International Water Management Institute

Spatio-temporal Analysis to Support Modelling and Mitigation of Anthropogenic Sand and Dust Storm Sources in Southern Iraq

Muhammad Khalifa, Kirubel Mekonnen Gebreyesus, Mitchell Chambers McTough, Karthikeyan Matheswaran, Sarfraz Munir, Naga Manohar Velpuri and Sandra Ruckstuhl

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Front Cover

Unlined earthen water conveyance channel within degraded and desertified farmland at Pilot Site 2, Al-Duraan Village, Al-Batha District, Dhi Qar Governorate, Iraq. (Photo credit: Women's Empowerment Organization, May 2026)

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Project

Wiqaya: Mitigation of sand and dust storms generation and impacts in Iraq and the Gulf region project (2025–2027) is supported financially and technically by the UK International Development and led by the International Water Management Institute in partnership with the American University of Iraq-Baghdad (AUIB), the Women Empowerment Organization (WEO) and UN-Habitat, with support of the Government of Iraq through the Ministry of Environment and the Ministry of Agriculture. Wiqaya aims to use evidence-based, locally grounded, and scalable resilient nature-based water solution (RNBWS) pilots to mitigate impacts of sand and dust storms (SDS) in Iraq and the broader MENA region.

Collaborators

International Water Management Institute (IWMI)

Government of Iraq

Ministry of Environment, Iraq

Ministry of Agriculture, Iraq

Office of Forestry and Combating Dessertification, Ministry of Agriculture, Iraq

The United Nations Human Settlements Programme (UN-Habitat)

The American University of Iraq – Baghdad (AUIB)

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Abbreviations and Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station Data
DEM	Digital Elevation Model
ET	Evapotranspiration
ETa	Actual Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FCDO	Foreign, Commonwealth & Development Office (United Kingdom)
FLDAS	Famine Early Warning Systems Network Land Data Assimilation System
GIS	Geographic Information System
GPW	Gridded Population of the World
IWMI	International Water Management Institute
MENA	Middle East and North Africa
MODIS	Moderate Resolution Imaging Spectroradiometer
NBS	Nature-Based Solutions
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
RNBWS	Resilient Nature-Based Water Solutions
SDS	Sand and Dust Storms
SIWA+	Scale-Invariant Water Accounting Plus
SPI	Standardized Precipitation Index
SRTM	Shuttle Radar Topography Mission
UNCCD	United Nations Convention to Combat Desertification
USD	United States Dollar
WA+	Water Accounting Plus
WaPOR	Water Productivity through Open-access of Remotely Sensed Derived Data
WMO	World Meteorological Organization

Summary

This report presents a spatio-temporal assessment to support modelling and mitigation of anthropogenic sand and dust storms (SDS) in southern Iraq. The analysis identifies Al-Muthanna, Iraq, as the highest-risk SDS source area, with >60% of its land showing low soil moisture and high bare-soil exposure. In Dhi-Qar, SDS hotspots are localized within the agricultural belt, where land abandonment and unsustainable cultivation practices increase soil exposure. Using six variables, i.e., soil moisture, wind speed, fraction of bare land, vegetation productivity, soil texture and soil temperature, the assessment reveals that SDS risk increases where vegetation loss, dry conditions, and highly erodible soils overlap. Water balance results indicate persistent negative water yields in Dhi-Qar and Al-Qadisiyah, suggesting increasing water stress and land degradation pressures. Although Al-Muthanna shows positive water yields in some years, it remains highly vulnerable to SDS due to extensive bare land, sparse vegetation, and low soil moisture conditions. However, the seasonal availability of water may provide opportunities for rainwater harvesting and landscape restoration interventions. These findings highlight clear entry points for Resilient Nature-Based Water Solutions (RNBWS), including soil-moisture conservation, vegetation recovery, and improved irrigation and land-use practices, to stabilize soils and reduce SDS emissions. The results provide a basis for more local-scale assessments and targeted, governorate-specific mitigation planning and prioritization. In addition, it provides a scaling potential to other MENA regions and beyond.

Key messages

- Sand and Dust Storms (SDS) risk increases where low water availability, vegetation loss, and erodible soils coincide, exposing large surfaces to wind erosion.
- Barren lands and abandoned or poorly managed agricultural fields are key SDS source areas that expand under drought and land degradation.
- Improving soil moisture and vegetation cover through Resilient Nature-based Water Solutions can reduce SDS generation and strengthen climate resilience.

1. Background and Context

1.1 Why This Matters?

SDS are a widespread global hazard, with 150 countries directly affected (Li et al. 2025), and 2 billion tonnes of dust emitted into the atmosphere annually (UNESCAP 2018). It has serious consequences on human health, society, economy and environment. Globally, dust-related welfare losses have been estimated at nearly 3.6 trillion USD. In the Middle East and North Africa (MENA), the annual economic cost is estimated at US$150 billion, approximately 2.5% of the regional GDP (World Bank 2019). In MENA, many countries such as Iraq, Kuwait, Saudi Arabia, Sudan, Egypt, Jordan, and Syria increasingly experience frequent and intense SDS.

Previous studies have shown that the frequency of SDS events in Iraq has increased, with cross-border impacts extending to Kuwait and Saudi Arabia (Sissakian et al. 2013). Rising temperatures, prolonged drought conditions, land degradation, and reduced vegetation cover have been identified as key drivers of increasing SDS activity in the region. Between 1960 and 2022, Iraq experienced an increase in average temperature of approximately 2 °C, while annual SDS events also increased from about 75 to nearly 200 events per year (Awadh 2023). SDS events occur more frequently during spring and summer when soil moisture is low. The Al-Samawah Desert in southern Iraq have been identified as one of the major SDS source, representing around 27.4% of all SDS sources in Iraq (Ismail et al. 2025). In addition to environmental impacts, SDS events can substantially affect agricultural productivity; Ahmadzai (2021) estimated that each SDS day may reduce crop yields in Iraq by about 0.9–3%.

SDS is largely a natural phenomenon, driven by natural processes such as aridity, wind speed, and sparse vegetation. However, human activities significantly intensify their frequency, duration, and severity. According to FAO (2023), roughly 25% of global dust generation are attributable to anthropogenic activities. Anthropogenic causes involve a wide range of factors, including inappropriate farm management, and mismanagement of water resources (Sissakian et al. 2013). Key biophysical factors driving SDS include: climatic variables (wind speed and direction, air temperature, precipitation, evapotranspiration and potential evapotranspiration, and air pressure); soil characteristics (soil type, particle composition, structure, organic matter, bulk density, moisture content); vegetation characteristics (type, coverage, density and distribution); and landform/landscape features such as slope and surface roughness (Shi et al. 2004).

1.2 Wiqaya Contribution

Wiqaya ("prevention" in Arabic) is an International Water Management Institute (IWMI)-led initiative funded by the UK Foreign, Commonwealth & Development Office (FCDO) and supported by the Government of Iraq, implemented together with local partners, including universities and non-governmental organisations. Wiqaya is part of the FCDO PHENOMENAL programme that involves multiple regional initiatives and projects IWMI also leads (Al Murunah, Al Murunah + and Jahez), that focus on implementing and scaling Resilient Nature-Based Water Solutions (RNBWS)[1] in several MENA countries, including, Egypt, Jordan, and Palestine. Wiqaya aims to reduce SDS generation at source in southern Iraq through community-led RNBWS and decision-support modelling, while building a national scaling and finance pathway for broader uptake. The core pilot is in Nasiriyah (Dhi Qar governorate), with targeted technical assessments in the Samawah Desert (Al-Muthanna governorate) and the Diwaniyah agricultural belt (Al-Qadisiyah governorate), focusing on anthropogenic, vegetation-based interventions in degraded farm belts.

Mitigation and adaptation measures for SDS are well documented, but their effectiveness depends strongly on local conditions. Therefore, selecting appropriate interventions requires a clear understanding of where SDS sources occur, how extensive they are, and the factors driving them. Effective solutions should be guided by spatially explicit assessments that identify SDS hotspots and their underlying causes. In regions such as MENA, however, limited in-situ observations make traditional ground-based assessments difficult, highlighting the importance of remote sensing and spatial analysis approaches.

Spatial analysis using gridded, public-domain data (e.g., remote sensing and models) can accelerate this

1 "RNBWS are spatially integrated combinations of nature-based solutions for water and agricultural water management. They encompass innovative agro-ecological and ecological water management techniques, coupled with social and market mechanisms that support long-term sustainability. In essence, RNBWS involve people working with their local natural environment to sustain water and ecosystems while improving livelihoods" (Fraj et al. 2025. p.1).

work. Such analyses provide insights into potential SDS sources and drivers; linking these layers helps identify potential mitigation options. Moreover, understanding water availability and use is essential for planning and implementing context-specific, resilient, nature-based water solutions to combat SDS.

In this brief, we present preliminary results from spatial analysis, including water accounting assessments, conducted under the Wiqaya project to support SDS modelling and mitigation in southern Iraq.

2. Area of Study

The Wiqaya project focuses on southern Iraq. The target area covers a significant portion of the country, and includes three governorates: Al-Muthanna, Dhi-Qar, and Al-Qadisiyah (Figure 1). Al-Muthanna is the largest of the three, and the Al-Samawah Desert lies within it, reported to experience high SDS activity. All three governorates show population growth, with the highest population density concentrated in Al-Qadisiyah.

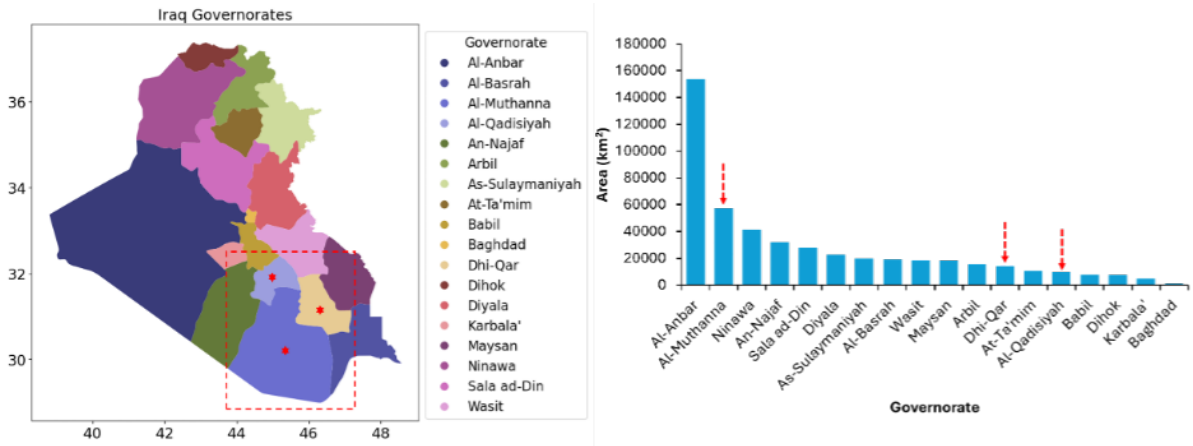

Figure 1. Location map of the study region in Iraq that includes the governorate Al-Muthanna, Dhi-Qar, and Al-Qadisiyah.

Source: Authors using DivaGIS dataset.

Note: The graph (to the right) displays areas of Iraq's governorates, including the three selected for this study.

Topographically, Al-Muthanna exhibits the highest elevations, reaching over 400 m above sea level, with an average elevation of approximately 220 m. In contrast, Al-Qadisiyah and Dhi-Qar are characterized by much lower elevations, averaging about 25 m and 10 m above sea level, respectively.

3. Methodological Approach

This analysis covers two dimensions: (i) mapping potential sources of SDS, and (ii) spatio-temporal analysis of biophysical elements in the region. This approach aims to quantify relationships between SDS sources and drivers. We used R, Python, GIS, and the Water Accounting Plus (WA+) framework.

3.1. Mapping Sand and Dust Storm Sources

We applied the United Nations Convention to Combat Desertification (UNCCD) framework to identify potential SDS source areas within the project region. A simplified workflow is presented in Figure 2. The assessment combined information on soil characteristics, wind conditions, vegetation cover, and land conditions using publicly available global datasets (Table 1). Data from 2010–2024 were analyzed to identify areas most vulnerable to SDS generation and to map the potential extent of SDS hotspots across the study area. The assessment can be further improved in the future as more detailed national and sub-national datasets become available.

The framework applied a grid-based analysis at 1-km spatial resolution to assess the susceptibility of each cell to generate sand and dust particles. The analysis first separated land areas from water bodies and identified bare land using land-cover data. Several biophysical indicators were then used to evaluate SDS potential across the remaining cells. The bare-land fraction was used to represent surface exposure, while soil moisture was used to indicate surface dryness, with lower soil moisture corresponding to higher SDS susceptibility. Soil texture, based on the relative proportions of sand, silt, and clay, was also used to assess soil erodibility, as soils with higher fine-particle content are generally more vulnerable to sand and dust generation.

To enhance the predictive accuracy of the UNCCD workflow, two additional biophysical indicators were incorporated: wind speed and the Normalized Difference Vegetation Index (NDVI). Wind speed was used to identify cells where velocities exceeded the threshold for particle mobilization, while NDVI, as a proxy for vegetation cover, indicated higher susceptibility to wind erosion at lower values. These indicators were combined to compute SDS generation potential score per grid cell, normalized to the 99th percentile. The resulting source-intensity values range from 0 to 1, >0.5 indicates a high potential for SDS generation (UNCCD and WMO 2024)

This spatially explicit analysis helps identify SDS hotspot areas where targeted Resilient Nature-Based Water Solutions (RNBWS) can be applied to reduce SDS risks and improve landscape resilience.

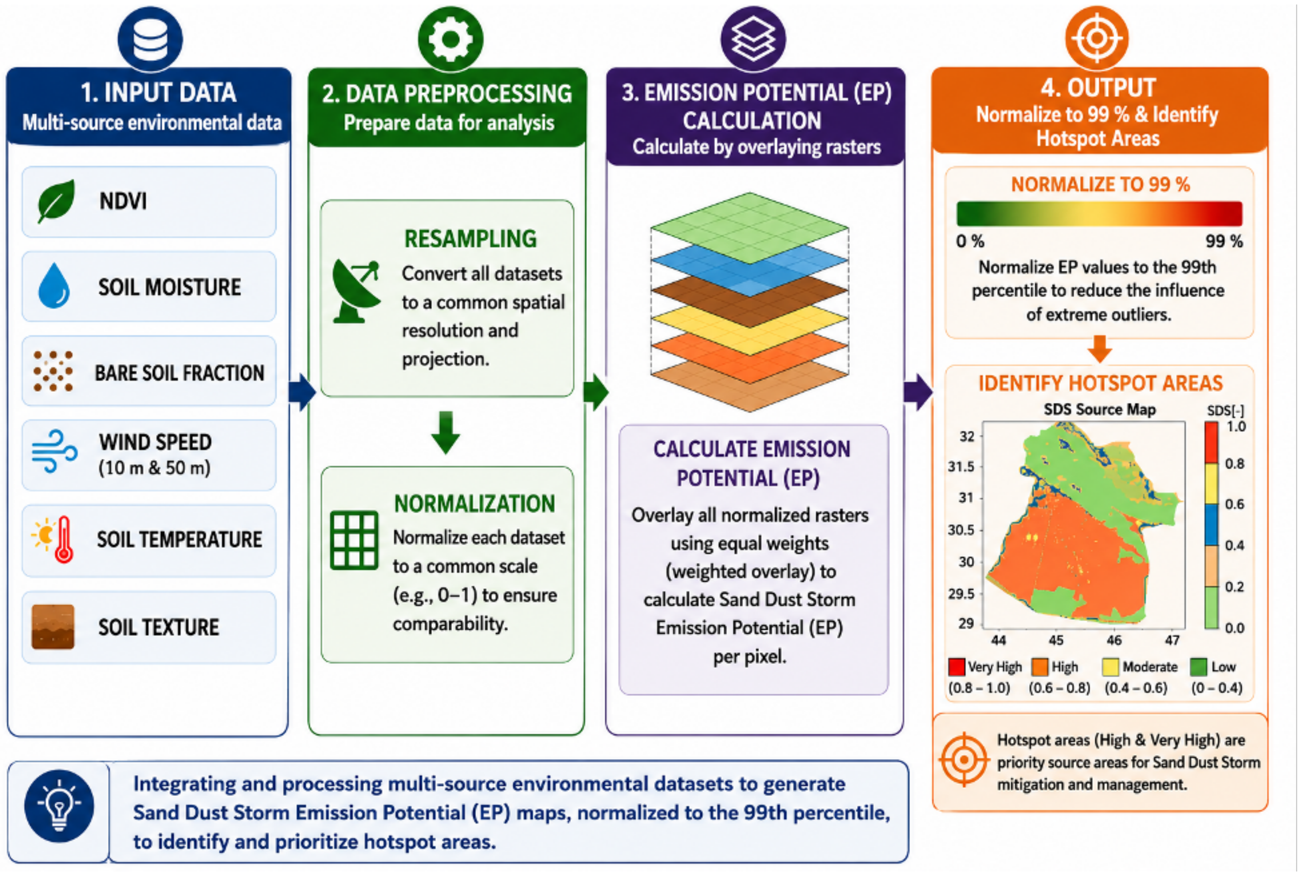

Figure 2. Simplified workflow for mapping sand and dust storm sources.
Source: Modified after UNCCD and WMO (2024).

3.2 Spatial Analysis of Biophysical Variables

Based on literature (e.g., Shi et al. 2004), we identified key biophysical factors associated with SDS generation, including land cover, rainfall (P), actual evapotranspiration (ETa), water yield (P–ETa), elevation, population density (exposure), drought conditions, and soil properties such as texture, bulk density, and soil moisture. We then analysed the spatial distribution of these factors across the three governorates to better understand the conditions contributing to SDS generation. This assessment provides a scientific basis for identifying high-risk areas and supporting targeted land and water management interventions to reduce SDS impacts.

Beyond biophysical drivers, understanding water availability and water use across the three governorates is essential for planning and sustaining nature-based solutions (NBS) to mitigate SDS. The Water Accounting Plus (WA+) framework, developed by IWMI and partners, provides a data-driven approach for assessing how water is distributed, used, and managed within a region (Karimi et al. 2013; Mekonnen et al. 2026).

This framework integrates remote sensing, hydrological data, and land use information to quantify inflows, evapotranspiration from natural landscapes and managed systems (e.g., irrigation), environmental flow requirements, and the remaining water leaving the region.

Traditionally applied at the river basin scale, the WA+ framework has been extended through the Scale-Invariant WA+ (SIWA+) approach, enabling water accounting across multiple spatial domains, including administrative units such as governorates (Owusu et al. 2025; Velpuri et al. in review). Integrating water accounting with SDS assessments is important because water availability and water use strongly influence vegetation cover, soil moisture, and land degradation. SIWA+ provides spatially explicit information on water availability, and water use conditions, which can support the planning and prioritization of NBS for SDS mitigation. Definitions of all hydrological variables used in the water accounting framework (e.g., inflow, managed flow, utilized flow, consumptive use, and outflow) are provided in Annex 1.

4. Data Specification and Sources

For this spatial analysis, a wide-range of data was retrieved from multiple public-domain sources (Table 1). Remote sensing datasets used in the assessment include the variables considered, their spatial and temporal resolutions, and the corresponding data sources used to identify potential SDS hotspot areas.

The SDS assessment integrates both static and dynamic variables that influence dust-emission potential. Static datasets, such as bare-soil fraction and soil texture, describe land-surface characteristics that affect soil exposure and erodibility. Dynamic datasets, including NDVI, soil moisture, soil temperature, and wind speed, were analyzed for the period 2010–2024. NDVI data derived from the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) were used to assess vegetation cover dynamics and surface exposure conditions. Soil moisture and soil temperature datasets (FLDAS NOAH, ~10 km resolution) were used to characterize near-surface conditions influencing soil stability and dust generation. Wind speed data from the Global Wind Atlas (~250 m resolution) were used to evaluate the erosive potential of surface winds, which play a critical role in dust mobilization. The spatial distribution of all input datasets used in the analysis is presented in Figure 3. To ensure consistency, all datasets were resampled to a common spatial resolution of 1 km.

Although this assessment uses long-term mean annual conditions to identify persistent SDS hotspots, SDS activity can vary considerably across seasons and months in response to changes in rainfall, vegetation cover, soil moisture, and wind regimes. As a result, the analysis is effective for identifying areas with sustained long-term susceptibility to SDS generation, but it does not fully represent short-term or seasonal variations in dust-emission dynamics.

Table 1. List of spatial data used for identifying sand and dust storm sources and spatial and temporal analysis of biophysical variables.

Purpose	Data	Spatial Resolution	Temporal Resolution	Source
Data used for identifying SDS potential sources	Bare soil fraction	1 km	Static	FAO
	NDVI	1km	2010–2024	The NOAA Climate Data Record (CDR) of AVHRR
	Soil texture (0-10cm)	250 m	Static	ISRIC
	Soil Moisture (m3/m3) (0-10cm)	10km	2010–2024	FLDAS NOAH
	Soil Temperature (0-10 cm) (k)	10km	2010–2024	FLDAS NOAH
	Wind speeds at 10 m (m/s)	250 m	2010–2024	Global Wind Atlas
	Wind speed at 50 m (m/s)	250 m	2010–2024	Global Wind Atlas
Data used for studying spatial and temporal patterns of biophysical variables	Elevation	30 m	Static	SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model)
	Population density	1 km	2000, 2005, 2010, 2015, 2020	GPW v.4
	Land cover	500 m	2001–2022	MODIS (MCD12Q1)
	Irrigated and rainfed water use	300 m	2010–2024	WaPOR as MODIS land-cover data do not distinguish irrigated and rainfed classes.
	Rainfall (P)	~ 5 km	1981–2024	CHIRPS (Climate Hazards Group InfraRed Precipitation with Station Data)
	Actual Evapotranspiration (ETa)	1 km	2009–2021	SSEBop
	Water Yield	~ 5 km	2009–2021	Calculated from CHIRPS (P) and SSEBop (ETa)
	Drought: Standardized Precipitation Index (SPI)	~ 5 km	1981–2024	Calculated from CHIRPS (P)
	Soil properties: Bulk density, sand content,	250 m	Static	SoilGrids

Source: Authors.

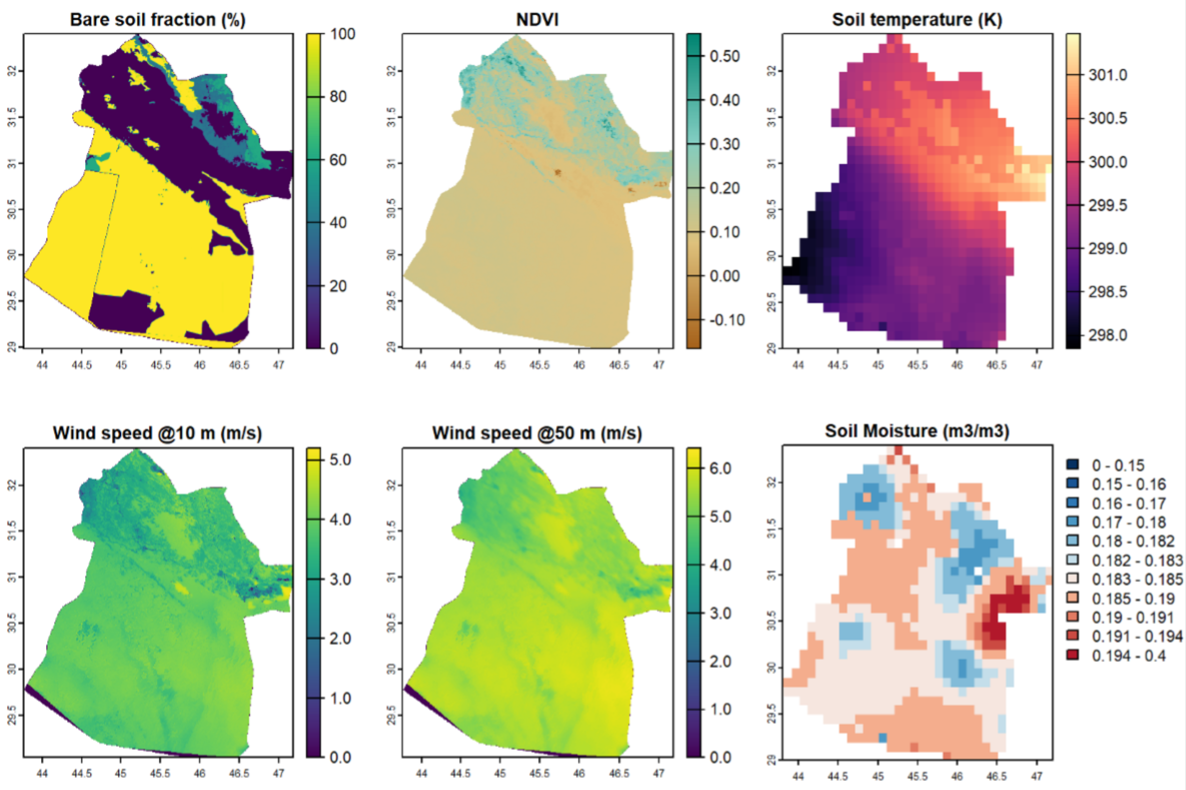

Figure 3. Spatial distribution of all the input data layers used for generating SDS source map.
Source: Authors' production using data sources listed in Table 1.

5. Key Findings

5.1. Modelled SDS Potential Sources and Hotspots

The SDS source map for southern Iraq shows strong spatial variability in SDS susceptibility across the study area (Figure 4). Al-Muthanna, located in the southwestern part of the country near the Saudi border, exhibits the highest susceptibility, with more than 60% of the governorate classified as highly prone to SDS generation. This high vulnerability is mainly associated with extensive desert landscapes, low soil moisture, and sparse vegetation cover, which increase exposure to wind erosion. In contrast, Al-Qadisiyah and Dhi-Qar show substantially lower proportions of high-susceptibility areas, accounting for approximately 8% and 6% of their land area, respectively. However, localized SDS hotspots remain present within parts of Dhi-Qar's agricultural belt, where exposed soils and unsustainable land-use practices may increase vulnerability to dust generation.

A visual comparison of the SDS source map and the Land Use/Land Cover (LULC) map show a strong spatial relationship between SDS susceptibility and land-cover conditions. Areas with high SDS susceptibility generally coincide with bare or sparsely vegetated land, which is highly vulnerable to wind erosion due to limited vegetation cover. However, high SDS susceptibility (SDS > 0.5) is not restricted to barren areas and is also observed within cropland and fallow land across the three governorates. In Al-Qadisiyah, cropland and fallow land account for nearly 3% of the area classified as highly susceptible to SDS, likely due to exposed soils, tillage activities, and seasonal fallowing. In Dhi-Qar, these land-use classes contribute slightly over 1% to highly susceptible areas, while their contribution in Al-Muthanna is comparatively limited. In contrast, irrigated cropland and areas with greater vegetation cover generally show lower SDS susceptibility, highlighting the important role of vegetation and soil moisture in reducing wind erosion and suppressing SDS generation.

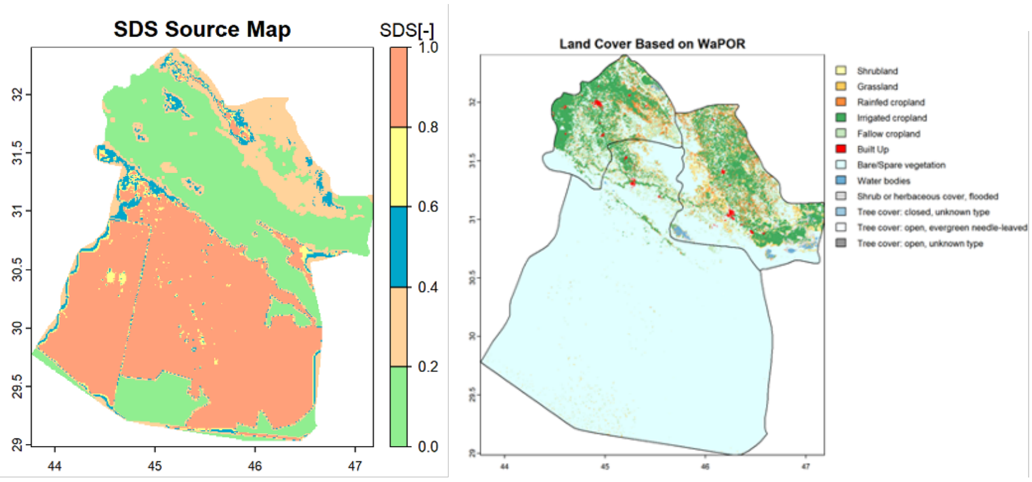

Figure 4. Sand and Dust Storm (SDS) source map (left) and land cover map of Al-Muthanna, Al-Qadisiyah and Dhi-Qar governorates (right).

Source: Authors production using methodology described above and input data listed in Table 1.

Note: The SDS source map (left) is illustrated at 1 km spatial resolution. The land cover map (right) is derived from the WaPOR 2023 dataset. The SDS index ranges from 0 to 1, where 0 indicates low susceptibility to SDS and 1 represents high susceptibility.

5.2. Water Availability and Use

Understanding water availability and water use is essential for designing and sustaining effective NBS to mitigate SDS in the study region. The surface water resource assessment for Dhi-Qar, Al-Qadisiyah, and Al-Muthanna regions highlights notable differences in water availability, and consumption during 2010–2023 (Figure 5 and Annex 2-3). Across all three governorates, water consumption exceeded available water resources, indicating increasing pressure on already stressed water systems. Dhi-Qar and Al-Muthanna exhibited particularly high levels of water stress, which may contribute to declining soil moisture, vegetation degradation, and increased land susceptibility to SDS.

The analysis also shows that substantial volumes of managed water, particularly in Dhi-Qar, create opportunities for targeted SDS mitigation interventions. Strategic allocation of water to support vegetation restoration, soil moisture conservation, and rehabilitation of degraded lands could help stabilize soils and reduce SDS risks. In contrast, continued allocation of water primarily toward intensive agricultural production, without adequate soil and land conservation measures, may further accelerate land degradation and increase vulnerability to SDS.

Overall, the water accounting results provide important insight into the availability, use, and distribution of water resources across the three governorates. These findings underscore the importance of integrating SDS mitigation measures into broader land and water management strategies. Key priorities include improving water-use efficiency, promoting sustainable agricultural practices, expanding vegetation and protected areas, and strategically allocating water resources to support ecosystem resilience and reduce SDS vulnerability across the region.

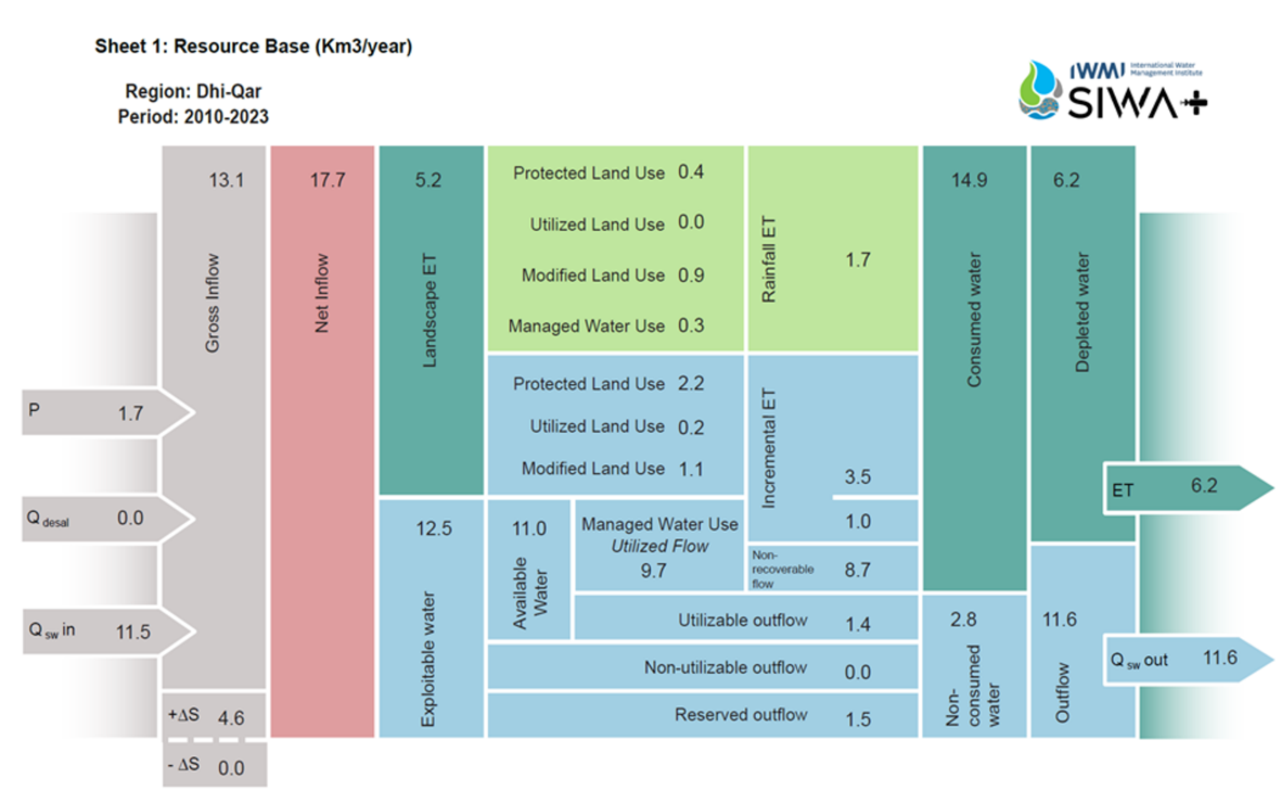

Figure 5. Long-term average annual water accounts (km3/yr) for Dhi-Qar governorate for the period 2010-2023.
Source: Authors, using SIWA+ approach developed by IWMI.
Note: The water accounts for other regions are provided in annexes 2 and 3.

To complement this analysis, we examined water-use dynamics in the study region by analysing temporal changes in irrigated and rainfed croplands using the WaPOR dataset across Al-Muthanna, Al-Qadisiyah, and Dhi-Qar governorates (Figure 6). The results show a clear shift during 2010–2013, marked by a substantial expansion of irrigated cropland accompanied by a concurrent decline in rainfed areas. For example, in Al-Qadisiyah, irrigated land increased from about 200,000 ha to 320,000 ha, while Al-Muthanna experienced an increase from about 50,000 ha to 75,000 ha.

This shift toward irrigated agriculture reflects growing dependence on managed water systems to sustain crop production. However, it also signals rising pressure on limited water and soil resources. Without the adoption of efficient irrigation practices (precision application, improved scheduling and soil moisture monitoring), trends could accelerate soil degradation, reduce vegetation cover and increase wind erosion, thereby heightening the risk of SDS occurrence. Strengthening irrigation efficiency and integrating SDS mitigation within the RNBWS framework is critical for maintaining agricultural productivity and enhancing landscape resilience.

Water-use trends (2010–2013) for irrigated and rainfed croplands across Al-Muthanna, Al-Qadisiyah, and Dhi-Qar governorates reveal distinct patterns, underscoring the importance of irrigation water management (Fig. 7). Al-Qadisiyah governorate records the highest irrigation water use, rising from ~1 km³/yr in 2010) to nearly 2 km³/yr in 2020, then a slight decline in recent years. This reduction likely reflects a combination of factors, including declining surface-water availability from the Euphrates, recurrent drought conditions, and growing pressure on groundwater resources. Dhi-Qar governorate shows a similar but less pronounced trend, peaking at ~1.5 km³/yr, while Al-Muthanna remains consistently <0.5 km³/yr throughout the period. These variations correspond closely with the expansion of irrigated cropland, particularly in Al-Qadisiyah and Dhi-Qar, indicating growing pressure on available water resources and underscoring the need for improved irrigation efficiency and allocation planning.

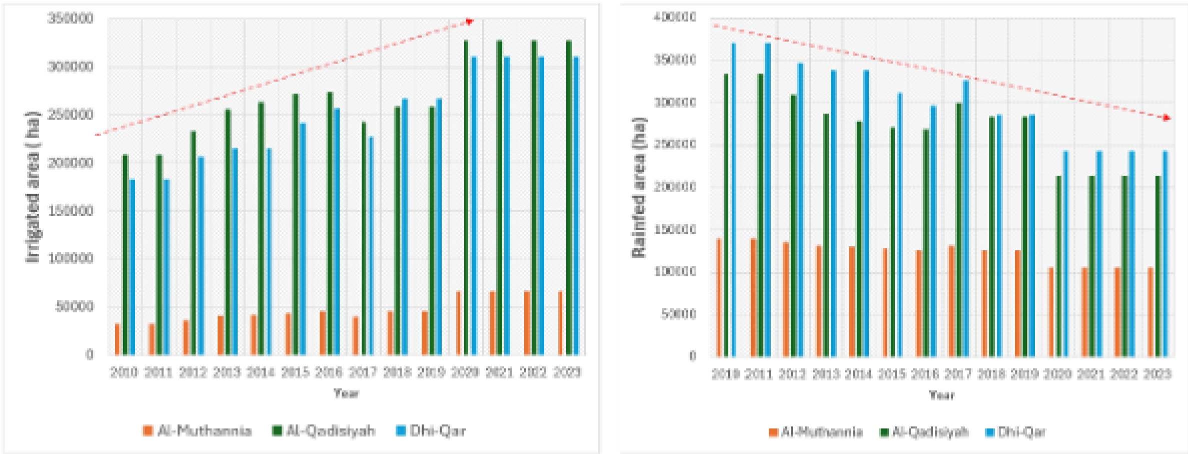

Figure 6. Temporal change in area of irrigated and rainfed croplands in the three governorates.
Source: Authors' production using land cover date retrieved from WaPOR.

Figure 7. Temporal change in water use in irrigated and rainfed croplands in the three governorates.
Source: Author production using land cover data from WaPOR and water use generated by SIWA+.

5.3. Water Yield

Temporal analysis of annual water yield reveals distinct patterns across the three governorates, reflecting spatial heterogeneity in rainfall, evapotranspiration, and land surface responses. Under prevailing arid to semi-arid conditions, particularly in the northern and eastern zones, runoff and recharge potential are limited. These hydrological deficits reduce soil moisture, weaken soil particle cohesion, and as a result increase susceptibility to wind erosion and SDS formation. Notable interannual variation is observed, particularly in response to episodic wet or dry years. For instance, in Al-Muthanna governorate, a marked anomaly occurred in 2018, when water yield values showed a sharp positive increase compared to preceding and subsequent years (Fig. 8). Such surplus likely enhanced surface runoff and localized groundwater recharge.

In contrast, Dhi-Qar and Al-Qadisyah Governorates displayed relatively stable water yield trends but negative values (Figure 8), consistent with their lower rainfall inputs and higher evapotranspiration rates. These areas remained largely deficit-driven, sustaining conditions favourable for soil desiccation and dust mobilization, and correlated with the previously identified potential sources for SDS.

Figure 8. Temporal pattern of rainfall, actual evapotranspiration, and water yield in the three governorates.

Source: Authors, using CHIRPS and SSEBop datasets.

Note: negative water yield = deficit. 2018 indicate opportunity year for rainwater harvesting and aquifer recharge in Al-Muthanna.

5.4. Land Cover Change and Land Degradation

Barren land dominates cover in the three studied governorates, particularly in Al-Muthanna (Figure 9). Vegetation loss, whether through overgrazing, drought stress, or reduced water availability, acts as a direct amplifier of dust source activation. It was noticed that some hotspots for SDS generation is located within and close to the agricultural belt in Dhi-Qar and Al-Qadisiyah governorate, suggesting potential contributions from unsustainable farming practices and/or field abandonment. Previous studies found correlation between agricultural practices and agriculture abandonment with SDS sources in Iraq (Hashemi et al. 2025). This linkage requires ground-truthing to verify current farming practices and extent of field abandonment, and their relationship with the SDS generation sources identified in the current investigation.

Figure 9. Maps of landcover types in the study region.

Source: Authors, using MODIS-MCD12Q1 product.

5.5. Soil Characteristics

Soil properties (texture bulk density, and organic carbon content) play crucial roles in SDS generation. Sandy and loose-textured soils with low organic content, typical of arid zones, are more erodible under wind action. High bulk density/compaction limits infiltration, exacerbating surface drying, particularly where vegetative or crust cover is minimal. In our assessment, Al-Muthanna and Dhi-Qar governorates show higher sand content and denser soils than Al-Qadisyah. Consistent with earlier findings that Al-Muthanna governorate is a hotspot for SDS generation, the high sand content and soil density along with the low soil organic content likely drive this elevated susceptibility.

5.6. Drought Assessment

Recurrent, prolonged drought depletes cumulative soil moisture depletion and causes vegetation mortality, expanding barren surfaces. Drought therefore serves as a trigger, transforming dust-prone surfaces into active SDS hotspots. The analysis of drought pattern in the region over 1981–2024 indicates that months of June to September are usually experiencing moderate to severe dry conditions (Figure10). Every July in the record is severely dry. In contrast, November–February conditions improve with rainfall. RNBWS need to consider this dryness signal for scheduling water harvesting and use of harvested water across space and time.

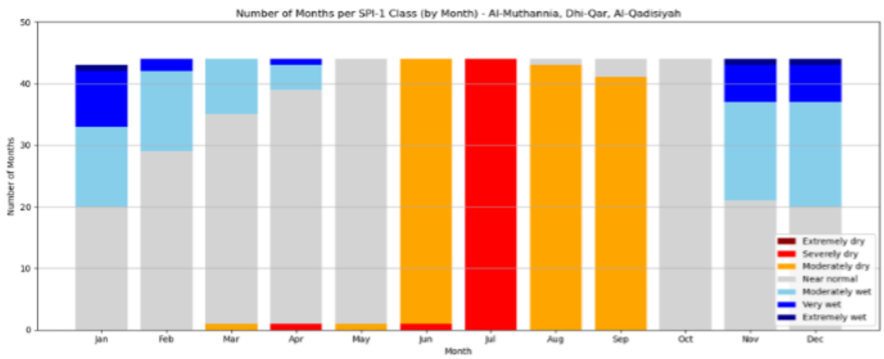

Figure 10. Number of months per SPI-1 class (by month) for the study region.

Source: Authors, using CHIRPS dataset.

5.7. Integrated Perspective

When coupled, low water yield, degraded vegetation cover, erodible soils with high sand content, high density and low organic carbon content, and recurring droughts form a reinforcing feedback loop that accelerates SDS generation. Water scarcity limits vegetation regrowth, exposing loose soils, which in turn enhances land degradation and dust emission potential. These interactions underscore the need for integrated water-land management strategies to mitigate SDS risk, especially interventions to conserve soil moisture and restore vegetation cover.

6. Resilient Nature-Based Water Solutions (RNBWS)

Resilient nature-based water solutions (RNBWS) offer an adaptive framework and a range of interventions that are effective to enhance water security and reduce vulnerability to SDS. RNBWS involves a wide range of interventions including wetland rehabilitation, managed aquifer recharge, and vegetative belts. These strategies help retain soil moisture and stabilize loose soils. Interventions such as vegetation restoration and green infrastructure increase surface roughness, reducing wind erosion and dust emission. Similarly, water harvesting and infiltration-enhancing measures where and when there is water surplus improve soil–water balance, supporting vegetation recovery. In arid and semi-arid regions, like this region in southern Iraq, where limited water yield and coupled with recurrent droughts and unstable vegetation cover drive SDS activity, the implementation of RNBWSs can simultaneously improve ecosystem services, strengthen local livelihoods, and enhance climate resilience. Such intervention could potentially turn vulnerable SDS areas into productive, sustainable landscapes.

7. Validation of Key Findings and Limitations

From 3 to 7 September 2025, Wiqaya held a workshop in Baghdad to launch the project and engage stakeholders drawn from relevant public institutions, academia, Non-Governmental Organizations (NGOs) and international actors. Interactive sessions were conducted to validate the conceptual framework, key variables for SDS generation and initial analytical results. The discussions also surfaced additional influences on SDS generation, offering perspectives on modelling hotpots and linking them with RNBWS.

Participants confirmed that soil moisture, wind speed, and wind direction are critical variables that must be incorporated to fully capture SDS dynamics. The validation also identified potential SDS source areas, notably barren lands and abandoned agricultural fields, where depleted vegetation and disturbed soils enhance wind erosion. Moreover, agricultural practices such as over-tillage can further expose fine sediments, increasing dust emission risk.

The workshop demonstrated the value of participatory and interdisciplinary engagement in strengthening SDS assessment and solution design. Through practical exercises on spatial analysis, scenario development, and water-based mitigation options, stakeholders explored pathways for identifying hotspots and prioritizing interventions. The discussions also highlighted strong interest in scalable, evidence-based approaches that integrate spatial intelligence, water management, and RNBWS to address SDS risks and support resilience and sustainable land restoration.

8. Recommendations and the Way Forward

SDS is a serious transboundary hazard that has multi-sectoral impacts, particularly on health, the economy, environment, and society. Their complexity arises from interacting drivers, which amplify SDS generation and its impact. The spatio-temporal analysis presented here represents an early-stage investigation that highlighted key variables contributing to SDS generation, identified potential hotspots for SDS, and provided potential entry points for RNBWS in mitigating SDS in anthropogenic sources southern Iraq. The assessment of water uses and availability across the three governorates adds a critical dimension for planning and implementing RNBWS.

Future work should advance the current analysis by integrating agricultural dynamics into SDS source modelling. Crop type, cultivation practices, and crop rotation patterns significantly influence soil exposure and moisture retention. All these factors affect SDS generation potential. Although such datasets were not available for this early-stage investigation, generating them through remote sensing, agricultural surveys, or collecting them from existing databases would substantially improve model accuracy and spatial representation of SDS hotspots.

Establishing a comprehensive water monitoring system using WA+ is essential. In this study, a rapid WA+ assessment was used to understand water status and use patterns across the three governorates. However, validation with in-situ measurements (e.g., rainfall, ETa, river discharge), which were unavailable for this investigation, remain a challenge, and need to be done in the coming phase of the project. As irrigated areas expand, improving irrigation water management becomes increasingly important. The WA+ can provide evidence-based guidance, but field-scale assessment requires higher-resolution datasets to accurately assess water use.

An interactive WA+-based dashboard can help stakeholders systematically track water-cycle dynamics, providing real-time insights into water balance and drought stress. Integrating the dashboard with SDS monitoring tools will enable a proactive approach that links water availability, land conditions, and climate drivers to guide targeted SDS mitigation and adaptation strategies.

Additionally, linking farming practices and farming-abandonment patterns, where they exist, with spatio-temporal variation in water-resource availability would help identify entry points where RNBWS can help mitigating SDS in the study region.

Temporally, RNBWS could target enhancing water availability during dry season (June – September), by, for example, harvesting wet-season rainfall and storing it for use in the dry months.

The spatial disparity in biophysical variables across the three governorates underscores the need for governorate-specific solutions, including RNBWS. For instance, leveraging occasional wet years, such as

2018 in Al-Muthanna, for managed aquifer recharge, small-scale storage, and drought preparedness can enhance resilience to future SDS activity.

This assessment contributes to the expanding body of work on RNBWS at IWMI, including research under projects IWMI implements through the FCDO PHENOMENAL Programme and other institutional initiatives. By focusing on SDS, the study introduces a spatial assessment of SDS and shed lights on RNBWS approaches to aid in addressing this severe, large-scale and transboundary phenomenon.

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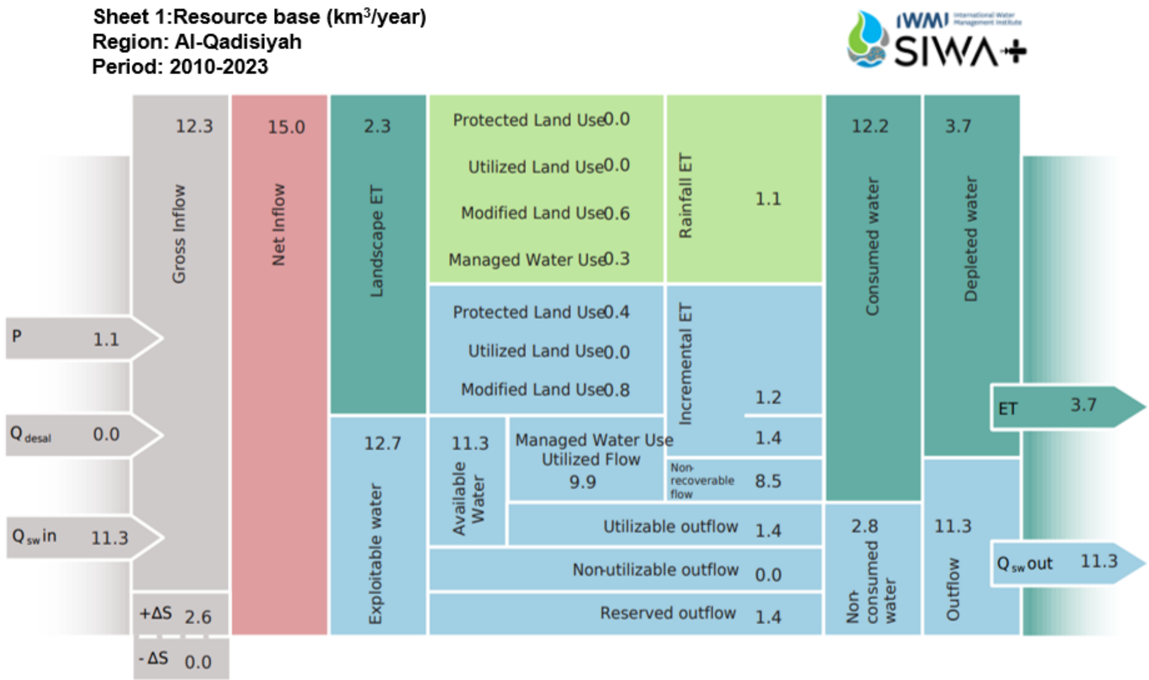
Annexes

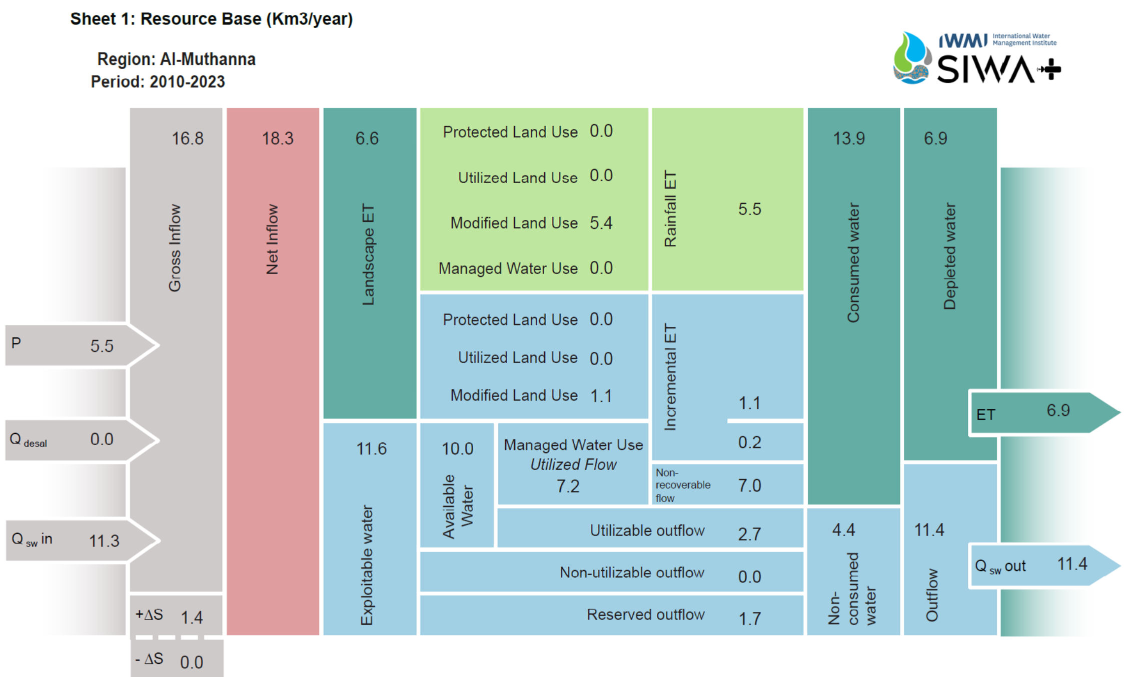
Annex 1. List of Key Hydrological Variables in the WA+ Framework

Category	Water Account	Definition	Calculation Procedure / Data Used
Inflow	P	Rainfall	CHIRPS
	Gross Inflow	Total inflow into the study region	P + any additional water sources
	Net Inflow	Total inflow minus the change in storage	Gross Inflow – ΔStorage
Evapotrans-piration	Total Actual ET (ET_a)	Actual evapotranspiration from the region	Selection of an appropriate ETa product
	Incremental ET (ET_{blue})	Actual evaporation from blue water sources (lakes, streams, reservoirs, ground-water via deep-root uptake, irrigation water)	Derived from the soil water balance mod-el
	Rainfall ET (ET_{green})	Actual evaporation from green water sources (pre-cipitation, unsaturated soil moisture)	$ET_a - ET_{blue}$
	Landscape ET (ET_{land})	Actual ET from natural/unmanaged landscapes (ex-cludes Managed Water Use classes)	Overlay WA+ water management classes on the ET map; compute zonal statistics
	Utilized Flow (U_{flow})	Incremental ET from managed water use classes (irrigated crops, managed reservoirs)	ET_{blue} is estimated specifically for man-aged water use areas
Availability	Exploitable Water (E_{water})	Water potentially available for use within the basin	Net Inflow – ET_{land}
	Available Water	Water remaining after meet-ing ET and reserve flow re-quirements	Exploitable Water – Reserved Flows – Non-utilizable Water
Outflow	Surface Water Out-flow (Qsw_{out})	Outflow from the study region	In-situ hourly inter-basin water transfer data
	Reserved Outflow ($R_{outflow}$)	Surface water allocated for navigation and environmental needs	EWRf × Qsw_{out}
	Utilizable Outflow ($U_{outflow}$)	Water available for further use after meeting current demand	$E_{water} - R_{outflow} - U_{flow}$ – Non-utilizable Out-flow
	Non-recoverable Flow	Water lost to further use due to pollution	Grey Water Fraction × Qsw_{out}
Consumption	Non-consumed Water	Water remaining unconsumed after all uses	$U_{outflow} + R_{outflow}$ + Non-recoverable Flow
	Consumed Water (C_{water})	Water withdrawn from the basin via evaporation and pollution	Landscape ET + Utilized Flow

Annex 2. Long-term Average Annual Water Accounts (km3/yr) for Al-Qadisiyah Governorate for the Period 2010–2023



Annex 3. Long-term average annual water accounts (km3/yr) for Al-Muthanna governorate for the period 2010–2023



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