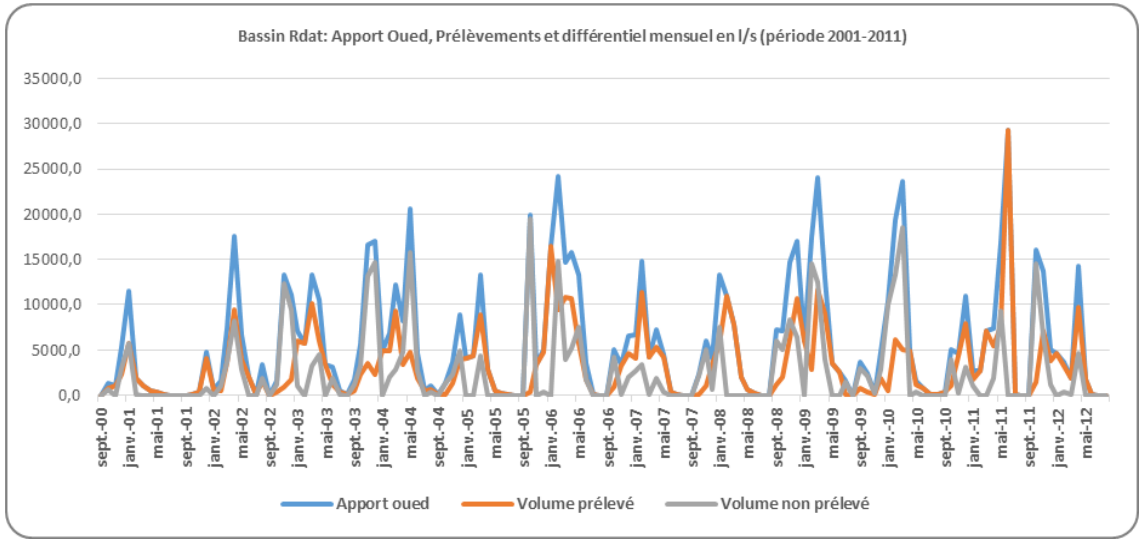
3. Inequity & Canal Performance

- **Water delivered per hectare** is extremely heterogeneous (Table 2 – délivrance à l'ha):
- **Afiad**: 1,808.3 l/s over 2,800 ha → **20,367 m³/ha/year** (very high supply).
- **Oum Ali**: 9,716 m³/ha/year; **Zaâraouia**: 8,204 m³/ha/year.
- **Tazamourte**: 5,662 m³/ha/year; **Fokra**: 6,369 m³/ha/year; **Takhiart**: 6,205 m³/ha/year; **Tamesnine**: 5,921 m³/ha/year.
- **Jdidia**: 0 m³/ha/year (non-operational or not supplied).
- At the scale of the **2010/2011 hydrological year**, annual volumes confirm the dominance of a few canals:
- **Afiad**: 517 Mm³ (**53.2%** of total withdrawals).
- **Takhiart**: 37.69 Mm³ (3.9%); **Tazamourte**: 24.95 Mm³ (2.6%).

Results (1): R'dat basin

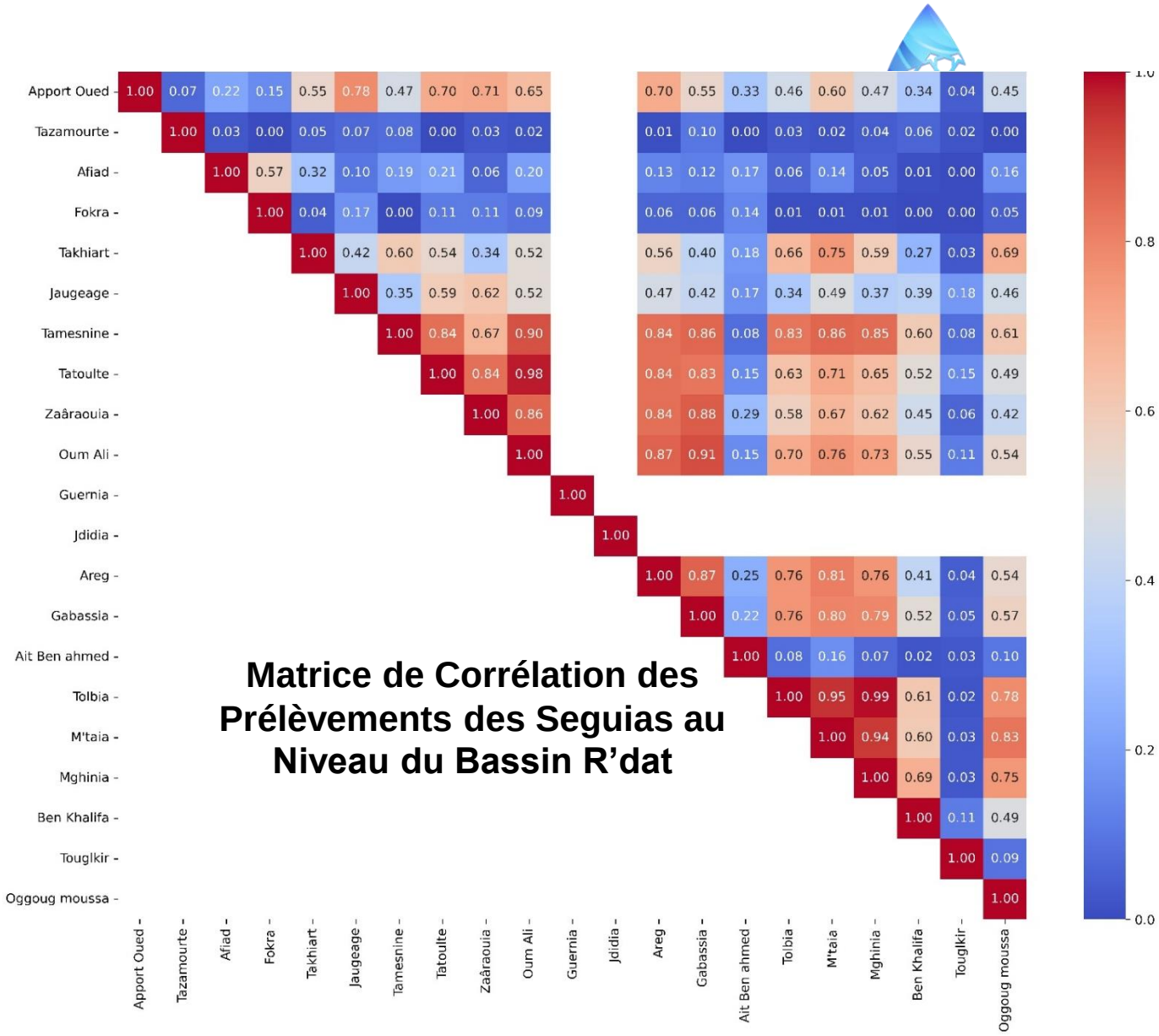
3. Inequity & Canal Performance

- Minor seguias (e.g. **Mghinia**) withdraw only **≈1.31 Mm³ (0.1%)**.
- Over the whole system, **four main seguias (Afiad, Tazamourte, Fokra, Takhiart)** alone account for **≈75–80%** of withdrawn volumes.
- Strong **upstream–midstream capture** limits water availability for downstream seguias and small users, generating **structural inequities in access**—exactly the type of inefficiency and unfair allocation highlighted in the abstract.
- Despite this intense exploitation, the conclusion notes that **theoretical water resources are still sufficient** to satisfy irrigation needs if **inefficiencies and monitoring issues are corrected**.



Results (1): R’dat basin

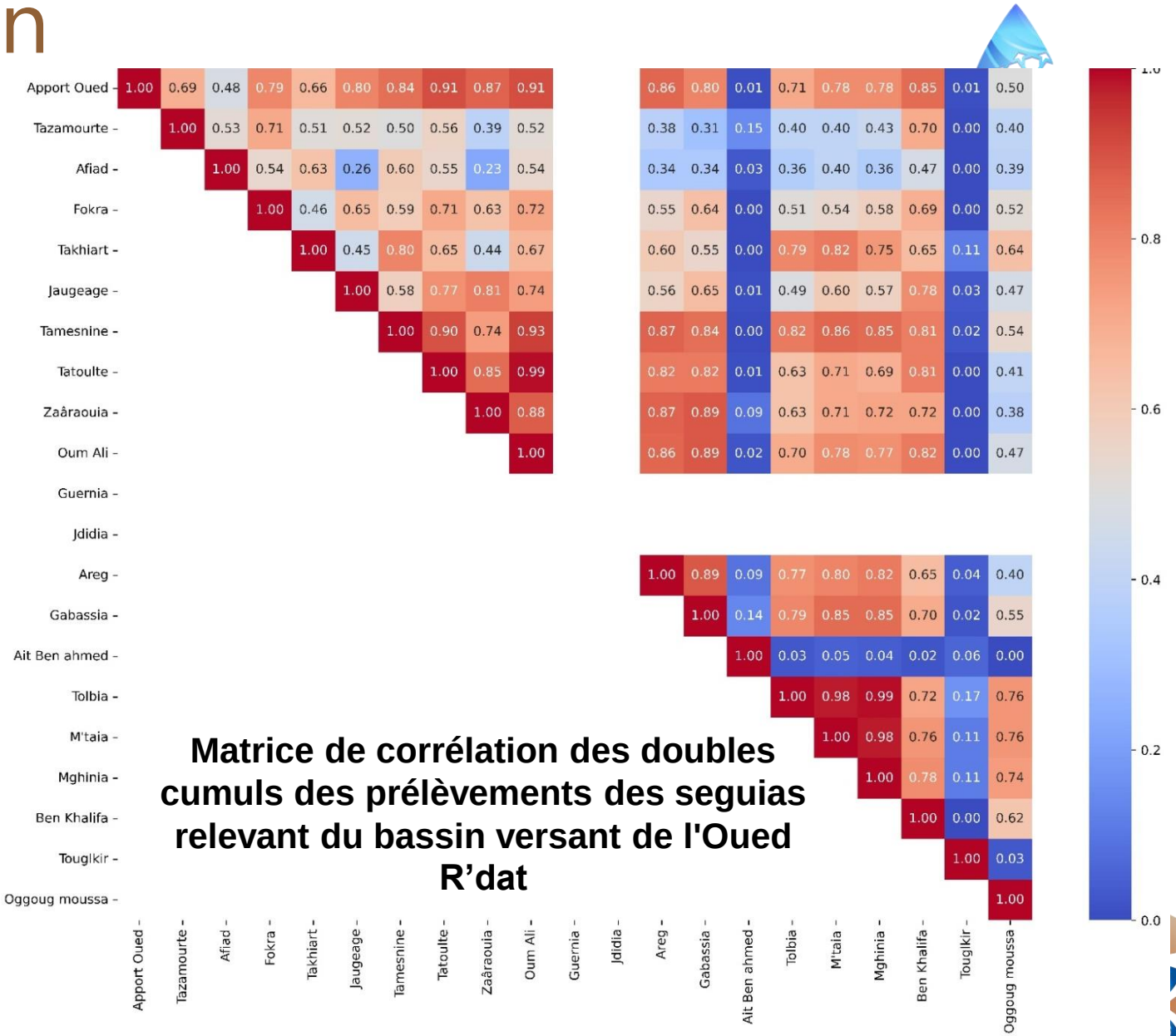
3. Inequity & Canal Performance



Matrice de Corrélation des Prélèvements des Seguias au Niveau du Bassin R’dat

Results (1): R’dat basin

3. Inequity & Canal Performance



Matrice de corrélation des doubles cumuls des prélèvements des seguias relevant du bassin versant de l'Oued R’dat

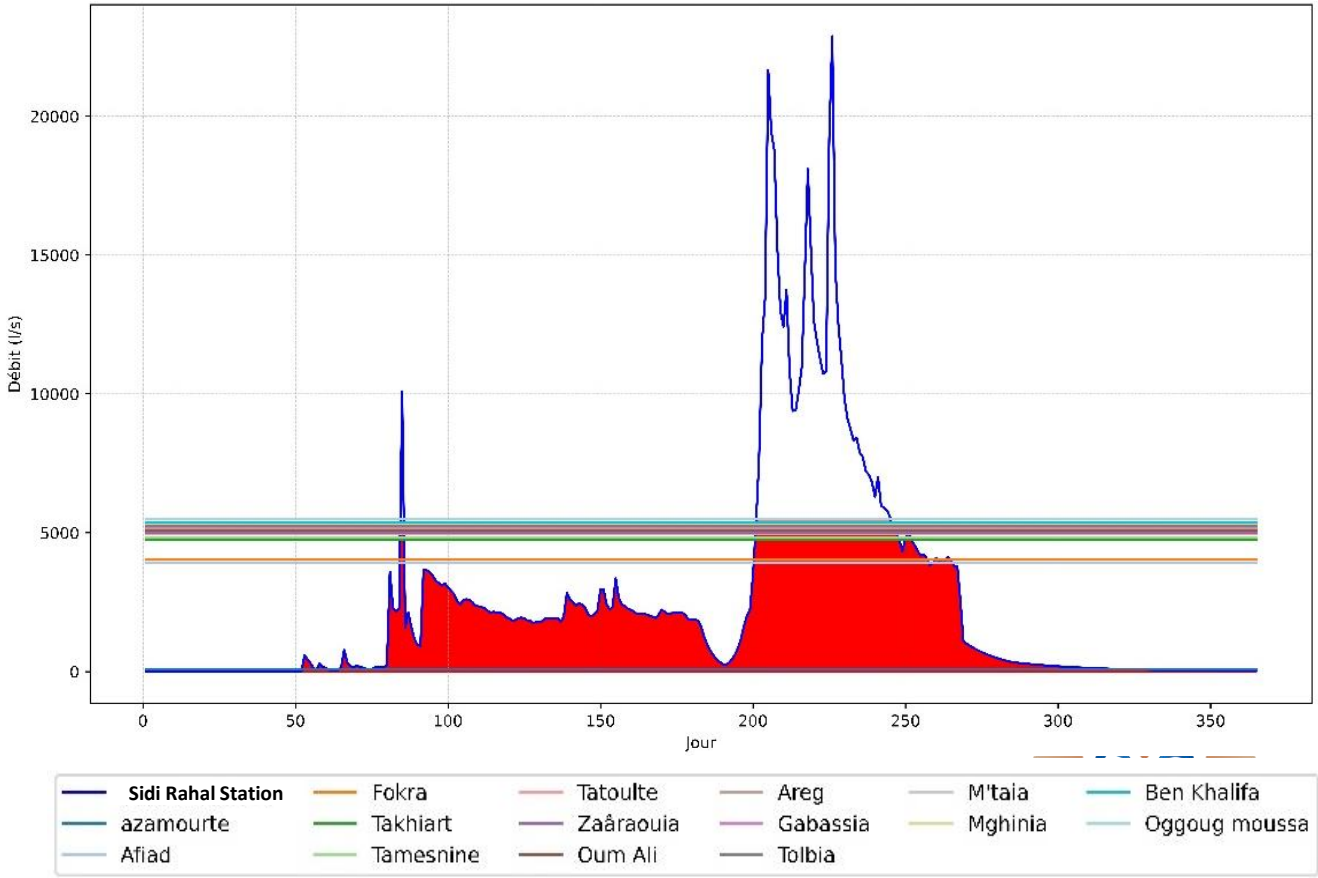
Results (1): R'dat basin

3. Inequity & Canal Performance

Récapitulatif du volume des apports et les volumes prélevés au niveau de l'oued R'dat pour l'année 2010/2011

Somme des débits jaugés au niveau de la station Sidi Rahal en Mm3 (2010/2011)			972.3	
Nom Seguia	**Volume prélevé déclaré en Mm3 (ORMVAH)**	**Volume prélevé calculé en Mm3**	**Différence (Déclaré – Calculé)**	**Pourcentage des débits prélevés**
Tazamourte	31	24.95	6.05	2.6
Afiad	1404.07	517.01	887.06	53.2
Fokra	40.38	6.91	33.47	0.7
Takhiart	253.72	37.69	216.03	3.9
Tamesnine	38.06	5.19	32.87	0.5
Tatoulte	39.74	5.33	34.41	0.5
Zaâraouia	21	2.76	18.24	0.3
Oum Ali	31.31	4.04	27.27	0.4
Areg	24.65	3.11	21.54	0.3
Gabassia	23.16	2.92	20.24	0.3
Tolbia	13.83	1.74	12.09	0.2
M'taia	19.03	2.4	16.63	0.2
Mghinia	10.57	1.31	9.26	0.1
Ben Khalifa	12.5	1.54	10.96	0.2
Oggoug moussa	45.45	5.6	39.85	0.6
Total des volumes prélevés pour l'année 2010/2011 en Mm3	2008.47	622.5	1385.97	64.0

Prélèvements réel vis-à-vis des potentialités de l'amont vers l'aval des seguias dépend de l'oued R'dat sur l'année de 2010/2011



Results (1): R'dat basin

4. Implications & Link to Predictive Modeling

- **R'Dat is the "extreme" case of the four basins:** unlike Ourika and Zat, which show declining withdrawals, R'Dat has seen its mean annual withdrawals more than **double** between 1970–1985 and 2001–2012.
- The basin shows **very intensive exploitation**, with up to **70.3%** of river inflows withdrawn in 2010/11, and a **strong dominance of the Afiad canal**, which alone captures about **58%** of total diversions.
- Data are **heterogeneous and sometimes inconsistent**, making the use of **double-mass curves and correlation matrices** essential to clean and interpret the series and to reveal strong **interdependence between seguias** (high R^2 values).
- For the predictive framework, R'Dat demonstrates how **climate variables + FAO Penman–Monteith ET + cropping scenarios** can be used to forecast irrigation needs in an already overexploited system, and why **governance reforms and modernization of canals** are crucial to achieve **flexible, fair and climate-resilient water allocation** in the Tensift basin

Results (1): R'dat basin

5. Conclusion

- **Volumes mensuels moyens :**
  - Période 1985-2000 : 3.75 millions de m^3.
  - 50% des prélèvements mensuels inférieurs ou égaux à 1.86 millions de m^3.
- **Observations sur les données ORMVAH :**
  - Surestimation des prélèvements à partir de 1992, liée à des changements de personnel ou des erreurs de mesure.
- **Seguias principales :**
  - Afiad (1813.8 l/s), Takhiart (394.1 l/s), et Foukra (99.8 l/s) dominent les prélèvements mensuels.

Homogénéité et dépendance entre seguias :

- **Corrélations très élevées ($R^2 \geq 0.80$) :**
  - Ex. Tamesnine-Oum Ali ($R^2 = 0.90$), Tatoulte-Tamesnine ($R^2 = 0.83$).
- **Corrélations modérées ($0.50 \leq R^2 < 0.80$) :**
  - Ex. Apport Oued-Tamesnine ($R^2 = 0.47$).
- **Corrélations faibles ($R^2 < 0.50$) :**
  - Ex. Fokra-Tamesnine ($R^2 = 0.00$), Tazamourte-Afiad ($R^2 = 0.03$).

Results (1): R'dat basin

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Results (1): R'dat basin

5. Conclusion

- **Volume total prélevé :**
  - Moyenne annuelle sur 1971-2011 : 58.3 millions de m³.
- **Anomalies relevées :**
  - Exagération des prélèvements à partir de 1996, principalement à la prise Afiad.

Prélèvements vis-à-vis des potentialités hydriques :

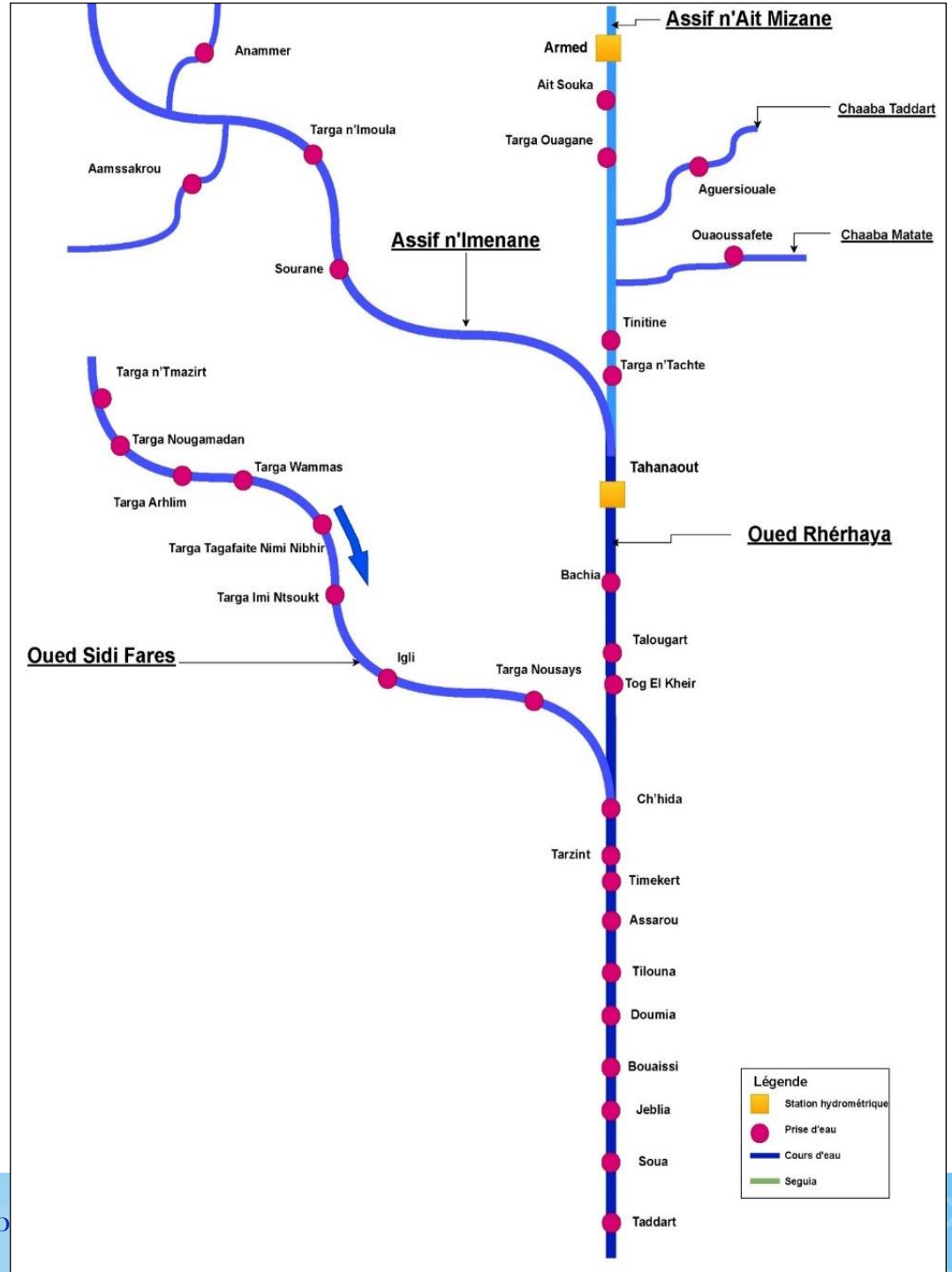
- **Année 2010/2011 :**
  - Apports de l'oued : 323.4 Mm³ (station Sidi Rahal).
  - Total prélevé : 227.2 Mm³ (70.3% des apports).
  - Seguia Afiad : plus grand volume prélevé (188.7 Mm³, 58.4%).
  - Seguias mineures : Mghinia (0.5 Mm³, 0.1%).

- **Augmentation significative des prélèvements annuels sur les dernières décennies.**
- Fortes interdépendances entre certaines seguias (ex. Tamesnine et Oum Ali).
- Surestimation probable des données ORMVAH après 1992.
- Le système hydrique du R'Dat ne présente pas de problème de satisfaction des besoins en eau, les apports étant suffisants.

Results (1): Rheraya basin

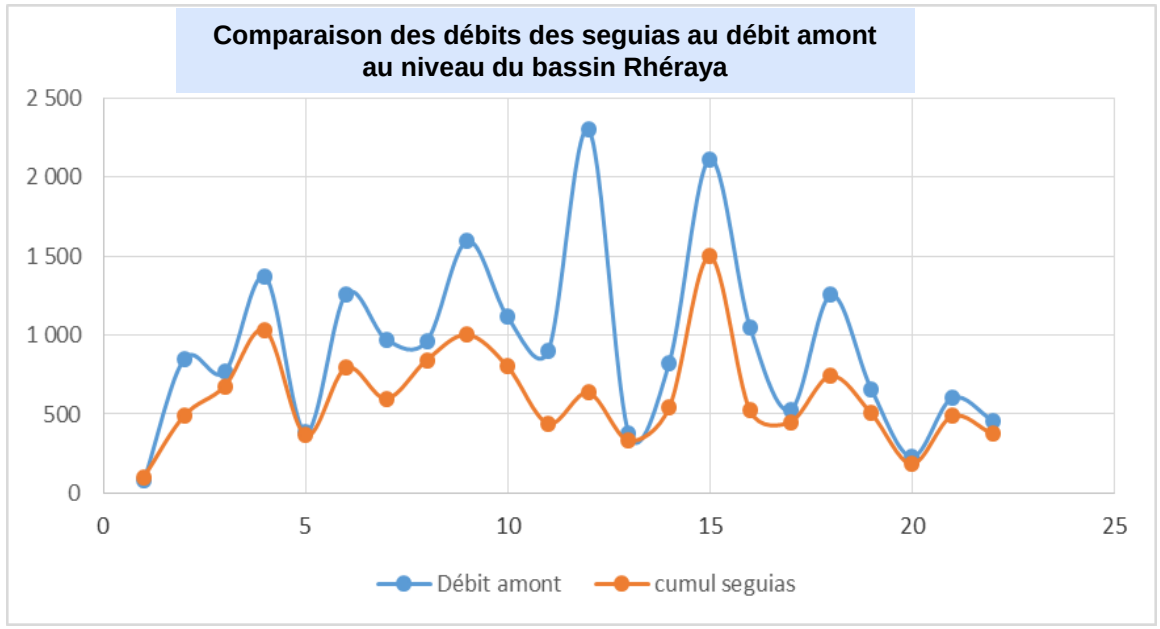
1. Quantifying Withdrawals

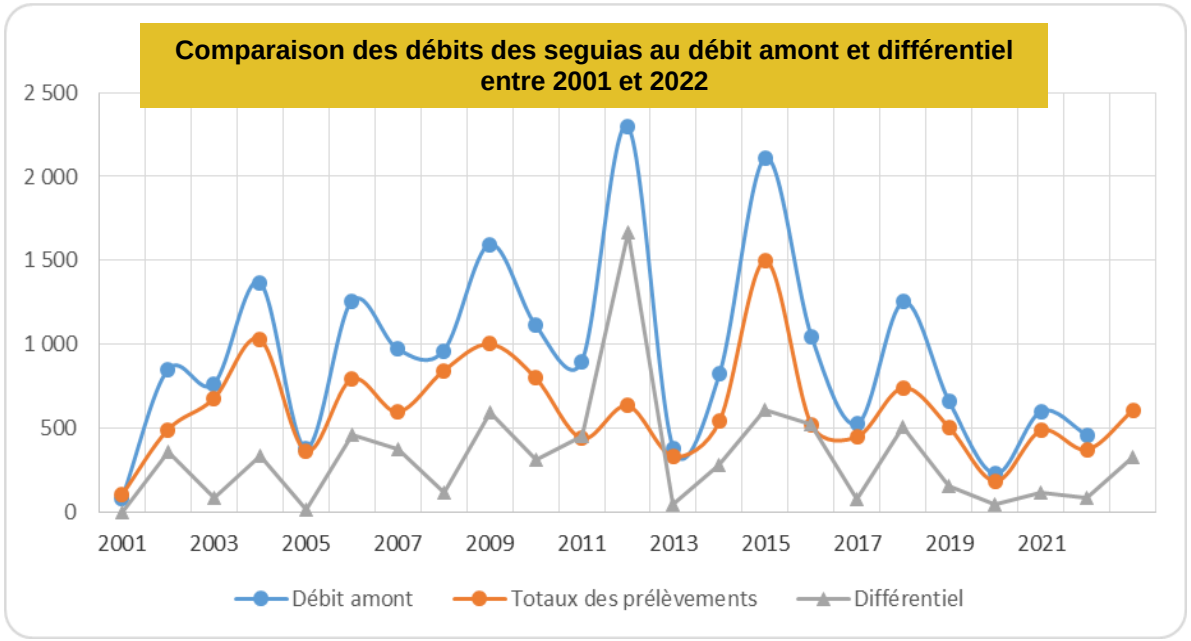
- Long history of traditional irrigation, with seguias diverting a **large share of river flows**.
- **Average annual withdrawals** by Seguias:
- ≈ **26 Mm³/year** over **1985–2000**.
- ≈ **14 Mm³/year** over **2001–2021**.
- This corresponds to a **46% reduction** in withdrawals between 1985 and 2022, linked to recurrent droughts, climate change and evolving practices.
- In some recent years, **about one-third (≈33%) of available water resources** were diverted for irrigation (e.g. 2016/2017).
- On average, double-mass analysis indicates a **derivation coefficient around 62%** of upstream flow for Rhéraya, confirming strong pressure on surface water.



Results (1): Rheraya basin

1. Quantifying Withdrawals





Results (1): Rheraya basin

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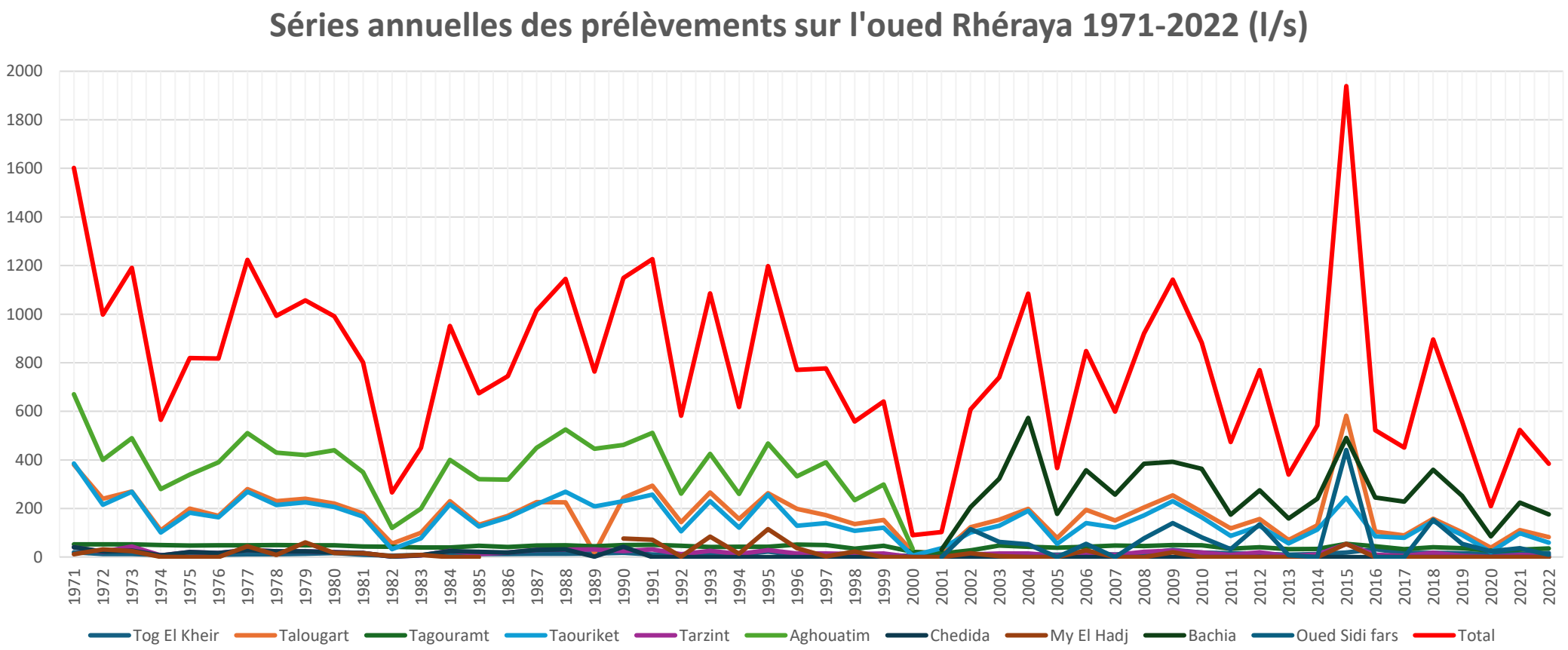
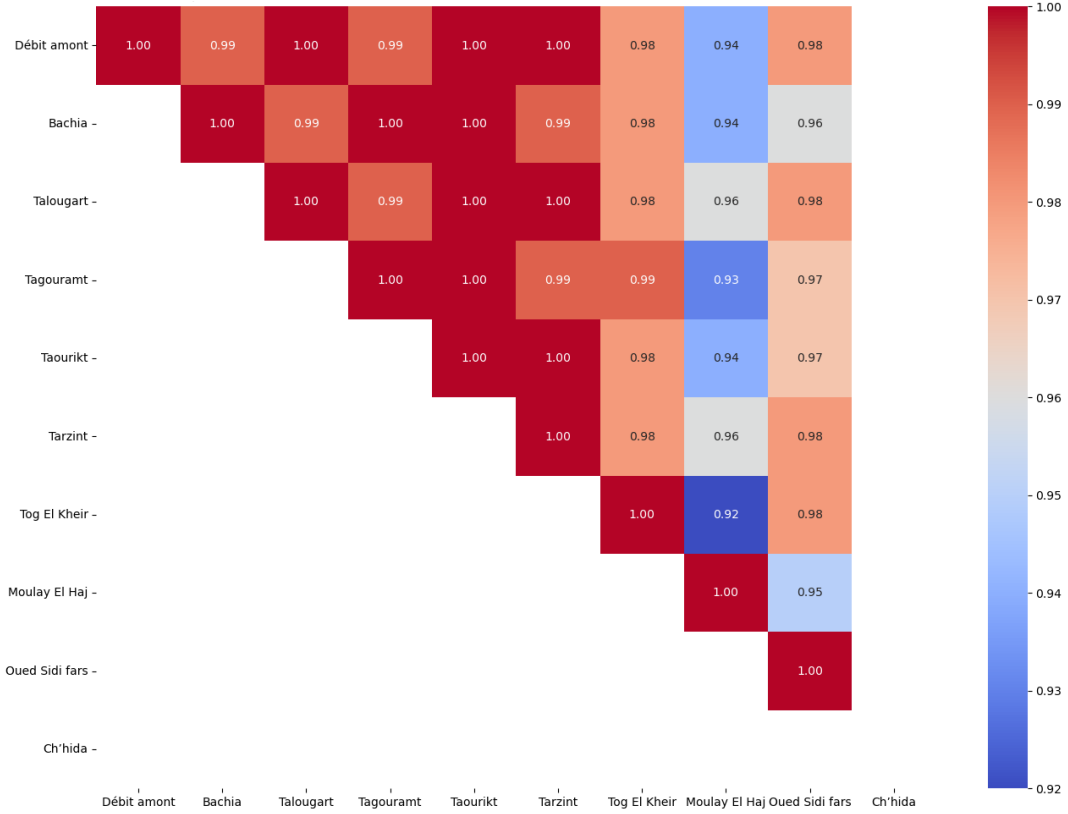
1. Quantifying Withdrawals

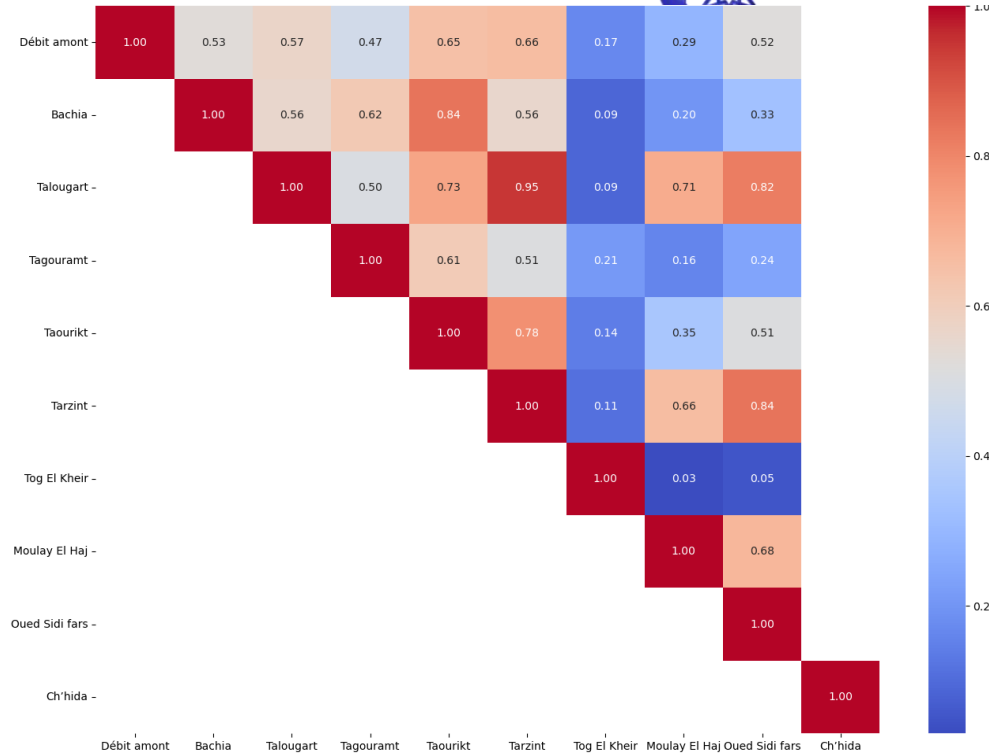


Results (1): Rheraya basin

2. Data Quality & Statistical Analysis

•Historical bilans and Anzar–ABHT (2003) show a **coherent annual withdrawal series** for 1971–2000, with an average of ~26 Mm^3/year and a homogeneous time series.
•**Double-mass curves** between upstream discharge and total withdrawals display **no structural break**, supporting the assumption of a relatively stable derivation coefficient over time.
•However, around **5% of months show anomalies**, with declared withdrawals exceeding availa ations.





•The **correlation matrix** shows:
•Strong dependence of several seguias on upstream discharge (R^2 ≈ 0.5–0.7 for Bachia, Talougart, Taourikt, Tarzint, Oued Sidi Fars).
•Weaker dependence and measurement issues for **Tog El Kheir** and **Moulay El Haj**, which deviate from the general pattern.

Results (1): Rheraya basin

3. Inequity & Canal Performance

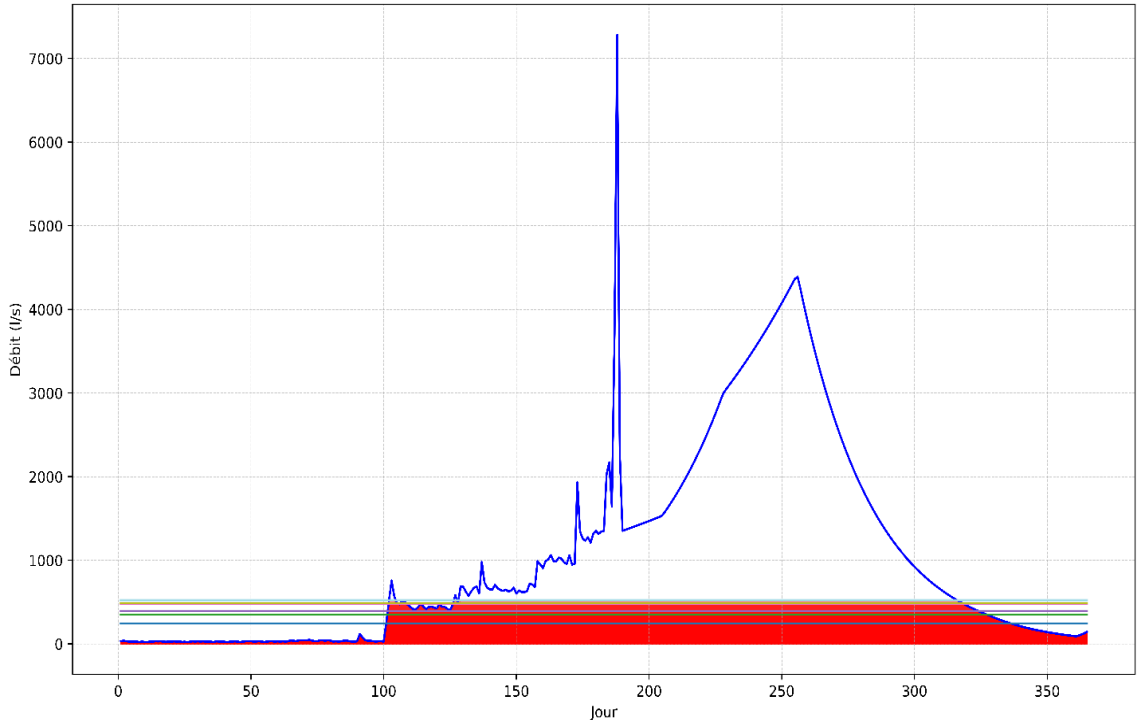
- The **Bachia seguia** is a "tête morte" canal that captures **about 60–70% of all diverted volumes** on Rhéraya, giving it a dominant position in the system.
- This concentration of withdrawals by Bachia **reduces water availability for downstream seguias**, generating structural inequities similar to those described in the abstract.
- Despite an overall **decline in total withdrawals** (26 → 14 Mm^3/year), the **spatial pattern of access remains highly asymmetric**, with upstream or privileged canals securing most of the flow.
- The combination of **high derivation rate (≈62%)**, dominance of a single canal, and persistent anomalies in some records confirms:
- **Intensive exploitation** of the resource.
- **Weak protection of downstream and ecological needs**, exactly as highlighted in the abstract for "regional disparities in water access and over-extraction."

STATION TAHANAOUT	380.8 Mm3			
Seguia	Volume prélevé déclaré en Mm3 (ORMVAH)	Volume prélevé corrigé en Mm3	Différence (Déclaré – corrigé)	Pourcentage des débits prélevés/station
Bachia	89.5	65.4	24.1	17.2
Talougart	38.2	24.1	14.1	6.3
Tagouramt	16.2	9.9	6.3	2.6
Taourikt	31.1	18	13.1	4.7
Tarzint	3.5	1.9	1.6	0.5
Tog El Kheir	11.9	6.3	5.6	1.7
Total	190.5	125.5	65	33.0

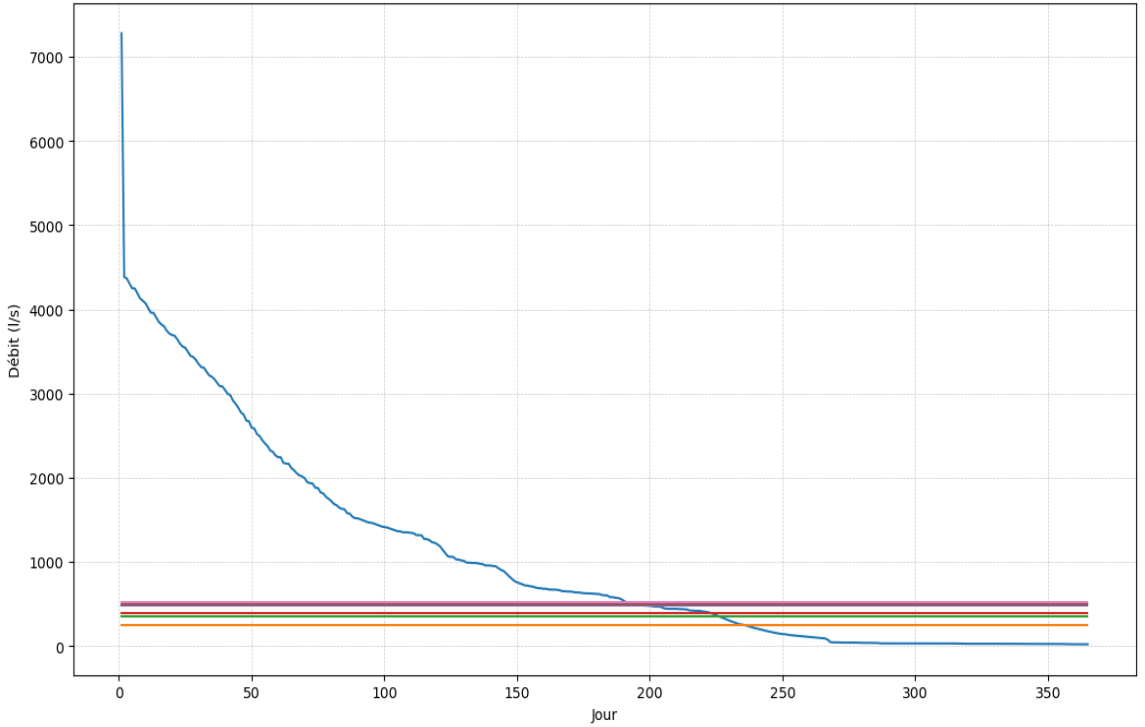
Results (1): Rheraya basin

3. Inequity & Canal Performance

Prélèvements vis-à-vis des potentialités de l'amont vers l'aval des seguias de l'oued Rhéraya sur l'année 2016/2017



Prélèvements cumulées vis-à-vis des potentialités de l'amont vers l'aval des seguias de l'oued Rhéraya sur 2016/2017



Station Tahanouat | Bachia | Talougart | Tagouramt | Taourikt | Tarzint | Tog El Kheir

Results (1): Rheraya basin

4. Implications & Link to Predictive Modeling

•Rhéraya is a **critical test case** for the predictive framework described in the abstract:
•Strong dependence of withdrawals on upstream flows.
•Already **high derivation ratios** and limited residual flows.
•Under climate-change scenarios (higher temperatures, more variable flows), **crop water requirements will increase**, while the system currently operates close to saturation.
•The predictive model combining **climate variables + FAO Penman–Monteith + cropping scenarios** can be used on Rhéraya to:
•Quantify **future irrigation demands** under different climate and cropping assumptions.
•Test **allocation rules** limiting over-withdrawal when flows are low.
•Identify **priority modernization actions** (e.g. reducing Bachia's capturing dominance, improving measurement and control).

Results (1): Rheraya basin

5. Conclusion

Bilan des prélèvements annuels (2001-2022) :

- Coefficient de dérivation moyen constant : 62%.
- Homogénéité générale des prélèvements sauf anomalies mineures (ex. seguia Tog El Kheir).
- Variabilité des prélèvements attribuée aux méthodes et fréquences de mesure.

Bilan des prélèvements mensuels :

- 28 mois sur 271 mois (5%) présentent des anomalies (prélèvements > apports).
- Anomalies dues à des prélèvements surestimés ou apports sous-estimés.
- Anomalies corrigées lorsque les causes sont identifiables

Série des prélèvements annuels (1971-2022) :

- Trois échantillons analysés :
    - 1971-1985, 1985-2001, 2001-2022.
- Légères cassures en 1985 et 2001 attribuées aux changements climatiques, méthodes de mesure et état des seuils.

Results (1): Rheraya basin

5. Conclusion

Analyse de dépendance entre seguias et débit amont :

- Fortes dépendances pour les seguias Bachia, Talougart, Taourikt, Tarzint, et Oued Sidi Fars ($R^2 > 0.5$).
- Dépendances faibles pour Tog El Kheir, Tagouramt, et Moulay El Haj.
- Seguias regroupées en deux familles selon leurs liaisons :
  - Liaisons fortes (ex. Talougart-Taourikt, $R^2=0.73$).
  - Liaisons faibles (ex. Bachia-Tog El Kheir, $R^2=0.1$).

Potentiel hydrique et prélèvements (2016-2017) :

- Débit total de l'oued Rhéraya : 380.8 Mm^3.
- Volume total prélevé par les seguias : 125.6 Mm^3 (33%).
- Seguia Bachia : plus gros prélèvement (65.4 Mm^3, 17%).
- Prélèvements variés selon les seguias :
  - Talougart (6%), Taourikt (5%), Tog El Kheir (1.7%), Tarzint (0.5%).

- ❑ **Homogénéité des prélèvements dans le temps sauf quelques exceptions.**
- ❑ **Réduction des prélèvements attribuée à la baisse des ressources en eau et au changement climatique.**
- ❑ **Besoin d'améliorations dans la précision des mesures et la gestion des seuils de prélèvements.**

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