NORTH MACEDONIA

STUDY AND MAPPING OF WATER AND LAND ISSUES IN POLOG, PELAGONIJA AND VARDAR REGIONS

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The study draws on publicly available official data and peer-reviewed sources, including the State Statistical Office of North Macedonia, the Ministry of Agriculture, Forestry and Water Economy, the European Commission's annual Progress Reports, the regional planning region development centres, and the published databases of the Food and Agriculture Organization, the International Labour Organization, the World Bank, and the United Nations Development Programme. All data has been cross-referenced across independent sources and is accurate to the best of the author's knowledge as of the reporting period.

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Abbreviation	Full Term
CCKP	Climate Change Knowledge Portal (World Bank)
CMIP6	Coupled Model Intercomparison Project Phase 6 (IPCC / WCRP)
ET_o	Reference Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
GHCN	Global Historical Climatology Network (NOAA)
GPS	Global Positioning System
HH	Household
HMSNM	Hydrometeorological Service of North Macedonia (also referred to as UHMR)
IPCC	Intergovernmental Panel on Climate Change
IPCC AR6	IPCC Sixth Assessment Report (2021)
M&E	Monitoring and Evaluation
MAFWE	Ministry of Agriculture, Forestry and Water Economy (North Macedonia)
NCEI	National Centers for Environmental Information (NOAA)
NHMS	National Hydrometeorological Meteorological Service (see also HMSNM/UHMR)
NOAA	National Oceanic and Atmospheric Administration (United States)
NPK	Nitrogen, Phosphorus, Potassium (mineral fertiliser)
RWH	Rainwater Harvesting
SDG	Sustainable Development Goal (United Nations)
ToR	Terms of Reference
UHMR	Upraven Hidrometeoroski Biro na Republika Severna Makedonija (see HMSNM)
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
WMO	World Meteorological Organization

1. Introduction and Objectives

This report presents the hydrometeorological and community field assessment conducted as part of the Harvesting Hope project — Community Rainwater Systems & Gardening for Gender Justice — implemented by Institute Circle and Legis with funding from the Government of the Republic of Slovenia. It directly fulfils the primary objective of the Terms of Reference (Legis, 2025): to identify, analyse and map rural areas facing water and land challenges in the Polog, Pelagonija and Vardar Regions of North Macedonia, and to inform both the selection of project communities and the design of project activities under Results 1 and 2.

The report integrates two complementary evidence streams. The first is a quantitative hydrometeorological baseline compiled from the national agrometeorological monitoring network (UHMR H. S., n.d.) - operated by the Hydrometeorological Service of North Macedonia (HMSNM/UHMR) and from global historical climatological records maintained by National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) Global Historical Climatology Network (GHCN)-Monthly (NCEI, n.d.), peer-reviewed literature, and the FAO Agro-Ecological Atlas of North Macedonia (Aksoy, 2020). The second is a body of primary qualitative and quantitative field data collected during structured community interviews in all three project villages between 26 February and 25 March 2026 (Harvesting Hope Field Visit Summary 03/2026, 2026). The report also includes an annex of FAO agro-climatic and hydrometeorological maps of North Macedonia, providing the national spatial context for the regional and village-level analysis.

1.1 Specific Objectives

Following the ToR (Legis, 2025), this report addresses the following specific objectives:

- Evaluate the status and trends of water resources — availability, quality, and management practices — across the Polog, Pelagonija and Vardar regions, with reference to available station data from agrometeo.mk and HMSNM.
- Assess land use patterns, soil management practices, and land-related issues affecting agricultural productivity and household livelihoods in each study community.
- Identify the communities most vulnerable to water scarcity and land degradation across the three regions.
- Recommend community selections and inform the design of Results 1 (RWH systems) and 2 (sustainable gardening and training) based on integrated quantitative and qualitative evidence.

The study covers three regions — Polog, Pelagonija and Vardar — and three villages selected within them: Trebiste (Polog), Lazhani (Pelagonija), and Koreshnica (Vardar). The Vardar region was added to the scope following an initial assessment visit, which found that it better met the project's intervention criteria than the originally planned South-East region, and that the project would deliver higher added value to communities in the Vardar valley context.

1.2 Methodology

The study applied a mixed-methods approach combining secondary data review and primary community fieldwork, consistent with the methodology specified in the ToR.

Secondary data review encompassed national and regional hydrometeorological records from HMSNM (UHMR, 2021) and the agrometeo.mk agrometeorological platform (UHMR H. S., н.д.);

global historical climatological datasets from NOAA NCEI GHCN-Monthly for three reference stations (Tetovo, Bitola, Demir Kapija) (NCEI, н.д.); the FAO Agro-Ecological Atlas of North Macedonia for soil-water-crop parameter reference values (Aksoy, 2020); IPCC AR6 climate change projections (IPCC, 2021); the World Bank Climate Change Knowledge Portal for CMIP6 model outputs (CMIP6/WCRP, 2021); national policy and planning documents including the National Drought Plan (UNCCD, 2021) and the FAO Adaptation Fund proposal for the Strumica basin (FAO, 2022).

Primary data collection consisted of structured community interviews conducted in all three project villages using the Harvesting Hope Field Interview Template (Harvesting Hope Field Visit Summary 03/2026, 2026). A total of ten respondents participated across three visits: four at Trebiste (26 February 2026), three at Lazhani (6 March 2026), and three at Koreshnica (25 March 2026). Interviews covered five thematic domains - water access and supply, agriculture and soil practices, climate risk and smart agriculture, RWH system readiness, and community capacity and gender - using a 1–3 urgency scoring system to prioritise findings for the project report.

Three villages were selected across the three regions — Trebiste (Polog), Lazhani (Pelagonija), and Koreshnica (Vardar) — on the basis of fulfilling all four of the following site selection criteria:

- location in rural mountain or hilly terrain with documented seasonal water access challenge
- reliance on a single water source with no supplementary storage or backup supply, creating vulnerability during peak summer demand
- households with challenging socio-economic conditions and high dependency on subsistence or small-scale commercial agriculture
- community openness and readiness for piloting RWH systems, confirmed through local contacts and field visit engagement

> *Source note on field data: All primary field data cited throughout this document are drawn from the Harvesting Hope Field Visit Summary 03/2026 (Harvesting Hope Field Visit Summary 03/2026, 2026), collected by Filip Zaevski and Jasmina Golubovska. Question codes (A1–E4) refer to the Field Interview Template. Scores: 1 = adequate/positive baseline; 2 = partial gap; 3 = significant gap requiring direct project intervention.*

1.3 Justification for Regional and Village Selection

North Macedonia is divided into eight statistical and planning regions (see Figure 11 in Section 2). Three of these — Polog, Pelagonija and Vardar — are the focus of this study. The remaining five regions (Skopje, North-East, Eastern, South-East and South-West) were considered and set aside. The short comparison below substantiates that decision and positions the project's geographic scope in the context of documented national water- and land-related pressures.

Skopje Region. Predominantly urban and peri-urban, encompassing the national capital. The dominant water and land pressures are urban-infrastructure related — network losses, pollution of the Vardar and Treska river corridors, and urban land-use conversion (Eptisa, 2018). These do not correspond to the rural household-scale water-scarcity profile targeted by Results 1 and 2, and the region is therefore not a fit for the intended RWH pilot modality.

North-East Region. Characterised by moderate rainfall and mixed rural-industrial land use centred on Kumanovo. Water and land pressures are real but less acute than in the Vardar or Pelagonija basins, and the regional settlement pattern contains fewer of the isolated mountain or hilly villages with single-source water supply that define this project's site-selection criteria (Section 1.2).

Eastern Region. The Eastern planning region, centred on the Bregalnica basin, faces significant seasonal drought pressure and was the region originally listed in the project's scope as the "Eastern Region". Following the initial assessment visit it was not retained, for the reasons set out in the Eastern-to-Vardar substitution paragraph at the end of this section.

South-East Region. The South-East planning region, anchored on the Strumica and Gevgelija–Valandovo basins, faces water-scarcity pressure broadly comparable to Vardar at the climatic level, but differs sharply in its agricultural development profile. The Strumica basin is the country's principal vegetable and early-crop production area, with approximately 8,130 ha of arable land, and hosts a dense concentration of professional agribusinesses. The region is also the primary site for FAO climate-smart agriculture demonstration activities at the "Dimitar Vlahov" high school in Strumica, and is covered by a separate FAO Adaptation Fund project on water management in the Radovis/Strumica basin (FAO, 2022). Three considerations therefore weighed against the South-East region: (i) its established professional agricultural capacity provides a stronger baseline asset than the project villages, reducing per-beneficiary additionality; (ii) concurrent donor-funded water and climate interventions in the same geography create a duplication risk; and (iii) baseline access to commercial agricultural extension services is comparatively higher.

South-West Region. The South-West planning region is dominated by the Lake Ohrid, Prespa and Struga basins. It is a water-abundant setting in absolute terms, and its dominant environmental issues are water-quality, eutrophication and trans-boundary ecological management of the lake systems — not rural household irrigation scarcity. Household-scale RWH is therefore not the intervention that best addresses this region's pressing water challenges.

Why Polog, Pelagonija and Vardar are the appropriate selection.

Against this comparison, the three selected regions fulfil each of the four site-selection criteria set out in Section 1.2 more completely than any of the regions set aside, and together span the full national gradient of rural water stress visible in the FAO Agro-Ecological Atlas (Aksoy, 2020; see Annex maps A3–A5).

Polog (Trebiste). Represents the "humid mountain with declining snowpack" profile. At approximately 920 m a.s.l., the village sits in the Humid mountainous forest agro-climatic zone (Aksoy, 2020). Its structural vulnerability is the progressive decline of the snowmelt-fed mountain spring that serves as the only fallback to the piped network — a single-point-of-failure that the project directly addresses. Strong existing community governance and unanimous training willingness make Trebiste the best-suited pilot site for the project's collective governance model under Result 1.

Pelagonija (Lazhani). Represents the "dry-agriculture plain with inefficient irrigation" profile. The Pelagonija basin is documented by the FAO feasibility study for small-scale irrigation schemes (Eptisa, 2018) as characterised by ageing canal infrastructure with high seepage losses. Lazhani combines this structural inefficiency with the highest single-crop income dependency observed across the three villages (tobacco 60–80%) and an ethnically diverse community (Macedonian, Albanian, Turkish, Bosniak), giving the project strong relevance for crop-diversification and inclusion outcomes under Result 2.

Vardar (Koreshnica). Represents the "semi-arid rain-shadow valley" profile — the most water-stressed rural profile in the country. The Demir Kapija area is classified by the FAO Agro-Ecological Atlas as Semi-arid agriculture (Aksoy, 2020) and the Vardar valley is flagged as a priority drought-risk zone in the National Drought Plan (UNCCD, 2021). Koreshnica combines the most severe growing-season water deficit of the three villages with the highest per-unit impact potential, and it lies outside the geographic footprint of the FAO Adaptation Fund project (FAO, 2022).

Substitution of the Eastern Region with the Vardar Region.

The project's original scope included the Eastern Region (Bregalnica basin). Following the initial assessment visit, the scope was amended to include the Vardar Region instead, for three converging reasons. First, the Eastern Region and the adjacent Radovis–Strumica corridor are already covered by an active FAO Adaptation Fund project on climate-resilient water management (FAO, 2022), creating a clear duplication risk and reducing the project's marginal value in that geography. Second, the South-East planning region, which partly overlaps the Eastern water-scarcity profile, is the country's most agriculturally developed region and hosts the principal concentration of professional agribusinesses (Wikipedia: Agriculture in North Macedonia, 2026) (Centre for Development of the South-East Planning Region, 2026); the rural additionality gap there is therefore narrower than in the less-served villages of the Vardar valley. Third, the Vardar Region — and specifically the Demir Kapija area where Koreshnica is located — is warmer and drier than either the Eastern or South-East regions: Demir Kapija is recognised as the hottest town in North Macedonia, where the national all-time temperature record of 45.7 °C was set on 24 July 2007, and mean annual precipitation along the Vardar river is below 500 mm, among the lowest in the country (Wikipedia: Demir Kapija, 2026) (Macedonia Timeless, 2026) (Climate Data South-East, 2026). The combination of highest water stress, no concurrent donor intervention and strongest per-beneficiary additionality justifies the substitution.

2. National Water and Land Context

2.1 Water Resources — National Overview

North Macedonia faces significant and growing challenges in rural water resource management. Despite substantial geographic variation in precipitation - from approximately 400 mm per year in the south-eastern lowlands to over 1,000 mm in the north-western mountain areas (ClimateChangePost, 2020) - the temporal distribution of rainfall is structurally unfavorable for agriculture: approximately 60–65% of annual precipitation falls between October and March, outside the primary growing season (UNCCD, 2021). This creates a persistent structural imbalance between precipitation supply and agricultural demand that affects all three project regions.

The national agrometeorological monitoring platform agrometeo.mk, developed under an FAO project and operated by HMSNM/UHMR (UHMR, 2021), provides continuous data from three automatic agrometeorological stations at Tetovo, Slavej and Gradsko. These stations measure air temperature and humidity, precipitation, wind speed and direction, solar radiation, soil moisture at multiple depths, soil temperature, and calculate daily and monthly ET_0 using the FAO Penman-Monteith formula. The Gradsko station on the agrometeo.mk platform is the closest available agrometeorological station to the Demir Kapija area, while the HMSNM Kavadarci/Demir Kapija station records provide long-term climate data for the South-East project site at Koreshnica.

The HMSNM station network comprises 14 main meteorological stations, 16 climatological stations, and approximately 160 precipitation stations across the country. In addition to the agrometeo.mk network, flood risk monitoring in the Polog region was strengthened under UNDP projects with the installation of 4 automatic meteorological stations and 4 automatic hydrological stations, directly relevant to the Trebiste study area (UHMR H. S., n.d.).

2.2 Land Resources — Challenges and Pressures

Rural land management in North Macedonia faces a complex set of overlapping pressures that are acute in all three project regions. Land fragmentation is a structural constraint: average agricultural plot sizes in the Western Balkans are among the smallest in Europe, and North Macedonia is no exception (Eptisa, 2018). Field data confirm plot sizes ranging from 0.1–0.4 ha in the mountain zone (Trebiste) to 0.5–1 ha in the lowland zones (Lazhani and Koreshnica) (Harvesting Hope Field Visit

Summary 03/2026, 2026). This fragmentation limits investment in irrigation infrastructure, mechanisation, and water storage systems.

Soil degradation through erosion, salinisation, and nutrient depletion is documented across the three regions. In the Polog uplands, steep slopes and seasonal water erosion are the primary degradation drivers. In the Pelagonija plain, intensive furrow irrigation and limited composting practices contribute to soil compaction and organic matter depletion. In the Demir Kapija / Vardar valley area (South-East), reliance on individual water sources in the context of dry summers raises documented concerns about sustainable water access (FAO, 2022).

A positive shared baseline across all three selected villages is the complete absence of chemical pesticide use, confirmed by all respondents. This de facto organic status represents an underutilized asset for market differentiation and organic certification that the project can explicitly build upon under Result 2.

2.3 agrometeo.mk — National Agrometeorological Platform

The national agrometeorological monitoring and advisory platform agrometeo.mk is operated by HMSNM/UHMR and was developed with technical and financial support from the FAO project 'Increased resilience of the agricultural sector by promoting smart climate practices in agriculture' (UHMR H. S., n.d.). The platform (accessible at https://agrometeo.mk/stanici) provides public access to near-real-time and historical agrometeorological data from the three automatic monitoring stations.

The agrometeo.mk Gradsko station is the closest agrometeorological monitoring point to the Demir Kapija area. Key parameters available from this station and applicable to RWH system design and irrigation planning include: daily and monthly precipitation totals; daily maximum, minimum, and mean air temperature; reference evapotranspiration (ET_0) calculated by the Penman-Monteith method; soil moisture at 10 cm, 30 cm, and 60 cm depth; and daily solar radiation. The ET_0 data from this station, combined with precipitation records, allows the computation of the actual growing-season crop water deficit — the primary driver of RWH storage sizing at Koreshnica.

For Polog and Pelagonija data in this study therefore rely primarily on HMSNM main station records (Tetovo and Bitola respectively) from NOAA NCEI GHCN-Monthly (NCEI, n.d.) and published normals **(Climate Data Polog, 2026) (Weather & Climate, 2026)**.



Figure 11. Statistical and Planning Regions of North Macedonia. (Wikipedia, 2026)

Figure 11 shows the eight statistical and planning regions of North Macedonia. The three project regions are clearly identifiable: the Polog Region in the north-west (Trebiste village), the Pelagonia Region in the south-west (Lazhani village), and the Vardar Region centred on the Vardar valley around Demir Kapija (Koreshnica village). The geographic spread across three climatically and agro-ecologically distinct regions ensures that the project's findings and system designs are representative of the diversity of rural water challenges across North Macedonia.

3. Regional Hydrometeorological Profiles

3.1 Polog Region — Trebiste Village (~920 m a.s.l.)

3.1.1 Climate Classification and Station Data

The Polog region is characterised by a high-altitude enclosed valley in the north-west of North Macedonia, surrounded by the Shar Planina range (peaking above 2,700 m) to the north, Suva Gora to the south, and the Macedonian-Albanian border ranges to the west. This topography produces a humid continental to sub-Alpine climate (Köppen Cfb/Dfb) with considerable orographic enhancement of precipitation and significantly cooler temperatures than the national average. The nearest principal HMSNM monitoring station is at Tetovo (UHMR H. S., n.d.) (NOAA NCEI station ID 135710 (NCEI, n.d.)), at an elevation of 462 m above sea level, recording a mean annual temperature of 9.9°C and annual precipitation of approximately 995 mm. The village of Trebiste is located at approximately 920 m a.s.l. in the Municipality of Mavrovo and Rostusa.

Village-level hydrometeorological estimates are derived by applying two standard physical adjustments to the Tetovo station records: an orographic precipitation gradient of 50–80 mm per 100 m elevation gain, consistent with established Balkan mountain precipitation enhancement factors (Aksoy, 2020); and a temperature lapse rate of 0.6°C per 100 m elevation gain, consistent with the standard environmental lapse rate for humid mountain environments (UHMR, 2021). Applying these adjustments, Trebiste is estimated to receive approximately 1,100–1,350 mm of precipitation annually, with a mean annual temperature in the range of 8.9–9.5°C.

Parameter	Tetovo HMSNM Station (462 m)	Trebiste Village (~920 m) — Estimated
Mean Annual Temperature	9.9°C	~8.9–9.5°C
July Mean Max. Temperature	~26–28°C	~22–24°C
January Mean Min. Temperature	~-1.8°C	~-4.0 to -5.0°C
Mean Annual Precipitation	~995 mm	~1,100–1,350 mm
Growing Season Precip (Apr–Sep)	~420–460 mm	~500–580 mm
Growing Season ET_0 (Apr–Sep)	~620–660 mm	~570–610 mm (cooler at altitude)
Growing Season Water Deficit (ET_0-P)	~180–240 mm	~80–110 mm (lowest of 3 sites)
Annual Sunshine Hours	~2,748 hrs	~2,400–2,600 hrs
Snow Cover Period	Dec–Feb (valley)	Nov–Mar (extended at altitude)
Frost Risk Period	Nov–Apr	Nov–Apr (extended risk at altitude)
Annual Relative Humidity	~68–72%	~72–78% (higher at altitude)

Table 1. Hydrometeorological parameters — Trebiste, Polog region. (Aksoy, 2020) (NCEI, n.d.) (UHMR H. S., n.d.) (Climate Data Polog, 2026).

3.1.2 Monthly Precipitation Distribution

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
88	81	86	100	118	92	72	65	76	90	95	95
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm

Table 2. Mean monthly precipitation (mm) at Tetovo HMSNM reference station, 1991–2021 normals. Teal shading = growing/spring season (Apr–Sep); orange = peak summer dry period (Jul–Aug). (Aksoy, 2020) (NCEI, n.d.) (UHMR H. S., n.d.) (Climate Data Polog, 2026) (Weather & Climate, 2026).

3.1.3 Water Balance and RWH System Sizing Basis

The Polog region's water balance is characterised by adequate annual precipitation but a moderate growing-season deficit. The peak irrigation demand months are July and August, when precipitation averages approximately 65–72 mm at Tetovo and approximately 80–95 mm at Trebiste altitude, while daily ET_0 can reach 4.0–5.0 mm/day during this period. For a standard 80 m² rooftop catchment with a runoff coefficient of 0.80, annual RWH yield is estimated at approximately 70,000–86,000 litres. To bridge a two-month summer deficit for a household kitchen garden of approximately 50–80 m², a minimum storage volume of 1,000–2,000 litres is recommended. The critical structural vulnerability at Trebiste is not the current water deficit level per se, but the absence of any supplementary storage or backup supply — a zero-resilience baseline that the RWH system will directly address.

3.2 Pelagonija Region — Lazhani Village (~580 m a.s.l.)

3.2.1 Climate Classification and Station Data

The Pelagonija basin is the largest agricultural plain in North Macedonia, covering an area of approximately 1,200 km² at elevations of 580–660 m above sea level in the south-west of the country. The climate is classified as humid continental (Köppen Cfb), characterised by cold winters — with recorded absolute minima below -29°C at Bitola — and warm, moderately dry summers. The Bitola HMSNM reference station (NOAA NCEI station ID 135830, elevation 589 m) records a mean annual temperature of approximately 11.1°C and annual precipitation of approximately 709–748 mm (Climate Data Pelagonija, 2026) (NCEI, n.d.). The village of Lazhani in the Municipality of Dolneni is at approximately 580 m — virtually the same elevation as the Bitola station — permitting direct application of station data.

The Pelagonija basin is heavily agricultural, dominated by tobacco, vegetables, and cereals. It is also the site of some of North Macedonia's most significant irrigation infrastructure challenges: the FAO feasibility study for small-scale irrigation schemes (Eptisa, 2018) identified the Pelagonija basin as characterised by ageing and inefficient canal systems with high seepage losses — a finding directly corroborated by field observations at Lazhani (B4, score 3) (Harvesting Hope Field Visit Summary 03/2026, 2026).

Parameter	Bitola HMSNM Station (589 m)	Lazhani Village (~580 m) — Estimated
Mean Annual Temperature	11.1°C	~11.0–11.5°C
July/August Max. Temperature	27.6°C (July)	~27–29°C
Absolute Recorded Minimum	-29.4°C (January)	~-25 to -29°C
Mean Annual Precipitation	~709–748 mm	~700–750 mm
Growing Season Precip (Apr–Sep)	~280–340 mm	~285–340 mm
Growing Season ET_0 (Apr–Sep)	~600–640 mm	~600–640 mm (similar elevation)
Growing Season Water Deficit (ET_0-P)	~280–360 mm	~280–360 mm
Annual Rainy Days	~123–146 days	~120–145 days
Frost Risk Period	October–April	October–April

Table 3. Hydrometeorological parameters — Lazhani, Pelagonija region. (Aksoy, 2020) (NCEI, n.d.) (Climate Data Pelagonija, 2026).

3.2.2 Monthly Precipitation Distribution

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
53	48	62	75	82	58	42	34	40	62	71	72
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm

Table 4. Mean monthly precipitation (mm) at Bitola HMSNM reference station, 1991–2021 normals, representative of Lazhani. (Aksoy, 2020) (NCEI, n.d.) (Climate Data Pelagonija, 2026).

3.2.3 Water Balance and RWH System Sizing Basis

Pelagonija faces a significantly more severe growing-season water deficit than Polog. With approximately 280–340 mm of growing-season precipitation against ET_0 demands of 600–640 mm, the shortfall of approximately 280–360 mm per season requires supplementary irrigation. Tobacco — the dominant crop at Lazhani — requires approximately 300–500 mm of water per growing season, and the current reliance on furrow irrigation from an ageing, seepage-prone canal system

results in low field-level irrigation efficiency. For a standard 80 m² rooftop, estimated annual RWH yield is 45,000–48,000 litres. A minimum storage of 1,000-2,000 litres is recommended to bridge the peak summer deficit, though actual sizing will depend on the outcome of the planned roof catchment assessment and the crop water demands of the community garden plots.

3.3 Vardar Region — Koreshnica Village (~356 m a.s.l.)

3.3.1 Climate Classification, Demir Kapija / Gradsko Station Data, and Secondary Data

The South-East region, anchored around the Vardar valley at Demir Kapija, is the warmest, driest, and most climatically vulnerable of the three project regions. At approximately 356 m above sea level in the Municipality of Demir Kapija, Koreshnica sits at the lowest elevation of the three project villages, in the Vardar River gorge open to modified Mediterranean air masses from the south and sheltered by the surrounding limestone mountains characteristic of the Demir Kapija ravine. The climate is classified as transitional continental to sub-Mediterranean (Köppen Cfa/Cfb), characterised by hot, dry summers and mild, moderately wet winters.

The closest agrometeorological station on the agrometeo.mk platform to the Demir Kapija area is the Gradsko station, which records continuous measurements of precipitation, temperature, humidity, solar radiation, and soil moisture and provides daily ET_0 calculations by the Penman-Monteith method (UHMR H. S., n.d.). The Gradsko station is the closest available agrometeo.mk monitoring point to the Demir Kapija area, recording continuous agrometeorological parameters for the Vardar valley zone (UHMR, 2021). Long-term climatic data for the Demir Kapija area are available from the HMSNM Demir Kapija station (NOAA NCEI station ID 135920, elevation 126 m) and published climate normals, recording a mean annual temperature of approximately 13.5–14.5°C and annual precipitation of approximately 450–500 mm — among the lowest in North Macedonia, reflecting the rain shadow of the Vardar gorge **(Climate Data South-East, 2026)** (NCEI, n.d.) **(World Weather Online, 2026)**.

The FAO Adaptation Fund proposal for North Macedonia (FAO, 2022) identifies the Vardar valley zone including Demir Kapija as characterised by the highest temperatures in the country — Demir Kapija is noted as the hottest town in North Macedonia — with ET_0 levels approaching and exceeding 700 mm per year combined with mean annual precipitation below 500 mm by the Vardar river, producing a structural annual water deficit. This deficit is exacerbated by reliance on individual water extraction from limited local sources as the Vardar valley aquifer experiences seasonal pressure.

Parameter	Demir Kapija Area Station (~113 m)	Koreshnica Village (~356 m) — Estimated
Mean Annual Temperature	13.5–14.5°C	~13.5–14.5°C (marginally warmer)
July/August Max. Temperature	29–31°C	~30–32°C
Mean Annual Precipitation	~526–563 mm	~500–550 mm
Wettest Month (May)	~59 mm	~55–60 mm
Driest Months (Jul–Sep)	~32–37 mm/month	~28–35 mm/month
Growing Season Precip (Apr–Sep)	~220–260 mm	~210–250 mm
Annual ET_0 (Penman-Monteith)	~677 mm (basin avg.)	~700–760 mm (hotter at lower elev.)
Growing Season ET_0 (Apr–Sep)	~540–580 mm	~560–600 mm
Growing Season Water Deficit (ET_0-P)	~320–360 mm	~350–390 mm (HIGHEST of 3 sites)

Annual Sunshine Hours	~2,300–2,500 hrs	~2,400–2,600 hrs
Summer Drought Period (days with <1mm)	~85–100 days (Jul–Sep)	~90–110 days

Table 5. Hydrometeorological parameters — Koreshnica, Vardar region. Reference: Demir Kapija area climate data. (Aksoy, 2020) (NCEI, n.d.) (Climate Data South-East, 2026) (UHMR H. S., n.d.).

3.3.2 Monthly Precipitation Distribution

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
59	55	50	48	56	44	41	40	42	47	58	75
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm

Table 6. Mean monthly precipitation (mm) at Demir Kapija reference station (historical multi-year averages; Demir Kapija climate normals) (Climate Data South-East, 2026) (NCEI, n.d.) (World Weather Online, 2026) (UHMR H. S., n.d.).

3.3.3 Water Balance and RWH System Sizing Basis

Koreshnica faces by far the most severe water balance challenge of the three project villages. Annual ET_0 estimated at 700–780 mm substantially exceeds annual precipitation of approximately 450–500 mm at Demir Kapija elevations, yielding a chronic annual water deficit. The summer growing-season shortfall — with combined July to September precipitation of only 70–90 mm against ET_0 of approximately 360–400 mm for the same period — creates a 90–110-day window of near-zero replenishment in which the community is entirely dependent on supplementary water sources. The agrometeo.mk Gradsko station data and Demir Kapija climate records confirm the pattern of near-zero daily precipitation for extended summer periods, with August being the driest month, punctuated by episodic high-intensity events that are increasing in frequency under climate change (UHMR H. S., n.d.) (Press, 2021).

For an 80 m² rooftop at Koreshnica, annual RWH yield is estimated at approximately 32,000–35,000 litres — the lowest of the three sites, given the lowest precipitation. Given the intensity of vegetable irrigation demand, minimum recommended storage is 2,000–4,000 litres per household, with a combined individual system providing the most viable long-term solution. Drip irrigation conversion from current furrow and sprinkler systems is the single highest-impact water efficiency intervention available at this site.

4. Community Field Assessment Findings

4.1 Trebiste — Polog Region (26 February 2026)

Village profile: Trebiste, Municipality of Mavrovo and Rostusa; GPS 41°37'39.0"N 20°35'21.6"E; altitude ~920 m. Four respondents; Macedonian Muslim (Torbesi) community; 1 women-headed household. Population: 498 residents (Census 2021). Dominant agro-ecological zone: mountain. Interview conducted in Macedonian. Local contact: Enver Bilali.

4.1.1 Water Access and Supply

The village piped network is confirmed operational year-round for all households, but water pressure drops significantly during July and August — coinciding precisely with the climatological dry period and peak irrigation demand (A1, score 1 for agricultural shortages, within expected seasonal pattern). Critically, no backup supply infrastructure exists beyond a natural, unmanaged mountain spring located at a distance from the settlement (A4, score 3). This spring is the sole

alternative in the event of a network failure — a single-point-of-failure vulnerability. The spring's long-term reliability is structurally linked to winter snowpack levels in the surrounding ranges, and community members consistently report a progressive decline in snowpack accumulation over the past decade (C1, score 2), directly threatening this informal fallback.

No drinking water shortage was reported — domestic water supply remains stable year-round — and no rainwater collection is practiced by any household: neither informal containers nor any cistern or tank storage (A5, score 3). Collective reservoir tanks located outside the village perimeter are fed from the same mountain spring as the emergency fallback (A6, score 2). The absence of any supplementary water storage infrastructure means the community currently has zero resilience to supply disruption beyond what the piped network provides.

4.1.2 Agriculture, Land Use, and Soil

Agricultural plots are small and fragmented, ranging from 0.1–0.4 ha per household, consistent with the mountain zone profile documented in the FAO Agro-Ecological Atlas (Aksoy, 2020). The livestock holding — 100 sheep and chickens — provides a significant organic manure resource for soil fertility management. The primary crops are Mountain Tea (Sideritis scardica, the only commercial product, sold to herbal processors), tomatoes, strawberries, beans, and apples — primarily subsistence with Tea as the principal income crop (B1, score 1). Approximately 30% of households have off-farm employment.

Irrigation is predominantly gravity-fed furrow from a local river channel; one farmer has independently introduced drip irrigation for strawberries (B4, score 2) and represents a natural peer-trainer for the project's smart agriculture training. No chemical pesticides are used by any household (B6, score 1) — establishing a de facto organic baseline that should be formally documented as a pre-project asset. Organic fertiliser from livestock manure is used exclusively across all households (B7, score 1), though only one in five farmers currently composts formally; the remaining four apply raw manure without processing (B8, score 2). Permaculture is entirely unknown (B9, score 3), and only one in five respondents has basic knowledge of organic fertiliser production (B10, score 2).

4.1.3 Observed Climate Signals

Farmer-reported climate observations at Trebiste corroborate the quantitative hydrometeorological data with significant precision. The consistent decline in winter snowpack — reported as visible, progressive, and accelerating across the past decade — is scientifically consistent with the documented national mean temperature increase of approximately +1.0–1.2°C and with IPCC AR6 projections for accelerated snowpack reduction in continental European mountain zones below approximately 1,500 m (Press, 2021). Given that the community's informal water fallback depends on snowmelt-fed springs, this trend constitutes a near-term water security risk that grows more acute as snowpack continues to diminish.

Declining apple yields attributable to early spring flowering followed by late frost blossom damage (C3, score 2) represent direct, quantifiable farm-level evidence of climate-driven agricultural loss. This phenological disruption — early bloom plus late frost — is a characteristic signal of the 3–4 week seasonal temperature advance reported by respondents for tomato planting (C4, score 2) and is consistent with the documented trend in the Western Balkans mountain zones **(ClimateChangePost, 2020)**. The community is already self-adapting: earlier planting, use of drip irrigation by one farmer, and organic-only inputs collectively indicate an existing adaptive capacity that the project can accelerate and formalise.

The gender dimension of water management at Trebiste is the most important finding of the field visit. Women are responsible for water collection and daily irrigation management, with a reported

time burden of approximately 3–4 hours per day during the irrigation season (C6, score 3). This substantially exceeds the SDG 6 threshold of 30 minutes per day for acceptable water-related time burden, and in a household of 4–5 members operating a 0.1–0.4 ha plot, this represents a significant economic and welfare cost borne disproportionately by women (Harvesting Hope Field Visit Summary 03/2026, 2026).

4.1.4 Community Capacity, RWH Readiness, and Next Steps

Strong community cooperation is confirmed by all respondents and evidenced by an existing, functioning collective infrastructure for snow clearance, road maintenance, and shared field machinery (E3, score 1). All four respondents confirmed unconditional willingness to participate in permaculture and composting training, explicitly including household women (E4, score 1).

All four respondents confirmed willingness to maintain RWH infrastructure and to participate in water quality training (D1, score 1) (Harvesting Hope Field Visit Summary 03/2026, POLOG sheet, D1 = Yes). The Result 1 sustainability assessment is therefore complete for Trebiste. Agreed next steps: (1) pilot RWH installation for 2 households, prioritising the confirmed women-headed household and the household most dependent on the mountain spring; (2) composting and organic fertiliser training with the existing composting farmer as co-trainer; (3) roof assessment and a women-only focus group conducted as part of the project's inception-phase activities.

Code	Theme	Key Finding	Score
A1	Agricultural water shortage	July–Aug pressure drops; annual seasonal occurrence	**1**
A2	Drinking water shortage	No drinking water shortage — agricultural stress only	**1**
A4	Backup water source	Single unmanaged snowmelt-fed mountain spring; no structured backup	**3**
A5	Existing RWH practice	Zero collection across all households — full installation opportunity	**3**
B4	Irrigation method	Gravity furrow dominant; 1 farmer uses drip (peer training asset)	**2**
B6	Pesticide use	Zero chemical pesticides — de facto organic baseline	**1**
B8	Composting practice	1/5 farmers composts; 80% apply raw manure (20% pre-training baseline)	**2**
B9	Permaculture knowledge	Unknown to all respondents — clean baseline for Result 2	**3**
C1	Snowpack / rainfall change	Consistent annual snowpack decline observed; pace increasing	**2**
C3	Crop losses from climate	Apple yield decline: early bloom + late frost phenology disruption	**2**
C4	Planting calendar shift	Tomato planting 3–4 weeks earlier than a decade ago	**2**
C6	Gender — water burden	Women: ~3–4 hrs/day; substantially exceeds SDG 6 threshold (0.5 hrs/day)	**3**
E3	Community cooperation	Strong; shared collective machinery governance already operational	**1**
E4	Training willingness	4/4 confirmed; household women explicitly included	**1**

Table 7. Field assessment scores — Trebiste, Polog, 26 Feb 2026 (Harvesting Hope Field Visit Summary 03/2026, 2026). Score 1 = adequate/positive (green); 2 = medium gap (amber); 3 = high urgency (red).

Water Urgency	Community Openness	Recommended System	Overall Priority
2/5 — Seasonal/moderate.	5/5 — Exceptionally welcoming; all	Individual HH; min. 1,000 L tank. Pilot 2 HH —	2 — Medium-high: escalating climate risk +

Structural fragility rising with snowpack decline	respondents actively engaged	prioritise women-headed HH	strongest governance readiness

Table 8. Overall field assessment — Trebiste (Harvesting Hope Field Visit Summary 03/2026, 2026).

4.2 Lazhani — Pelagonija Region (6 March 2026)

Village profile: Lazhani, Municipality of Dolneni; GPS 41°26'32.2"N 21°18'46.3"E; altitude ~580 m. Three respondents; Macedonians, Albanians, Turks, Bosniaks; 1 women-headed household. Population: 1,755 residents (Census 2021). Dominant agro-ecological zone: continental (Pelagonija plain). Local contact: Adelaj.

4.2.1 Water Access and Supply

Lazhani presents an elevated water access urgency compared to Trebiste, with both agricultural and domestic water supply affected during summer months (A1, score 2; A2, score 2). The piped network reaches all households, but pressure drops significantly during the July–August peak irrigation period. Crucially, domestic water also becomes limited in some areas due to high combined network demand — a finding that distinguishes Lazhani from Trebiste, where only irrigation was affected. Households employ individually-dug hand wells (15–20 m depth) as informal backup supply, but these are unregulated and water quality is unverified (A4, score 2). No rainwater collection is practiced by any household (A5, score 3).

4.2.2 Agriculture, Land Use, and Soil

Lazhani is defined by a high degree of single-crop income dependency: tobacco constitutes 60–80% of household income for most respondents (B3, score 3). This represents the highest single-crop dependency of the three villages and creates significant climate exposure — tobacco yields fluctuate in both extreme drought and excessive rainfall years, creating a bimodal crop risk profile that the project's diversification component directly addresses. Plot sizes are 0.5–2 ha under tobacco with supplementary subsistence vegetables.

The irrigation infrastructure at Lazhani is the most problematic of the three sites from an efficiency perspective. Furrow irrigation from an ageing village canal system with documented seepage losses (B4, score 3) is consistent with the findings of the FAO irrigation feasibility study for Pelagonija **(Eptisa, 2018)**. Tobacco's growing season water requirement of approximately 400–600 mm combined with zero water conservation practices (no mulching, no drip, no cover crops) results in the highest irrigation water losses of the three sites. No composting is practised; permaculture and organic fertiliser production are entirely unknown (B8–B10, scores 3). No pesticides are used and organic manure from horse and cattle is applied (B6, score 1; B7, score 1).

4.2.3 Observed Climate Signals and Gender

Respondents at Lazhani identified drier summers, less predictable and reduced spring rainfall, and shortened winters relative to a decade ago (C1, score 2). The planting calendar has advanced by approximately one month — a stronger shift than reported at Trebiste and affecting both tobacco and vegetable crops (C4, score 2). This approximately one-month advance corresponds to a mean growing season temperature increase of approximately 1.5–2.0°C relative to the previous decade, broadly consistent with national and regional warming trends documented in the Second National Communication (UNFCCC, 2023) and confirmed by IPCC AR6 continental Europe projections **(Press, 2021)**.

Water management responsibilities at Lazhani are shared between men and women, but the specific time burden on women was not precisely quantified during the initial visit (C6, score 2). A women-only focus group will be conducted as an inception-phase activity under the project's M&E framework to fully characterise the gendered distribution of water and agricultural labour at this site; women's participation in Result 2 trainings is already confirmed (E4, score 1).

Code	Theme	Key Finding	Score
A1	Agricultural water shortage	July–Aug; higher urgency than Polog in lowland context	2
A2	Drinking water shortage	Both domestic and agricultural shortage in summer	2
A4	Backup water source	Individual hand-dug wells 15–20 m — unregulated, unverified quality	2
A5	Existing RWH practice	Zero rainwater collection — full installation opportunity	3
B3	Agricultural income	Tobacco: 60–80% of HH budget — highest single-crop dependency of 3 sites	3
B4	Irrigation method	Furrow from ageing canal with seepage losses; zero conservation measures	3
B6	Pesticide use	No pesticides reported	1
B8	Composting practice	Zero composting — abundant organic waste from livestock/crop residues	3
B9	Permaculture knowledge	Unknown to all respondents	3
B10	Organic fertiliser knowledge	Zero knowledge — significant training need	3
C1	Climate signals	Drier summers, reduced spring rain, shorter winters — drought trend	2
C4	Planting calendar shift	~1 month earlier — stronger shift than Trebiste	2
C5	Water conservation	Tobacco 400–600 mm/season; zero conservation measures	3
C6	Gender — water burden	Shared burden; women's time to be quantified at inception-phase focus group	2
D1	RWH training willingness	All 3 respondents confirmed — high Result 1 readiness	1
E3	Community cooperation	Municipal governance channel — formal coordination available	1
E4	Training willingness	All confirmed; women's participation explicitly included	1

Table 9. Field assessment scores — Lazhani, Pelagonija, 6 Mar 2026 (Harvesting Hope Field Visit Summary 03/2026, 2026).

Water Urgency	Community Openness	Recommended System	Overall Priority
3/5 — Medium-high: agricultural + domestic shortage	5/5 — Very welcoming and engaged	Communal or cluster system. The tank would be approximately 4,000 liters intended for several families in close proximity.	2 — Medium-high: irrigation efficiency + crop diversification urgency

Table 10. Overall field assessment — Lazhani (Harvesting Hope Field Visit Summary 03/2026, 2026).

4.3 Koreshnica — Vardar Region (25 March 2026)

Village profile: Koreshnica, Municipality of Demir Kapija; GPS 41°26'00"N 22°14'11"E; altitude ~356 m. Three respondents; mixed community (Turks, Serbs, Macedonians); 1 women-headed

household. Population: ~500 residents. Dominant agro-ecological zone: transitional Mediterranean (Vardar valley / Demir Kapija gorge).

4.3.1 Water Access and Supply — Most Acute Site

Koreshnica presents the highest water access urgency (4/5) of the three project villages. The severity is multi-dimensional: some areas of the village have no water at all during June, July and August (A1, score 3), and both agricultural and domestic/technical water supply fail during peak summer months — with only the drinking water source (a mountain spring stored in a communal reservoir) remaining stable year-round (A2, score 3). The complete cessation of irrigation water supply during the peak tobacco, grapes growing period represents a direct threat to household income.

All households rely on privately drilled boreholes (15–20 m depth) as individual backup supply (A4, score 2). Widespread borehole use is providing a temporary coping mechanism but is contributing to groundwater pressure in the Demir Kapija area **(FAO, 2022)**. The agrometeo.mk Gradsko station and Demir Kapija climate records provide an instrumental record of the rainfall gaps during the extended dry period - typically a continuous period of 85–110 days with near-zero daily precipitation from late June to late September (UHMR H. S., n.d.). No rainwater collection is practised by any household (A5, score 3), representing both the highest urgency RWH installation site and the greatest potential per-unit water security impact of the three villages.

4.3.2 Agriculture, Land Use, and Soil

Tobacco, grapes dominate also spinach, onion and lettuce as secondary the agricultural system at Koreshnica, accounting for 60-90% of household income — the highest agricultural income dependency of the three sites (B3, score 3). Tobacco, grapes (main cash crop, sold at market and to processors), also spinach, onion and lettuce as secondary crops. Plot sizes of 0.5–3 ha is intensively cultivated. This high income dependency on a single highly water-sensitive and temperature-sensitive crop creates severe exposure to climate-driven crop failure.

Koreshnica is the only project site using synthetic fertiliser inputs — NPK mineral crystals are combined with animal manure (B7, score 2) — distinguishing it from the fully organic practice at Trebiste and Lazhani. All properties irrigate using potable water with some draw-off systems (B4, score 3); vegetables identified as the most water-intensive crop but no moisture conservation measures — no mulching, drip irrigation, or cover crops — are employed. Drip irrigation conversion represents the single highest-impact smart agriculture intervention available at this site, and the project's training component should prioritise this. No composting is practised and organic waste from crop residues is ploughed back into the soil without structured processing (B8, score 3). Permaculture and organic fertiliser production methods are entirely unknown (B9, score 3; B10, score 3).

4.3.3 Observed Climate Signals — Most Complex Risk Profile

Koreshnica exhibits the most complex and severe climate risk profile of the three villages. Respondents clearly identified both intensified drought conditions and sudden, high-intensity rainfall events as observed phenomena in recent years (C1, score 3). This bimodal signal — drought intensification combined with extreme precipitation events — is the most challenging climate risk pattern for RWH system design, requiring both high storage capacity (to buffer the extended dry period) and overflow/first-flush management infrastructure (to handle peak flow events safely).

The planting calendar has shifted by 1–2 months earlier than a decade ago (C4, score 3) — the strongest documented seasonal shift of the three villages. This advance corresponds to a mean

growing-season warming of approximately 2.0–3.0°C relative to conditions 10 years ago, broadly consistent with the national trend but at the upper bound, reflecting the amplified warming signal in low-elevation south-eastern areas that are already warmer and drier than the national average (ClimateChangePost, 2020) (UNFCCC, 2023). Crop losses from both extreme drought and excessive rainfall were reported for tobacco, grapes (C3, score 3), reinforcing the bimodal risk narrative.

Irrigation management at Koreshnica is primarily carried out by men (husbands) as an all-day activity during the growing season (C6, score 2). A women-only focus group will be conducted as an inception-phase activity under the project's M&E framework to assess whether women's domestic water burden has been underreported — a common finding in communities where men control agricultural water management; women's participation in Result 2 trainings is already confirmed (E4, score 1).

4.3.4 Community Capacity, RWH Readiness, and Next Steps

Koreshnica has an established informal cooperative irrigation practice: neighboring households alternate irrigation scheduling and assist each other with water management during the growing season (E3, score 1). This cooperative irrigation governance — already functioning without formal institutional structures — provides an excellent practical foundation for a communal or cluster RWH system. All respondents confirmed willingness to participate in RWH maintenance training (D1, score 1) and all confirmed women's participation in training activities (E4, score 1).

The FAO Adaptation Fund project for the Radovis municipality in the neighboring south-eastern region (FAO, 2022) was identified at the field visit as a relevant precedent for community-based water management — a precedent the project team should review and incorporate into the Koreshnica system design and community governance planning.

Code	Theme	Key Finding	Score
A1	Agricultural water shortage	MOST ACUTE: some areas have no water at all Jun–Aug	**3**
A2	Drinking water shortage	Technical water fails in peak months; drinking source stable	**3**
A4	Backup water source	Individual boreholes 15–20 m — unsustainable extraction trend documented	**2**
A5	Existing RWH practice	Zero collection — highest-urgency RWH installation site	**3**
B3	Agricultural income	tobacco, grapes: 60–90% of HH budget — highest climate exposure of 3 sites	**3**
B4	Irrigation method	Furrow + partial sprinkler; no conservation measures — critical gap	**3**
B6	Pesticide use	No pesticides reported — positive baseline	**1**
B7	Fertiliser type	Mixed: NPK minerals + manure — only site with synthetic inputs	**2**
B8	Composting practice	Zero — large post-harvest vegetable waste stream underutilised	**3**
B9	Permaculture knowledge	Unknown — consistent across all three villages	**3**
C1	Climate signals	Bimodal: drought intensification AND sudden heavy rainfall — highest complexity	**3**
C3	Crop losses	Losses from drought AND flooding — bimodal risk for vegetables	**3**
C4	Planting calendar shift	1–2 months earlier — STRONGEST shift of the three villages	**3**

C5	Water conservation	Vegetables most water-intensive; zero conservation measures	**3**
C6	Gender — water burden	Men dominant in irrigation; women's role to be assessed at inception-phase focus group	**2**
D1	RWH training willingness	All 3 respondents confirmed — highest Result 1 readiness	**1**
E3	Community cooperation	Alternating irrigation scheduling already practised informally	**1**
E4	Training willingness	All confirmed; women's participation included	**1**

Table 11. Field assessment scores — Koreshnica, South-East, 9 Mar 2026 (Harvesting Hope Field Visit Summary 03/2026, 2026).

Water Urgency	Community Openness	Recommended System	Overall Priority
4/5 — High: agricultural + domestic; most severe of 3 villages	5/5 — Very welcoming and engaged	Individual 2,000–4,000 L; combine with drip irrigation training	1 — HIGHEST PRIORITY: most severe water stress + strongest and most complex climate signals

Table 12. Overall field assessment — Koreshnica (Harvesting Hope Field Visit Summary 03/2026, 2026).

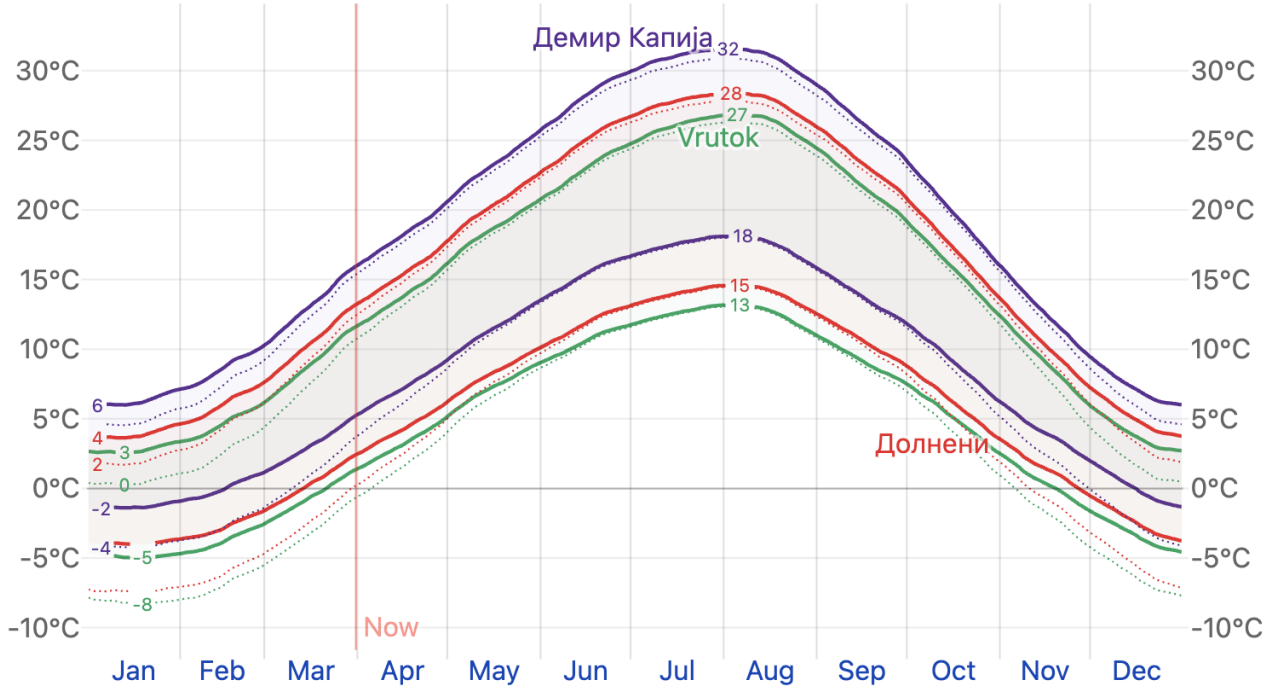


Figure 1. Average Daily High and Low Temperature — Demir Kapija, Vrutok, and Dolneni. (Weather Spark, 2026).

Figure 1 shows the average daily high and low temperatures throughout the year for the three reference locations closest to the project villages. Demir Kapija (serving Koreshnica, South-East) is consistently the warmest of the three locations, with summer highs reaching 32°C in August and winter lows averaging around -2°C in January — the mildest winter minimum of the three sites, reflecting its transitional Mediterranean character in the Vardar gorge. Dolneni (serving Lazhani, Pelagonija) occupies the middle range, with summer highs peaking at 28°C in August and January lows around -4°C. Vrutok (serving Trebiste, Polog) is the coolest, with summer highs of 27°C in August and winter lows dropping to -5°C to -8°C. This clear temperature gradient — 5°C between Demir Kapija and Vrutok at peak summer — directly shapes the length and intensity of the growing

and irrigation season across the three project sites, and underpins the significantly higher ET_0 and water deficit calculated for Koreshnica relative to Trebiste.

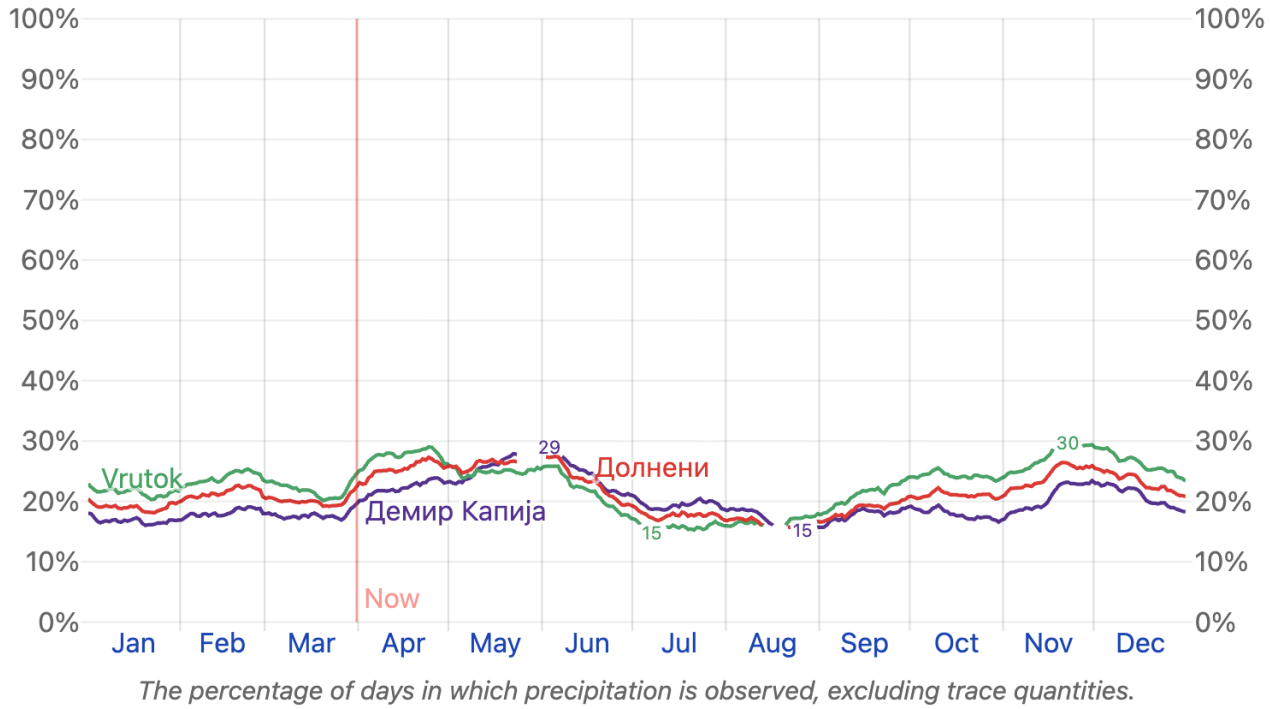


Figure 2. Daily Chance of Precipitation — Demir Kapija, Vrutok, and Dolneni. (Weather Spark, 2026).

Figure 2 shows the daily probability of measurable precipitation throughout the year. All three locations maintain a broadly consistent 15–30% daily chance of precipitation, but with a notable pattern: Demir Kapija consistently registers the lowest probability of all three sites, remaining in the 15–20% range year-round and dropping to around 15% in July–August and again in September. Vrutok (Polog) and Dolneni (Pelagonija) run higher, peaking at approximately 29–30% in late May–June and in November respectively. This means Koreshnica not only receives the least total rainfall (Figure 3), but also experiences the fewest rain days, making individual events more sporadic and the case for storage capture stronger. Even at the summer minimum, precipitation events do occur across all three sites — but as Figure 3 confirms, their accumulated volume is negligible during the critical July–September window, reinforcing the essential role of rainwater storage infrastructure.

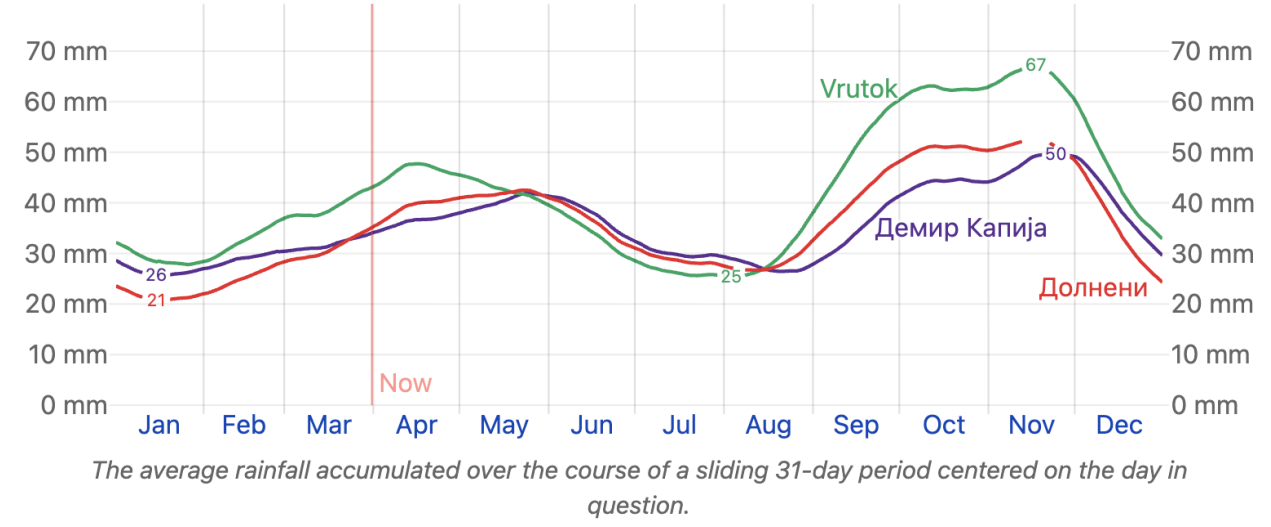


Figure 3. Average Monthly Rainfall — Demir Kapija, Vrutok, and Dolneni. (Weather Spark, 2026).

Figure 3 compares average monthly rainfall accumulation across the three reference locations. Vrutok (Polog) receives by far the most rainfall, with a pronounced autumn peak reaching 67 mm in

November, driven by orographic enhancement from the Shar Planina range. Demir Kapija and Dolneni display broadly similar bimodal patterns — a spring peak around April–May (~40–42 mm) and an autumn recovery — but at consistently lower totals than Vrutok. Both Demir Kapija and Dolneni reach their minimum in August at approximately 25 mm per month, with Demir Kapija registering 26 mm in January and a November peak of around 50 mm. Importantly, Demir Kapija's overall annual rainfall profile closely mirrors Dolneni's at the monthly scale, though with a slightly lower January baseline (26 mm vs 21 mm for Dolneni). These seasonal patterns define the rainwater harvesting window: the spring rains (April–May) and autumn recovery (October–November) represent the primary capture opportunities, while the July–August trough of ~25 mm across all three sites creates the critical gap that RWH storage must bridge.

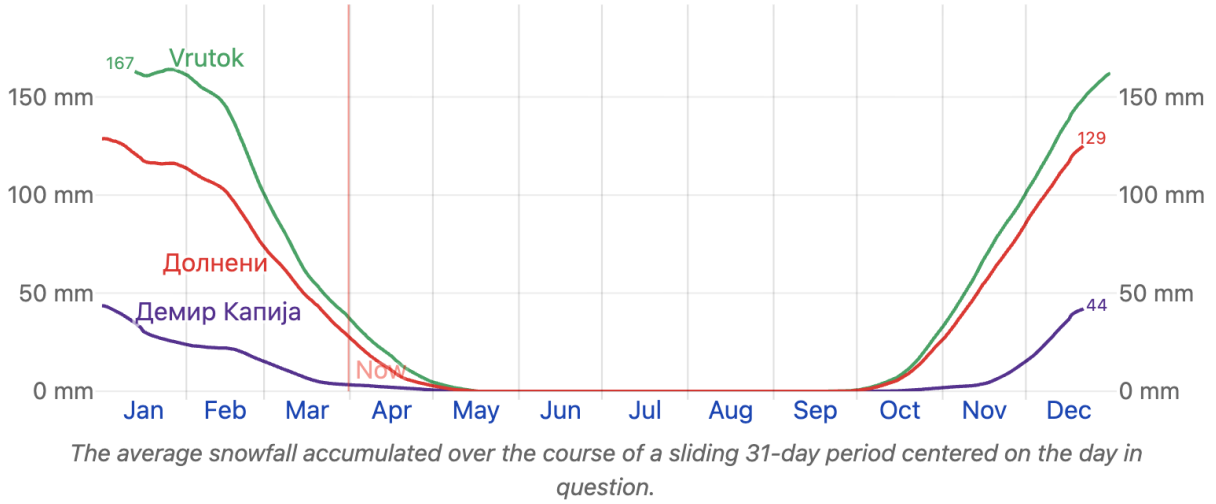


Figure 4. Average Monthly Snowfall

Figure 4. Average Monthly Snowfall — Demir Kapija, Vrutok, and Dolneni. (Weather Spark, 2026)

Figure 4 reveals the stark contrasts in snowfall between the three reference locations. Vrutok (Polog, ~920 m a.s.l.) receives substantial snowfall from November through March, peaking at approximately 167 mm per month in January — the highest snow accumulation of the three sites by a wide margin. This snowpack is the primary feed for the mountain springs that serve as Trebiste's emergency water fallback, and its progressive decline as reported by community members represents a growing structural risk to village water security. Dolneni (Pelagonija) also receives significant snowfall, peaking at 129 mm in December and maintaining measurable snow cover through April, reflecting the Pelagonija basin's cold continental winters. Demir Kapija (South-East) stands in sharp contrast: snowfall is near-zero from April through November, and even at peak winter it reaches only approximately 44 mm in December — less than one-third of Dolneni's peak and less than one-quarter of Vrutok's. This near-absence of snowfall at Koreshnica confirms its transitional Mediterranean character, removes any snowmelt contribution to local water supply, and means RWH tanks can be designed for surface installation year-round without frost-proofing requirements, unlike Trebiste where insulated or buried tanks are essential.

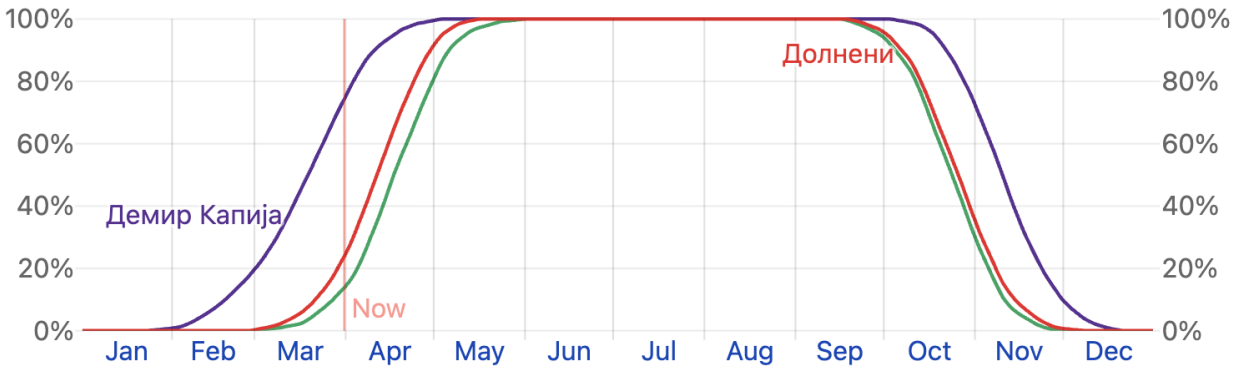


Figure 5. Growing Season Length — Demir Kapija, Vrutok, and Dolneni. (Weather Spark, 2026).

Figure 5 shows the probability that a given day falls within the growing season, defined as the longest continuous frost-free period (temperatures ≥ 0°C). Demir Kapija has by far the longest growing season of the three locations, reaching 100% frost-free probability from late March and maintaining that through late September — a growing window of approximately seven to eight months. Dolneni (Pelagonija) follows a near-identical onset curve but exits the growing season slightly earlier in autumn, around mid-October. Vrutok (Polog) has the shortest and latest growing season, beginning approximately three to four weeks after Demir Kapija in spring and ending earlier in autumn, reflecting its higher altitude. This extended frost-free window drives the high irrigation demand for spinach, onion lettuce and тobacco, grapes at Koreshnica and explains the village's severe water deficit relative to the other two sites. The progressive advance in growing season onset reported by farmers at all three sites — 1–2 months earlier than a decade ago at Koreshnica, approximately one month at Lazhani, and 3–4 weeks at Trebiste — is consistent with the warming trend visible across this metric, and underscores the urgency of water storage infrastructure as the irrigation season continues to lengthen.

5. Comparative Analysis — Three Project Villages

5.1 Water Stress and Hydrometeorological Comparison

The three project villages represent a clear gradient of water stress from moderate-and-escalating (Trebiste, Polog) through significant (Lazhani, Pelagonija) to severe-and-acute (Koreshnica, South-East). This gradient is directly reflected in the hydrometeorological data: annual precipitation decreases from an estimated 1,100–1,350 mm at Trebiste to 700–750 mm at Lazhani and 500–550 mm at Koreshnica, while ET_0 increases with decreasing altitude and increasing temperature. The resulting growing-season water deficit — the most operationally critical parameter for RWH system sizing — spans from approximately 80–110 mm at Trebiste to 280–360 mm at Lazhani and 350–390 mm at Koreshnica.

The zero-baseline for rainwater collection is consistent across all three villages: no household in any of the three communities currently practices any form of RWH. This confirms that the project is not duplicating existing practice and that installation and awareness-raising activities can proceed without conflict with current water management norms.

Parameter	Trebiste — Polog (~920 m)	Lazhani — Pelagonija (~580 m)	Koreshnica — South-East (~356 m)
Field visit date	26 Feb 2026	6 Mar 2026	25 Mar 2026

Population	~150	1,755 (Census 2021)	505 (Census 2021)
Annual Precipitation	**~1,100–1,350 mm (HIGHEST)**	~700–750 mm	**~500–550 mm (LOWEST)**
Annual ET_0	~580–640 mm	~630–680 mm	~700–760 mm (HIGHEST)
Growing Season Water Deficit	~80–110 mm (lowest)	~280–360 mm	~350–390 mm (MOST SEVERE)
agrometeo.mk station coverage	HMSNM Tetovo primary	Indirect (Gradsko); HMSNM Bitola primary	Gradsko agrometeo.mk station (nearest); Demir Kapija HMSNM data
Estimated Annual RWH Yield (80 m²)	~70,000–86,000 L/yr	~45,000–48,000 L/yr	~32,000–35,000 L/yr
Recommended Min. Storage	1,000–2,000 L	1,000–3,000 L	2,000–4,000 L
Water Urgency Rating	2/5 — Seasonal/moderate	3/5 — Medium-high	4/5 — HIGH
Main commercial crop	Mountain Tea (*Sideritis scardica*)	Tobacco (60–80% income)	tobacco, grapes (60–90% income)
Planting calendar shift	3–4 weeks earlier	~1 month earlier	1–2 months earlier (STRONGEST)
Primary gener water burden	Women: 3–4 hrs/day (SDG 6 exceeded)	Shared — to be quantified at inception phase	Men dominant — women's role to be assessed at inception phase
Zero pesticide use	YES — all households	YES — all households	YES — all households
Overall Installation Priority	2 — Medium-high	2 — Medium-high	1 — HIGHEST

Table 13. Comparative summary — three project villages (Harvesting Hope Field Visit Summary 03/2026, 2026) (Aksoy, 2020) (Climate Data Polog, 2026) (UHMR H. S., n.d.) (Weather Spark, 2026).

5.2 Comparative Climate Charts — Three Project Locations

The five charts below compare weather patterns across the three reference locations closest to the project villages — Demir Kapija (South-East / Koreshnica), Dolneni (Pelagonija / Lazhani), and Vrutok (Polog / Trebiste). Together they illustrate the temperature gradient, precipitation regime, snowfall differences, and growing season lengths that underpin the comparative water stress analysis and the differentiated RWH system recommendations in Section 8. Demir Kapija is used as a reference, providing a more accurate climatic representation of the Koreshnica project site in the Vardar valley. (Weather Spark, 2026). Together they illustrate the temperature gradient, precipitation regime, snowfall differences, and growing season lengths that underpin the comparative water stress analysis and the differentiated RWH system recommendations in Section 8.

6. Climate Change Projections and Implications

6.1 Temperature Projections

Climate projections for North Macedonia derived from CMIP6 multi-model ensembles (Bank, 2021) and the Fourth National Communication **(UNFCCC, 2023)** indicate consistent warming across all three project regions: approximately +1.0–1.1°C above the 1961–1990 baseline by 2025–2030; +1.9–2.2°C by mid-century (2050) under intermediate scenarios (SSP2-4.5); and +2.9–5.4°C by end-of-century (2100) under high-emission scenarios (SSP5-8.5) (Press, 2021). The summer

season is projected to experience the largest absolute increases, with southern and low-elevation regions such as the Vardar valley at Demir Kapija at greatest risk of exceeding human and agricultural heat thresholds — Demir Kapija is already noted as the hottest town in North Macedonia.

The farmer-reported planting calendar advances recorded across all three villages provide community-level quantitative corroboration of the temperature trend already in progress: 3–4 weeks at Trebiste, approximately one month at Lazhani, and 1–2 months at Koreshnica — a gradient precisely consistent with the south-to-north decrease in baseline temperature and the amplification of warming at lower elevations (Harvesting Hope Field Visit Summary 03/2026, 2026). These observations, recorded independently by farmers in three geographically separated communities, substantially strengthen the project's evidence base for climate change impact.

6.2 Precipitation and Drought Trends

Precipitation projections from CMIP6 models indicate decreasing summer and growing-season rainfall across all three regions **(Bank, 2021)**, with the largest reductions expected in the south-east — precisely the most vulnerable current site. The IPCC AR6 (Press, 2021) identifies *medium-to-high confidence* in increased drought frequency, duration, and intensity for southern and south-eastern Europe, extending directly to North Macedonia's continental and sub-Mediterranean zones. The National Drought Plan (UNCCD, 2021) designates the Vardar valley and south-eastern lowlands as priority drought risk zones at the national level.

For Koreshnica, the already severe growing-season water deficit of approximately 350–390 mm is projected to increase toward 420–480 mm by mid-century under intermediate warming scenarios — a 20–25% increase that would extend the annual dry gap from approximately 90–110 days to potentially 110–130 days (Bank, 2021) (FAO, 2022). For Lazhani, the seasonal water deficit may expand from 280–360 mm to approximately 350–420 mm by 2050. For Trebiste, the primary risk is not increased summer deficit per se, but the progressive loss of the snowmelt-fed spring fallback as winter snowpack continues to decline — a qualitative shift in supply resilience rather than a quantitative increase in the current deficit.

6.3 Extreme Events and RWH Design Implications

IPCC AR6 (Press, 2021) projects increasing frequency of both extended dry periods and high-intensity precipitation events across the region — the bimodal signal that Koreshnica respondents have already observed **(Harvesting Hope Field Visit Summary 03/2026, 2026)**. For RWH system design, this has four direct implications:

- Overflow management: Systems must be engineered to handle single-event precipitation of 30–50 mm/hour without roof or storage overflow, including first-flush diverters and overflow bypass pipes.
- Storage safety margin: RWH storage volumes calculated from historical climatological averages should incorporate a 20–30% safety margin to account for increasing inter-event dry periods and reduced recharge frequency in a changing climate
- Longevity of design parameters: Designs based on 1991–2021 normals should be reviewed and updated at the project's mid-term evaluation (2027) using the most recent agrometeo.mk station data
- Snowpack monitoring for Trebiste: The agrometeo.mk platform should be extended to include a monitoring point in the Polog mountain zone to provide instrumental, continuous

snowpack and temperature data that can quantify the rate of spring flow decline from the community's fallback spring.

7. Vulnerability Assessment and Priority Ranking

7.1 Vulnerability Framework

Vulnerability to water scarcity and land degradation in the project context is assessed as the interaction of three dimensions: exposure (the degree to which a community is subject to water stress and climate hazards based on physical conditions), sensitivity (the degree to which a community depends on reliable water access and agricultural productivity), and adaptive capacity (the degree to which the community can manage and respond to water stress through existing resources, governance, and practices). This framework is consistent with the IPCC AR6 vulnerability framework **(Press, 2021)** and with the ToR specification that priority should go to communities where long-term sustainability and project upgrade potential can be ensured.

7.2 Priority Ranking and Justification

Village	Exposure	Sensitivity	Adaptive Capacity	Priority Assessment
Koreshnica	VERY HIGH: severe deficit, 90–110 dry days, borehole depletion, bimodal climate risk	VERY HIGH: 60–90% income from single water-dependent crop; domestic water fails in summer	MODERATE: cooperative irrigation norms; full RWH training readiness; formal collective governance to be established as an inception-phase activity	**PRIORITY 1 — Highest urgency and highest potential impact. Immediate installation recommended.**
Lazhani	HIGH: significant deficit 280–360 mm; domestic + agricultural shortage; irrigation inefficiency	HIGH: 60–80% income from tobacco; domestic supply affected in summer	MODERATE-GOOD: municipal governance channel; full RWH training readiness; zero composting baseline	PRIORITY 2 — Medium-high urgency. Install concurrently with Trebiste; system sizing to be finalised following inception-phase roof assessment.
Trebiste	MODERATE but rising: snowpack decline threatens spring fallback; seasonal summer pressure drops	MODERATE: mixed crop portfolio; mountain spring fallback declining; domestic supply currently stable	HIGH: strongest existing governance; unanimous training willingness; 1 drip adopter; 1 composter	PRIORITY 2 — Moderate urgency rising with climate change. Best pilot site for system governance model.

Table 14. Vulnerability-based priority ranking — three project villages (Aksoy, 2020) (Harvesting Hope Field Visit Summary 03/2026, 2026) (UHMR H. S., n.d.) (Weather Spark, 2026) (NCEI, n.d.).

8. Recommendations

8.1 Community Selection and Installation Sequencing

Based on the integrated hydrometeorological analysis and community field assessment, the following community selection and installation sequencing is recommended:

Priority 1 — Koreshnica (South-East): Immediate Installation

Koreshnica should be the first village to receive a full RWH system installation under Result 1. The combination of the most severe multi-dimensional water stress (water urgency 4/5), the highest

agricultural income dependency on a climate-sensitive single crop, the strongest and most complex climate signals already manifesting, and confirmed RWH training readiness across all respondents makes Koreshnica the highest-impact installation site. The recommended system is an individual with a minimum tank capacity of 2,000–4,000 litres per household, sized to account for the 90–110 day summer dry period documented by Demir Kapija area climate records and the agrometeo.mk Gradsko station data (UHMR H. S., n.d.). System design should incorporate first-flush diverters and overflow infrastructure to manage the high-intensity rainfall events that are increasingly frequent in the Vardar valley zone. Drip irrigation conversion from current furrow and sprinkler systems should be integrated into the installation as the single highest-impact smart agriculture measure available.

Priority 2 — Lazhani (Pelagonija) and Trebiste (Polog): Concurrent

Lazhani and Trebiste should be installed concurrently as the second implementation phase. Lazhani requires a communal or cluster system. The tank would be approximately 4,000 liters intended for several families in proximity. The framing of the project at Lazhani must explicitly address crop diversification as a risk reduction strategy — single-crop tobacco dependency is the primary contextual risk and the project's training component provides the most credible pathway toward diversification. Trebiste, with the highest community governance capacity and the strongest training readiness baseline among the three villages, is recommended as the primary governance model demonstration site — the approach to collective system management developed at Trebiste should be documented and adapted for the other two villages.

8.2 Gender-Responsive Design Requirements

- The 3–4 hour daily water burden on women at Trebiste must be explicitly addressed in the system design: the RWH system should be installed within or immediately adjacent to the household compound (not at a remote communal point) to eliminate collection time as the primary beneficiary action.
- Women-only focus groups are required at Lazhani and Koreshnica before installation to assess the gendered water burden baseline, inform gender-sensitive placement of infrastructure, and ensure women are primary participants in the maintenance training programme.
- Training schedules for all three villages must accommodate women's existing time constraints — sessions should be planned at times identified through the focus groups as available for women, not defaulting to standard working hours.
- Post-installation M&E must include measurement of the reduction in women's daily water collection and management time as a primary gender impact indicator, with the SDG 6 threshold of 30 minutes/day as the target benchmark.

8.3 Result 2 — Training and Capacity Building Priorities

- Composting training is the highest priority Result 2 activity at Lazhani and Koreshnica, where composting practice is completely absent despite abundant organic waste from livestock and crop residues. The Trebiste farmer who currently composts (1/5 farmers, 20% pre-training baseline) should be invited as a peer trainer for cross-village knowledge exchange sessions.
- Zero pesticide use across all three villages is a shared pre-existing asset that should be formally documented before training begins and leveraged as the baseline for organic certification pathways. Mountain Tea certification at Trebiste and grapes organic certification at Koreshnica represent specific near-term market opportunities.

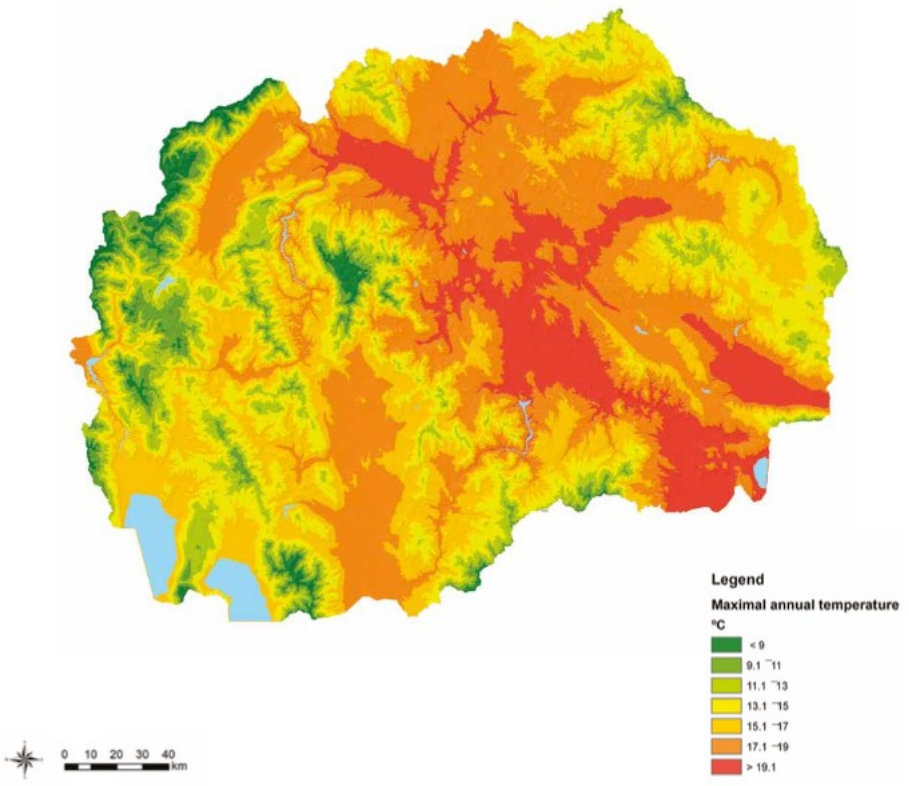
- Drip irrigation transition at Koreshnica should be the primary smart agriculture training module — the Trebiste farmer already using drip provides a local demonstration case. The agrometeo.mk Gradsko station ET_0 data
- Seed-saving and climate-resilient variety training is relevant at Trebiste (local tomato and bean varieties are maintained) and Koreshnica (bell pepper seeds are self-propagated). These traditional seed systems represent a climate adaptation asset that the project should preserve and strengthen.

8.4 Data and Monitoring Recommendations

- The agrometeo.mk Gradsko station and Demir Kapija climate data
- A simple rain gauge should be installed at each of the three RWH sites during installation to begin building a locally-grounded precipitation time series. Data should be recorded monthly and entered into the Harvesting Hope M&E framework.
- Planting calendar shifts documented in the field (3–4 weeks / ~1 month / 1–2 months earlier) should be formally recorded as baseline climate adaptation indicators in the M&E framework, with annual updates during the project period to track continued seasonal shift.
- The D1 confirmation obtained at Trebiste during the field visit (4/4 respondents, score 1; Harvesting Hope Field Visit Summary 03/2026, POLOG D1) should be formally recorded as a Result 1 baseline indicator in the project M&E framework, alongside the D1 confirmations at Lazhani and Koreshnica.

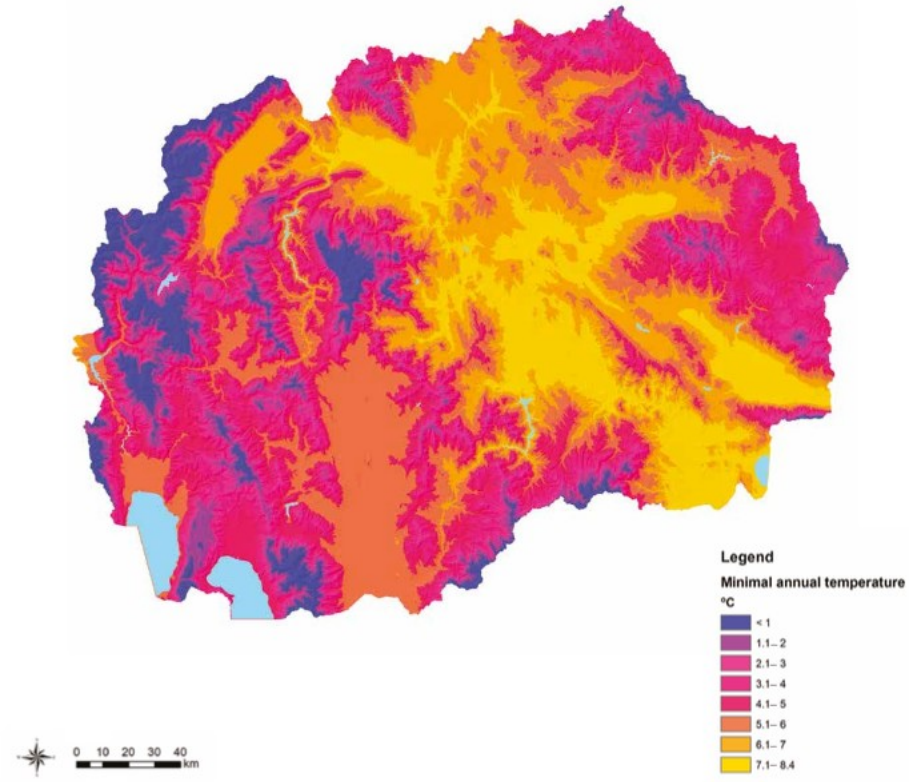
Annex. FAO Agro-Climatic and Hydrometeorological Maps of North Macedonia

The following maps are reproduced from the FAO Agro-Ecological Atlas of the Republic of North Macedonia (Aksoy, 2020) and provide the national-scale spatial context for the hydrometeorological analysis presented in this report. They are referred to throughout Sections 2 and 3 and inform the vulnerability assessment in Section 7. The maps are presented in logical thematic sequence: temperature regime (maximum and minimum), evapotranspiration demand, water deficit, and agro-climatic zoning. Each map caption identifies the specific zone or parameter relevant to the three project villages (Trebiste, Lazhani, and Koreshnica).



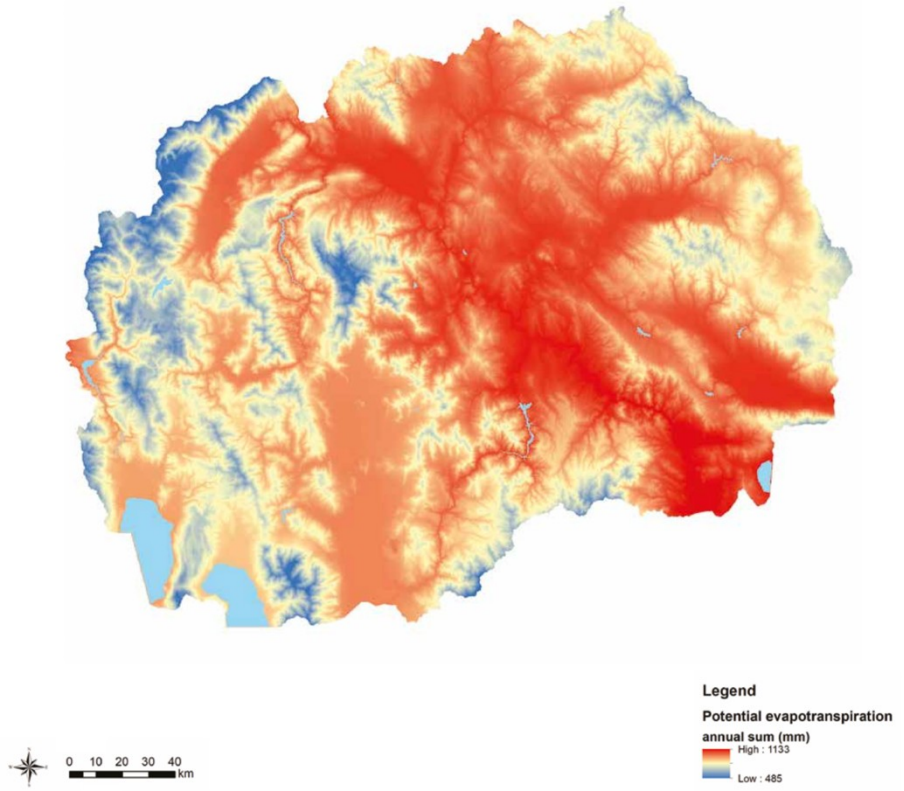
Map A1. Maximal Annual Temperature (°C) — North Macedonia (Aksoy, 2020).

The maximum annual temperature map shows that the warmest areas in North Macedonia are in the south-eastern and central Vardar lowlands, where mean annual maxima exceed 19°C (dark red). The Vardar valley around Demir Kapija — where Koreshnica is located — falls in this highest temperature zone, consistent with field observations of 1–2 month advances in growing season onset. The Polog region and Pelagonija basin exhibit intermediate maximum temperatures (13–17°C), while mountain zones remain below 11°C.



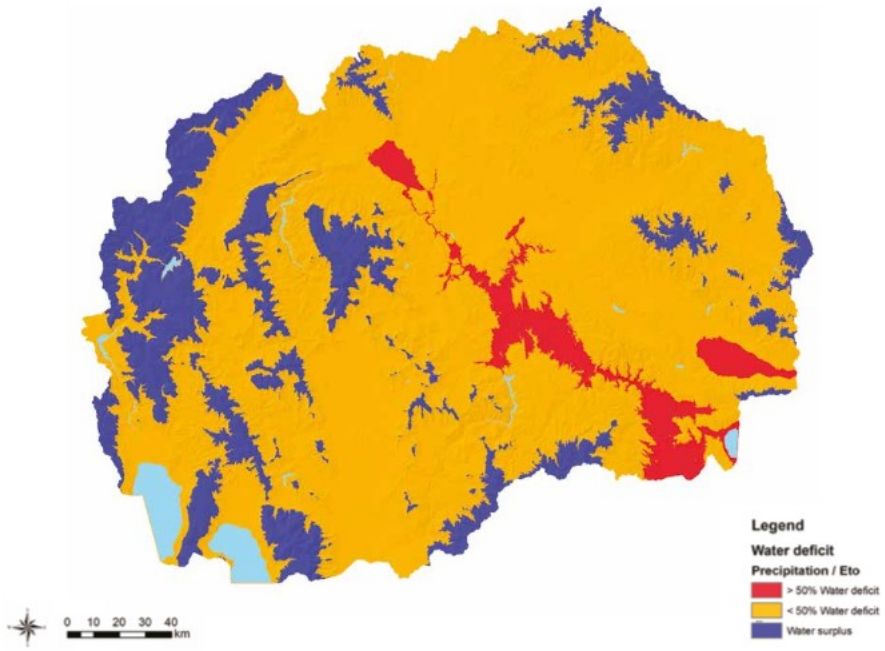
Map A2. Minimal Annual Temperature (°C) — North Macedonia (Aksoy, 2020).

The minimum annual temperature map shows the vulnerability to frost across the country. The Polog region (Trebiste) falls in the lowest minimum temperature zones, with annual minima below 1°C (purple). Pelagonija (Lazhani) experiences minima of 1.1–3°C. The South-East region (Koreshnica) is notably milder at 4.1–6°C. These differences directly determine storage infrastructure requirements: Polog systems require frost-proof insulated or buried tanks; Koreshnica can use surface storage year-round.



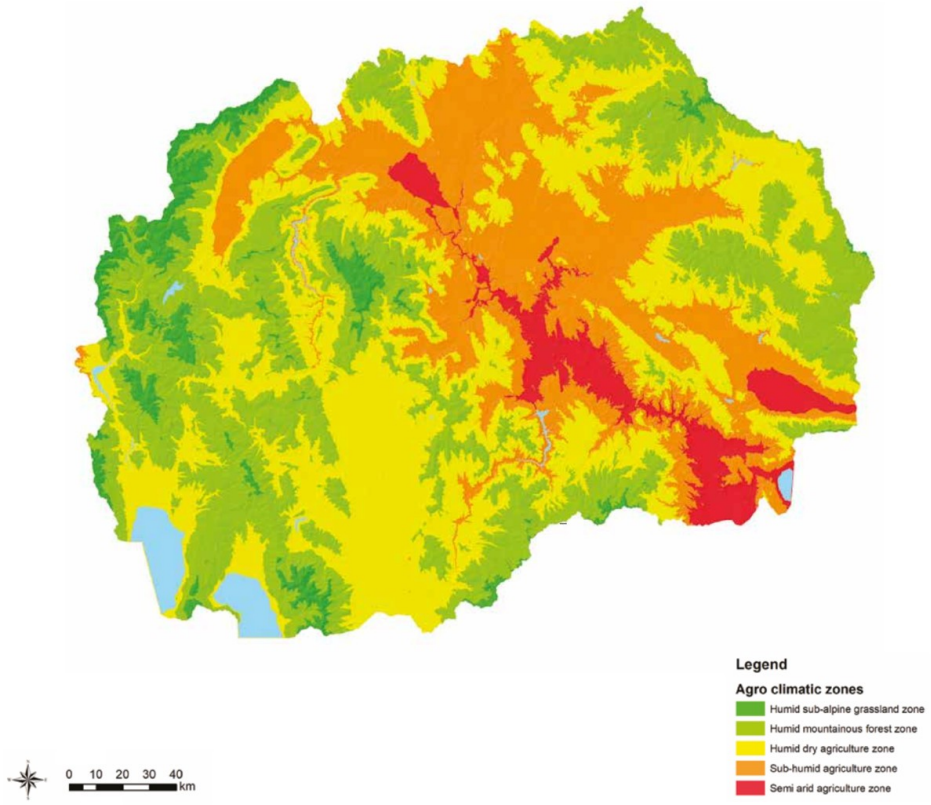
Map A3. Potential Evapotranspiration — Annual Sum (mm) — North Macedonia (Aksoy, 2020).

The potential evapotranspiration (ET_0) map reveals the spatial pattern of atmospheric water demand across North Macedonia. The highest ET_0 values (dark red, exceeding 1,100 mm per year) concentrate in the south-eastern lowlands including the Strumica valley, consistent with the Demir Kapija area climate estimates used in this study. Demir Kapija, in the Vardar gorge, is one of the hottest and most water-stressed locations in the country. The Pelagonija basin shows moderately high ET_0 (800–900 mm range), while the Polog mountain zone exhibits substantially lower values due to cooler temperatures and greater cloud cover.



Map A4. Water Deficit (Precipitation / ET_0 Ratio) — North Macedonia (Aksoy, 2020).

The water deficit map is the most operationally critical for this study. It shows the ratio of precipitation to ET_0 across North Macedonia. Areas in red (Precipitation/ET_0 > 50% deficit) face the most severe structural water scarcity — this zone includes the Demir Kapija / Vardar valley where Koreshnica is located. Orange zones (< 50% deficit) cover most of the agricultural lowlands including Pelagonija. Blue zones (water surplus) are limited to high mountain areas. All three project villages fall within the deficit zones, confirming the universal need for supplementary water storage across the project area.



Map A5. Agro-Climatic Zones — North Macedonia (Aksoy, 2020).

The agro-climatic zones map provides the integrated classification of agricultural potential across North Macedonia. Trebiste (Polog) falls within the Humid mountainous forest zone (light green) at the boundary with the Humid sub-alpine grassland zone — confirming the mixed mountain agriculture profile observed in the field. Lazhani (Pelagonija) lies within the Humid dry agriculture zone (yellow), consistent with the rain-fed tobacco and vegetable production system. Koreshnica (South-East) is classified within the Semi-arid agriculture zone (red) — the most water-stressed agricultural classification — directly justifying the highest priority ranking for RWH installation.

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