Univerza *v Ljubljani*
Filozofska fakulteta

Dela 59

Oddelek za geografijo,
Filozofska fakulteta Univerze v Ljubljani

Department of Geography,
Faculty of Arts, University of Ljubljana

LJUBLJANA 2023

ISSN 0354-0596
DELA
59
2023

Elektronska izdaja — Electronic edition
ISSN 1854-1089

Založnik — Published by
Založba Univerze v Ljubljani

Izdajatelj — Issued by
Znanstvena založba Filozofske fakultete Univerze v Ljubljani;
Oddelek za geografijo, Filozofska fakulteta Univerze v Ljubljani

Za založbo — For the Publisher
Gregor Majdič, rektor Univerze v Ljubljani

Za izdajatelja - For the Issuer
Mojca Schlamberger Brezar, dekanja Filozofske fakultete

Oblikovna zasnova — Design
Žiga Valetič

Prelom — Layout
Irena Hvala

Tisk — Printed by
Birografika Bori, d. o. o.

Naklada — Edition
320 izvodov

Naslov uredništva — Publisher's address
Oddelek za geografijo, Filozofska fakulteta Univerze v Ljubljani, Aškerčeva 2, SI-1000 Ljubljana

Elektronski dostop — On-line access: https://journals.uni-lj.si/Dela

DELA so vključena v – DELA is included in
Scopus, CGP – Current Geographical Publications, DOAJ, ERIH PLUS, GEOBASE,
Central and Eastern European Academic Source, GeoRef, Russian Academy of Sciences Bibliographies,
TOC Premier, International Bibliography of the Social Sciences

Izdano s finančno pomočjo Javne agencije za znanstvenoraziskovalno in inovacijsko dejavnost Republike Slovenije in Oddelka za geografijo FF Univerze v Ljubljani.

VSEBINA CONTENTS

RAZPRAVE PAPERS

Darko Ogrin*, Blaž Repe*, Lenart Štaut**,
Domen Svetlin***, Matej Ogrin*

PODNEBNA TIPIZACIJA SLOVENIJE PO PODATKIH ZA OBDOBJE 1991–2020

Izvirni znanstveni članek
COBISS 1.01
DOI: 10.4312/dela.59.5-89

Izvleček

V prispevku je predstavljena podnebna tipizacije Slovenije za klimatološko obdobje 1991–2020. Izhodišče za členitev je bila Köppen-Geigerjeva klasifikacija, ki pa je pregroba za prikaz vseh podnebnih specifik Slovenije. Z upoštevanjem dodatnih temperaturnih in padavinskih kriterijev smo slovensko podnebje razčlenili na štiri osnovne tipe z devetimi podtipi: zmerno sredozemsko (obalno in zaledno), zmerno celinsko (severovzhodne, vzhodne in jugovzhodne ter osrednje Slovenije), gorsko (višjega in nižjega gorskega sveta) in podgorsko podnebje (zelo vlažno in vlažno).

Ključne besede: klimatogeografija, podnebna klasifikacija, Köppen-Geigerjeva podnebna klasifikacija, podnebni tipi, Slovenija

*Oddelek za geografijo Filozofske fakultete Univerze v Ljubljani, Aškerčeva 2, SI-1000 Ljubljana, Slovenija
**Znanstvenoraziskovalni center Slovenske akademije znanosti in umetnosti, Geografski inštitut Antona Melika, Novi trg 2, 1000 Ljubljana, Slovenija
*** Cesta Radomeljske čete 23, SI-1235 Radomlje, Slovenija
e-pošta: darko.ogrin@ff.uni-lj.si, blaz.repe@ff.uni-lj.si, lenart.staut@zrc-sazu.si, domen.svetlin@gmail.com, matej.ogrin@ff.uni-lj.si
ORCID: 0000-0002-2458-6435 (D. Ogrin), 0000-0002-5530-4840 (B. Repe), 0000-0003-0095-3920 (L. Štaut), 0000-0002-4742-3890 (M. Ogrin)

1 UVOD

Slovenija je skromnih geografskih dimenzij, vendar je njeno podnebje zaradi lege v srednjih geografskih širinah na stiku Sredozemlja, Panonske kotline, Alp in Dinarskega gorstva ter s stikom povezane reliefne razgibanosti zelo raznoliko. Splošne poteze zmerno toplega in vlažnega podnebja se prepletajo z značilnostmi sredozemskega, gorskega in celinskega podnebja, ki jim na lokalni ravni dajejo močan pečat reliefne razmere.

Na globalnem in makro nivoju je bila narejena množica podnebnih regionalizacij in tipizacij. Tipizacije v glavnem razvrščamo v dve skupini: vzročne (genetske) in posledične (efektivne). Med vzročnimi, ki skušajo pojasniti vzroke za nastanek določenega podnebja, je v geografskih krogih med bolj poznanimi Strahlerjeva klasifikacija (Strahler, 2013). Od posledičnih, ki pojasnjujejo vpliv podnebja na naravne razmere, predvsem na naravno rastlinstvo (in tudi določene značilnosti kulturne rabe pokrajine), je v klimatoloških krogih in širše najbolj poznana Köppenova klasifikacija (tudi Köppen-Geigerjeva podnebna klasifikacija). Nastala je v začetku 20. stoletja (Köppen, 1918) in v stoletju obstoja doživela več dopolnitev in posodobitev (npr. Cui in sod., 2021; Geiger, Pohl, 1954; Köppen, 1936; Peel in sod., 2007; Strässer, 1998). Omenjene klasifikacije omogočajo dober vpogled v globalni podnebni sistem in sistem večjih prostorskih enot, za prostorske enote slovenskih dimenzij pa so preveč grobe in ne odražajo vseh pomembnih podnebnih specifik.

Za ozemlje Slovenije je bilo v zadnjih 100 letih izdelanih več podnebnih klasifikacij in regionalizacij. Prvo shemo podnebnih tipov je postavil Melik (1935). Poudaril je, da se na slovenskem ozemlju stikajo sredozemsko, panonsko in srednjeevropsko alpinsko podnebje ter da se meje med posameznimi podnebji neprestano spreminjajo. Furlan (1960) je razčlenil Slovenijo po podatkih za obdobje 1925–1956. Pri temperaturah je izločil morski, prehodni in notranji pas, pri padavinah pa območje z modificiranim sredozemskim in srednjeevropskim režimom. Celovite členitve ni naredil. Na osnovi toplotnega in padavinskega režima je Slovenijo v okviru Jugoslavije razčlenil Ilešič (1970). Izločil je dve glavni podnebni območji: jadransko in zmerno celinsko. V okviru prvega seže v Slovenijo severnojadransko območje. Pri drugem pa v okviru zahodno-panonskega celinskega območja loči v Sloveniji dve podobmočji: pravo panonsko celinsko in prehodno panonsko-jadransko območje.

Gams (1972) je Slovenijo delil na podlagi razmerja med mesečnimi temperaturami in padavinami v vegetacijski dobi oziroma vlažnostnim presežkom in primanjkljajem, višino temperatur in dolžino vegetacijske dobe. Z izborom kriterijev je hotel predvsem pojasniti razlike v naravnem rastlinstvu in gojenju kulturnih rastlin. Glavna podnebna območja (primorsko, osrednjeslovensko in subpanonsko) je razdelil v več podnebnih provinc in rajonov. Gams (1996) je izdelal tudi bioklimatsko delitev Slovenije. Glede na aridnost oziroma humidnost podnebja je izločil dve podnebni regiji z več podregijami. V okviru Primorja z zaledjem loči podnebje Koprskega primorja, podnebje zaledja Tržaškega zaliva in prehodno podnebje Brkinov. Podnebje celinske

Slovenije pa je razdelil na zelo vlažno podnebje alpskega in dinarskega višavja, na vlažno podnebje osrednje Slovenije, na zmerno vlažno podnebje na prehodu proti subpanonskemu podnebju in na subpanonsko podnebje s semiaridnim do semihumidnim poletjem. Obe Gamsovi členitvi imata tudi kartografski prikaz.

D. Ogrin (1996) je naredil tipizacijo slovenskega podnebja po podatkih za obdobje 1961–1990. Kot izhodišče za členitev je uporabil Köppen-Geigerjeve kriterije, po katerih ima večina Slovenije zmerno toplo vlažno podnebje s toplim poletjem (Cfb), najvišji predeli gorsko podnebje (H) in jugozahodni ob Tržaškem zalivu zmerno toplo vlažno podnebje z vročim poletjem (Cfa). V nadaljevanju so bili osnovni tipi, glede na padavinski režim, povprečno temperaturo najhladnejšega in najtoplejšega meseca ter razmerje med oktobrskimi in aprilskimi temperaturami, razčlenjeni na devet podtipov. Leta 2009 je nastala posodobitev te klasifikacije po podatkih za obdobje 1971–2000 (Ogrin, 2009), ki je ohranila izhodišča in kriterije predhodne klasifikacije. V njej se lepo zrcalijo regionalni odzivi na globalne podnebne spremembe, ki so dobile pospešek po letu 1980: širjenje zmerno sredozemskega podnebja proti notranjosti Slovenije, pomik podnebja nižjega gorskega sveta v višje lege, blažitev celinskega temperaturnega režima zaradi dviga zimskih temperatur, pri padavinah pa pomik zmerno sredozemskega padavinskega režima proti vzhodu države.

Predstavljenim klasifikacijam je skupno, da so narejene na osnovi točkovnih podatkov relativno redke mreže meteoroloških postaj v Sloveniji, kar še posebej velja za meritve temperature zraka. Meje med podnebnimi enotami so v veliki meri določene subjektivno, z upoštevanjem vpliva površja na prostorsko razporejanje posameznih podnebnih elementov in avtorjevo ekspertno poznavanje lokalnih in regionalnih podnebnih razmer. Upoštevano je tudi prostorsko razporejanje naravnega rastlinstva in značilnosti kulturne rabe površja. Ker so v zadnjih letih na razpolago tudi podatki v pravilni kilometrski prostorski mreži za najpomembnejše podnebne elemente (Dolinar, 2016), so Kozjek in sod. (2017) izdelali t. i. objektivno opredelitev podnebnih regij Slovenije za obdobje 1981–2010. S pomočjo faktorske analize in metode razvrščanja v skupine po metodi voditeljev so ugotovili, da je podnebje Slovenije najbolj smiselno in reprezentativno razvrstiti v šest regij oziroma tipov: primorsko regijo (omiljeno sredozemsko podnebje), zelo namočeno regijo severozahodnega dela alpsko-dinarske pregrade (vlažno podnebje hribovitega sveta), dvignjeno regijo dinarsko-alpskega sveta (omiljeno gorsko podnebje), regijo visokogorja (gorsko podnebje), suho regijo nižinskega sveta vzhodne in osrednje Slovenije (omiljeno celinsko podnebje) ter višjo in malo bolj namočeno regijo osrednje Slovenije (zmerno podnebje hribovitega sveta). Prostorska razporeditev predstavljenih podnebnih regij oziroma tipov se bistveno ne razlikuje od Ogrinovih tipizacij.

S ciljem določiti referenčne podnebne postaje, ki bi bile reprezentativne za širšo okolico in bi hkrati čim bolje opisale podnebne spremembe v zadnjih desetletjih, so Kozjek in sod. (2016a; 2016b) prvotno klasifikacijo nadgradili še z izračunom mer spremenljivosti najpomembnejših podnebnih elementov za obdobje 1961–2011. Z upoštevanjem vseh izbranih mer spremenljivosti (trendi, medletna in meddnevna spremenljivost) so Slovenijo razdelili na štiri regije, ki imajo podobne značilnosti spreminjanja podnebja. Regij niso posebej poimenovali, sovpadajo pa z obsredozemskimi pokrajinami, najvišjimi predeli alpsko-dinarske pregrade, širšim območjem alpsko-dinarske pregrade in območjem Slovenije na vzhodu države z bolj celinskimi podnebnimi značilnostmi.

Z letom 2020 se je zaključilo standardno klimatološko obdobje 1991–2020, ki narekuje tudi izdelavo podnebne tipizacije za ta čas. Toliko bolj, ker je splošno znano in v strokovni literaturi temeljito podprto, da se podnebje na vseh prostorskih nivojih, tudi v Sloveniji (Bertalanič in sod., 2010; Dolinar, Vertačnik, 2010; Ogrin, 2003; 2014; 2015; Podnebne spremembe…, 2021; Vertačnik in sod., 2013), v zadnjih desetletjih zelo hitro spreminja. Podnebne tipizacije, ki so nastale na osnovi podatkov za prejšnja obdobja, imajo zato zaradi sprememb vrednosti klimatskih elementov in meja med podnebnimi tipi in podtipi omejeno uporabno vrednost. Glavni namen prispevka je zato prikazati značilnosti podnebnih tipov v Sloveniji in značilnosti njihove prostorske razporeditve za obdobje 1991–2020. Ker so na razpolago, smo ob točkovnih podatkih uporabili tudi podatke v pravilni prostorski mreži. Pri njihovi obdelavi, prostorski interpolaciji in prikazih smo uporabili GIS orodja (programski orodji ArcGIS Pro 3.1 in QGIS). Da bi ohranili osnovno primerljivost z zadnjima dvema klasifikacijama, ki sta nastali na Oddelku za geografijo Filozofske fakultete Univerze v Ljubljani za obdobje 1961–1990 (Ogrin, 1996) in 1971–2000 (Ogrin, 2009), smo ohranili enaka metodološka izhodišča. V celoti pa primerjava ni možna, ker smo v prejšnjih klasifikacijah uporabljali kontrolirane, vendar ne homogenizirane točkovne podatke, prostorsko interpolacijo točkovnih podatkov in meje med posameznimi podnebnimi tipi pa smo določali ekspertno.

2 METODE

Točkovne (62 temperaturnih postaj, 174 padavinskih postaj) in prostorske podatke za obdobje 1991–2020 (ARSO, 2021) smo pridobili na Agenciji Republike Slovenije za okolje (ARSO). Na ARSO so podatke najprej kontrolirali in jih s pomočjo sodobnih programskih orodij homogenizirali ter odstranili spremembe, ki niso posledica podnebnega dogajanja (Vertačnik in sod., 2016). Homogenizirani podatki so bili podlaga za preračun v pravilno kilometrsko mrežo. Za računanje vrednosti podnebnih spremenljivk v mreži je bila uporabljena metoda optimalne prostorske interpolacije, ki upošteva odvisnost podnebne spremenljivke od geografskih dejavnikov. V vsaki mrežni točki je bila vrednost spremenljivke izračunana na podlagi vrednosti na okoliških meteoroloških postajah (tudi obmejnih v Italiji, Avstriji in na Hrvaškem), nadmorske višine, geografske dolžine in širine mrežne točke ter v nekaterih primerih tudi drugih izpeljanih geografskih spremenljivk (npr. relativna nadmorska višina orografske pregrade v smeri severovzhod za padavine). Zaradi manjšega števila meteoroloških postaj so podatki manj zanesljivi za mrežne točke z nadmorsko višino nad 1000 m (Dolinar, 2016; Kozjek in sod., 2017).

Izhodišče za podnebno tipizacijo Slovenije je bila Köppen-Geigerjeva opredelitev podnebnih tipov in kriterijev zanje (Peel in sod., 2007). Po Köppenu je vsako podnebje opredeljeno z določeno vrednostjo povprečnih mesečnih in letnih temperatur in padavin. Pri kartografskem prikazu posameznih temperaturnih pragov oziroma podnebnih razredov in tipov smo se opirali na potek izoterm, ki izhajajo iz Köppenove klasifikacije: januarska izoterma –3 °C (meja med zmerno toplimi in vlažnimi podnebji ter snežno-gozdnimi podnebji), julijska izoterma 22 °C (meja med podnebji z vročimi oziroma toplimi poletji), julijska izoterma 10 °C (meja med snežno-gozdnimi in snežnimi podnebji). Interpolacijo podnebnih spremenljivk in vse nadaljnje računske operacije ter Köppenovo podnebno klasifikacijo Slovenije samo smo izvedli v programskem jeziku R, karte pa so izrisane s programom QGIS. Ker je Köppen-Geigerjeva klasifikacija pregroba za prikaz vseh podnebnih specifik Slovenije, smo upoštevali še dodatne temperaturne kriterije. Upoštevali smo januarski izotermi 0 in 3 °C, julijski 15 in 20 °C ter povprečno letno temperaturno amplitudo. Če je povprečna letna amplituda nad 20 °C, je to pokazatelj celinskega značaja temperaturnega režima, pod 15 °C morskih potez, če pa je med 15 in 20 °C pa gre za prehodni režim (Supan, 1921, str. 110; Šegota, Filipčić, 1996, str. 71). Vrednosti smo izračunali iz kilometrske mreže temperaturnih podatkov, vertikalne temperaturne gradiente in povprečne nadmorske višine posameznih izoterm pa s pomočjo digitalnega modela višin (GURS, 2021). Pri opredeljevanju celinskega značaja temperaturnega režima smo se ozirali tudi na primerjavo povprečnih aprilskih in oktobrskih temperatur (Tokt. > Tapr.: morske poteze temperaturnega režima; Tokt. < Tapr.: celinske poteze padavinskega režima). Velja, da so višje oktobrske temperature od aprilskih posledica vpliva toplega morja in morskih zračnih gmot, saj se morje jeseni počasneje ohlaja, spomladi pa počasneje segreva. Zato je v območjih daleč od morja april praviloma toplejši od oktobra.

Predhodne klasifikacije slovenskega podnebja, še posebej klasifikaciji Kozjek in sod. (2016a; 2016b; 2017), so pokazale na velik pomen padavinskih in z njimi povezanih vlažnostnih razmer. Za lažjo diferenciacijo Slovenije glede na ta dejavnik smo ob višini padavin upoštevali tudi Langov padavinski faktor, ki vključuje povprečno letno višino padavin in povprečno letno temperaturo zraka in podnebje členi glede na stopnjo humidnosti oziroma aridnosti (Žiberna, 1992, str. 76):

$$L = \frac{RR_l}{T_e}$$

L – Langov padavinski faktor
RR_l – povprečna letna višina padavin
Te – povprečna letna temperatura zraka

Pri določanju stopnje humidnosti oziroma aridnosti podnebja smo upoštevali standardno razdelitev v razrede (Žiberna, 1992, str. 76):

L	
od 0 do 40	aridno (suho) podnebje
od 41 do 60	semiaridno (polsuho) podnebje
od 61 do 100	semihumidno (polvlažno) podnebje
od 101 do 160	humidno (vlažno) podnebje
več kot 160	perhumidno (zelo vlažno) podnebje

Pri opredeljevanju padavinskega režima smo izhajali iz Köppenovih kriterijev, ki smo jih za potrebe Slovenije nekoliko prilagodili, in sicer smo z w' označili padavinski režim z viškom padavin v enem od jesenskih mesecev in najmanj padavin v enem od zimskih mesecev (ponekod marca ali v enem od poletnih mesecev), z oznako x' pa režim s padavinskim viškom v enem od poletnih mesecev (ponekod tudi maja) in najmanj padavin v enem od zimskih mesecev. Dodatno smo padavinski režim opredeljevali s pomočjo indeksa mediteranskosti padavin (Koppany, Unger, 1992), ki primerja povprečno višino v oktobru in novembru (višek padavin pri sredozemskem padavinskem režimu) z višino padavin maja in junija (višek padavin pri celinskem padavinskem režimu) ter letno višino padavin. Pozitivne vrednosti indeksa pomenijo sredozemske poteze padavinskega režima, negativne pa celinske. Ker se v Sloveniji jesenski višek padavin pojavlja tudi septembra, poletni pa tudi julija, smo indeks nekoliko modificirali:

$$MI = \frac{\left(P_{sep-nov} - P_{maj-jul}\right) \cdot 100}{P_l}$$

MI – indeks mediteranskosti padavin
Psep-nov – višina padavin v obdobju september–november
Pmaj-jul – višina padavin v obdobju maj–julij
Pl – povprečna letna višina padavin

Celinski oziroma morski (sredozemski) značaj padavinskega režima smo ugotavljali tudi s primerjavo višine padavin v topli polovici leta (april–september) in hladni polovici leta (oktober–marec). Večji delež padavin v topli polovici leta nakazuje celinski značaj padavinskega režima, v hladni polovici pa morskega (sredozemskega).

Ker je bil Köppen tudi fitogeograf, je mejne vrednosti med posameznimi podnebnimi razredi in tipi izbiral tako, da je lahko z njimi vsaj približno opredelil tudi glavne rastlinske tipe. Za potrebe podrobnejše podnebne členitve Slovenije smo to izhodišče razširili tudi na nekatere značilnosti kulturne pokrajine, ki so v večji meri odvisne od toplotnih razmer (območje oljkarstva in vinogradništva). Izvirne Köppenove termine za posamezne podnebne tipe smo prilagodili slovenskim razmeram.

3 REZULTATI

3.1 Köppen-Geigerjeva klimatska členitev Slovenije 1991–2020

Glede na Köppen-Geigerjev podnebni sistem so v Sloveniji zastopani trije podnebni razredi:

- **C (zmerno toplo podnebje):** povprečna temperatura najhladnejšega meseca (v gorah je to običajno februar, v nižinah januar) nad –3 °C, vsaj en mesec s povprečno temperaturo nad 10 °C;
- **D (snežno-gozdno podnebje):** povprečna temperatura najhladnejšega meseca pod –3 °C, povprečna temperatura najtoplejšega meseca (v nižinah julij, v gorah običajno avgust) nad 10 °C;
- **E (snežno podnebje):** povprečna temperatura najtoplejšega meseca pod 10 °C .

Podnebna razreda D in E sta v Sloveniji omejena na gorski svet, vsa ostala Slovenija sodi v razred C.

Z upoštevanjem dodatnih kriterijev lahko v Sloveniji izločimo 6 osnovnih podnebnih tipov, ki imajo večji prostorski obseg, in še 6 z manjšo prostorsko zastopanostjo. Slednje smo pridružili osnovnim tipom (slika 1):

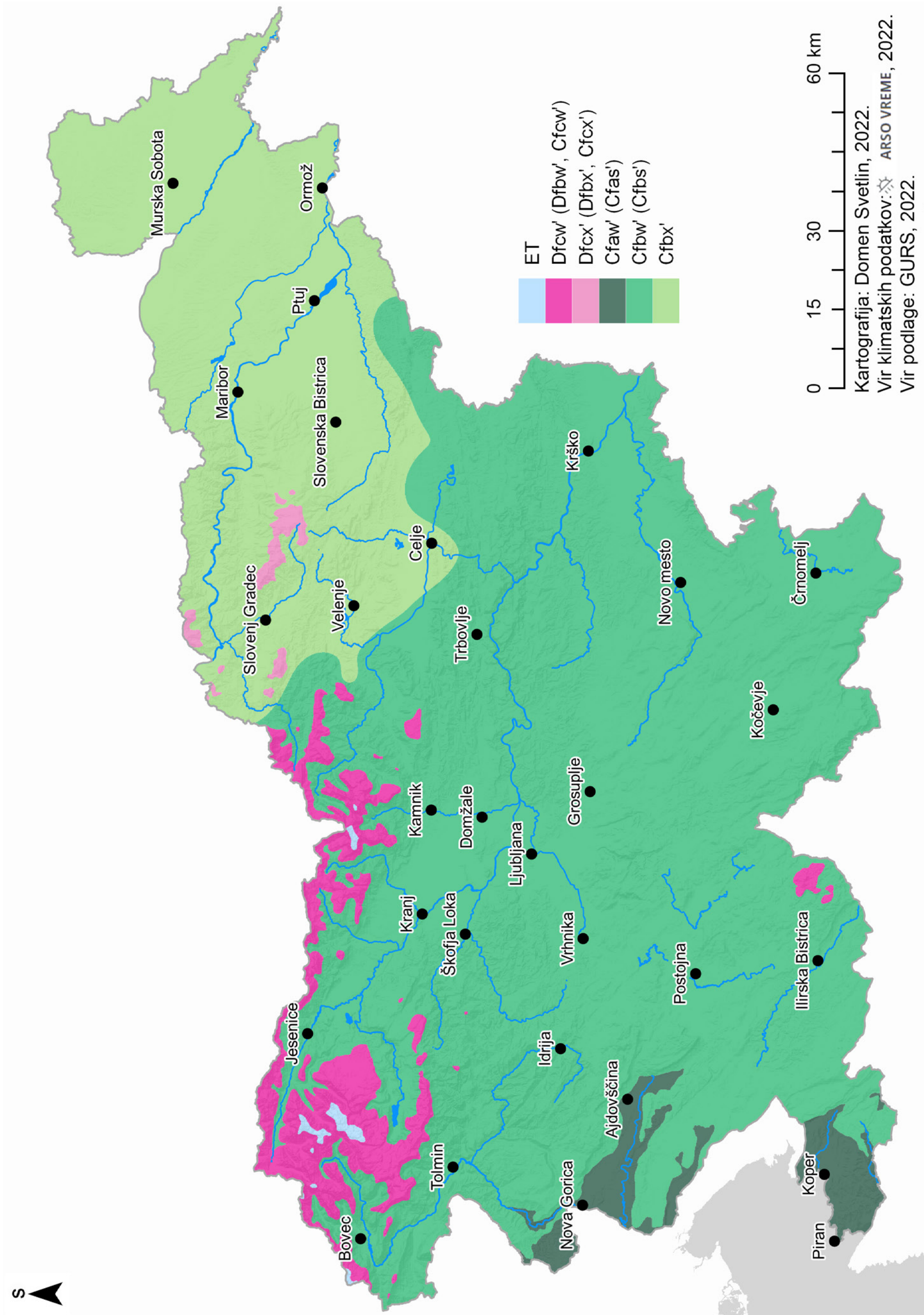
- **ET; podnebje gorske tundre:**
  - povprečna temperatura najtoplejšega meseca med 0 in 10 °C;
  - podnebje zavzema 0,2 % Slovenije, ima ga visokogorje Julijskih in Kamniško-Savinjskih Alp nad višino okoli 2200 m.
- **Dfcw‘ (Dfbw‘, Cfcw‘); snežno-gozdno vlažno podnebje s toplim oziroma hladnim poletjem in viškom padavin v enem od jesenskih mesecev (zmerno toplo vlažno podnebje s hladnim poletjem in viškom padavin v jeseni):**
  - ni suhega obdobja – povprečna višina padavin najbolj suhega meseca v topli polovici leta nad okoli 40 mm;
  - povprečna temperatura najtoplejšega meseca pod 22 °C, vsaj 4 meseci s povprečno temperaturo nad 10 °C (toplo poletje);
  - 1 do 4 meseci s povprečno temperaturo nad 10 °C, najhladnejši mesec nad –3 °C (hladno poletje);
  - mesec z največ padavinami v jeseni, z najmanj padavinami pozimi;
  - podnebje pokriva 5,1 % Slovenije, zastopano je v Julijskih Alpah, Karavankah in Kamniško-Savinjskih Alpah z gorskimi dolinami, izven Alpskih pokrajin pa na Menini planini, na posameznih vrhovih zahodnega Predalpskega hribovja ter na Snežniku in Trnovskem gozdu (Golaki).
- **Dfcx‘ (Dfbx‘, Cfcx‘); snežno-gozdno vlažno podnebje s toplim oziroma hladnim poletjem in viškom padavin v enem od poletnih mesecev ali maja (zmerno-toplo vlažno podnebje s hladnim poletjem in viškom padavin poleti ali maja):**

- enako kot pri Dfcw‘ (Dfbw‘, Cfcw‘), le da je višek padavin v enem od poletnih mesecev, ponekod konec pomladi maja, najmanj padavin pozimi;
- podnebje pokriva 0,5 % površja Slovenije, imajo ga Pohorje, Košenjak, Strojna in Uršlja gora.

Podnebne tipe ET ter Dfcw‘ in Dfcx‘ s pridruženimi tipi z manjšim obsegom, ki vsi skupaj zavzemajo le 5,8 % površja Slovenije, lahko po verzijah Köppen-Geigerjeve klasifikacije (npr. Ahrens, 2005; Henderson-Sellers, 1999), ki vpeljujejo poseben **razred H** za višje ležeča območja našega planeta, kjer prihaja do hitrih sprememb podnebja z višino in je razmejitev med podnebnimi tipi težavna, združimo v mozaik, ki ga predstavlja **gorsko podnebje**.

- **Cfaw‘; zmerno toplo vlažno podnebje z vročim poletjem in viškom padavin v enem od jesenskih mesecev:**
  - ni suhega obdobja, povprečna temperatura najtoplejšega meseca nad 22 °C;
  - višek padavin v jeseni, mesec z najmanj padavinami pozimi, ponekod poleti (Cfas‘);
  - podnebje zavzema 2,8 % Slovenije, ima ga obalno območje Slovenske Istre, severozahodni del Krasa, Vipavska dolina, Goriška brda in dolina Soče do Kanala.
- **Cfbw‘; zmerno toplo vlažno podnebje s toplim poletjem in viškom padavin v enem od jesenskih mesecev:**
  - ni suhega obdobja, povprečna temperatura najtoplejšega meseca pod 22 °C, vsaj 4 meseci s povprečno temperaturo nad 10 °C;
  - višek padavin v jeseni, mesec z najmanj padavinami pozimi (redko marca), ponekod v južni Sloveniji tudi poleti (Cfbs‘);
  - podnebje ima večina Slovenije (66,6 %) razen gorskega sveta, nižje ležečih območij Obsredozemskih pokrajin in severovzhodne Slovenije.
- **Cfbx‘; zmerno toplo vlažno podnebje s toplim poletjem in viškom padavin v enem od poletnih mesecev ali maja:**
  - višek padavin poleti (ponekod pozno pomladi maja), najmanj padavin pozimi;
  - podnebje zavzema slabo četrtino Slovenije (24,8 %) in ga najdemo v severovzhodni Sloveniji vzhodno od Pece, Golt in Dobrovelj ter severno od Posavskega hribovja, Boča in Haloz.

Slika 1: Köppen-Geigerjeva klimatska klasifikacija Slovenije za obdobje 1991–2020.



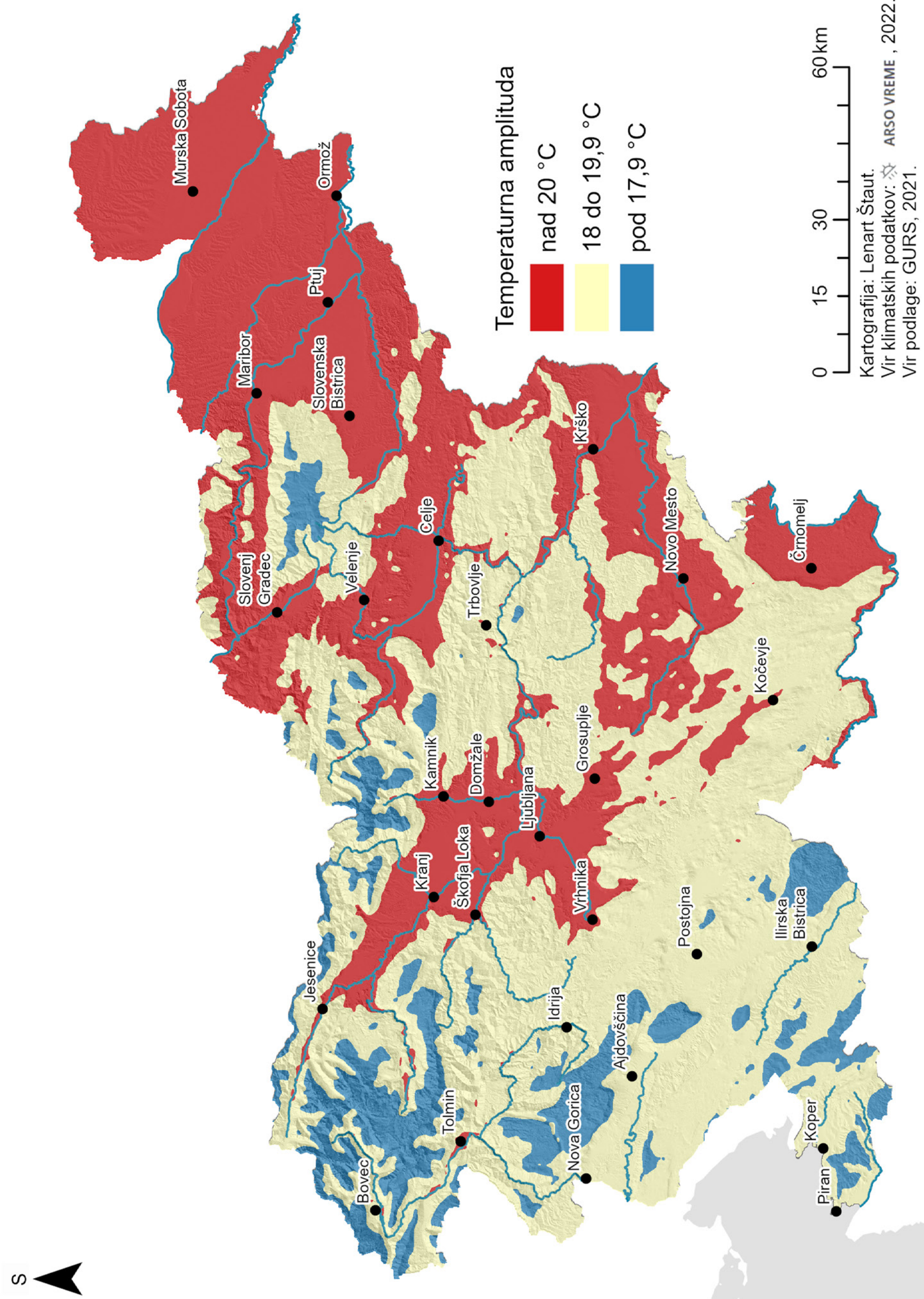
3.2 Temperaturni režim

Podnebna členitev Slovenije z upoštevanjem Köppenovih kriterijev daje pregrobo sliko, ki ne odraža vseh specifik slovenskega podnebja. S ciljem, da bi dodatno razčlenili obsežno območje s podnebjem Cfb, smo ob januarskih izotermah 0 in 3 °C ter julijskih 20 in 22 °C upoštevali tudi značilnosti temperaturnega režima. S pomočjo **povprečne letne temperaturne amplitude** in **razmerja med povprečnimi aprilskimi in oktobrskimi temperaturami** smo želeli razmejiti območja Slovenije, ki imajo celinske poteze temperaturnega režima, od območij, kjer je večji vpliv morja. Glede na razpon povprečne letne temperaturne amplitude (med 16 in 22 °C) lahko ugotovimo, da temperaturni režim v Sloveniji nima izrazitih celinskih oziroma morskih potez, ampak predstavlja prehodno območje. Povprečno letno temperaturno amplitudo nad 20 °C in s tem zmeren celinski temperaturni režim imajo nižje ležeča območja na severu, vzhodu in jugovzhodu Slovenije, nizki Dolenjski kras in Ljubljanska kotlina. Po najvišji povprečni letni temperaturni amplitudi (nad 21 °C) izstopajo nižine na severovzhodu Slovenije, spodnji del Mežiške in Mislinjske doline ter dolina Drave med Dravogradom in Radljami ob Dravi. Najbolj morske poteze, če izvzamemo hribovite in gorate predele, kjer je amplituda manjša zaradi višje nadmorske višine (Kredarica, 15,4 °C; Rogla, 16,5 °C; Krvavec, 16,7 °C), imajo nekoliko višje ležeča območja v zaledju Tržaškega zaliva, kjer je povprečna letna temperaturna amplituda pod 18 °C (slika 2, preglednica 1). V večjem delu Slovenije je amplituda med 18 in 20 °C.

Da imajo nižje ležeča območja na vzhodu Slovenije in deli Ljubljanske kotline omiljene poteze celinskega temperaturnega režima, lahko sklepamo tudi po višjih povprečnih aprilskih temperaturah od oktobrskih. V celinskih predelih se namreč ozračje spomladi hitreje segreje (in v jeseni hitreje ohladi) kakor v območjih ob morju oziroma pod večjim vplivom morskih zračnih gmot, ker ima morje zadrževalni učinek na segrevanje oziroma ohlajanje ozračja. Na vzhodu Slovenije so aprilske temperature višje od oktobrskih do 0,8 °C, v zahodni in osrednji Sloveniji pa oktobrske od aprilskih do 2 °C, najbolj v gorah (preglednica 1, slika 3). Hladnejša pomlad v gorah je tudi posledica slabše pregretosti višjih plasti ozračja v primerjavi z jesenjo.

Območje Slovenije, ki izkazuje celinske poteze temperaturnega režima glede na povprečno letno temperaturno amplitudo (slika 2, preglednica 1), se dobro prekriva z območjem, ki ima aprilske temperature višje od oktobrskih (slika 3). Sovpadanje je veliko pri nižje ležečih pokrajinah na vzhodu Slovenije, nekoliko manjše pri Ljubljanski kotlini.

Slika 2: Povprečna letna temperaturna amplituda v obdobju 1991–2020.

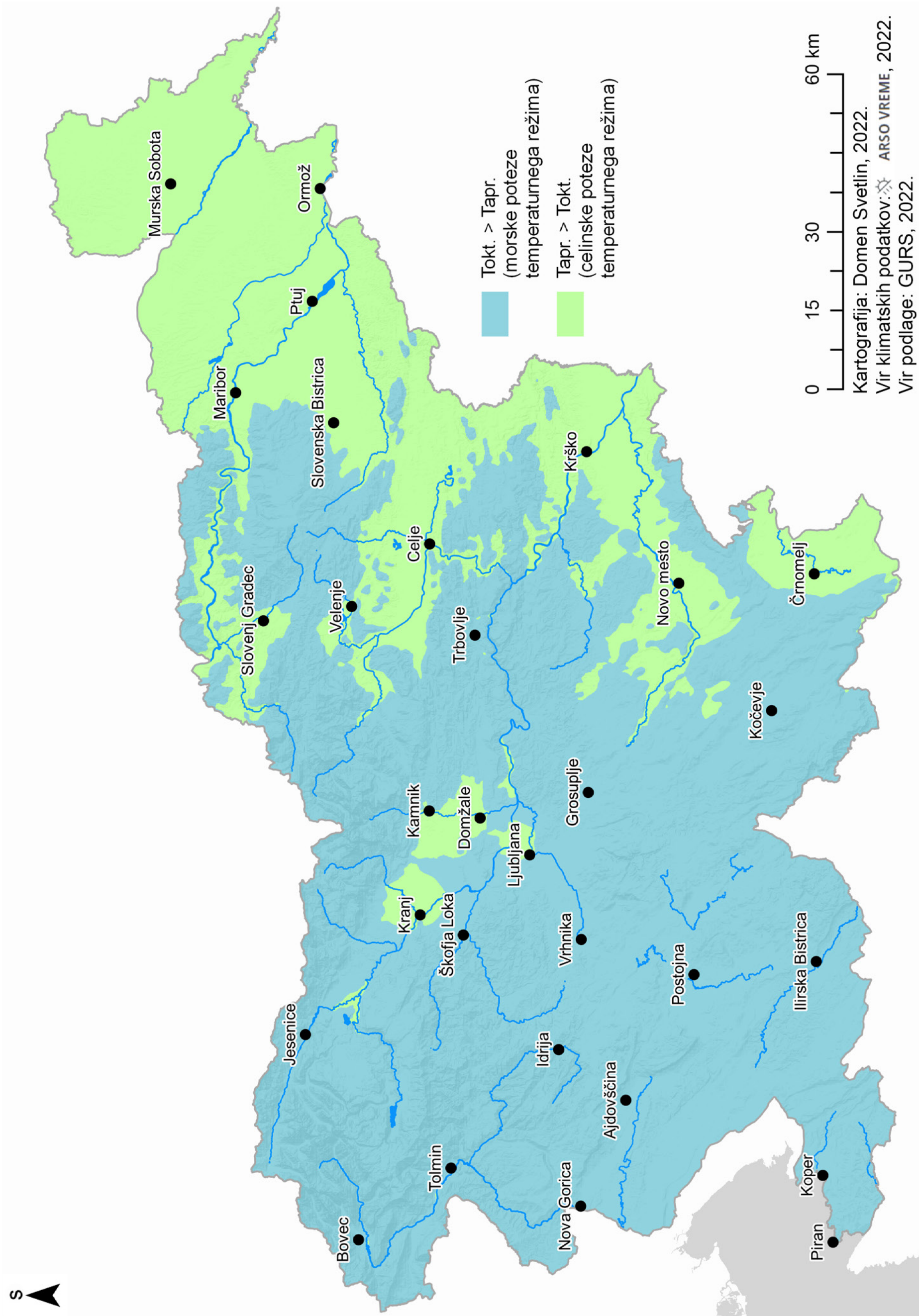


Preglednica 1: Razlika med povprečnimi aprilskimi in oktobrskimi temperaturami (D) in povprečna letna temperaturna amplituda (A) v obdobju 1991–2020.

Meteorološka postaja	D (°C)	A (°C)	Meteorološka postaja	D (°C)	A (°C)
Krvavec	–2,7	16,7	Miklavž na Gorjancih	–1,2	18,3
Jezersko	–0,7	18,7	Trojane-Limovce	–0,5	19,2
Planina pod Golico	–1,3	17,9	Gornji Grad	–0,3	19,1
Rateče	–0,5	19,8	Malkovec	0,1	19,8
Kredarica	–2,2	15,4	Letališče J. P. Brnik	0,0	20,4
Rudno polje	–2,3	18,1	Ljubljana-Bežigrad	–0,1	20,8
Bohinjska Češnjica	–0,8	19,4	Vrhnika	–0,6	19,7
Vogel	–2,2	17,1	Kranj	0,3	21,0
Zgornja Sorica	–1,0	17,8	Lesce-letališče	0,0	20,4
Krn	–1,0	17,9	Ravne na Koroškem	0,6	22,0
Tolmin-Volče	–0,4	19,2	Šmartno pri Sl. Gradcu	0,0	20,9
Vojsko	–0,9	18,6	Velenje	0,1	20,1
Vedrijan	–1,1	18,5	Celje-Medlog	0,1	20,2
Bilje	–0,8	19,0	Slovenske Konjice	0,0	19,5
Podnanos	–1,3	18,6	Črnomelj-Dobliče	0,3	20,4
Godnje	–1,0	19,0	Metlika	0,4	20,4
Ilirska Bistrica	–0,7	18,3	Novo mesto	0,5	20,4
Kubed	–1,4	18,2	Cerklje-letališče	0,4	20,9
Portorož-letališče	–1,5	18,4	Trebnje	0,1	20,3
Babno Polje	–1,1	19,4	Bizeljsko	0,6	20,8
Kočevje	–0,5	19,1	Rogaška Slatina	0,4	19,8
Nova vas-Bloke	–1,1	19,2	Letališče E. R. Maribor	0,3	21,0
Postojna	–1,1	18,8	Polički vrh	0,6	21,0
Logatec	–0,9	19,5	Jeruzalem	0,1	20,2
Litija	–0,3	19,4	M. Sobota-Rakičan	0,8	21,1
Rogla	–2,0	16,5	Ptuj	0,4	20,4
Sevno	–0,2	19,4	Maribor-Vrbanski plato	0,3	20,3
Lisca	–0,8	18,6	Lendava	0,7	21,2

Opomba: D > 0 april toplejši od oktobra.

Slika 3: Morski oziroma celinski značaj temperaturnega režima glede na primerjavo povprečnih aprilskih in oktobrskih temperatur (1991–2020).



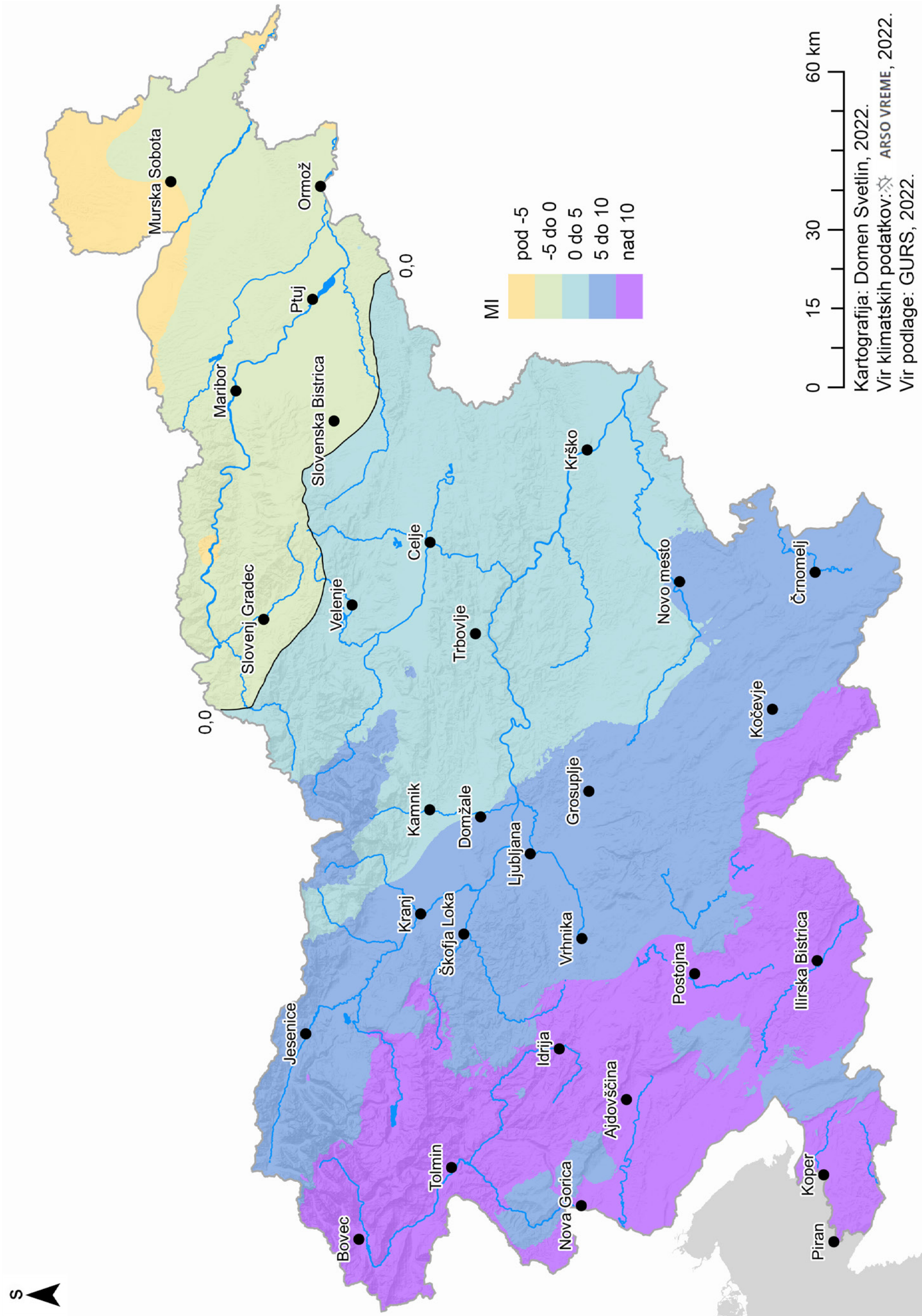
3.3 Padavinski režim

Ob Köppenovih kriterijih za prostorsko diferenciacijo padavinskega režima v Sloveniji smo upoštevali tudi indeks mediteranskosti padavin (MI) in razmerje med višino padavin v topli in hladni polovici leta. MI in razmerje med padavinami v topli in hladni polovici leta dajeta podobno prostorsko sliko. Najbolj celinske poteze (delež padavin v topli polovici leta nad 60 %, negativne vrednosti MI, kar pomeni, da je poletni višek padavin izrazitejši od jesenskega) ima severovzhodna Slovenija (sliki 4 in 5). Proti zahodu in jugozahodu se delež padavin v topli polovici leta zmanjšuje, glavni padavinski višek pa se prestavlja na jesenske mesece.

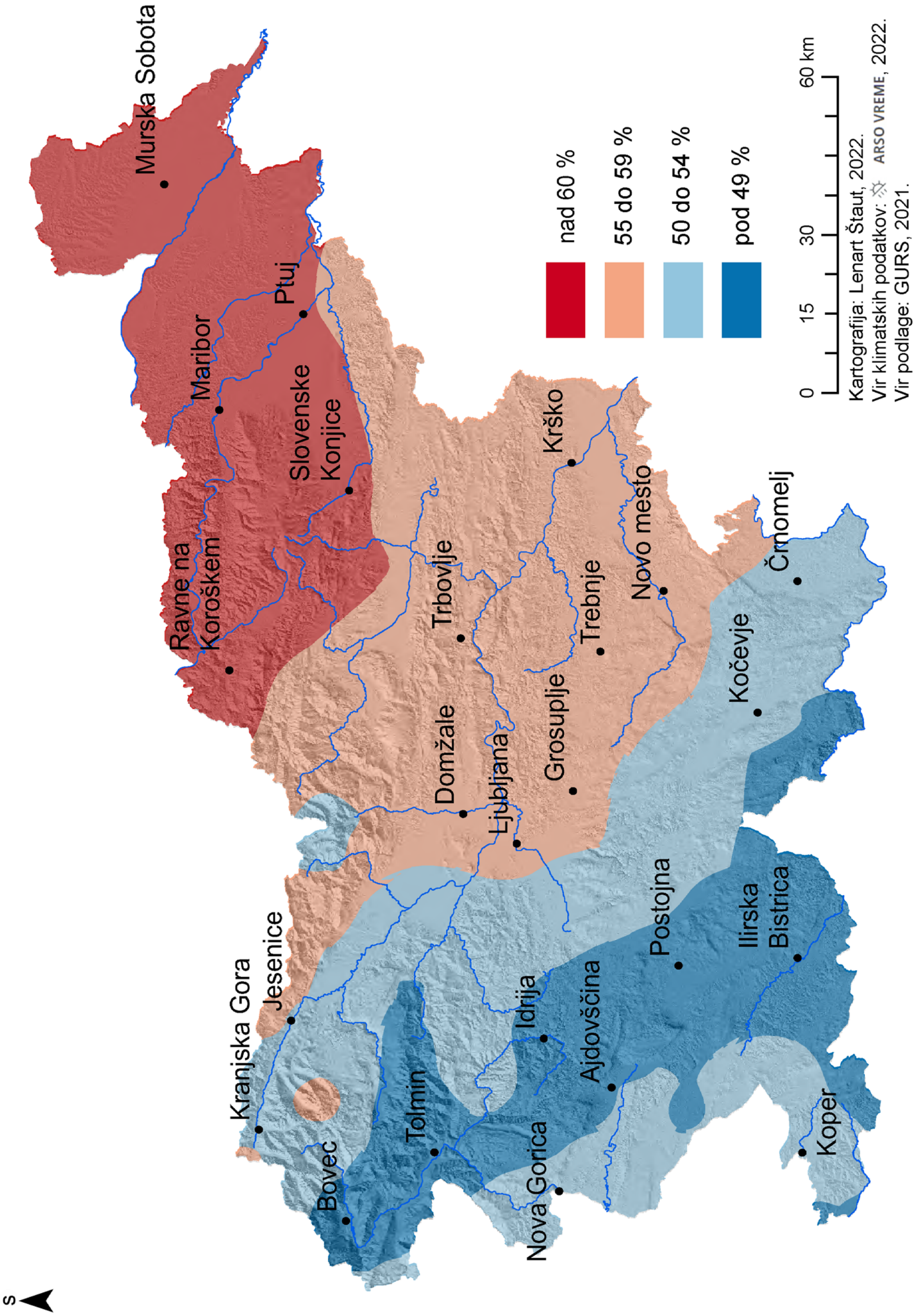
Tudi pri padavinskem režimu je Slovenija prehodno območje med zmerno sredozemskimi (morskimi) in zmerno celinskimi potezami. Zahodna, južna in osrednja Slovenija imajo zmerno sredozemske poteze padavinskega režima z viškom v jesenskih mesecih in najmanj padavin v drugi polovici zime vključno z marcem ter julija in avgusta. Severovzhodni del pa ima zmerno celinske poteze z viškom padavin poleti in nižkom pozimi. V omenjeni smeri se MI spreminja od pozitivnih proti negativnim vrednostim. Najvišji je v zahodni Sloveniji, kjer je med 15 in 18 (Dražgoše 17,5; Bovec 16,2; Vogel 15,7; Strunjan 15,4; Seča 15,2), najnižji pa na skrajnem severovzhodu med –5 in –8 (Šentilj v Slovenskih goricah –5,4; Mačkovci –5,6; Cankova –6,1; Podgorje v Slovenskih goricah –6,2; Jeruzalem –6,9; Martinje –7,1). Za Evropo, za katero sta Koppany in Unger (1992) računala MI za obdobje 1901–1950, so bile te vrednosti v razponu med 22 in –16. Tudi razlika med deležem padavin v topli in hladni polovici leta med zahodno in jugozahodno ter severovzhodno Slovenijo ni pretirana. Najvišji deleži padavin v topli polovici leta se v severni in severovzhodni Sloveniji večinoma gibljejo med 60 in 65 %, najvišji deleži v hladni polovici v južnem in jugozahodnem delu države pa med 51 in 57 %.

Padavinski režim je od leta do leta in od obdobja do obdobja zelo spremenljiv in ne moremo z gotovostjo računati na s povprečji ugotovljene viške oziroma nižke. Povprečna letna in sezonska variabilnost padavin je med 20 in 30 %, običajna mesečna povprečja pa so lahko presežena tudi čez 100 % ali padavin (tudi v povprečno najbolj namočenih mesecih) praktično ni. Indeks mediteranskosti padavin omogoča izračun teoretične meje med zmerno sredozemskim in zmerno celinskim padavinskim režimom (MI = 0,0). Po podatkih za obdobje 1961–1990 je meja potekala na črti Solčavsko–Ljubljana–Suha Krajina–Gorjanci (Ogrin, 1996), v obdobju 1971–2000 se je pomaknila proti vzhodu na črto Strojna–zahodna Celjska kotlina–Suha Krajina–Gorjanci (Ogrin, 2009), za obdobje 1991–2020 pa poteka od Mežice po Vitanjskem podolju do Slovenskih Konjic in pod Bočem in Halozami do meje s Hrvaško. To pomeni, da se je proti vzhodu Slovenije razširilo območje z viškom padavin v jeseni in se v zadnjih 60 letih močno skrčilo območje s poletnim viškom padavin. Hkrati je na severovzhodu Slovenije oslabel poletni višek padavin na račun povečanja jesenskih padavin. Opazno je tudi, da se jesenski višek padavin v zahodnih delih Slovenije večinoma pojavlja novembra ali oktobra, proti vzhodu in severovzhodu pa vse pogosteje septembra ali ponekod oktobra oziroma postajata jesenski in poletni višek vse bolj izenačena.

Slika 4: Indeks mediteranskosti padavin (MI) v Sloveniji (1991–2020).



Slika 5: Delež padavin v topli polovici leta (1991–2020).



Preglednica 2: Indeks mediteranskosti padavin (MI) in delež padavin v topli polovici leta (DT) na izbranih padavinskih postajah Slovenije v obdobju 1991–2020.

Padavinska postaja	MI	DT (%)	Padavinska postaja	MI	DT (%)
Ambrož po Krvavcem	3,9	55	Brod v Podbočju	4,2	55
Zgornje Jezersko	7,2	52	Moravče	3,3	57
Planina pod Golico	7,2	54	Gornji Grad	5,7	54
Rateče	7,9	54	Letališče J. P. Brnik	5,6	54
Kredarica	4,9	57	Ljubljana-Bežigrad	3,1	56
Zgornja Radovna	10,4	51	Vrhnika	7,5	50
Bohinjska Bistrica	13,3	48	Škofja loka	8,9	50
Vogel	15,7	46	Javorniški rovt	7,6	54
Zgornja Sorica	11,2	47	Črnomelj-Dobliče	7,9	52
Kneške Ravne	12,0	46	Metlika	5,9	55
Tolmin-Volče	11,1	47	Novo mesto	5,4	56
Vojsko	12,2	46	Cerklje-letališče	3,4	58
Vedrijan	10,1	51	Mokronog	2,6	57
Bilje	11,9	50	Bizeljsko	3,0	55
Razdrto	9,5	48	Velenje	0,4	59
Godnje	11,2	48	Celje-Medlog	0,5	59
Ilirska Bistrica	13,7	46	Slovenske Konjice	0,6	60
Movraž	6,7	48	Rogaška Slatina	0,5	58
Portorož-letališče	14,8	49	Ravne na Koroškem	–3,2	63
Babno Polje	12,6	47	Šmartno pri Sl. Gradcu	–2,3	62
Kočevje	7,4	52	Ribnica na Pohorju	–2,6	61
Nova vas-Bloke	7,9	52	Letališče E. R. Maribor	–2,7	62
Planina-Rakek	11,6	47	Polički vrh	–3,8	63
Logatec	10,8	47	Jeruzalem	–6,9	61
Litija	4,3	57	M. Sobota-Rakičan	–4,8	64
Malkovec	2,8	57	Ptuj	–1,9	60
Sevno	3,6	56	Maribor-Vrbanski plato	–1,7	62
Lisca	1,8	59	Lendava	–1,8	60

3.4 Vlažnost podnebja

V povprečju pade v Sloveniji okoli 1450 mm padavin letno, kar jo uvršča med najbolj namočene države v Evropi, so pa padavine prostorsko zelo neenakomerno razporejene. Največ jih pade na alpsko-dinarski pregradi, tudi več kot 2000 mm letno, v najbolj namočenem delu Julijskih Alp tudi več kot 3200 mm. Od Alp in Visokih dinarskih planot se padavine zmanjšujejo proti jugozahodu in severovzhodu. Ob morju jih pade med 900 in 1000 mm (Strunjan 947 mm; Letališče Portorož 958 mm; Koper 989 mm), v Prekmurju pa pod 850 mm (Kobilje 772 mm; Lendava 790 mm; Murska Sobota 812 mm; Cankova 830 mm).

Velike regionalne razlike v namočenosti in vlažnosti podnebja so zato eden pomembnejših dejavnikov pri podnebni členitvi Slovenije. Prostorske razlike v vlažnosti podnebja smo ugotavljali s pomočjo Langovega padavinskega faktorja. Alpsko-dinarska pregrada ima po tem kazalcu zelo vlažno (perhumidno) podnebje. Slovenska Istra, severovzhodna Slovenija, Krško-Brežiško polje s spodnjo Krško dolino in nekatera manjša območja na vzhodu Slovenije pol vlažno (semihudno) podnebje, preostala Slovenija pa humidno (vlažno) podnebje (slika 5).

Preglednica 3: Langov padavinski faktor (L) na izbranih meteoroloških postajah Slovenije v obdobju 1991–2020.

Meteorološka postaja	L	Meteorološka postaja	L
Krvavec	519	Miklavž na Gorjancih	130
Jezersko	276	Trojane-Limovce	136
Planina pod Golico	254	Gornji Grad	154
Rateče	220	Malkovec	97
Bovec - letališče	236	Letališče J. P. Brnik	136
Rudno polje	444	Ljubljana-Bežigrad	110
Bohinjska Češnjica	215	Vrhnika	144
Vogel	715	Kranj	125
Zgornja Sorica	258	Lesce-letališče	135
Krn	299	Ravne na Koroškem	108
Tolmin-Volče	173	Šmartno pri Sl. Gradcu	126
Vojsko	342	Velenje	98
Vedrijan	104	Celje-Medlog	103
Bilje	106	Slovenske Konjice	89
Podnanos	115	Črnomelj-Dobliče	109
Godnje	111	Metlika	92

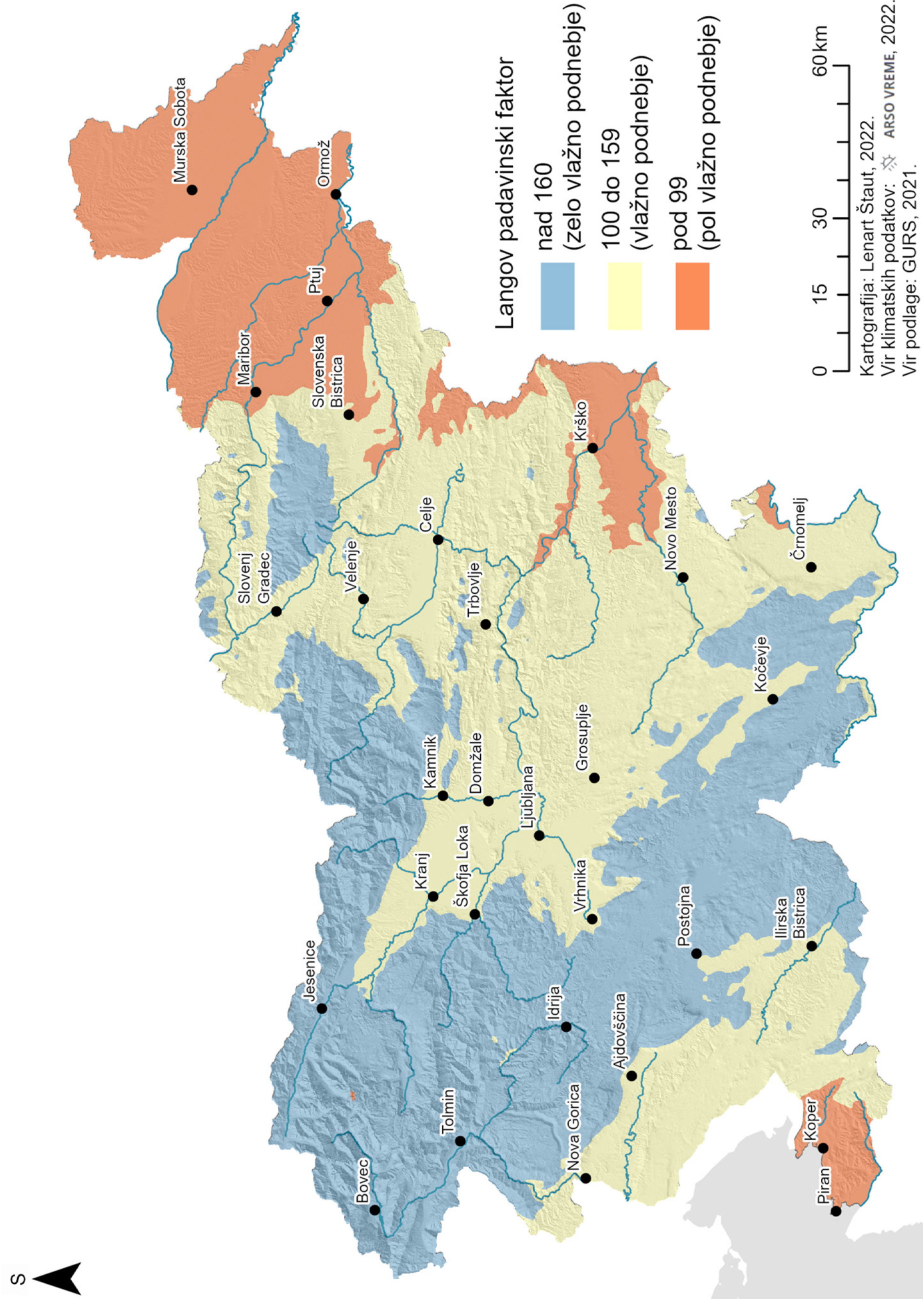
Meteorološka postaja	L	Meteorološka postaja	L
Ilirska Bistrica	133	Novo mesto	101
Kubed	101	Cerklje-letališče	97
Portorož-letališče	66	Trebnje	108
Babno Polje	230	Bizeljsko	87
Kočevje	158	Rogaška Slatina	92
Nova vas-Bloke	198	Letališče E. R. Maribor	84
Postojna	195	Polički vrh	97
Logatec	203	Jeruzalem	72
Litija	109	Murska Sobota-Rakičan	73
Rogla	295	Ptuj	82
Sevno	114	Maribor-Vrbanski plato	89
Lisca	140	Lendava	66

3.5 Podnebni tipi v Sloveniji za obdobje 1991–2020

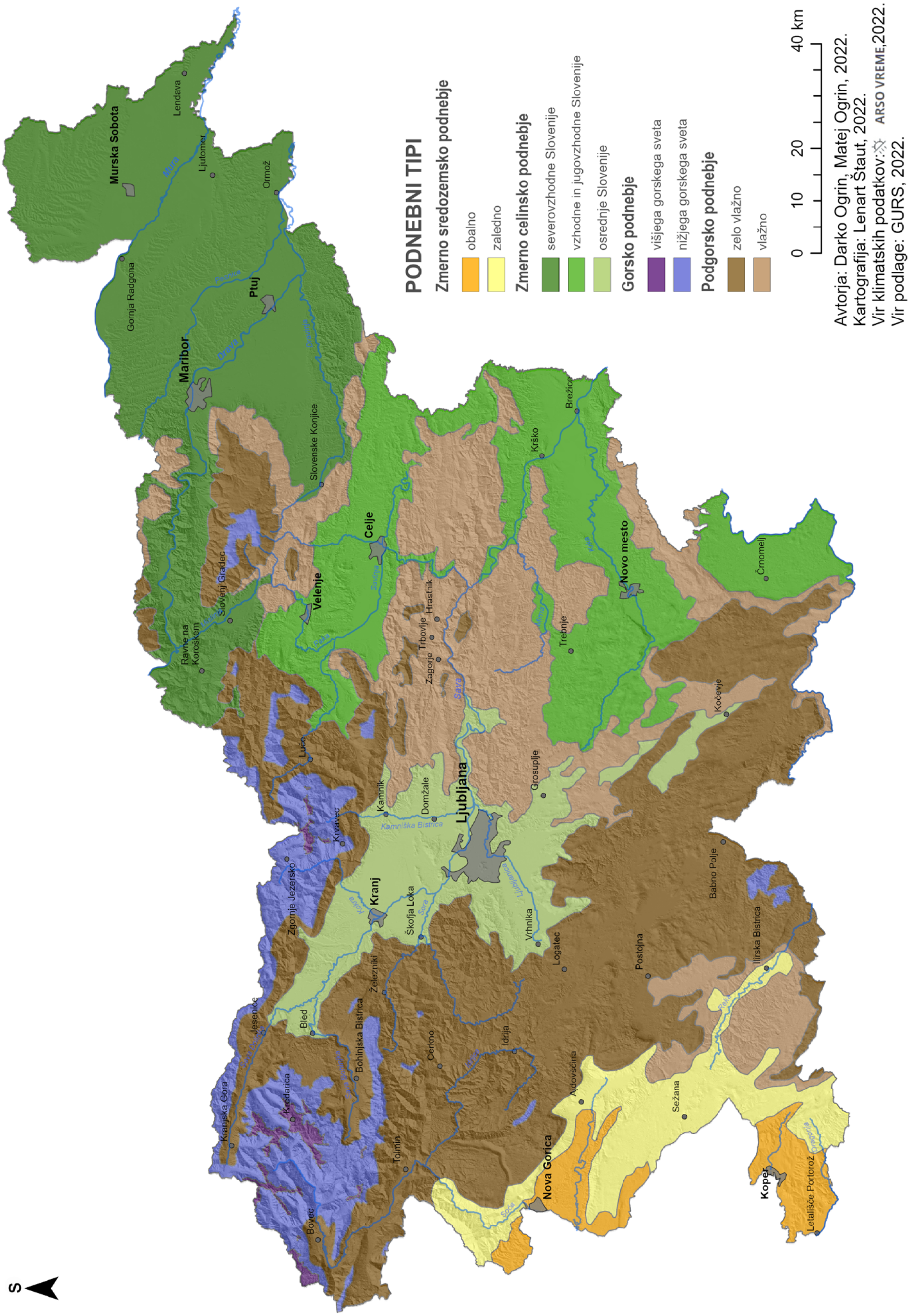
Predhodne podnebne členitve (npr. Kozjek in sod., 2017; Melik, 1935; Ogrin, 1996; 2009) izpostavljajo dejstvo, da na ozemlju Slovenije prihaja do stika in prepletanja gorskega (montanskega, alpskega), sredozemskega (mediteranskega) in celinskega (kontinentalnega, panonskega) podnebja. Podnebna stičnost in prehodnost je izziv za podnebne členitve, za ugotovljene tipe podnebja je značilna netipičnost, če jih primerjamo s pravim celinskim, sredozemskim ali gorskim podnebjem. To je razlog, da jih označujemo za »zmerno« ali dodajamo predpone »sub«, »ob« ali »pod« (npr. zmerno celinsko, submediteransko, obpanonsko, podgorsko). Na splošno se z oddaljevanjem od alpsko-dinarske pregrade proti vzhodu in severovzhodu države krepijo celinske podnebne značilnosti, proti jugozahodu sredozemske, z naraščanjem nadmorske višine v Alpskih, Predalpskih in Dinarskokraških pokrajinah pa značilnosti gorskega podnebja. Meje med tipi in podtipi podnebij na kartografskih prikazih moramo zato razumeti kot prehodna območja in ne v smislu ostrih ločnic.

Z upoštevanjem izhodišč in kriterijev, predstavljenih na predhodnih straneh, smo izločili štiri osnovne tipe podnebij: zmerno sredozemsko, zmerno celinsko, gorsko in podgorsko podnebje. V drugem koraku smo jih razdelili na 9 podtipov: zmerno sredozemsko na obalno in zaledno, zmerno celinsko na zmerno celinsko severovzhodne, vzhodne in jugovzhodne Slovenije ter osrednje Slovenije, gorsko podnebje na podnebje višjega in nižjega gorskega sveta ter podgorsko na zelo vlažno in vlažno podgorsko podnebje (slika 6).

Slika 6: Vlažnost podnebja glede na Langov padavinski faktor (1991–2020).



Slika 7: Podnebni tipi v Sloveniji v obdobju 1991–2020.

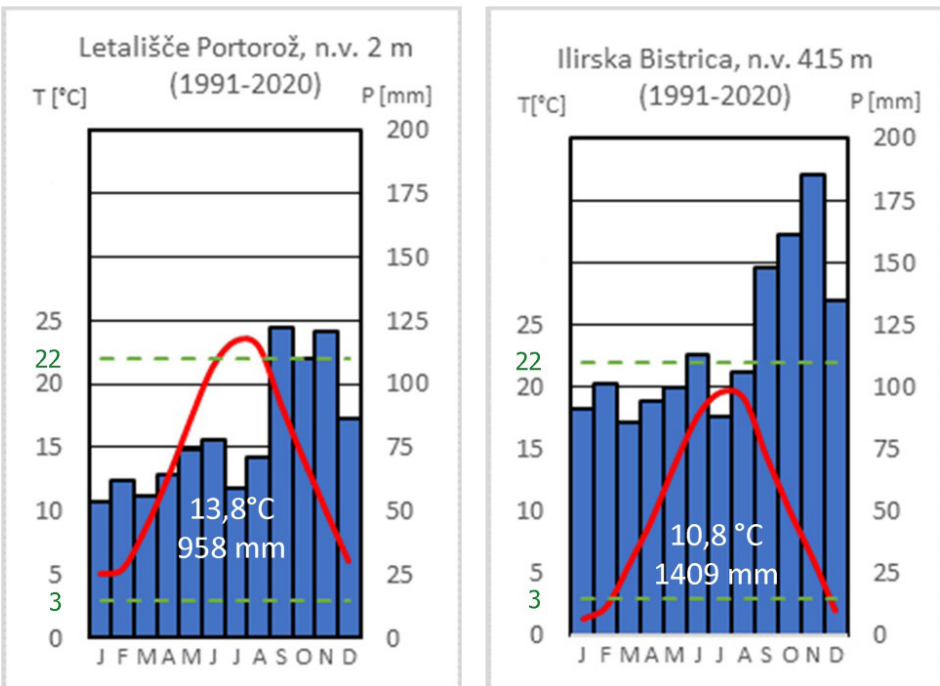


Zmerno sredozemsko podnebje

Zaradi odprtosti površja proti Jadranskemu morju in Sredozemlju se južno in jugozahodno od alpsko-dinarske pregrade pojavlja zmerno sredozemsko podnebje, ki ima največ jasnih dni v Sloveniji. Zaradi vpliva morja so povprečne temperature najvišje v Sloveniji, predvsem jesenske in zimske. V najhladnejšem mesecu se v povprečju ne spustijo pod ledišče, v najtoplejšem so nad 20 °C. Povprečna letna temperaturna amplituda je manjša od 20 °C, saj vpliv morja blaži zimski mraz, poleti pa vročino. Padavinski režim je zmerno sredozemski z viškom padavin v jesenskih mesecih. Snežna odeja je redek pojav.

V hladni polovici leta je pogosta burja, pred poslabšanji vremena zlasti v hladni polovici leta piha jugo. Omeniti moramo tudi pojav lokalnih termičnih vetrov ob anticiklonalnem vremenu, podnevi je to maestral (mornik, zmorec), ponoči pa burin (kopnik), ki je ob slovenski obali manj izrazit od maestrala. Od obale proti alpsko-dinarski pregradi se temperature znižujejo, naraščajo pa padavine, kar je osnova za delitev zmerno sredozemskega podnebja na toplejše in manj vlažno obalno ter nekoliko hladnejše in bolj vlažno zaledno. Na prehodu zime v pomlad ter julija in avgusta je običajno suša, ki je zaradi značilnosti površja izrazitejša na kraškem svetu.

Slika 8: Klimograma za obalno (Letališče Portorož) in zaledno (Ilirska Bistrica) zmerno sredozemsko podnebje.



Preglednica 4: Osnovne značilnosti zmerno sredozemskega podnebja.

<table>
<tr><td colspan="2">Zmerno sredozemsko podnebje
- Povprečna temperatura najhladnejšega meseca nad 0 °C
- Povprečna temperatura najtoplejšega meseca nad 20 °C
- Oktober toplejši od aprila
- Povprečna letna temperaturna amplituda pod 20 °C
- Povprečna letna višina padavin od 900 do 1400 mm
- Zmerno sredozemski padavinski režim (MI >10)</td></tr>
<tr><td>Obalno zmerno sredozemsko podnebje
(Cfaw‘ po Köppenu)
- Povpr. temp. najhladnejšega meseca nad 3 °C
- Povpr. temp. najtoplejšega meseca nad 22 °C
- Delež padavin v hladni polovici leta od 45 do 50 %
- Semihumidno podnebje (L < 99)</td><td>Zaledno zmerno sredozemsko podnebje
(Cfbw‘ po Köppenu)
- Povpr. temp. najhladnejšega meseca med 0 in 3 °C
- Povpr. temp. najtoplejšega meseca med 20 in 22 °C
- Delež padavin v hladni polovici leta večinoma nad 50%
- Humidno podnebje (L = od 100 do 159)</td></tr>
</table>

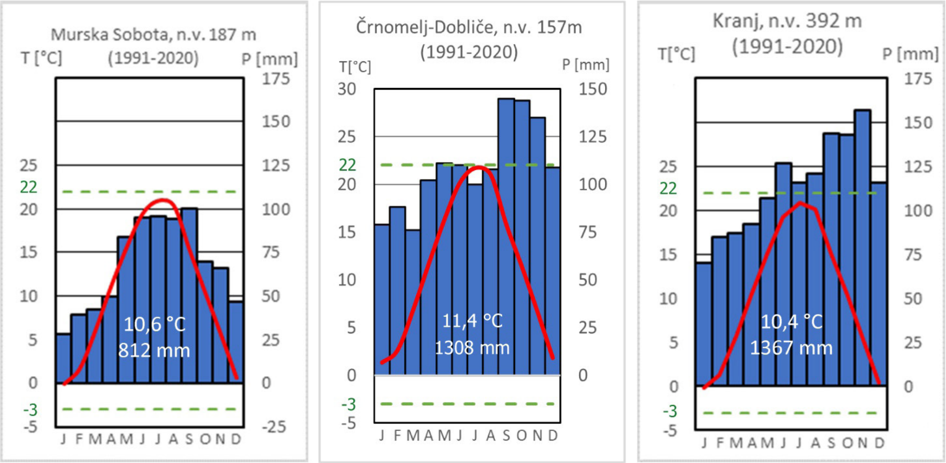
V območjih Slovenije z zmerno sredozemskim podnebjem prevladuje kulturna pokrajina. Podnebje sovpada s Primorsko vinorodno deželo, obalno podnebje, kjer so januarske temperature nad 3 °C in julijske nad 22 °C, pa z območjem oljke (podnebje oljke). Naravno rastlinstvo je posledično zelo spremenjeno. Podnebne razmere ustrezajo toploljubnim in na sušo prilagojenim listopadnim gozdovom, značilnim za obrobje Sredozemlja. Najbolj razširjene so zmerno toploljubne in listopadne združbe, kjer prevladujejo hrast puhavec (*Quercus pubescens*), črni gaber (*Ostrya carpinifolia*) in mali jesen (*Fraxinus ornus*). Najpogostejši gozdni združbi sta združba črnega gabra in puhastega hrasta (*Ostryo-Quercetum pubescentis*) in združba črnega gabra in jesenske vilovine (*Seslerio autumnalis-Ostryetum*) (Repe, 2012). Na bolj toplih rastiščih se jim pridružita še kraški gaber (*Carpinetum orientalis*) in trokrpi javor (*Acer monspessulanum*). Na najtoplejših rastiščih v Sloveniji (kraški rob, južna pobočja Nanosa) s toplimi talnimi razmerami so ohranjeni tudi fragmenti vednozelene trdolistne makije (*Ostryo-Quercetum ilicis*), ki jo sestavljajo vednozelena sredozemska drevesa in grmičevje, npr. hrast črnika (*Quercus ilex*), zelenika (*Phyllirea latifolia*), lovor (*Laurus nobilis*). Vmes se pojavljajo tudi druge listopadne toploljubne vrste, npr. navadni derak (*Paliurus spina-christi*) in vednozelene ovijalke, npr. ostrolistni beluš (*Asparagus acutifolius*) (Kaligarič, 2004). Antropogeno je na tem območju močno prisoten črni bor (*Pinus nigra*), kot posledica pogozdovanja v prvi polovici prejšnjega stoletja (Repe, 2020). Več kot pravih sredozemskih naravnih vrst je kulturnih rastlin, ob oljki tudi figa, mandljevec, granatno jabolko idr.

Slika 9: Otoček makije v steni nad osapsko zatrepno dolino (foto: D. Ogrin).

Zmerno celinsko podnebje

Zmerno celinsko podnebje imajo nižje ležeča območja v severovzhodni, vzhodni, jugovzhodni in osrednji Sloveniji. Za zmerno sredozemskim je drugo najtoplejše podnebje v Sloveniji. Zanj je značilna največja povprečna letna temperaturna amplituda (nad 20 °C) in visoke poletne maksimalne temperature. Prejme podpovprečno letno količino padavin (pod 1400 mm), večina jih pade v topli polovici leta. Najbolj izrazite celinske podnebne poteze ima severovzhodna Slovenija, kjer je april toplejši od oktobra (celinski predeli se spomladi hitreje segrejejo od območij pod vplivom morja), pade najmanj padavin (tudi pod 1000 mm) in ima zmerno celinski padavinski režim. Nižje ležeča območja na vzhodu in jugovzhodu Slovenije, ki so prav tako odprta proti Panonski nižini, imajo podobne temperaturne značilnosti, le da prejmejo več padavin in imajo zmerno sredozemski padavinski režim. Slednji je značilen tudi za zmerno celinsko podnebje osrednje Slovenije, ki je zaradi lege v bližini alpsko-dinarske pregrade še bolj vlažno, večji vpliv morskih zračnih gmot je razviden tudi iz toplejšega oktobra od aprila.

Slika 10: Klimograma za zmerno celinsko podnebje severovzhodne (Murska Sobota), vzhodne in jugovzhodne (Črnomelj-Dobliče) in osrednje Slovenije (Kranj).



Preglednica 5: Osnovne značilnosti zmerno celinskega podnebja.

<table>
<tr><td colspan="2">Zmerno celinsko podnebje
- Povprečna letna temperaturna amplituda nad 20 °C
- Povprečna julijska temperatura od 20 do 22 °C
- Povprečna letna temperatura od 9 do 12 °C
- Povprečna letna višina padavin pod 1400 mm
- Nad 50 % letne višine padavin v topli polovici leta</td></tr>
<tr><td>Severovzhodne Slovenije
(Cfbx‘ po Köppenu)
- April toplejši od oktobra
- Letna višina padavin med 750 in 1200 mm
- Nad 60 % padavin v topli polovici leta
- Zmerno celinski padavinski režim (MI = od 0 do −10)
- Semihumidno do humidno podnebje</td><td>Vzhodne in jugovzhodne Slovenije
(Cfbw‘ po Köppenu)
- April toplejši od oktobra
- Letna višina padavin od 1000 do 1400 mm
- Od 50 do 60 % letne višine padavin v topli polovici leta
- Zmerno sredozemski padavinski režim (MI = 0 do 5)
- Semihumidno do humidno podnebje</td></tr>
<tr><td colspan="2">Zmerno celinsko podnebje osrednje Slovenije (Cfbw‘ po Köppenu)
- Oktober toplejši od aprila
- Letna višina padavin od 1200 do 1400 mm
- Od 50 do 60 % letne višine padavin v topli polovici leta
- Zmerno sredozemski padavinski režim (MI = od 0 do 10)
- Humidno podnebje (L = od 100 do 159)</td></tr>
</table>

Kljub večjemu deležu padavin v topli polovici leta so poletja v severovzhodni, vzhodni in jugovzhodni Sloveniji, deloma tudi v osrednji Sloveniji na prodnih in peščenih nanosih, zaradi sorazmerno nizke količine padavin in visokih temperatur (povprečne julijske temperature so nad 20 °C) na robu sušnosti. Zmrzal je pozimi pogosta, pojavljajo se tudi ledeni dnevi (dnevne temperature ostanejo pod lediščem). Snežna odeja se pojavlja v vseh območjih tega podnebnega tipa, na letni ravni približno 4 tedne, a snega pade precej manj kot pred desetletji, obdobja s snežno odejo pa so vse krajša. Razmeroma pogoste so pomladanske pozebe, zlasti so izpostavljene nižine, kotline in doline. Poletna vroča obdobja pogosto prekinejo nevihte (tudi s točo in močnim vetrom), ki povzročajo večjo škodo v kmetijstvu in na objektih. Nevihtam so bolj izpostavljena nižinska območja v vzhodni polovici Slovenije. Zlasti nižine vzhodne in jugovzhodne Slovenije so zaradi nizke nadmorske višine, odprtosti proti Panonski kotlini in zavetrne lege ob jugozahodnih vetrovih (Bela krajina, Krško-Brežiško polje) poleti pogosto območja največje vročinske pregretosti, kjer najvišje dnevne temperature lahko presežejo tudi tiste v Vipavski dolini in ob obali.

V območju z zmerno celinskim podnebjem prevladuje zaradi ugodnih naravnih razmer kulturna pokrajina, tu so najbolj obsežna območja obdelovalnih površin v Sloveniji, ki so poleti pogosto izpostavljene suši. Zmerno celinsko podnebje severovzhodne, vzhodne in jugovzhodne Slovenije (imenovali bi ga lahko tudi obpanonsko podnebje) približno sovpada s Podravsko in Posavsko vinorodno deželo. Zaradi ugodnejših lokalnih podnebnih razmer so vinogradi in sadovnjaki večinoma urejeni v prisojah toplega pasu. V ravninah in dolinah, kjer so pogosti temperaturni obrati, so predvsem njivske in travniške površine. Večje kotline kot npr. Ljubljanska in Celjska in nižine (Mursko polje, Dravsko-Ptujsko polje) imajo pogosto jutranjo meglo, ta je najtrdovratnejša v jeseni in v prvi polovici zime. Nižine veljajo za neprevetrene in brez energetskega potenciala vetra ter z manjšimi samočistilnimi sposobnostmi zraka, kar povečuje onesnaženost zraka zlasti v hladni polovici leta (Ogrin, Vintar Mally, 2013; Strle in sod., 2020). Stalnih močnejših vetrov po nižinah ni, le ponekod v Savinjski dolini in po nižinah vzhodne polovice države pred poslabšanjem vremena zapiha okrepljen jugozahodni veter, z južnih pobočij Karavank, Kamniško-Savinjskih Alp in Pohorja pa še redkejši severni fen, ki lahko povzroča škodo.

Slika 11: Prisoje gričevij Obpanonskih pokrajin v toplem pasu so manj ogrožene zaradi spomladanskih pozeb, imajo več sonca ter nižjo zračno in talno vlažnost, zato nudijo ugodne pogoje za uspevanje vinske trte. Na sliki je vinogradniška pokrajina Trške gore pri Novem mestu (foto: D. Ogrin).

Z vidika rastlinstva lahko območje z zmerno celinskim podnebjem razdelimo na tri dele:

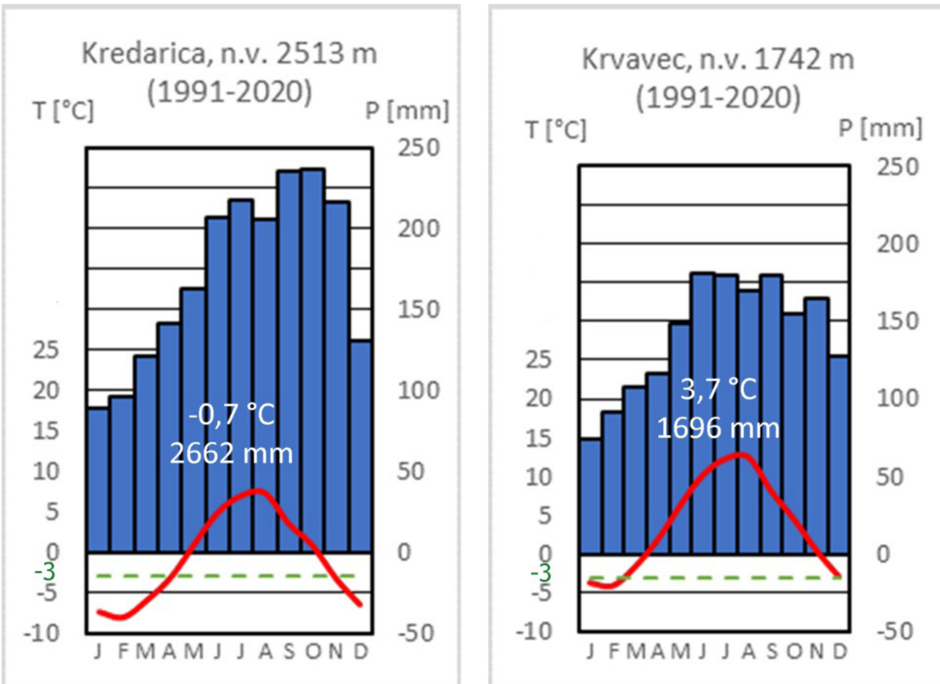
a) prekomerno vlažni ravninski deli neposredno ob vodotokih (logi) in območja z visoko podtalnico (poplavni in močvirski gozdovi);
b) dobro odcejena ravninska območja;
c) gričevja in vznožja hribovij.

Za vlažne nižinske dele je značilno vlagoljubno gozdno rastlinstvo s hrastom dobom (*Quercus robur*), črno in sivo jelšo (A*lnus glutinosa in A. incana*), velikim jesenom (*Fraxinus excelsior*), vrbami (npr. bela vrba, *Salix alba*) in topoli (črni in beli, *Populus nigra* in *P. alba*). Pogosti združbi sta združba črne jelše (*Alnetum glutinosae*) in bele vrbe (*Salicetum albae*). Kjer voda ne zastaja, so ravnine v preteklosti poraščali hrastovi (*Quercus petraea*) in belogabrovi gozdovi (*Carpinus betulus*). Ker gre za ena najboljših rastišč v Sloveniji, so danes skoraj povsem izkrčena. Vzpeti deli so porasli z listopadnimi gozdovi. Nad ravnino hraste in gabre hitro zamenja bukev (*Fagus sylvatica).* Še posebej na osojnih pobočjih postane prevladujoča vrsta. Na silikatnih kamninah bukev najpogosteje uspeva skupaj s kostanjem (*Castanea Sativa*, kisloljubna združba *Castaneo sativae-Fagetum*), kjer so primešani še navadna breza (*Betula pendula*) in rdeči bor (*Pinus sylvestris*), v podrasti pa borovnica (*Vaccinium myrtilus*). Na karbonatnih kamninah uspevajo bukove združbe npr. s tevjem (*Hacquetio-Fagetum*) ali veliko mrtvo koprivo (*Lamio orvalae-Fagetum*), značilne za bolj milo obliko celinskega podnebja. Na izrazito prisojnih in nadpovprečno toplih ter sušnih pobočjih iz apnenca in dolomita uspeva toploljubna in sušovzdržna združba bukve in črnega gabra (*Ostryo-Fagetum*) (Marinček, Čarni, 2002; Repe, 2020). S podnebnimi spremembami je pričakovati, da bo slednja med tistimi, ki se bo v prihodnosti najbolj razširila (Gregorčič in sod., 2022; Kutnar, Kobler, 2014).

Gorsko podnebje

Z višino se običajno temperatura zraka znižuje, narašča količina padavin, povečujeta se trajanje in višina snežne odeje, povečuje se vetrovnost, krajša se rastna doba ipd. Zato so ena glavnih značilnosti gorskega podnebja višinski podnebno-rastlinski pasovi, v Sloveniji predvsem gorski, subalpski in alpski pas (manjka pravi nivalni pas). Gorsko podnebje, ki ga imajo Alpe, Pohorje in najvišji predeli Zahodnega predalpskega hribovja ter Visokih dinarskih planot, je najhladnejše in najbolj vlažno v Sloveniji (in med najbolj vlažnimi v Evropi), z dolgo trajajočo in visoko snežno odejo, ki v povprečnih zimah preseže 150 cm. Povprečna temperatura najhladnejšega meseca je nižja od −3 °C, letna višina padavin pa večinoma nad 1600 mm. Zahodna območja z gorskim podnebjem so bolj namočena (letno pade tudi nad 2500 mm padavin) in imajo višek padavin v pozni jeseni, vzhodna pa prejmejo manj padavin, najbolj namočen del leta se premakne v poletni čas. Najmanj padavin je pozimi. Reliefna razčlenjenost gorskega sveta pogojuje tudi zelo raznolike topoklimatske razmere z veliko mikroklimatsko pestrostjo. V sredogorskih in visokogorskih mraziščih so temperaturne razmere lahko ekstremne, saj so tam temperature lahko tudi okoli 30 °C nižje kot v območjih izven mrazišč na enaki nadmorski višini (Dovečar in sod., 2009; Ogrin, Ogrin, 2005; Ogrin, 2007; Ogrin in sod., 2012; Ortar, 2011; Svetlin, 2020; Trošt, 2008). V gorskih območjih pa poleg največje količine padavin beležimo tudi največje padavinske gradiente. Zlasti to velja za območja nekaterih alpskih dolin (Ogrin, Kozamernik, 2018; 2020a; 2020b). Višje lege, zlasti grebeni in vrhovi, so vetru najbolj izpostavljene lege v Sloveniji, proti dolinam pa prevetrenost hitro slabi. Dna dolin so kljub temu bolje prevetrena od nižin in kotlin, saj se ob anticiklonalnem tipu vremena redno pojavlja dnevna termika, ki povečuje samočistilne sposobnosti ozračja. V zadnjih desetletjih se obseg gorskega podnebja v Sloveniji zaradi segrevanja ozračja zmanjšuje.

Slika 12: Klimograma za podnebje višjega (Kredarica) in nižjega gorskega sveta (Krvavec).



Preglednica 6: Osnovne značilnosti gorskega podnebja.

<table>
<tr><td colspan="2">Gorsko podnebje
- Povprečna temperatura najhladnejšega meseca pod –3 °C (januarska izoterma –3 °C na okoli 1530 m)
- Oktober toplejši od aprila
- Povprečna letna temperatura pod 6 °C
- Povprečna letna temperaturna amplituda pod 18 °C
- Letna višina padavin nad 1600 mm (Pohorje od 1400 do 1600 mm)
- Perhumidno podnebje (L >160)</td></tr>
<tr><td>Podnebje višjega gorskega sveta
(ET po Köppenu)
- Povpr. temp. najtoplejšega meseca pod 10 °C (julijska izoterma 10 °C na okoli 2200 m)
- Povpr. letna temperatura pod 3 °C
- Letna višina padavin nad 2000 mm
- Zmerno sredozemski padavinski režim (MI nad 10)</td><td>Podnebje nižjega gorskega sveta
(Dfcw‘ (x‘), Dfbw‘ (x‘) in Cfcw‘ (x‘) po Köppenu)
- Od 1 do 4 meseci s povprečno mesečno temperaturo nad 10 °C
- Povpr. letna temp. od 3 do 6 °C
- Povprečna letna višina padavin od 1400 do 2000 mm
- Zmerno sredozemski padavinski režim (MI >10); Pohorje zmerno celinski padavinski režim</td></tr>
</table>

Podnebje višjega gorskega sveta imajo najvišji grebeni Julijskih in Kamniško-Savinjskih Alp, kjer temperatura najtoplejšega meseca v povprečju ne preseže 10 °C. Tako v najvišjih in najhladnejših območjih (nad 2400 m, subnivalni pas), kjer so srednje letne temperature okoli ali malo pod 0 °C, uspeva nesklenjeno rastlinstvo, s tipičnimi predstavniki gorskih rož, npr. triglavska roža (*Potentilla nitida*), triglavska neboglasnica (*Eritrichium nanum*) idr.

Približno med 2000 in 2400 m so srednje letne temperature stopinjo ali dve višje kot v subnivalnem pasu, kar je dovolj, da se pojavi alpski pas. Tu kot naravno rastje uspevajo trate in blazinaste trajnice, ki jih tvorijo različni šaši (npr. vednozeleni, rjasti, čvrsti), alpska velesa (*Dryas octopetala*) idr. Nižje se začne pojavljati pas hladoljubnega grmovja. Najpogostejše je planinsko ruševje (*Pinus mugo*), kjer pod njim uspevajo še dlakavi sleč (*Rhododendron hirsutum*), navadni slečnik (*Rhodothamnus chamaecistus*) in spomladanska resa (*Erica carnea*) (Blatnik, Repe, 2012). Med alpskim pasom in gozdno mejo je še subalpski pas, ki obsega območja večinoma med 1500 in 2000 m. Srednje letne temperature so približno med 4 in 2 °C. V tem pasu je za pojav strnjenega gozda še prehladno. Mešano z rušjem se začno najprej pojavljati posamezni macesni (*Larix decidua*) in smreke (*Picea abies*), tudi jerebika (*Sorbus aucuparia*). Število drevesnih vrst se z nižanjem nadmorske višine povečuje, dokler ne preidejo v gozdne sestoje z bujno grmovno podrastjo. Poleg planinskega rušja uspevajo v grmovni plasti še planinsko kosteničevje (*Lonicera alpigena*), alpski srobot (*Clematis alpina*), navadni volčin (*Daphne mezereum*) idr. (Repe, 2017).

Slika 13: Zgornja drevesna in gozdna meja na južnem pobočju Golice (foto: D. Ogrin).

Nižje, pod zgornjo drevesno in gozdno mejo, kjer imajo od eden do štirje meseci povprečno temperaturo nad 10 °C, je do nadmorske višine približno 1200 m podnebje nižjega gorskega sveta. To seže tudi v nekatere gorske doline in visoko ležeče kraške kotanje, kjer so temperature podobne gorskim predvsem zaradi močnih temperaturnih obratov. Z vidika naravnega rastlinstva bi to območje lahko uvrstili v nižji montanski pas, med drevesnimi vrstami tu prevladuje smreka (*Picea abies*), pogosta je tudi bukev (*Fagus sylvatica*), nižje dele tega območja poraščajo tudi jelka (*Abies alba*), javorji (npr. gorski javor, *Acer psudoplatanus*), višje pa se uveljavlja macesen (*Larix decidua*). Pogoste so bukove združbe (s trilistno vetrnico (*Anemono trifoliae-F.*), platanolistno zlatico (*Ranunculo platanifoliae-F.*), gozdnim planinščkom (*Homogyno sylvestris-F.*) idr.) in naravne smrekove gozdne združbe (s kranjsko krhliko (*Rhamno fallici-P.*), golim lepenom (*Adenostylo glabrae-Piceetum*) idr.). Na prisojnih pobočjih bukev uspeva s črnim gabrom (Repe, 2019). Do zgornje gozdne meje se je v preteklosti marsikje v gorah oblikovala kulturna pokrajina gorskih pašnikov, saj namočena poletja omogočajo bujno rast trave. Ta proces je marsikje antropogeno znižal naravno zgornjo gozdno mejo, ki se v zadnjih desetletjih zaradi opuščanja paše in tudi podnebnih sprememb postopno dviguje.

Podgorsko podnebje

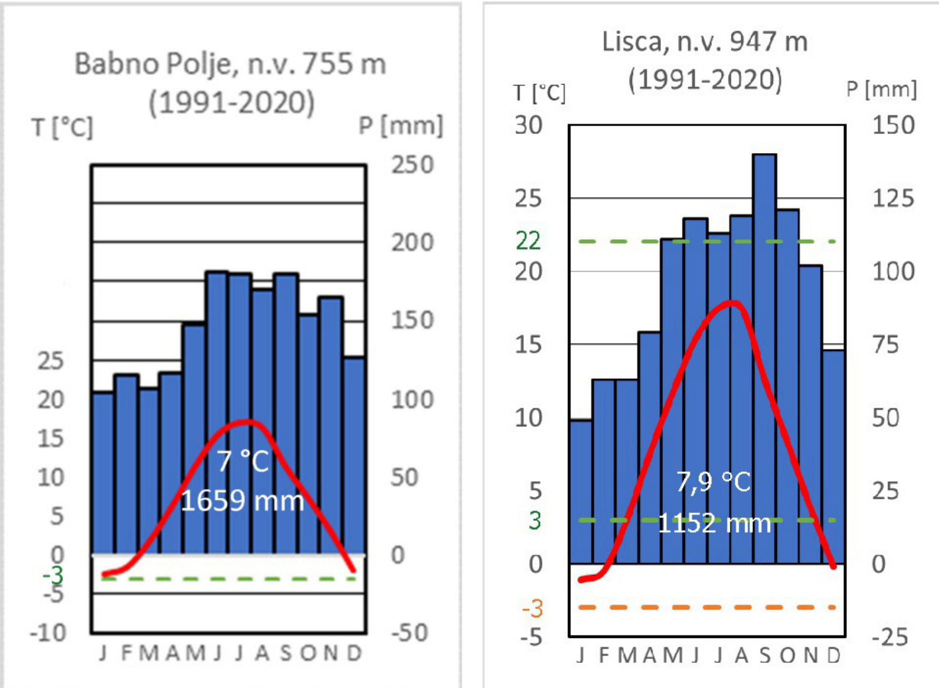
Podgorsko podnebje ima predgorje Alp in velika večina Predalpskega hribovja ter dinarskokraških planot in hribovij. Je prehodno podnebje med gorskim in zmerno celinskim na vzhodni strani oziroma gorskim in zmerno sredozemskim na jugozahodni strani alpsko-dinarske pregrade. Povprečne januarske temperature so večinoma med 0 in −3 °C, julijske pa med 16 in 20 °C. Zaradi lege v območju alpsko-dinarske pregrade je podnebje nadpovprečno namočeno, z najmanj padavinami pozimi. Snežna odeja je manj zanesljiva kot pri gorskem podnebju zaradi nižjih nadmorskih višin in višjih temperatur. Padavinske in temperaturne razmere so osnova za delitev podgorskega podnebja na zelo vlažno, ki ga ima osrednji, najvišji, najhladnejši in najbolj namočen del pregrade, in vlažno, ki ga imajo nižji in nekoliko toplejši robni predeli na celinski in primorski strani pregrade.

Zaradi manj ugodnih podnebnih, reliefnih in talnih razmer je v območjih Slovenije s predgorskim podnebjem in podnebjem nižjega gorskega sveta veliko gozda. Na celotnem območju izrazito prevladujejo bukovi gozdovi, ki imajo na karbonatnih kamninah značilnosti podnebno-višinske pasovitosti. V najnižjih višinah se pojavljata že omenjeni bukovi združbi s tevjem in veliko mrtvo koprivo. Z višanjem nadmorske višine se prične povečevati delež iglavcev, najprej predvsem jelke (*Abies alba*), višje še smreke (*Picea abies*). Tako na visokih dinarskih kraških planotah povsem prevladajo jelovo bukovi gozdovi (združba bukve in spomladanske torilnice, *Omphalodo-Fagetum*), ki proti Alpam preidejo v združbo s trilistno vetrnico (*Anemono trifoliae-Fagetum*). V mraziščih dinarskega krasa bukev najprej zamenja smreka in nato še rušje. Prisojna pobočja poraščajo bukovi gozdovi s črnim gabrom (*Ostryo-Fagetum*). Na silikatnih kamninah uspevajo kisloljubni bukovi gozdovi s kostanjem in z rebrenjačo (*Blechno-Fagetum*), kjer so mestom obilno primešane smreka, jelka in rdeči bor (Gregorčič in sod., 2022; Marinček, Čarni, 2002; Repe, 2020).

V območjih s podgorskim podnebjem z ugodnimi reliefnimi, talnimi in lokalnimi podnebnimi razmerami je naravno pokrajino preoblikovalo kmetijstvo. V nižjih vzpetih delih se nahaja topli pas, ki je zaradi manjše nevarnosti pozeb in manj vlažnih noči ugoden za sadno drevje. Višje prevladujejo gozdovi že omenjenih vrst, ki so marsikje prekinjeni s travniki, ki jim razmeroma vlažna poletja ustrezajo. Velika namočenost Zahodnega Predalpskega hribovja se zlasti v jesenskem času pogosto odraža v izrazitih padavinskih dogodkih, ki lahko povzročijo obilne hudourniške poplave, na kraških poljih pa manj uničevalne kraške poplave. V Dinarskokraških pokrajinah se v tem podnebnem tipu na kraških poljih, podoljih in drugih depresijskih reliefnih oblikah pojavlja izrazit temperaturni obrat. Tako npr. kraška polja ob jasnih jutrih pogosto postanejo prava mrazišča, naselja v teh poljih pa najhladnejša poseljena območja v Sloveniji (npr. Babno Polje, Rakitna, Retje, Travnik) (Ogrin in sod., 2006).

Pojav temperaturne inverzije v poseljenih kraških poljih in podoljih je povezan tudi nizkimi samočistilnimi sposobnostmi zraka in njegovo povečano onesnaženostjo kot posledico lokalnih izpustov gospodinjstev in prometa zlasti v hladni polovici leta (Glojek in sod., 2018; 2020; 2022). Višja območja tega podnebnega tipa so zmerno prevetrena, v nižinah pa izrazitejših vetrov ni, izjeme so lahko doline alpskega in predalpskega sveta, kjer se ob anticklonalnem tipu vremena pojavlja dnevna termika (gornik ponoči in dolnik čez dan).

Slika 14: Klimogram za zelo vlažno (Babno Polje) in vlažno (Lisca) podgorsko podnebje.



Preglednica 7: Osnovne značilnosti podgorskega podnebja.

<table>
<tr><td colspan="2">Podgorsko podnebje (Cfbw‘ in Cfbx‘ po Köppenu)
- Povprečna januarska temperatura od 0 do −3 °C, povprečna julijska temperatura od 16 do 20 °C, povprečna letna temperatura od 6 do 9 °C
- Povprečna letna temperaturna amplituda od 18 do 20 °C
- Oktober toplejši od aprila
- Letna višina padavin nad 1400 mm
- Zmerno sredozemski padavinski režim (razen Pohorja in Kozjaka s Košenjakom)</td></tr>
<tr><td>Zelo vlažno podgorsko podnebje
- Perhumidno podnebje (L >160)</td><td>Vlažno podgorsko podnebje
- Humidno podnebje (L = od 100 do 159)</td></tr>
</table>

Slika 15: V gorskem svetu pade veliko padavin. Tudi v Bohinju, za katerega ljudje pravijo, da ima tam dež mlade. Dežnik je zato eden od simbolov v teh krajih (foto: D. Ogrin).

4 RAZPRAVA

Podnebna tipizacija Slovenije za obdobje 1991–2020 deloma temelji na drugačnih kriterijih kot vse prejšnje, zato neposredna primerjava s prejšnjimi klasifikacijami ni mogoča. Čeprav deloma ohranja poimenovanje določenih podnebnih tipov, npr. zmerno celinsko podnebje, podnebje nižjega in višjega gorskega sveta, obalno in zaledno zmerno sredozemsko podnebje, se kriteriji razlikujejo od preteklih študij, kar je posledica globalnega segrevanja ozračja in spreminjanja podnebja. Hkrati določene podnebne tipe tudi ukinja (npr. zmerno celinsko podnebje zahodne in južne Slovenije ali podnebje nižjega gorskega sveta in vmesnih kotlin in dolin severne Slovenije) in uvaja nove. Metoda, na kateri temelji tipizacija, tudi ni primerljiva s tipizacijami podnebja v sosednjih državah, saj je njen namen identifikacija podnebnih tipov Slovenije z opisom njihovih lastnosti in iskanjem različnosti ter podobnosti med slovenskimi regijami. Območje Slovenije je stičišče štirih velikih geografskih enot (Ogrin, Plut, 2009), kar posledično vodi v veliko geografsko pestrost slovenskih pokrajin, ki se kaže v veliki abiotski pestrosti (geodiverziteti), kamor lahko uvrščamo tudi podnebne tipe. Podnebni tipi so posledica ustaljenih vremenskih procesov in njihovih lastnosti, ti pa so posledica delovanja ostalih abiotskih in biotskih dejavnikov (geološka sestava, relief, vodovje, rastje), hkrati pa nanje tudi vplivajo in jih oblikujejo.

Največji delež Slovenije je v podnebnem tipu podgorsko podnebje (46,4 %), sledijo mu zmerno celinsko (40 %), zmerno sredozemsko (7,1 %) in gorsko podnebje (6,5 %). Prevlada podgorskega podnebja v dobršni meri sovpada s Predalpskimi in Dinarskokraškimi pokrajinami, z izjemo Ljubljanske kotline in nižjih delov dinarskokraških pokrajin. Hkrati nakazuje prehodnost podnebnih značilnosti med gorskimi, zmerno sredozemskimi in zmerno celinskimi območji. Tudi drugi največji podnebni tip, zmerno celinsko podnebje, nakazuje prehodnost med gorskimi in podgorskimi območji Slovenije ter izrazito celinskimi območji vzhodno od nje. Ta podnebni tip poznajo tudi na Hrvaškem (Zaninović in sod., 2008), v Bosni in Hercegovini (Bosnia and…, 2023) in v Srbiji (Republički hidrometeorološki…, 2023). Zmerno sredozemsko podnebje je rezultat prehodnosti med sredozemskimi pokrajinami južno od Slovenije in pokrajinami v njeni notranjosti. Razumljiva posledica izrazite prehodnosti podnebja Slovenije se kaže tudi v dejstvu, da od podnebnih tipov zavzema najmanjšo površino gorsko podnebje, ki ni prehodni tip.

Pri podtipih zavzema največji delež Slovenije (30 %) zelo vlažno podgorsko podnebje. Je edini podtip, ki obsega več kot 20 % površine. Sledita mu zmerno celinsko podnebje severovzhodne Slovenije (19 %) in vlažno podgorsko podnebje (17 %). Več kot 10 % ozemlja Slovenije pokriva še zmerno celinsko podnebje vzhodne in jugovzhodne Slovenije (14 %). Manj kot 10 % pa zmerno celinsko podnebje osrednje Slovenije (7 %) ter oba gorska (6,5 oziroma 0,5 %) in zmerno sredozemska (4,7 oziroma 2,7 %) podtipa podnebij (preglednica 8). Najmanjši delež pripada podnebju višjega gorskega sveta, ki zavzema le 0,5 % površja Slovenije, kar približno sovpada z ozemljem nad nadmorsko višino okoli 2200 m.

Po demografski gostoti po podnebnih podtipih in tipih izrazito izstopa zmerno celinski tip, v katerem živi skoraj ¾ prebivalcev Slovenije (74,6 %). Znotraj tega tipa pa izstopa zmerno celinsko podnebje osrednje Slovenije, kjer živi kar 31 % njenega prebivalstva (gostota 421 preb./m^2). V podgorskem podnebju živi slaba šestina (16,1 %), v zmerno sredozemskem pa slaba desetina (9,5 %) prebivalcev, od tega v zalednem podtipu le slabi 3 %. Stik morja in kopnega in prijazno podnebje obalnega pasu sta vzrok za drugo največjo gostoto poselitve med podnebnimi podtipi v Sloveniji, ki znaša 277 preb./km^2. Območje gorskega podnebja je praktično brez prebivalstva, saj tu živi le 1 ‰ prebivalcev Slovenije, pri čemer v podnebju višjega gorskega sveta prebivalcev ni.

Preglednica 8: Prostorska in demografska zastopanost podnebnih tipov v Sloveniji.

Tip podnebja	Povprečna n. v. (m)	Površina (km^2)	Delež površja (%)	Število prebiv.	Delež prebiv.	Gostota pos. (preb./km^2)
Zmerno celinsko	327	8111	40,0	1.516.291	74,4	187
Zmerno celinsko severovzhodne Slovenije	311	3824	18,9	511.722	25,1	134
Zmerno celinsko vzhodne in jugovzhodne Slovenije	285	2786	13,7	372.479	18,3	134
Zmerno celinsko osrednje Slovenije	384	1501	7,4	632.090	31	421
Zmerno sredozemsko	245	1441	7,1	193.194	9,4	134
Obalno zmerno sredozemsko	123	488	2,4	134.973	6,6	277
Zaledno zmerno sredozemsko	367	953	4,7	58.221	2,9	61
Gorsko podnebje	1734	1314	6,5	2516	0,1	1,9
Višjega gorskega sveta	2096	102	0,5	0	0	0
Nižjega gorskega sveta	1372	1212	6,0	2516	0,1	2
Podgorsko podnebje	635	9404	46,4	327.114	16,1	35
Zelo vlažno podgorsko	788	6015	29,7	168.537	8,3	28
Vlažno podgorsko	517	3389	16,7	158.577	7,8	47

Demografski podatki se nanašajo na leto 2016, (SURS, 2016).

5 ZAKLJUČEK

Za območje Slovenije so geografi od tridesetih let 20. stoletja do konca stoletja pripravili šest podnebnih členitev, ki so se metodološko dopolnjevale in nadgrajevale, obsegale so tudi druga časovna obdobja, a trenda globalnega segrevanja ozračja še ne prepoznajo. Leta 2009 je nastala posodobitev Ogrinove klasifikacije po podatkih za obdobje 1971–2000 (Ogrin, 2009), ki je ohranila kriterije predhodne klasifikacije (Ogrin, 1996). V tej klasifikaciji se že odraža globalno segrevanje, kot npr. širjenje zmerno sredozemskega podnebja proti notranjosti Slovenije, pomik podnebja nižjega gorskega sveta v višje lege, blažitev celinskega temperaturnega režima zaradi dviga zimskih temperatur, pri padavinah pa pomik zmerno sredozemskega padavinskega režima proti vzhodu države. Leta 2017 so podnebno klasifikacijo za obdobje

1981–2010 s pomočjo faktorske analize in metode razvrščanja v skupine po metodi voditeljev pripravili tudi meteorologi (Kozjek in sod., 2017) ter jo nadgradili z izračunom mer spremenljivosti najpomembnejših podnebnih elementov za obdobje 1961–2011. V naši raziskavi smo pripravili prenovljeno podnebno tipizacijo glede na predhodni Ogrinovi tipizaciji, ki obsega zadnje zaključeno 30-letno referenčno obdobje (1991–2020) in jo metodološko nadgradili. Metodološka nadgradnja glede na predhodni Ogrinovi tipizaciji je v upoštevanju Langovega padavinskega faktorja pri opisu vlažnostnih razmer, prilagodili smo Kōppenove kriterije padavinskega režima in indeks mediteranskosti padavin, vključili pa smo tudi razlike v namočenosti med toplo in hladno polovico leta. Klasifikacija temelji tudi na večji gostoti točkovnih podatkov, na podatkih v kilometrski mreži in objektivnejši prostorski interpolaciji.

Novejši podatki odsevajo aktualne podnebne razmere, te pa so posledica podnebnih sprememb, ki se kažejo v pozitivnih odklonih temperatur od vrednosti, ki smo jih bili na določenih območjih vajeni doslej. Spremembe se kažejo tudi pri nekaterih drugih kriterijih, npr. pri letnih temperaturnih amplitudah in indeksu mediteranskosti. Izkazalo se je, da nova tipizacija ne more temeljiti zgolj na širitvi ali krčenju obstoječih podnebnih tipov, pač pa je bilo treba uvesti tudi nov podnebni tip, nekateri uveljavljeni podnebni tipi pa so izginili. Večja prostorska gostota vhodnih podatkov in bolj objektivna prostorska interpolacija omogočata tudi bolj natančno zamejevanje podnebnih tipov, ki se, tudi po opravljeni osnovni generalizaciji, še vedno pojavljajo v manj pravilnih oziroma bolj kompleksnih prostorskih oblikah (poligonih). Glavni modifikatorji podnebja in podnebnih tipov v Sloveniji ostajajo nadmorska višina, relief in oddaljenost od Jadranskega morja, upoštevati moramo tudi geografsko lego glede na najpogostejše vetrove.

Tudi v naši raziskavi se je potrdila izrazita prehodnost podnebja Slovenije, hkrati pa tudi velika podnebna pestrost, ki je posledica variabilnosti glavnih podnebnih modifikatorjev. Razen gorskega so vsi podnebni tipi v Sloveniji prehodni podnebni tipi, pri čemer območje gorskega podnebja obsega le 6,5 % ozemlja Slovenije in ga poseljuje le 1 ‰ prebivalstva. Prostorsko najobsežnejši podnebni tip je podgorsko podnebje, ki pokriva 46 % Slovenije, najbolj poseljeno pa je območje z zmerno celinskim podnebjem (75 % prebivalstva, 421 preb./km^2), ki prevladuje v največjih in najgosteje poseljenih nižinah notranje Slovenije. Po gostoti poselitve izstopa tudi območje, ki ga pokriva obalno zmerno sredozemsko podnebje (277 preb./km^2), kar je bolj posledica sitka z morjem kot ugodnega podnebja.

Z našo raziskavo smo analizirali podnebne razmere za zadnje 30-letno referenčno obdobje, kar daje osnovo novi interpretaciji podnebnih razmer v Sloveniji, pri čemer pa se moramo zavedati, da dinamika podnebnih sprememb narekuje prilagajanje podnebnih tipizacij hitreje, kot je bilo to potrebno v večjem delu 20. stoletja. Čeprav namen naše raziskave ni bil primerjava podnebnih tipov starejših tipizacij s sedanjimi, smo z analizo in obdelavo podatkov zadnjega referenčnega obdobja dobili dobro osnovo tudi za pripravo tovrstnih študij.

Zahvala

Avtorji se za nesebično pomoč pri pripravi in pridobivanju podnebnih podatkov za obdobje 1991–2020 iskreno zahvaljujemo Renatu Bertalaniču z Ministrstva za okolje in prostor, ARSO.

Raziskava je deloma potekala v okviru programa raziskovanja Trajnostni regionalni razvoj Slovenije (P6–0229), ki ga sofinancira Javna agencija za znastvenoraziskovalno in inovacijsko dejavnost Republike Slovenije.

Literatura in viri

Ahrens, C. D., 2005. Essentials of meteorology, an invitation to the atmosphere. Michigan: Thomson Brooks/Cole.

ARSO [Agencija Republike Slovenije za okolje], 2021. Temperaturni in padavinski podatki za Slovenijo za obdobje 1991–2020. Ljubljana: Agencija Republike Slovenije za okolje.

Bertalanič, R., Demšar, M., Dolinar, M., Dvoršek, D., Nadbath, M., Pavčič, B., Roethel-Kovač, M., Vertačnik,G., Vičar, Z., 2010. Spremenljivost podnebja v Sloveniji. Ljubljana: MOP ARSO.

Blatnik, M., Repe, B., 2012. Vegetacijski pasovi na meliščih v slovenskih Alpah. Dela, 37, str. 45–63. DOI: 10.4312/dela.37.45-63.

Bosnia and Herzegovina, Climate change knowledge portal, 2023. URL: https://climateknowledgeportal.worldbank.org/country/bosnia-and-herzegovina/climate--data-historical (citirano 5. 6. 2023).

Cui, D., Liang, S., Wang, D., Liu, Z., 2021. A 1 km global dataset of historical (1979–2013) and future (2020–2100) Köppen-Geiger climate classification and bioclimatic variables. Earth System Science Data, 13, str. 5087–5114. DOI: 10.5194/essd-13-5087-2021.

Dolinar, M., 2016. Monthly gridded datasets for temperature and precipitation over Slovenia. Proceedings of GeoMLA – Geostatistics and Machine Learning, Applications in climate and environmental science. Beograd, Univerza v Beogradu, Gradbena fakulteta. URL: http://geomla.grf.bg.ac.rs/site_media/static/Proceedings%20of%20GeoMla%202016%20Conference.pdf (citirano 13. 5. 2023).

Dolinar, M., Vertačnik, G., 2010. Spremenljivost temperaturnih in padavinskih razmer v Sloveniji. V: Okolje se spreminja – Podnebna spremenljivost Slovenije in njen vpliv na vodno okolje. Ljubljana: MOP ARSO, str. 37–40.

Dovečar, M., Ogrin, M., Sinjur, I., Vertačnik, G. 2009. Najnižja temperatura v Sloveniji. Geografski obzornik 56, 1/2, str. 27–31.

Furlan, D., 1960. Klimatska razmejitev Slovenije. Geografski vestnik, 32, str. 45–57.

Gams, I., 1972. Prispevek h klimatogeografski delitvi Slovenije. Geografski obzornik, 19-1, str. 1–9.

Gams, I., 1996. Geografske značilnosti Slovenije. Ljubljana: Mladinska knjiga.

Geiger, R., Pohl, W., 1954. Eine neue Wandkarte der Klimagebiete der Erde. Erdkunde, 8, 1-4, str. 58–61.
Glojek, K., Gregorič, A., Ogrin, M., 2018. Onesnaženost zraka s črnim ogljikom : študija primera iz Loškega Potoka = Black carbon air pollution: case study of Loški Potok. Dela 50, str. 5 –43. DOI: 10.4312/dela.50.5-43.
Glojek, K., Gregorič, A., Močnik, G., Cuesta-Mosquera, A., Wiedensohler, A., Drinovec, L., Ogrin, M., 2020. Hidden black carbon air pollution in hilly rural areas: a case study of Dinaric depression. European Journal of Geography, 11, 2, str. 105–122. DOI: 10.48088/ejg.k.glo.11.2.105.122.
Glojek, K., Močnik, G., Alas, H. D. C., Cuesta-Mosquera, A., Drinovec, L., Gregorič, A., Ogrin, M.,Weinhold, K.. Ježek, I., Rigler, M., Remškar, M., Markelj, M., 2022. The impact of temperature inversions on black carbon and particle mass concentrations in a mountainous area. Atmospheric chemistry and physics, 22, 8, str. 5577–5601. DOI: 10.5194/acp-22-5577-2022.
Gregorčič, T., Rozman, A., Repe, B., 2022. Uporaba metode maksimalne entropije pri proučevanju potencialnega vpliva podnebnih sprememb na slovenske gozdove. Dela, 57, str. 57–88. DOI: 10.4312/dela.57.57-88.
GURS, 2021. Digitalni model višin. Ljubljana: Geodetska uprava Republike Slovenije.
Henderson-Sellers, A., Robinson, P. J., 1999. Contemporary climatology. Harlow, Essex: Pearson Prentice Hall.
Ilešič, S., 1970. Klimatska območja Jugoslavije. Geografski obzornik, 17, str. 4–10.
Kaligarič, M., 2004. Rastlinske združbe. V: Narava Slovenije, Ljubljana, Mladinska knjiga, str. 183–197.
Koppany, G., Unger, J., 1992. Mediterranean climatic character in the annual march of precipitation. Acta Climatologica, 24-26, str. 1–4, 24–26.
Köppen, W, 1936. Das geographische System der Klimate. Handbuch der Klimatologie, B. I., Teil C. Berlin.
Köppen, W., 1918. Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf. Petermanns Mitteilungen, 64, str. 193–203, 243–248.
Kozjek, K., Dolinar, M., Skok, G., 2017. Objective climate classification of Slovenia. International Journal of Climatology, 37 (Supl. 1), str. 848–860. DOI: 10.1002/joc.5042.
Kozjek, K., Dolinar, M., Vertačnik, G., 2016. Podnebni tipi Slovenije na podlagi podnebnih povprečij, trendov in spremenljivosti. Vetrnica, 9/16, str. 79–90.
Kozjek, K., Dolinar, M., Vertačnik, G., 2016a. Climate types in Slovenia, based on climate normals, trends and variability. Proceedings of 16th EMS Annual meeting and 11th European conference on applied climatology, ECAC, Trieste.
Kutnar, L., Kobler, A., 2014: Possible impacts of global warming on forest tree species composition in Slovenia. V: Sustainable land management and climate changes: international conference on land conservation – LANDCON 1209, Beograd, 17.–21. september 2012 (prispevek na konferenci), str. 107.

Marinček, L., Čarni, A., 2002. Komentar k vegetacijski karti gozdnih združb Slovenije v merilu 1:400.000. Ljubljana: Založba ZRC SAZU.

Melik, A., 1935. Slovenija – Geografski opis. Ljubljana: Slovenska matica.

Ogrin D., 2015: Long-term air temperature changes in Ljubljana (Slovenia) in comparison to Trieste (Italy) and Zagreb (Croatia). Moravian Geographical Reports 23, 3, str. 17–26. DOI: 10.1515/mgr-2015-0014.

Ogrin, D., 1996. Podnebni tipi v Sloveniji. Geografski vestnik, 68, str. 39–56.

Ogrin, D., 2003. Spreminjanje temperature zraka in padavin po letnih časih v Ljubljani in Trstu v obdobju 1851–2022. Dela, 20, str. 115–131.

Ogrin, D., 2009. Podnebni tipi. V: Ogrin, D., Plut, D. Aplikativna fizična geografija Slovenije. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, str. 88–91.

Ogrin, D., 2014. Tendence spreminjanja podnebja po 2. svetovni vojni na jugovzhodu Krasa. Dela, 41, str. 81–100.

Ogrin, D., Ogrin, M., 2005. Predhodno poročilo o raziskovanju minimalnih temperatur v mraziščih pozimi 2004/2005. Dela, 23, str. 221–233.

Ogrin, D., Plut, D., 2009. Aplikativna fizična geografija Slovenije. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani.

Ogrin, M. 2007. The minimum temperatures in the winter 2006/07 in Slovenian frost hollows and cold basins. Dela, 28, str. 221–237.

Ogrin, M., Kozamernik, E., 2018. Horizontalni padavinski gradienti v alpskih dolinah severozahodne Slovenije/Horizontal precipitation gradients in alpine valleys of Northwestern Slovenia. Dela, 49, str. 5–36. DOI: 10.4312/dela.49.5-36.

Ogrin, M., Kozamernik, E., 2020a. Vertical precpitation gradients: a case study of alpine valleys of Northwestern Slovenia. Theoretical and Applied Climatology, 140, 1-2, str. 401–409. DOI: 10.1007/s00704-019-03051-z.

Ogrin, M., Kozamernik, E., 2020b. Padavinski gradienti v alpskih dolinah na primeru izbranih dolin Julijskih Alp. Vetrnica, 12-13, str. 70–76.

Ogrin, M., Ortar., J., Sinjur, I. 2012. Topoklimatska pestrost Slovenije. Geografija v šoli, 21, str. 4–13.

Ogrin, M., Sinjur, I., Ogrin, D., 2006. Minimalne temperature v slovenskih mraziščih pozimi 2005/2006. Geografski obzornik, 53, 2, str. 4–12.

Ogrin, M., Vintar Mally, K. 2013. Primerjava poletne onesnaženosti zraka z dušikovim dioksidom v Ljubljani med letoma 2005 in 2013. Dela, 40, str. 55–72. DOI: 10.4312/dela.40.4.55-72.

Ortar, J., 2008. Tipizacija in regionalizacija slovenskih mrazišč. Diplomsko delo. Ljubljana: Univerza v Ljubljani.

Peel, M. C., Finlayson, B. L., McMahon T. A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11, str. 1633–1644.

Podnebne spremembe 2021, fizikalne osnove in stanja v Sloveniji, poročilo IPCC 2021, povzetek za odločevalce z dodanim vpisom stanja v Sloveniji, 2021. Ljubljana:

ARSO, Urad za meteorologijo, hidrologijo in oceanografijo. URL: https://meteo.arso.gov.si/met/sl/climate/change/ (citirano: 11. 3. 2023).
Repe, B., 2012. Biogeografska pestrost Slovenske Istre. V: Ogrin, D. (ur.). Geografija stika Slovenske Istre in Tržaškega zaliva. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, str. 177–192.
Repe, B., 2017. Izbrane pedo in fitogeografske značilnosti doline Kamniške Bistrice s členitvijo. V: Ogrin, D. (ur.). Kamniška Bistrica – geografska podoba gorske doline. Ljubljana– Znanstvena založba Filozofske fakultete Univerze v Ljubljani, str. 21–44.
Repe, B., 2019. Izbrane pedo in fitogeografske značilnosti Jezerskega. V: Repe, B. (ur.). Fizična geografija Jezerskega z dolino Kokre. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, str. 107–142.
Repe, B., 2020. Natural vegetation. V: Rogelj, B. (ur.). Geography of Slovenia. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, str. 89–98.
Republički hidrometeorološki zavod, Osnovne klimatske karakteristike na teritoriji Srbije, 2023. URL: https://www.hidmet.gov.rs/latin/meteorologija/klimatologija_srbije.php (citirano 5. 6. 2023).
Strahler, A., 2013. Introducing physical geography. Hoboken: Wiley.
Strässer, M., 1998. Klimadiagramme zur Köppenschen Klimaklassifikation. Gotha: Kleth-Perthes.
Strle, D., Svetlin, D., Glojek, K., Kobal, M., Pogačnik, K., Ogrin, M, 2020. Meritve koncentracij črnega ogljika in dušikovega dioksida na Lavrici in v Kranju = Measurements of black carbon and nitrogen dioxide concentrations in Lavrica and Kranj. Dela, 54, str. 5–52. DOI: 10.4312/dela.54.5-52.
Supan, A., 1921. Grundzüge der Physischen Erdkunde. Berlin, Leipzig: Vereinigung Wissenschaftlicher Verleger, Walter de Gruyter &Go.
SURS, 2016. 100 m mreža števila prebivalcev.
Svetlin, D., 2020. Analiza temperaturnih razmer v mraziščih Komne. Magistrsko delo. Ljubljana: Univerza v Ljubljani.
Šegota, T., Filipčić, A., 1996. Klimatologija za geografe. Zagreb: Školska knjiga.
Trošt, A., 2008. Mrazišča na Komni. Diplomsko delo. Ljubljana: Univerza v Ljubljani.
Vertačnik, G., Dolinar, M., Bertalanič, R., Klančar, M., Dvoršek, D., Nadbath, M., 2013. Podnebne značilnosti Slovenije: glavne značilnosti gibanja zraka v obdobju 1961–2011. Ljubljana: ARSO, Ministrstvo za kmetijstvo in okolje.
Vertačnik, G., Vičar, Z., Bertalanič, R., 2016. Podnebna spremenljivost Slovenije v obdobju 1961–2011, 2 Kontrola in homogenizacija podatkov. Ljubljana: Agencija RS za okolje.
Zaninović, K., Gajić-Čapka, M., Perčec Tadić, M. in sod., 2008: Klimatski atlas Hrvatske/Climate atlas of Croatia 1961–1990, 1971–2000. Zagreb: Državni hidrometeorološki zavod.
Žiberna, I., 1992. Izbrane numerične metode v klimatogeografiji. Geografija v šoli, 2, str. 75–79.

Darko Ogrin*, Blaž Repe*, Lenart Štaut**,
Domen Svetlin***, Matej Ogrin*

CLIMATE CLASSIFICATION OF SLOVENIA BASED ON DATA FROM THE PERIOD 1991–2020

Izvirni znanstveni članek
COBISS 1.01
DOI: 10.4312/dela.59.5-89

Abstract

This article presents a climate classification for Slovenia for the climatological period 1991–2020. It is based on the Köppen-Geiger classification, but this classification is too coarse-grained to show all the specific climatic features of Slovenia. Taking into account additional temperature and precipitation criteria, we divided the Slovenian climate into four basic types with nine subtypes: moderate Mediterranean (coastal and inland), moderate continental (of northeast, east and southeast, and central Slovenia), mountain (of higher and lower mountains) and submontane climates (very humid and humid).

Keywords: climate geography, climate classification, Köppen-Geiger climate classification, climate types, Slovenia

*Department of Geography, Faculty of Arts, University of Ljubljana, Aškerčeva cesta 2, SI-1000 Ljubljana, Slovenia
** Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute, Novi trg 2, SI-1000 Ljubljana, Slovenia
*** Cesta Radomeljske čete 23, SI-1235 Radomlje, Slovenia
e-mail: darko.ogrin@ff.uni-lj.si, blaz.repe@ff.uni-lj.si, lenart.staut@zrc-sazu.si, domen.svetlin@gmail.com, matej.ogrin@ff.uni-lj.si
ORCID: 0000-0002-2458-6435 (D. Ogrin), 0000-0002-5530-4840 (B. Repe), 0000-0003-0095-3920 (L. Štaut), 0000-0002-4742-3890 (M. Ogrin)

1 INTRODUCTION

Slovenia is small in scale geographically, but its climate is highly diverse due to its location at mid-latitudes where the Mediterranean, the Pannonian Basin, the Alps and the Dinarides come together, and the varied topography associated with this junction. The general features of a moderate warm and humid climate are blended with the characteristics of Mediterranean, mountain and continental climates, which at the local level are strongly influenced by topography.

A multitude of climate regionalizations and classifications have been made at the global and macro levels. Classifications are mainly divided into two groups: causal (genetic) and consequential (effective). Among the genetic ones, which try to explain the causes of the formation of a certain climate, is Strahler's classification (Strahler, 2013). Of the genetic ones, which explain the influence of climate on natural conditions, especially on natural vegetation (and also certain characteristics of the cultural use of the landscape), the most well-known in climatological circles and beyond is the Köppen classification (also called the Köppen-Geiger climate classification). It was created at the beginning of the 20th century (Köppen, 1918) and has undergone several additions and revisions over the century of its existence (e.g. Cui et al., 2021; Geiger, Pohl, 1954; Köppen, 1936; Peel et al., 2007; Strässer, 1998). These classifications provide a good insight into the global climate system and a system of larger spatial units, but for spatial units of Slovenian dimensions, they are not sufficiently fine-grained and do not reflect all of the important climatic features.

Over the past 100 years, several climate classifications and regionalizations have been developed for the territory of Slovenia. The first classification scheme of climate types was created by Melik (1935). He noted that the Mediterranean, Pannonian and Central European Alpine climates intersect on Slovenian territory, and that the boundaries between particular climate types are constantly changing. Furlan (1960) analysed climate of Slovenia based on data for the period 1925–1956. With respect to temperatures, he distinguished marine, transitional and inland zones, and with respect to precipitation, areas with a modified Mediterranean and Central European regime. He did not elaborate a comprehensive classification. Ilešič (1970) analysed Slovenia within Yugoslavia on the basis of temperature and precipitation regimes. He distinguished two main climate zones: Adriatic and moderate continental. As part of the first, the northern Adriatic area extends into Slovenia. In the second, within the framework of the western Pannonian continental zone, he divided Slovenia into two subzones: the true Pannonian continental zone and the transitional Pannonian-Adriatic zone.

Gams (1972) classified Slovenia into different zones based on the relationship between monthly temperatures and precipitation in the growing season, or moisture surplus and deficit, temperatures and the length of the growing season. By selecting these criteria, he primarily wanted to explain the differences in natural vegetation and the cultivation of crops. He classified the main climatic zones (littoral, central Slovenia and sub-Pannonian) into several climatic provinces and districts. Gams (1996) also produced a bioclimatic classification of Slovenia. Based on how arid or humid the climate, he distinguished two climatic zones with several subzones. He divided the coastal region and its hinterland into the following climate zones: the Koper littoral, the climate of the hinterland of the Gulf of Trieste, and the transitional climate of Brkini. He divided the climate of continental Slovenia into the very humid climate of the Alpine and Dinaric mountains, the humid climate of central Slovenia, the moderately humid climate in the transition zone to the sub-Pannonian climate, and the sub-Pannonian climate with semi-arid to semi-humid summers. Both of Gams's classifications are also presented in maps.

D. Ogrin (1996) classified the climate in Slovenia based on data for the period 1961–1990. As a starting point for the classification, he used the Köppen-Geiger criteria, according to which most of Slovenia has a moderate warm, humid climate with warm summers (Cfb), the highest elevation areas have a mountain climate (H), and the southwestern parts along the Gulf of Trieste have a moderate warm, humid climate with hot summers (Cfa). The basic types were then subdivided into nine subtypes based on the precipitation regime, the average temperature of the coldest and warmest months, and the ratio between October and April temperatures. In 2009, this classification was updated based on data for the period 1971–2000 (Ogrin, 2009), which maintained the starting points and criteria of the earlier classification. It reflects well the regional responses to global climate change that accelerated after 1980: the spread of the moderate Mediterranean climate towards the interior of Slovenia, the shift of the climate of lower-elevation mountain areas to higher elevations, the mitigation of the continental temperature regime due to the rise in winter temperatures, and as regards precipitation a shift of the moderate Mediterranean precipitation regime towards the eastern part of the country.

The classifications presented have in common that they are made on the basis of point data from relatively sparse networks of weather stations in Slovenia, which is especially true for air temperature measurements. The boundaries between climatic units are largely determined subjectively, taking into account the influence of the topography on the spatial distribution of particular climatic elements and the researcher's familiarity with local and regional climatic conditions. The spatial distribution of natural vegetation and the characteristics of the cultural use of the land are also taken into account. Since in recent years, data in a kilometre grid for the most important climatic elements have also become available (Dolinar, 2016), Kozjek et al. (2017) produced what they call an objective definition of the climatic regions of Slovenia for the period 1981–2010. Using factor analysis and classification based on cluster analysis, they found that the climate of Slovenia can be most logically and representatively classified into six zones or types: the littoral zone (moderate Mediterranean climate), the very wet zone of the northwestern part of the Alpine-Dinaric barrier (humid climate of lower mountains), the higher elevation zone of the Dinarides and Alps (moderate mountain climate), the high elevation zone (mountain climate), the dry zone of the lowlands of eastern and central Slovenia (moderate continental climate) and the higher and slightly wetter region of central

Slovenia (moderate climate of highland areas). The spatial distribution of the climatic zones and types presented does not differ significantly from Ogrin's classifications.

With the aim of determining reference climate stations that would be representative of the wider area and at the same time describe climate changes in recent decades as accurately as possible, Kozjek et al. (2016a; 2016b) built on the original classification by calculating the measures of variability of the most important climatic elements for the period 1961–2011. Taking into account all the selected measures of variability (trends, interyear and interday variability), they divided Slovenia into four zones that have similar climate characteristics. The zones were not specifically named, but they coincide with the Mediterranean areas, the highest parts of the Alpine-Dinaric barrier, the wider area of the Alpine-Dinaric barrier and the area of eastern Slovenia with more continental climatic features.

The year 2020 marked the end of the standard climatological period 1991–2020, which dictates the creation of a climate classification for this time. This is all the more indicated since it is widely known and thoroughly supported in the literature that the climate at all spatial levels, including in Slovenia (Bertalanič et al., 2010; Climate change..., 2021; Dolinar, Vertačnik, 2010; Ogrin, 2003; 2014; 2015; Vertačnik et al., 2013), has been changing very rapidly in recent decades. Due to changes in the values of climate elements and the boundaries between climatic types and subtypes, climate classifications created on the basis of data for previous periods are of limited usefulness. The main purpose of this paper is therefore to show the characteristics of climatic types in Slovenia and the characteristics of their spatial distribution for the period 1991–2020. In addition to point data, we also used data in the spatial grid since these are available. In their processing, spatial interpolation and displays, we used GIS tools (ArcGIS Pro 3.1 and QGIS software tools). In order to maintain basic comparability with the last two classifications that were created at the Department of Geography of the Faculty of Arts of the University of Ljubljana for the period 1961–1990 (Ogrin, 1996) and 1971–2000 (Ogrin, 2009), we proceeded from the same methodological starting points. However, a full comparison is not possible because in the previous classifications we used controlled but not homogenized point data, and the spatial interpolation of point data and the boundaries between individual climate types were determined by expert assessment.

2 METHODS

Point (62 temperature stations, 174 precipitation stations) and spatial data for the period 1991–2020 were obtained from the Slovenian Environment Agency (ARSO). The data were first checked and homogenized at ARSO using modern software tools, and changes that were not the result of climatic events were removed (Vertačnik et al., 2016). The homogenized data formed the basis for conversion into a kilometre grid. The optimal spatial interpolation method, which takes into account the dependence of the climatic variable on geographical factors, was used to calculate the values of the climatic variables in the grid. At each grid point, the value of the variable was calculated on the basis of the values at the surrounding meteorological stations (including stations near the border in Italy, Austria and Croatia), elevation, geographic longitude and latitude of the grid point, and in some cases also other derived geographical variables (e.g. relative elevation of the orographic barrier to the northeast for precipitation). Due to the smaller number of meteorological stations, the data are less reliable for areas with an elevation above 1000 m (Dolinar, 2016; Kozjek et al., 2017).

The starting point for the climate classification of Slovenia was the Köppen-Geiger definition of climate types and their criteria (Peel et al., 2007). According to Köppen, each climate is defined by a certain value of average monthly and annual temperatures and precipitation. In mapping particular temperature thresholds or climate classes and types, we relied on the location of isotherms derived from the Köppen classification: the January isotherm of –3 °C (boundary between moderate warm and humid climates and snow-forest climates), the July isotherm of 22 °C (boundary between climates with hot or warm summers), and the July isotherm of 10 °C (boundary between snow-forest and snow climates). The interpolation of climate variables and all further calculation operations, as well as the Köppen climate classification of Slovenia itself, were carried out in the R programming language, and the maps were drawn with the QGIS program. Since the Köppen-Geiger classification is too coarse-grained to show all the specific climatic features of Slovenia, we took additional temperature criteria into account: January isotherms of 0 and 3 °C, July isotherms of 15 and 20 °C, and the average annual temperature amplitude. If the average annual temperature amplitude is above 20 °C, this is an indicator of the continental character of the temperature regime, if it is below 15 °C it indicates marine characteristics, and if it is between 15 and 20 °C, it is a transitional temperature regime (Supan, 1921, p. 110; Šegota, Filipčić, 1996, p. 71). The values were calculated from the kilometre grid of temperature data, and the vertical temperature gradients and average heights of particular isotherms were calculated using a digital elevation model (GURS, 2021). In defining the continental character of the temperature regime, we also looked at a comparison of average April and October temperatures (Tokt. > Tapr.: marine features of the temperature regime; Tokt. < Tapr.: continental features of the precipitation regime). Higher temperatures in October compared to April are considered to be the result of the influence of a warm sea and sea air masses, as the sea cools down more slowly in autumn and warms up more slowly in spring. Therefore, in areas far from the sea, April is generally warmer than October.

Previous classifications of the Slovenian climate, especially the classification by Kozjek et al. (2016a; 2016b; 2017), indicated the great importance of precipitation and related humidity conditions. To make it easier to differentiate Slovenia with regard to this factor, together with the amount of precipitation, we also took into account Lang's rain factor, which includes the average annual amount of precipitation and the average annual air temperature and climate elements according to the degree of humidity or aridity (Žiberna, 1992, p. 76):

$$L = \frac{RR_l}{T_e}$$

L – Lang's rain factor
RR_l – average annual amount of precipitation
Te –average annual air temperature

In determining the degree of humidity or aridity of the climate, we took into account the standard division into classes (Žiberna, 1992, p. 76):

L	
0–40	arid climate
41–60	semi-arid climate
61–100	semi-humid climate
101–160	humid climate
above 160	perhumid climate

In defining the precipitation regime, we started from Köppen's criteria, which we slightly adapted for the needs of Slovenia, denoting with w' the precipitation regime with peak precipitation in one of the autumn months and the least precipitation in one of the winter months (sometimes in March or in one of the summer months), and with x' the regime with peak precipitation in one of the summer months (in some places also in May) and the least precipitation in one of the winter months. The precipitation regime was further defined using the Mediterranean precipitation index (Koppany, Unger, 1992), which compares the average amount in October and November (peak precipitation in the Mediterranean precipitation regime) with the amount of rainfall in May and June (peak rainfall in the continental precipitation regime) and the annual amount of precipitation. Positive values of the index indicate Mediterranean features of the precipitation regime, while negative values indicate continental features. Since in Slovenia the autumn peak of precipitation also occurs in September, and the summer peak also occurs in July, we modified the index slightly:

$$MI = \frac{\left(P_{sep-nov} - P_{may-july}\right) \cdot 100}{P_l}$$

MI – Mediterranean precipitation index
Psep–nov – amount of precipitation in the period September-November
Pmay–july – amount of precipitation in the period May-July
Pl – average annual precipitation

The continental or marine (Mediterranean) character of the precipitation regime was also determined by comparing the amount of precipitation in the warmer half of the year (April–September) and the colder half of the year (October–March). A larger proportion of precipitation in the warmer half of the year indicates a continental character of the precipitation regime, while in the colder half it is marine (Mediterranean).

Since Köppen was also a phytogeographer, he chose the threshold values between particular climate classes and types in such a way that he could also at least approximately determine the main vegetation types coinciding with them. For the needs of a more detailed climate classification of Slovenia, we also extended this starting point to some characteristics of the cultural landscape, which depend in large extent on thermal conditions (olive growing and viticulture region). We adapted the original Köppen terms for particular climate types to Slovenian conditions.

3 RESULTS

3.1 Köppen-Geiger climatic classification of Slovenia 1991–2020

Three climate classes in the Köppen-Geiger system are represented in Slovenia:

- **C (moderate warm climate):** average temperature of the coldest month (usually February in the mountains and January in the lowlands) above –3 °C, at least one month with an average temperature above 10 °C;
- **D (snow-forest climate):** average temperature of the coldest month below –3 °C, average temperature of the warmest month (July in the lowlands, usually August in the mountains) above 10 °C;
- **E (snow climate):** average temperature of the warmest month below 10 °C.

D and E climate classes in Slovenia are limited to mountain areas, all of the rest of Slovenia is in class C.

By taking into account additional criteria, we can distinguish six basic climate types in Slovenia with greater spatial extent, and another six with smaller spatial representation. We added the following to the basic types (Figure 1):

- **ET; mountain tundra climate:**
  - average temperature of the warmest month between 0 and 10 °C;
  - this climate covers 0.2% of Slovenia, in the high mountain areas of the Julian and Kamnik-Savinja Alps at elevations of about 2200 m.
- **Dfcw‘ (Dfbw‘, Cfcw‘); snow-forest humid climate with warm or cold summers and peak precipitation in one of the autumn months (moderate warm humid climate with cool summers and peak precipitation in autumn):**
  - there is no dry period – the average rainfall of the driest month in the warmer half of the year is over 40 mm;
  - average temperature of the warmest month below 22 °C, and at least four months with an average temperature above 10 °C (warm summer);
  - one to four months with an average temperature above 10 °C, the coldest month above –3 °C (cold summer);
  - the month with the most precipitation in autumn, with the least precipitation in winter;

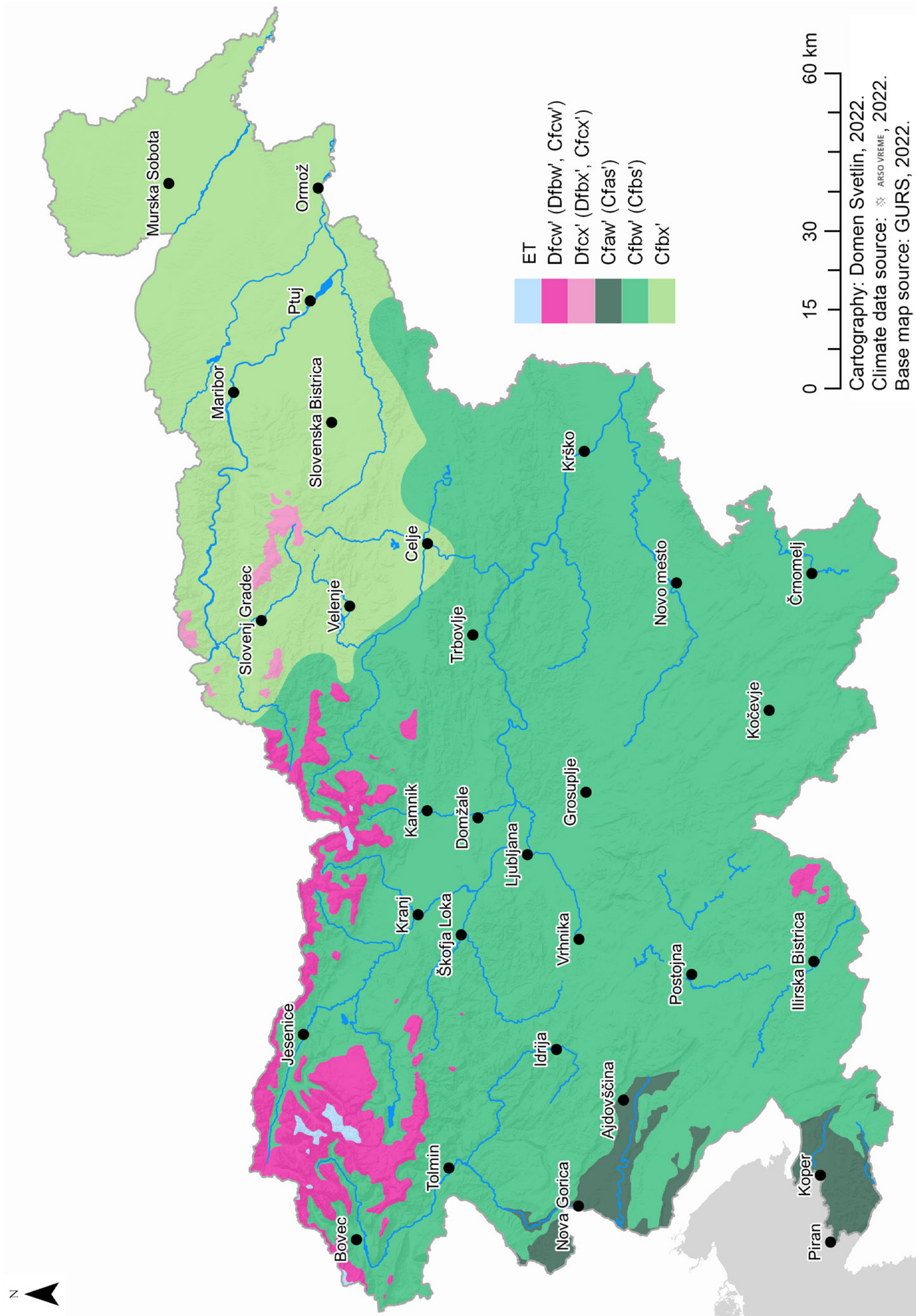
- this climate covers 5.1% of Slovenia, represented in the Julian Alps, the Karawanks and the Kamnik-Savinja Alps including mountain valleys, and outside the Alpine regions on the Menina planina Plateau, on some peaks of the western Prealps and on Mt. Snežnik and Trnovski gozd Plateau (Golak Peaks).

- **Dfcx‘ (Dfbx‘, Cfcx‘); snow-forest humid climate with warm or cold summers and peak precipitation in one of the summer months or May (moderate warm humid climate with cold summers and peak precipitation in summer or May):**
  - as for Dfcw‘ (Dfbw‘, Cfcw‘), except that peak precipitation is in one of the summer months and in some places
  - in May, lowest amount of precipitation in winter;
  - this climate covers 0.5% of Slovenia and is found on Pohorje, Košenjak, Strojna and Uršlja Gora.

Climate types ET and Dfcw‘ and Dfcx‘ with associated types of smaller extent, which taken together cover only 5.8% of the surface of Slovenia, can be grouped into a mosaic represented by a **mountain climate** based on versions of the Köppen-Geiger classification (e.g. Ahrens, 2005; Henderson-Sellers, 1999) which introduce a special **class H** for higher-elevation areas of our planet, where climate changes rapidly with altitude and the demarcation between climate types is difficult.

- **Cfaw‘; moderate warm humid climate with hot summers and peak precipitation in one of the autumn months:**
  - no dry period, average temperature of the warmest month above 22 °C;
  - peak precipitation in autumn, month with the least precipitation in winter, in some places summer (Cfas‘);
  - this climate covers 2.8% Slovenia, found in Slovenian Istria, the northwestern part of the Karst, the Vipava Valley, the Gorizia Hills, and the Soča Valley as far as Kanal.
- **Cfbw‘; moderate warm humid climate with warm summers and peak precipitation in one of the autumn months:**
  - no dry period, average temperature of the warmest month above 22 °C, at least four months with an average temperature above 10 °C;
  - peak precipitation in autumn, month with the least precipitation in winter (rarely March), in some places in southern Slovenia also summer (Cfbs‘);
  - this climate covers most of Slovenia (66.6 %) apart from mountain areas, lower-lying parts of regions near the Mediterranean and northeastern Slovenia.
- **Cfbx‘; moderate warm humid climate with warm summers and peak precipitation in one of the summer months or May:**
  - peak precipitation in summer (in some places in late spring, May), least precipitation in winter;
  - this climate covers just under a quarter of Slovenia (24.8 %) and can be found in northeastern Slovenia east of Peca, Golte and Dobrovlje and north of the Sava Hills, Boč and Haloze.

Figure 1: Köppen-Geiger climatic classification of Slovenia for the period 1991–2020.



3.2 Temperature regime

The classification of the Slovenian climate based on the Köppen criteria results in a picture that is too coarse-grained and does not adequately reflect all the special features of the Slovenian climate. In order to further analyse the extensive area with Cfb climate, we have also considered the characteristics of the temperature regime based on January isotherms of 0 and 3 °C and July isotherms of 20 and 22 °C. Using the **average annual temperature amplitude** and the **ratio between the average April and October temperatures**, we wanted to demarcate the areas of Slovenia having continental features of the temperature regime from the areas where the influence of the sea is greater. Considering the range of the average annual temperature amplitude (between 16 and 22 °C), we can conclude that the temperature regime in Slovenia does not have distinct continental or marine features, but represents a transition zone. The lower-lying areas in the north, east and southeast of Slovenia, the low-lying Dolenjska Karst and the Ljubljana Basin have an average annual temperature amplitude of more than 20 °C and thus a moderate continental temperature regime. In terms of the highest average annual temperature amplitude (more than 21 °C), the lowlands in the northeast of Slovenia, the lower part of the Mežica and Mislinja valleys, and the Drava Valley between Dravograd and Radlje ob Drava stand out. The most marine features, if we exclude the hilly and mountainous areas, where the amplitude is lower due to the higher altitude (Kredarica, 15.4 °C; Rogla, 16.5 °C; Krvavec, 16.7 °C), are seen in slightly higher lying areas in the hinterland of the Gulf of Trieste, where the average annual temperature amplitude is less than 18 °C (Figure 2, Table 1). In most of Slovenia, the amplitude is between 18 and 20 °C.

That the lower-lying areas in the east of Slovenia and parts of the Ljubljana Basin have moderate features of a continental temperature regime can also be concluded from the higher average temperatures in April compared to October. In continental areas, the air warms up faster in spring (and cools down faster in autumn) compared to areas near the sea or under the greater influence of sea air masses, because the sea has a mitigating effect on the warming or cooling of the atmosphere. In the east of Slovenia, April temperatures are up to 0.8 °C higher than October temperatures, and in western and central Slovenia, October temperatures are higher than April ones by up to 2 °C, mostly in the mountains (Table 1, Figure 3). The colder spring in the mountains is also the result of weaker warming of the upper layers of the atmosphere compared to autumn.

The area of Slovenia that shows continental features of the temperature regime in terms of the average annual temperature amplitude (Figure 2, Table 1) overlaps well with the area that has higher temperatures in April than in October (Figure 3). The overlapping is strong in the lower-lying regions in the east of Slovenia, and somewhat less in the Ljubljana Basin.

Figure 2: Average annual temperature amplitude 1991–2020.

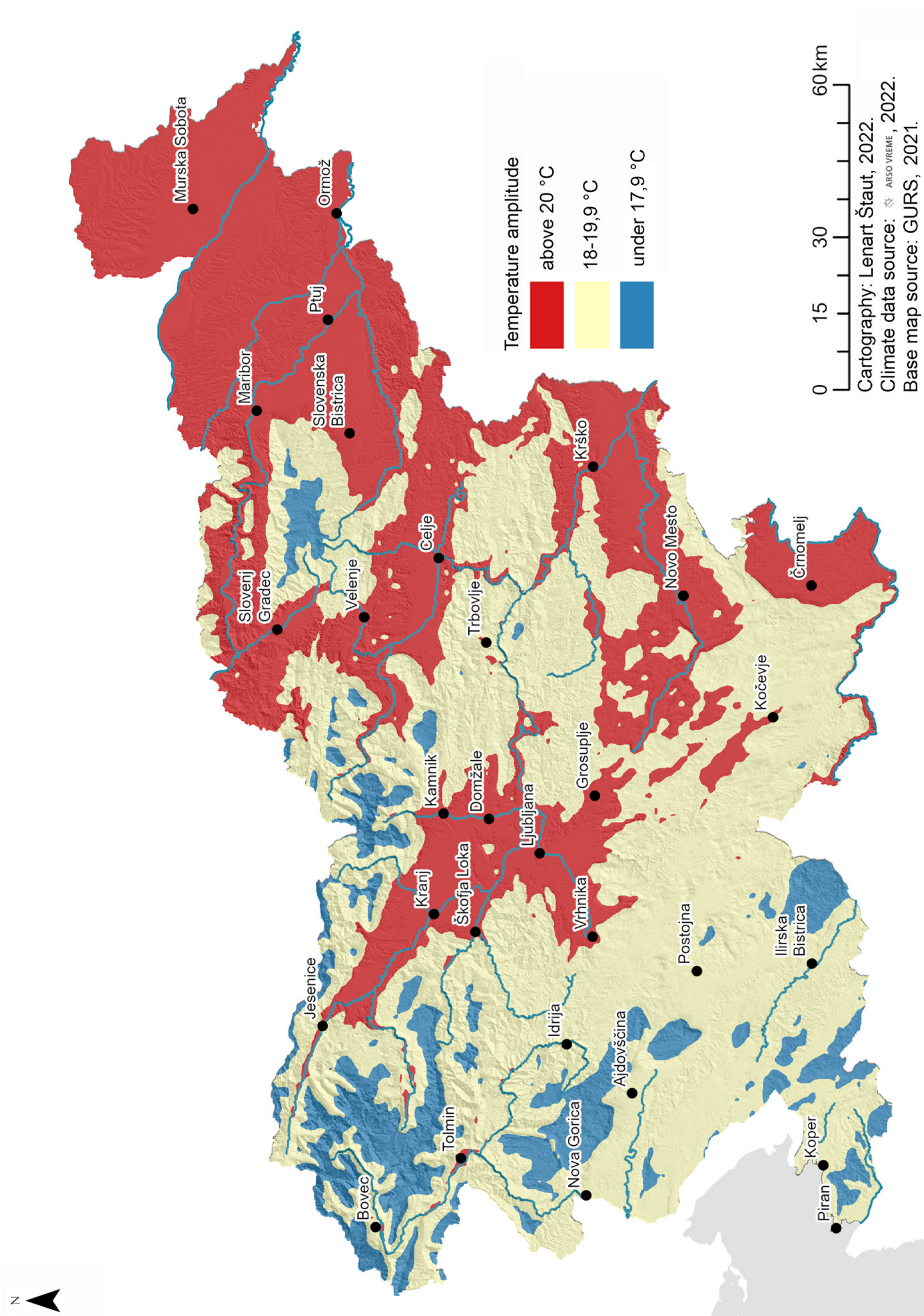


Table 1: Difference between average April and October temperatures (D) and average annual temperature amplitude (A) in the period 1991–2020.

Meteorological station	D (°C)	A (°C)	Meteorological station	D (°C)	A (°C)
Krvavec	–2.7	16.7	Miklavž na Gorjancih	–1.2	18.3
Jezersko	–0.7	18.7	Trojane-Limovce	–0.5	19.2
Planina pod Golico	–1.3	17.9	Gornji Grad	–0.3	19.1
Rateče	–0.5	19.8	Malkovec	0.1	19.8
Kredarica	–2.2	15.4	Airport J.P. Brnik	0.0	20.4
Rudno polje	–2.3	18.1	Ljubljana-Bežigrad	–0.1	20.8
Bohinjska Češnjica	–0.8	19.4	Vrhnika	–0.6	19.7
Vogel	–2.2	17.1	Kranj	0.3	21.0
Zgornja Sorica	–1.0	17.8	Lesce-airport	0.0	20.4
Krn	–1.0	17.9	Ravne na Koroškem	0.6	22.0
Tolmin-Volče	–0.4	19.2	Šmartno pri Sl. Gradcu	0.0	20.9
Vojsko	–0.9	18.6	Velenje	0.1	20.1
Vedrijan	–1.1	18.5	Celje-Medlog	0.1	20.2
Bilje	–0.8	19.0	Slovenske Konjice	0.0	19.5
Podnanos	–1.3	18.6	Črnomelj-Dobliče	0.3	20.4
Godnje	–1.0	19.0	Metlika	0.4	20.4
Ilirska Bistrica	–0.7	18.3	Novo mesto	0.5	20.4
Kubed	–1.4	18.2	Cerklje-airport	0.4	20.9
Portorož-airport	–1.5	18.4	Trebnje	0.1	20.3
Babno Polje	–1.1	19.4	Bizeljsko	0.6	20.8
Kočevje	–0.5	19.1	Rogaška Slatina	0.4	19.8
Nova vas-Bloke	–1.1	19.2	Airport E.R. Maribor	0.3	21.0
Postojna	–1.1	18.8	Polički vrh	0.6	21.0
Logatec	–0.9	19.5	Jeruzalem	0.1	20.2
Litija	–0.3	19.4	M. Sobota-Rakičan	0.8	21.1
Rogla	–2.0	16.5	Ptuj	0.4	20.4
Sevno	–0.2	19.4	Maribor-Vrbanski plato	0.3	20.3
Lisca	–0.8	18.6	Lendava	0.7	21.2

Note: D > 0 – April warmer than October.

Figure 3: Marine or continental character of the temperature regime based on a comparison of average April and October temperatures (1991–2020).

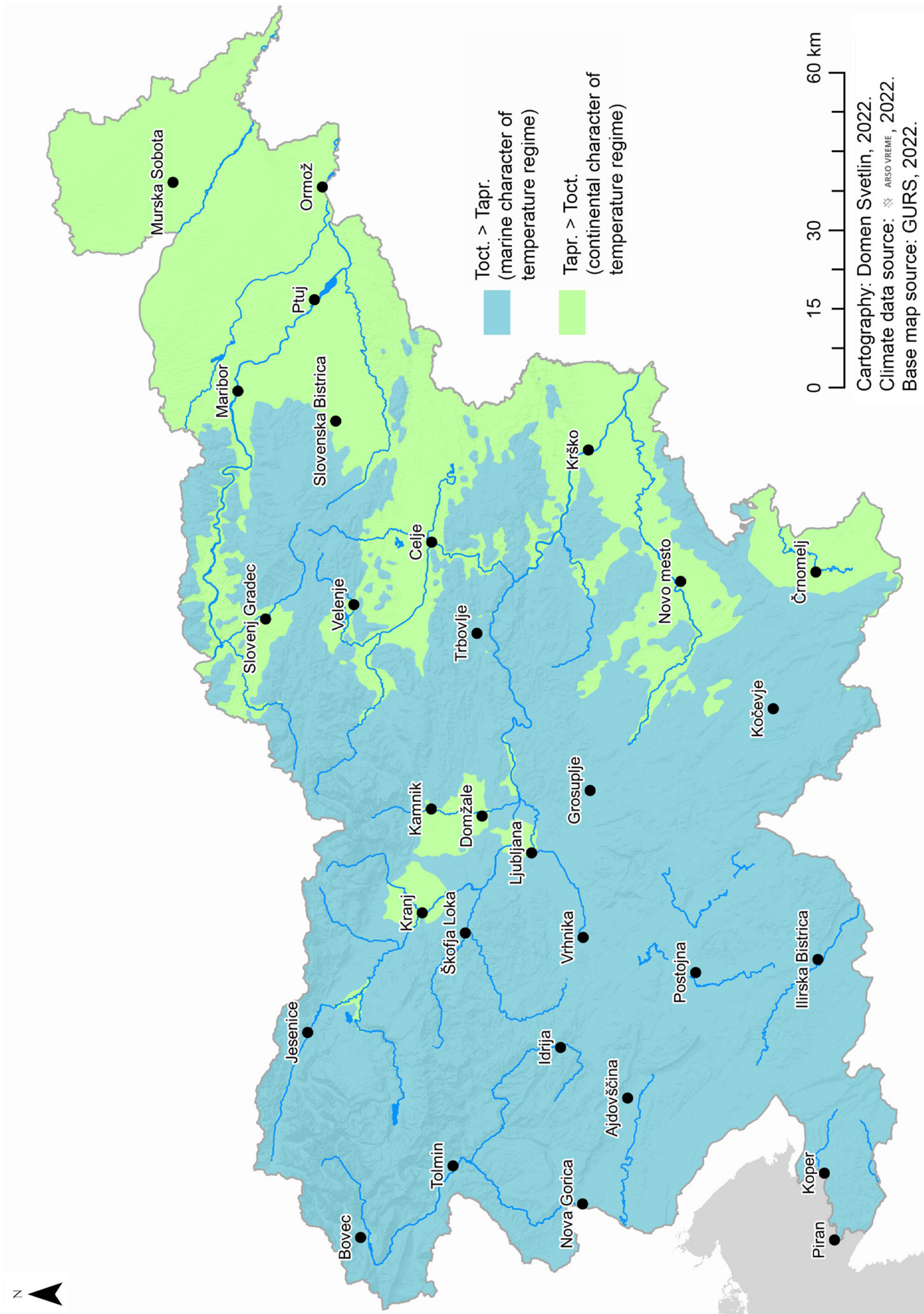


Figure 4: Mediterranean precipitation index (MI) in Slovenia (1991–2020).

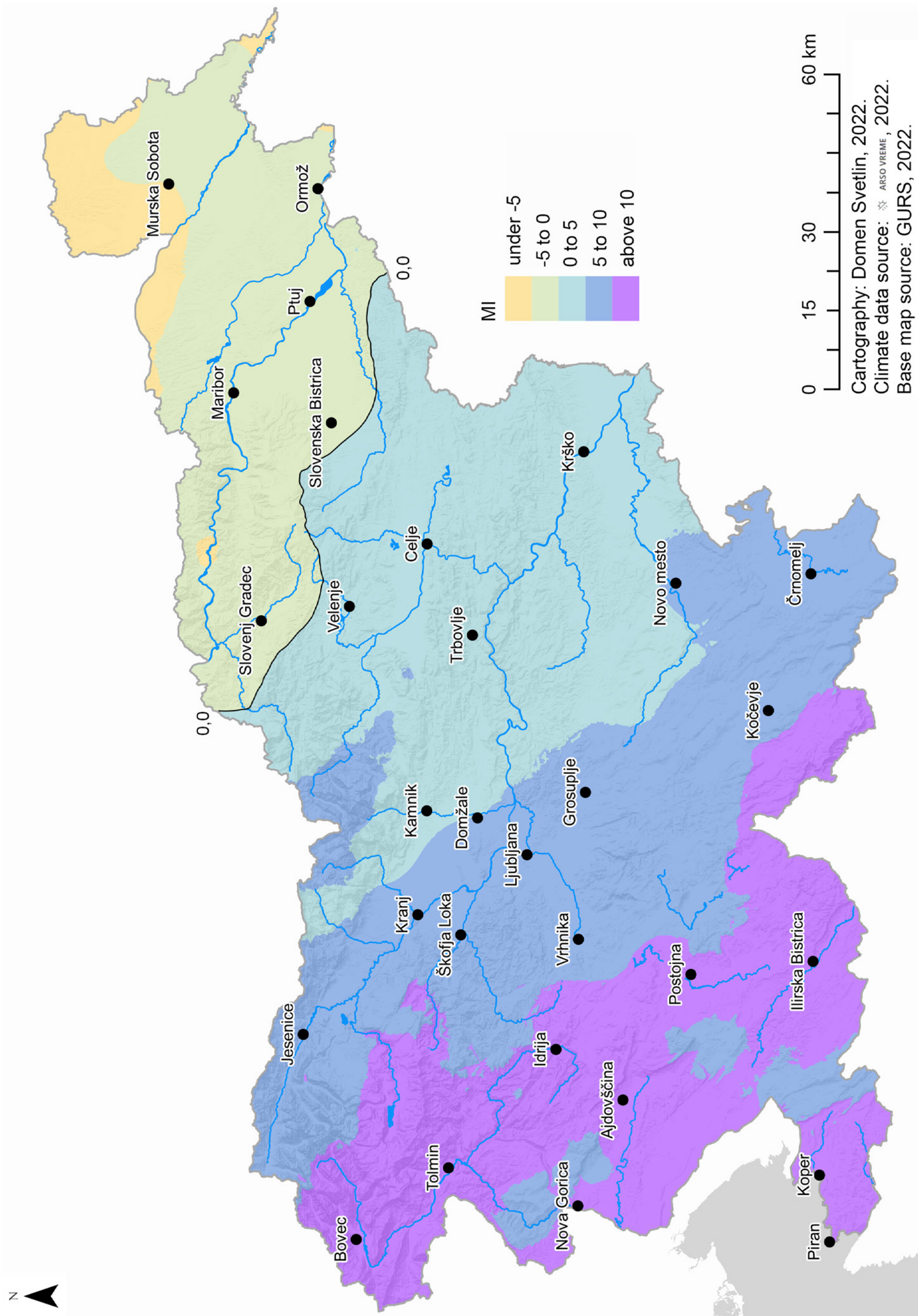
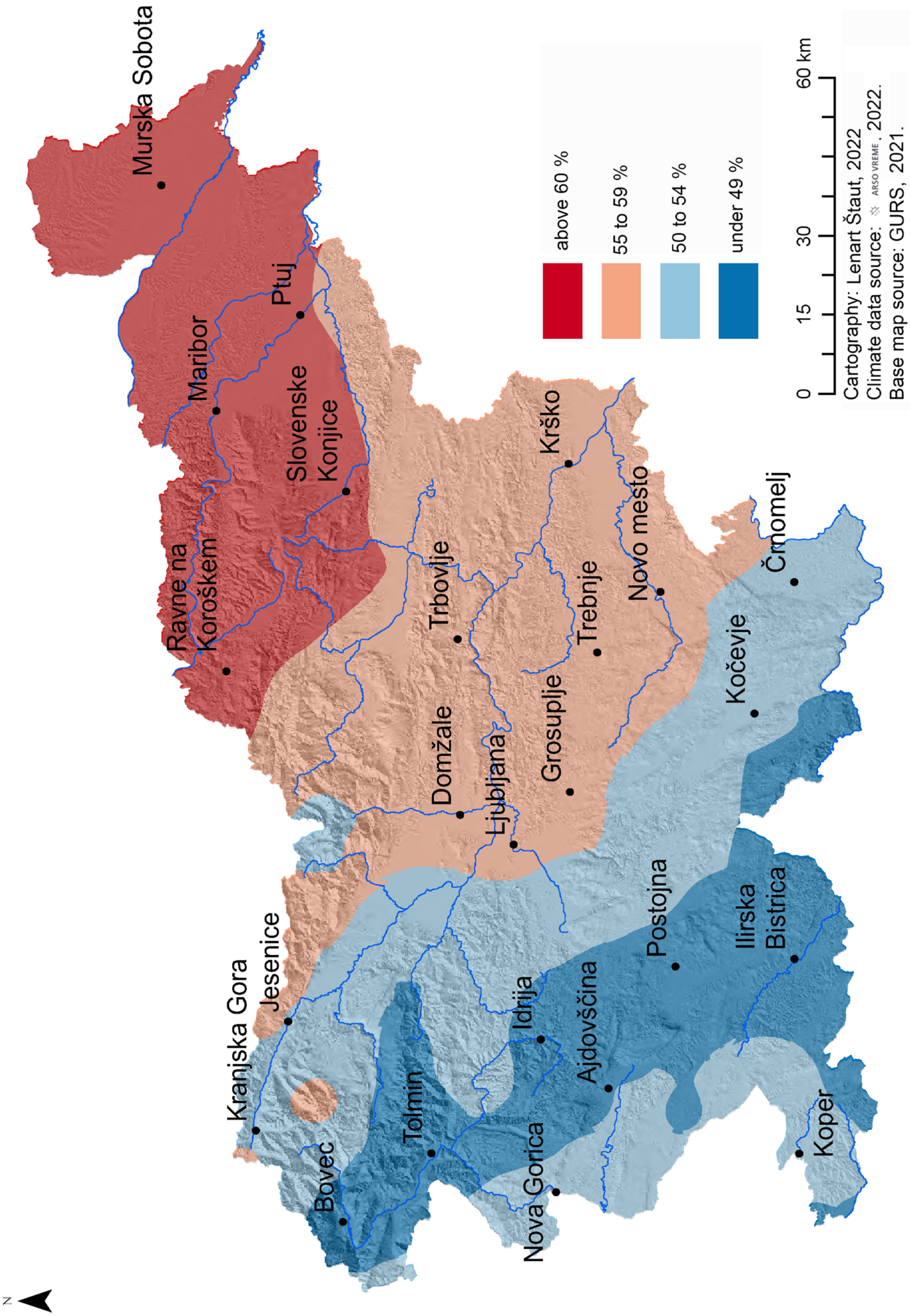


Figure 5: Proportion of precipitation in the warmer half of the year (1991–2020).



3.3 Precipitation regime

Along with the Köppen criteria for the spatial differentiation of the precipitation regime in Slovenia, we also took into account the Mediterranean precipitation index (MI) and the ratio between the amount of precipitation in the warmer and colder halves of the year. These give a similar spatial picture. Northeastern Slovenia has the most continental features (the share of precipitation in the warmer half of the year is over 60%, negative MI values, which means that peak summer precipitation is greater than that of autumn) (Figures 4 and 5). Towards the west and southwest, the proportion of precipitation in the warmer half of the year decreases, and the main peak precipitation shifts to the autumn months.

Slovenia is also a transition zone between moderate Mediterranean (marine) and moderate continental features with respect to the precipitation regime. Western, southern and central Slovenia have moderate Mediterranean features of the precipitation regime with a peak in the autumn months and the least rainfall in the second half of winter, including March, and July and August. The northeastern part, however, has moderate continental features with peak precipitation in summer and minimum precipitation in winter. The MI changes from positive to negative values going in this direction. It is highest in western Slovenia, where it is between 15 and 18 (Dražgoše 17.5; Bovec 16.2; Vogel 15.7; Strunjan 15.4; Seča 15.2), and the lowest in the extreme northeast between −5 and −8 (Šentilj in the Slovenian Hills −5.4; Mačkovci −5.6; Cankova −6.1; Podgorje in the Slovenian Hills −6.2; Jeruzalem −6.9; Martinje −7.1). For Europe, for which Koppany and Unger (1992) calculated the MI for the period 1901–1950, these values ranged between 22 and −16. The difference between the share of precipitation in the warmer and colder halves of the year between western and southwestern and northeastern Slovenia is also not extreme. The highest percentages of precipitation in the warmer half of the year in northern and northeastern Slovenia are mostly between 60 and 65% while the highest percentages in the colder half in the southern and southwestern parts of the country are between 51 and 57%.

The precipitation regime is highly variable from year to year and from period to period and we cannot rely on with certainty the peaks or minimums as determined by the averages. The average annual and seasonal variability of precipitation is between 20 and 30%, and the usual monthly averages can be exceeded by even more than 100% or (even in the wettest months on average) there may be virtually no precipitation. The Mediterranean precipitation index enables the calculation of the theoretical boundary between moderate Mediterranean and moderate continental precipitation regimes (MI = 0.0). According to data for the period 1961–1990, this boundary ran along the line Solčava–Ljubljana–Suha Krajina–Gorjanci (Ogrin, 1996), in the period 1971–2000 it moved east to the line Strojna-western Celje Basin-Suha Krajina-Gorjanci (Ogrin, 2009), and for the period 1991–2020 it ran from Mežica along the Vitanje Lowlands to Slovenske Konjice and beneath under Boč and Haloze to the border with Croatia. This means that the area with peak precipitation in autumn has expanded towards the east of Slovenia, and the area with peak precipitation in summer has shrunk significantly in the last 60 years. At the same time, the summer precipitation peak weakened in the northeast of Slovenia at the expense of an increase in autumn precipitation. It is also noticeable that autumn peak precipitation in the western parts of Slovenia mostly occurs in November or October, while towards the east and northeast it is more frequent in September or in some places in October, i.e. the autumn and summer peaks are becoming more and more equal.

Table 2: Mediterranean precipitation index (MI) and the proportion of precipitation in the warmer half of the year (DT) at selected precipitation stations in Slovenia in the period 1991–2020.

Precipitation station	MI	DT (%)	Precipitation station	MI	DT (%)
Ambrož po Krvavcem	3.9	55	Brod v Podbočju	4.2	55
Zgornje Jezersko	7.2	52	Moravče	3.3	57
Planina pod Golico	7.2	54	Gornji Grad	5.7	54
Rateče	7.9	54	Airport J.P. Brnik	5.6	54
Kredarica	4.9	57	Ljubljana-Bežigrad	3.1	56
Zgornja Radovna	10.4	51	Vrhnika	7.5	50
Bohinjska Bistrica	13.3	48	Škofja loka	8.9	50
Vogel	15.7	46	Javorniški rovt	7.6	54
Zgornja Sorica	11.2	47	Črnomelj-Dobliče	7.9	52
Kneške Ravne	12.0	46	Metlika	5.9	55
Tolmin-Volče	11.1	47	Novo mesto	5.4	56
Vojsko	12.2	46	Cerklje-airport	3.4	58
Vedrijan	10.1	51	Mokronog	2.6	57
Bilje	11.9	50	Bizeljsko	3.0	55
Razdrto	9.5	48	Velenje	0.4	59
Godnje	11.2	48	Celje-Medlog	0.5	59
Ilirska Bistrica	13.7	46	Slovenske Konjice	0.6	60
Movraž	6.7	48	Rogaška Slatina	0.5	58
Portorož-airport	14.8	49	Ravne na Koroškem	−3.2	63
Babno Polje	12.6	47	Šmartno pri Sl. Gradcu	−2.3	62
Kočevje	7.4	52	Ribnica na Pohorju	−2.6	61
Nova vas-Bloke	7.9	52	Airport E.R. Maribor	−2.7	62
Planina-Rakek	11.6	47	Polički vrh	−3.8	63

Precipitation station	MI	DT (%)	Precipitation station	MI	DT (%)
Logatec	10.8	47	Jeruzalem	−6.9	61
Litija	4.3	57	M. Sobota-Rakičan	−4.8	64
Malkovec	2.8	57	Ptuj	−1.9	60
Sevno	3.6	56	Maribor-Vrbanski plato	−1.7	62
Lisca	1.8	59	Lendava	−1.8	60

3.4 Humidity of the climate

On average, about 1450 mm of precipitation falls in Slovenia annually, which makes it one of the wettest countries in Europe, but precipitation is spatially very unevenly distributed. Most of it falls on the Alpine-Dinaric barrier, more than 2000 mm annually, and in the wettest part of the Julian Alps, more than 3200 mm. From the Alps and the High Dinaric Plateaus, precipitation decreases towards the southwest and northeast. Along the sea it is between 900 and 1000 mm (Strunjan 947 mm; Portorož Airport 958 mm; Koper 989 mm), and in Prekmurje less than 850 mm (Kobilje 772 mm; Lendava 790 mm; Murska Sobota 812 mm; Cankova 830 mm).

Large regional differences in the wetness and humidity of the climate are therefore one of the most important factors in the climate classification of Slovenia. Spatial differences in climate humidity were determined using Lang's rain factor. According to this indicator, the Alpine-Dinaric barrier has a perhumid climate. Slovenian Istria, northeastern Slovenia, the Krško-Brežice Plain with the lower Krka Valley and some smaller areas in the east of Slovenia have a semi-humid climate, while the rest of Slovenia has a humid climate (Figure 6).

Table 3: Lang's rain factor (L) at selected meteorological stations in Slovenia in the period 1991–2020.

Meteorological station	L	Meteorological station	L
Krvavec	519	Miklavž na Gorjancih	130
Jezersko	276	Trojane-Limovce	136
Planina pod Golico	254	Gornji Grad	154
Rateče	220	Malkovec	97
Bovec-airport	236	Airport J.P. Brnik	136
Rudno polje	444	Ljubljana-Bežigrad	110
Bohinjska Češnjica	215	Vrhnika	144
Vogel	715	Kranj	125
Zgornja Sorica	258	Lesce-airport	135

Meteorological station	L	Meteorological station	L
Krn	299	Ravne na Koroškem	108
Tolmin-Volče	173	Šmartno pri Sl. Gradcu	126
Vojsko	342	Velenje	98
Vedrijan	104	Celje-Medlog	103
Bilje	106	Slovenske Konjice	89
Podnanos	115	Črnomelj-Dobliče	109
Godnje	111	Metlika	92
Ilirska Bistrica	133	Novo mesto	101
Kubed	101	Cerklje-airport	97
Portorož-airport	66	Trebnje	108
Babno Polje	230	Bizeljsko	87
Kočevje	158	Rogaška Slatina	92
Nova vas-Bloke	198	Airport E.R. Maribor	84
Postojna	195	Polički vrh	97
Logatec	203	Jeruzalem	72
Litija	109	Murska Sobota-Rakičan	73
Rogla	295	Ptuj	82
Sevno	114	Maribor-Vrbanski plato	89
Lisca	140	Lendava	66

3.5 Climate types in Slovenia for the period 1991–2020

Previous climate classifications (e.g. Kozjek et al., 2017; Melik, 1935; Ogrin, 1996; 2009) highlight the fact that mountain, Mediterranean and continental climates come into contact and intermingle on the territory of Slovenia. Climatic contact and transition represent a challenge for climate classifications: the identified climate types are atypical as compared to true continental, Mediterranean or mountain climates. This is why we characterize them as "moderate" or add the prefix "sub", or "peri" to the type (e.g. moderate continental, sub-Mediterranean, submontane, peri-Pannonian). In general, as we move away from the Alpine-Dinaric barrier towards the east and northeast of the country, continental climate characteristics become stronger, while towards the southwest Mediterranean climate characteristics are more in evidence, and with increasing elevation in the Alpine, pre-Alpine and Dinaric Karst regions, the climate takes on the characteristics of a mountain climate. The boundaries between types and subtypes of climates on maps must therefore be understood as transition zones, and not in the sense of sharp dividing lines.

Figure 6: Humidity of the climate based on Lang's rain factor (1991–2020).

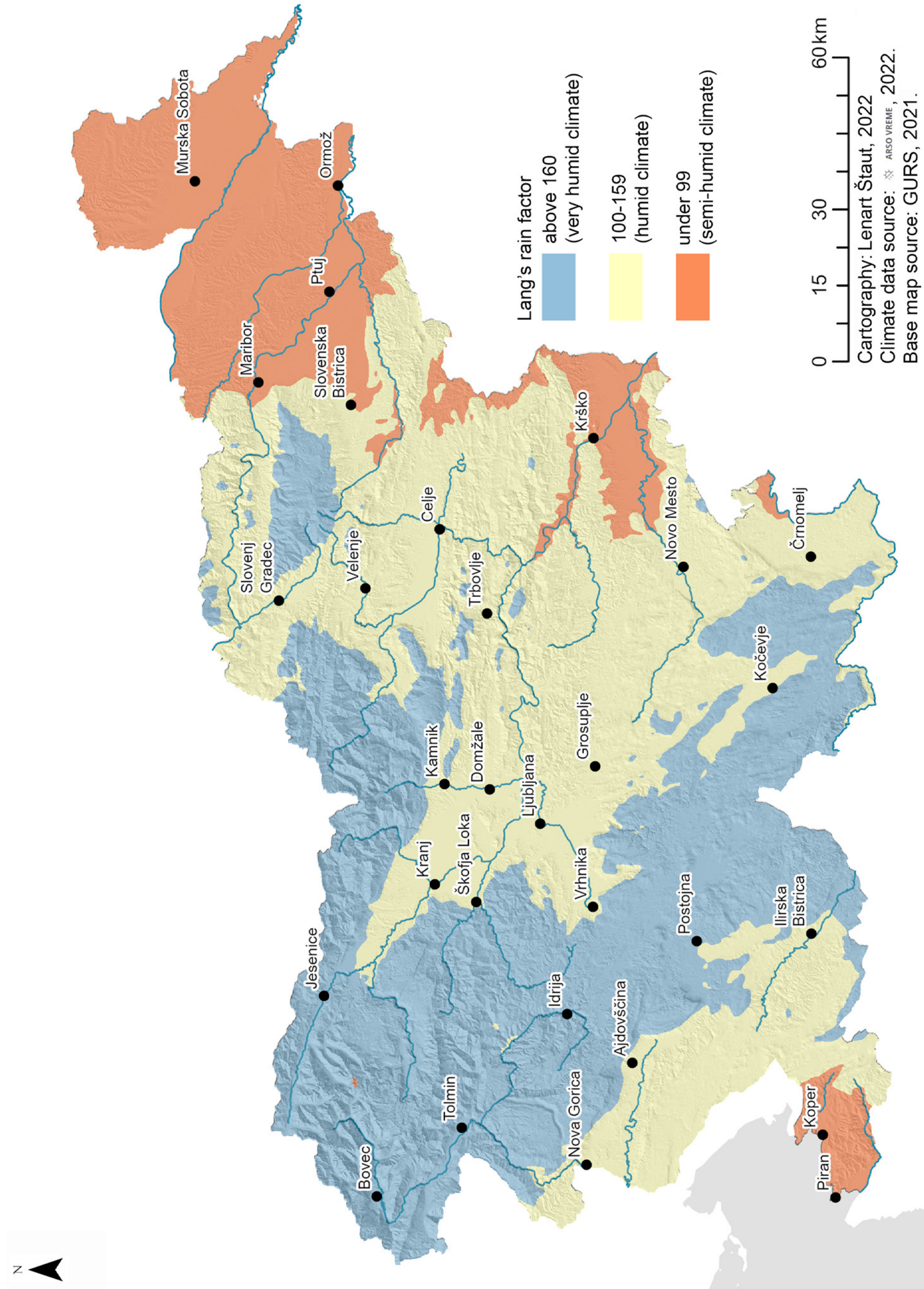
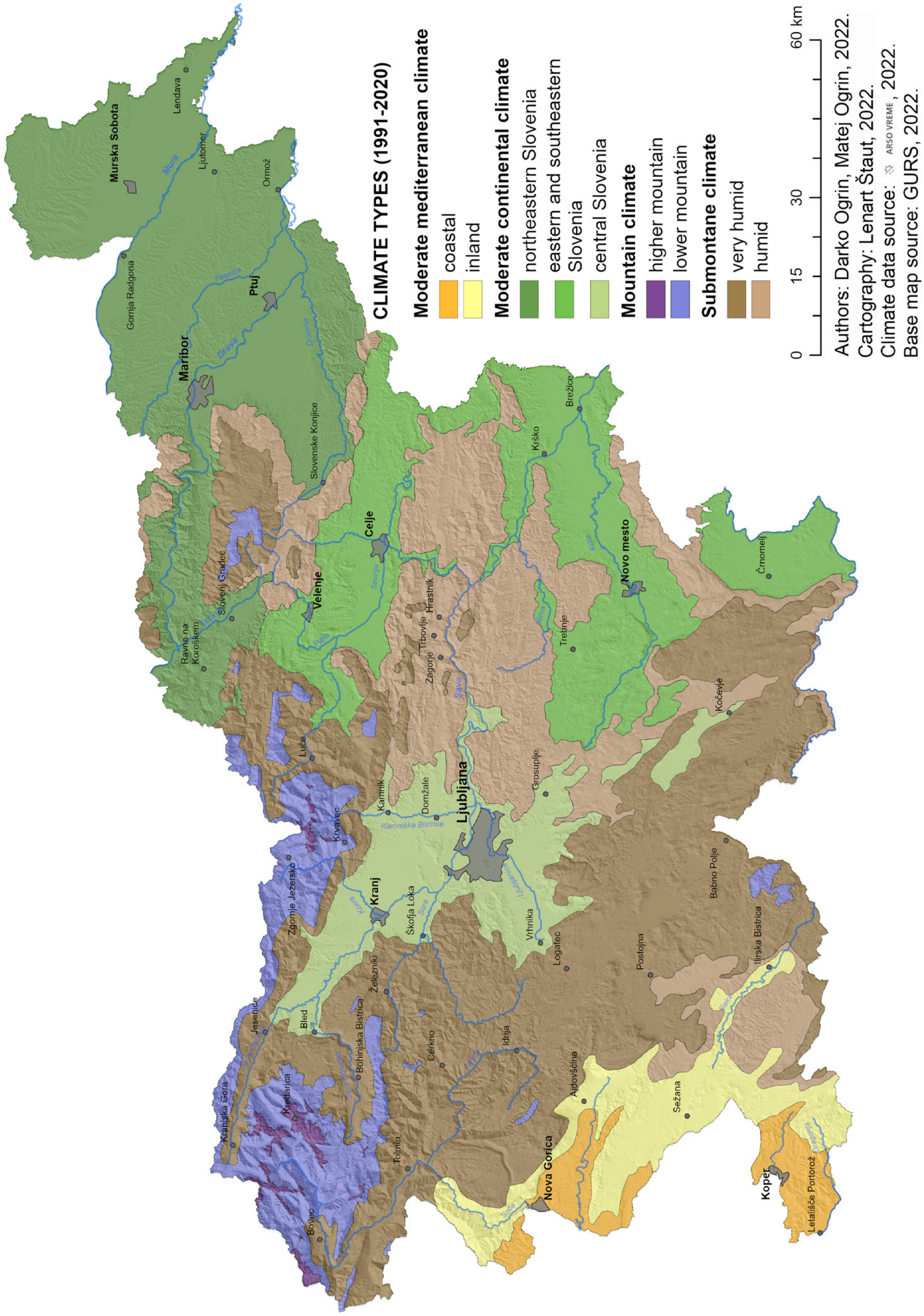


Figure 7: Climate types in Slovenia 1991–2020.



Taking into account the starting points and criteria presented in the previous sections, we distinguished four basic types of climate: moderate Mediterranean, moderate continental, mountain and submontane climate. In the second step, we divided these into nine subtypes: moderate Mediterranean into coastal and inland: moderate continental into moderate continental of northeastern, of eastern and southeastern, and of central Slovenia; mountain climate into higher mountain climate, lower mountain climate; and submontane into very humid and humid submontane climates (Figure 7).

Moderate Mediterranean climate

Due to the openness of the land towards the Adriatic Sea and the Mediterranean, a moderate Mediterranean climate occurs in the areas to the south and southwest of the Alpine-Dinaric barrier, which have the greatest number of clear days in Slovenia. Due to the influence of the sea, average temperatures are the highest in Slovenia, especially in autumn and winter. In the coldest month, on average, they do not drop below freezing, while in the warmest they are above 20 °C. The average annual temperature amplitude is less than 20 °C, as the influence of the sea mitigates the cold in winter and the heat in summer. The precipitation regime is moderate Mediterranean with peak precipitation in the autumn months. Snow cover is rare.

Bora wind is frequent in the colder half of the year and jugo wind blows before the weather deteriorates, especially in the colder half of the year. The occurrence of local thermal winds during anticyclonic weather is also noteworthy: during the day the sea breeze (maestral) and at night the land breeze (burin) which is less pronounced than the sea breeze along the Slovenian coast. From the coast towards the Alpine-Dinaric barrier, temperatures decrease and precipitation increases, which is the basis for dividing the moderate Mediterranean climate into warmer and less humid coastal and slightly cooler and more humid inland. During the transition from winter to spring and in July and August, there is usually a drought, which is more pronounced in karst areas due to surface features.

Areas of Slovenia with a moderate Mediterranean climate are dominated by a cultural landscape. The climate overlaps with the Littoral wine-growing region, and areas with a coastal climate, where January temperatures are above 3 °C and July temperatures above 22 °C, overlap with the area of olive cultivation (olive-growing climate). As a result, the natural vegetation is greatly altered. The climatic conditions suit the heat-tolerant and drought-resistant deciduous forests typical of the Mediterranean fringes. The most widespread are moderately heat-loving and deciduous associations dominated by downy oak (*Quercus pubescens*), hop-hornbeam (*Ostrya carpinifolia*) and flowering ash (*Fraxinus ornus*). The most common forest associations are the association of hop-hornbeam and downy oak (*Ostryo-Quercetum pubescentis*) and the association of hop-hornbeam and autumn moorgrass (*Sesleria autumnalis-Ostryetum*) (Repe, 2012). On warmer sites, they are joined by the oriental hornbeam

(*Carpinetum orientalis*) and Montpellier maple (*Acer monspessulanum*). On the warmest sites in Slovenia (the Karst Rim, the southern slopes of Nanos), with warm soil conditions, fragments of evergreen maquis (*Ostryo-Quercetum ilicis*) are also preserved, consisting of evergreen Mediterranean trees and shrubs, such as holm oak (*Quercus ilex*), green olive (*Phillyrea latifolia*), laurel (*Laurus nobilis*). Other heat-loving deciduous species also appear in between, e.g. Jersualem thorn (*Paliurus spina-christi*) and evergreen climbing plants, e.g. wild asparagus (*Asparagus acutifolius)* (Kaligarič, 2004). Black pine (*Pinus nigra*) is anthropogenically present in this area, as a result of afforestation in the first half of the 20th century (Repe, 2020). There are more cultivated plants than true Mediterranean natural species: in addition to the olive tree, there are also fig trees, almond trees, pomegranate trees, etc.

Figure 8: Climograms for coastal (Portorož Airport) and inland (Ilirska Bistrica) moderate Mediterranean climate.

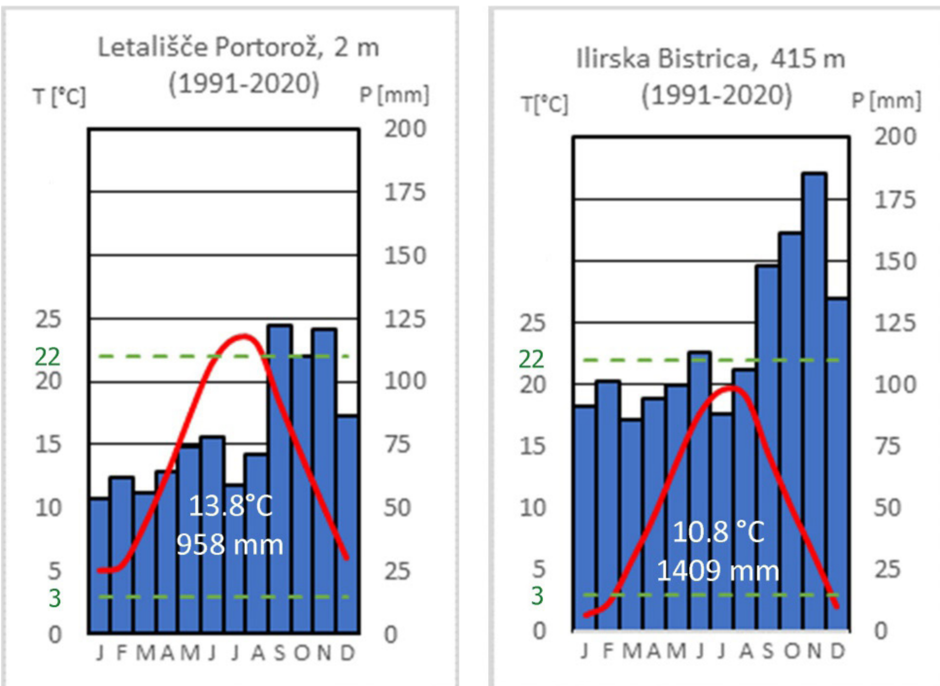


Table 4: Basic characteristics of a moderate Mediterranean climate.

Moderate Mediterranean climate - Average temperature of the coldest month above 0 °C - Average temperature of the warmest month above 20 °C - October warmer than April - Average annual temperature amplitude below 20 °C - Average annual amount of precipitation 900 to 1400 mm - moderate Mediterranean precipitation regime (MI >10)	
Coastal moderate Mediterranean climate (Cfaw‘ according to Köppen) - Avg. temp. of the coldest month above 3 °C - Avg. temp. of the warmest month above 22 °C - Percentage of precipitation in the colder half of the year 45 to 50% - semi-humid climate (L < 99)	**Inland moderate Mediterranean climate** (Cfbw‘ according to Köppen) - Avg. temp. of the coldest month between 0 and 3 °C - Avg. temp. of the warmest month between 20 and 22 °C - Percentage of precipitation in the colder half of the year generally above 50% - Humid climate (L = 100 do 159)

Moderate continental climate

A moderate continental climate is found in lower-lying areas in northeastern, eastern, southeastern, and central Slovenia. It is the second warmest climate in Slovenia after the moderate Mediterranean climate, and is characterized by the greatest average annual temperature amplitude (more than 20 °C) and high summer maximum temperatures. It receives below-average annual precipitation (below 1400 mm), most of which falls in the warmer half of the year. Northeastern Slovenia has the most pronounced continental climate features, where April is warmer than October (inland areas warm up faster in spring than areas influenced by the sea), receives the least precipitation (even under 1000 mm) and has a moderate continental precipitation regime. Lower-lying areas in the east and southeast of Slovenia, which are also open towards the Pannonian Plain, have similar temperature characteristics, except that they receive more precipitation and have a moderate Mediterranean precipitation regime. The latter is also characteristic of the moderate continental climate of central Slovenia, which is even more humid due to its location near the Alpine-Dinaric barrier, and the greater influence of sea air masses is also evident as October is warmer than April.

Figure 9: A maquis patch in the wall above the Osp Valley (photo: D. Ogrin).

Figure 10: Climograms for the moderate continental climate of northeastern (Murska Sobota), eastern and southeastern (Črnomelj-Dobliče), and central Slovenia (Kranj).

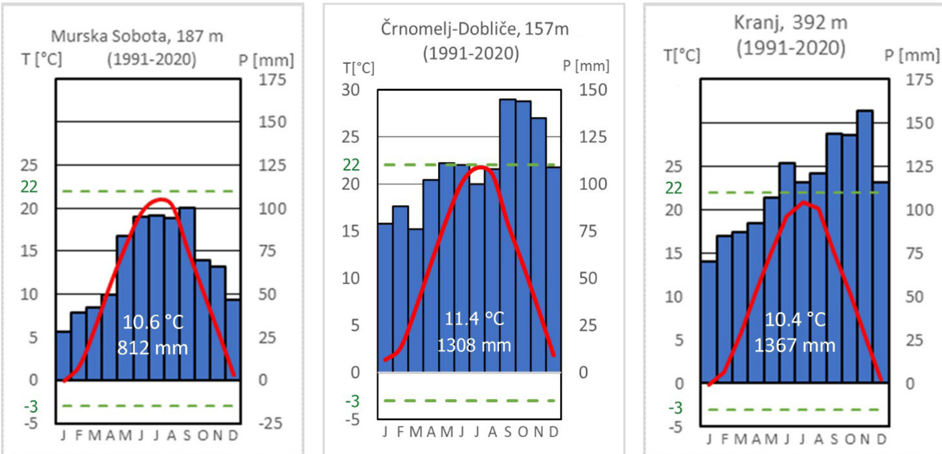


Table 5: Basic characteristics of a moderate continental climate.

<table>
<tr><td colspan="2">Moderate continental climate
- Average annual temperature above 20 °C
- Average July temperature 20 to 22 °C
- Average annual temperature 9 to 12 °C
- Average annual amount of precipitation below 1400 mm
- Over 50% of the annual amount of precipitation occurs in the warmer half of the year</td></tr>
<tr><td>Northeastern Slovenia
(Cfbx' according to Köppen)
- April warmer than October
- Annual amount of precipitation between 750 and 1200 mm
- Over 60% of precipitation occurs in the warmer half of the year
- Moderate continental precipitation regime (MI = 0 to –10)
- Semi-humid to humid climate</td><td>Eastern and southeastern Slovenia
(Cfbw' according to Köppen)
- April warmer than October
- Annual amount of precipitation 1000 to 1400 mm
- 50 to 60% of the annual amount of precipitation occurs in the warmer half of the year
- Moderate Mediterranean precipitation regime (MI = 0 do 5)
- Semi-humid to humid climate</td></tr>
<tr><td colspan="2">Moderate continental climate of central Slovenia (Cfbw' according to Köppen)
- October warmer than April
- Annual amount of precipitation 1200 to 1400 mm
- 50 to 60% of the annual amount of precipitation occurs in the warmer half of the year
- Moderate Mediterranean precipitation regime (MI = 0 to 10)
- Humid climate (L = 100 do 159)</td></tr>
</table>

Despite the higher proportion of precipitation in the warmer half of the year, summers in northeastern, eastern and southeastern Slovenia, and partly also in central Slovenia on gravel and sand deposits, are susceptible to drought due to the relatively low amount of precipitation and high temperatures (average July temperatures are above 20 °C). Freezes are common in winter, and cold days also occur (daily temperatures stay below freezing). Snow cover occurs in all areas of this climate type, about four weeks out of the year, but snowfall is much less compared to previous decades, and periods with snow cover are getting shorter. Spring frosts are relatively common, with lowlands, basins and valleys especially susceptible. Periods of summer heat are often punctuated by storms (including hail and high winds) that cause major damage to agriculture and buildings. Lowland areas in the eastern half of Slovenia are more exposed to storms. In particular, the lowlands of eastern and southeastern Slovenia, due to their low elevation, the openness to the Pannonian Basin, and their leeward location with respect to southwesterly winds (Bela Krajina, Krško-Brežiško polje), are often the areas of greatest heat in summer, where the highest daily temperatures can even exceed those in the Vipava Valley and along the coast.

Due to the favourable natural conditions, areas with a moderate continental climate have a predominantly cultural landscape; this is where the largest areas of arable land in Slovenia are located, which are often exposed to drought in summer. The moderate continental climate of northeastern, eastern and southeastern Slovenia (it could also be called a Pannonian climate) roughly overlaps with the Drava Valley and Lower Sava Valley wine-growing regions. Due to the more favourable local climatic conditions, vineyards and orchards are mostly located in sun-exposed areas of the thermal belt. In the plains and valleys, where there are frequent temperature inversions, there are mainly crop fields and meadows. Larger basins such as Ljubljana and Celje and the lowlands (Mura Plain, Drava – Ptuj Plain) often have morning fog, which is most persistent in autumn and in the first half of winter. The lowlands are poorly ventilated and without wind energy potential and have lower air self-cleaning capacities, which increases air pollution especially in the colder half of the year (Ogrin, Vintar Mally, 2013; Strle et al., 2020). There are no constant strong winds in the lowlands; only in some places in the Savinja Valley and in the lowlands of the eastern half of the country is there a stronger southwesterly wind before the weather deteriorates, while an even less frequent Foehn wind can blow from the southern slopes of the Karawanks, the Kamnik Savinja Alps and the Pohorje Massif, which can also cause damage.

Figure 11: The sun-exposed hills of the peri-Pannonian regions in the thermal belt are less susceptible to spring frosts, having more sun and lower air and soil humidity, which is why they offer favourable conditions for the growth of grapevines. The photo shows the vineyard landscape of Trška Gora near Novo Mesto (photo: D. Ogrin).

With respect to vegetation, the area with a moderate continental climate can be divided into three parts:

a) excessively humid flat areas directly next to water bodies (wet meadows) and areas with high levels of groundwater (riparian forest);
b) well-drained flat areas;
c) hills and foothills.

Humid lowland areas are characterized by moisture-loving forest vegetation with oak (*Quercus robur*), black and grey alder (*Alnus glutinosa* and *A. incana*), European ash (*Fraxinus excelsior*), willows (e.g. white willow, *Salix alba*) and poplars (black and white, *Populus nigra* and *P. alba*). Common associations are black alder (*Alnetum glutinosae*) and white willow (*Salicetum albae*). Where water does not accumulate, the plains were once covered with oak (*Quercus petraea*) and European hornbeam (*Carpinus betulus*) forests. Since it is one of the best growing areas in Slovenia, today these forests have been almost completely cleared. The elevated parts are overgrown with deciduous trees. Above the plain, oak and hornbeam are quickly replaced by beech (*Fagus sylvatica*), which becomes the dominant species particularly on the shaded slopes. On silicate rocks, beech most often grows together with chestnut (*Castanea sativa*, the acid-loving *Castaneo sativae-Fagetum* association), where silver birch (*Betula pendula*) and Scots pine (*Pinus sylvestris*) are also mixed in, and blueberry (*Vaccinium* *myrtilus*) in the understorey. Beech associations thrive on carbonate rocks, e.g. with haquetia (*Hacquetio-Fagetum*) or dead nettle (*Lamio orvalae-Fagetum*), characteristic of the milder form of the continental climate. A heat-loving and drought-tolerant association of beech and hop-hornbeam (*Ostryo-Fagetum*) thrives on particularly sunny and above-average warm and dry slopes of limestone and dolomite (Marinček, Čarni, 2002; Repe, 2020). With climate change, it can be expected that the latter will be among those that will spread the most in the future (Kutnar, Kobler, 2014; Gregorčič et al., 2022).

Mountain climate

With altitude, the air temperature usually decreases, the amount of precipitation increases, the duration and depth of the snow cover increases, there is more wind, the growing season shortens, etc. Therefore, one of the main characteristics of a mountain climate are the altitude climatic-vegetation zones, in Slovenia mainly the mountain, sub-alpine and alpine zones (there is no real nival zone). The mountain climate of the Alps, Pohorje and the highest areas of the Western Pre-Alpine Hills and the High Dinaric Plateaus is the coldest and wettest in Slovenia (and among the wettest in Europe), with long-lasting and deep snow cover that in average winters exceeds 150 cm. The average temperature of the coldest month is lower than −3 °C, and the annual precipitation mostly above 1600 mm. Western areas with a mountain climate are wetter (over 2500 mm of precipitation annually) and have peak precipitation in late autumn, while eastern areas receive less precipitation, and the wettest part of the year shifts to summer. The least precipitation occurs in winter. The highly dissected relief of mountain areas also engenders very diverse topoclimatic conditions with a great variety of microclimates. Temperature conditions can be extreme in mid-mountain and high-mountain frost hollows, as temperatures there can be around 30 °C lower than in areas outside frost hollows at the same altitude (Dovečar et al.,. 2009; Ogrin, Ogrin, 2005; Ogrin, 2007; Ogrin et al., 2012; Ortar, 2011; Svetlin, 2020; Trošt, 2008). In mountain areas, in addition to the greatest amount of precipitation, we also observe the greatest precipitation gradients. This is especially true of some Alpine valleys (Ogrin, Kozamernik 2018, 2020a, 2020b). Higher areas, especially ridges and peaks, are the areas most exposed to the wind in Slovenia, and towards the valleys the ventilation quickly weakens. The valley floors are, however, better ventilated than the plains and basins, because with anticylonic weather, daily thermal winds occur regularly, which increases the self-cleaning capacity of the atmosphere. In recent decades, the extent of the mountain climate in Slovenia has been decreasing due to the warming of the atmosphere.

Figure 12: Climogram for the climate of higher (Kredarica) and lower (Krvavec) mountain areas.

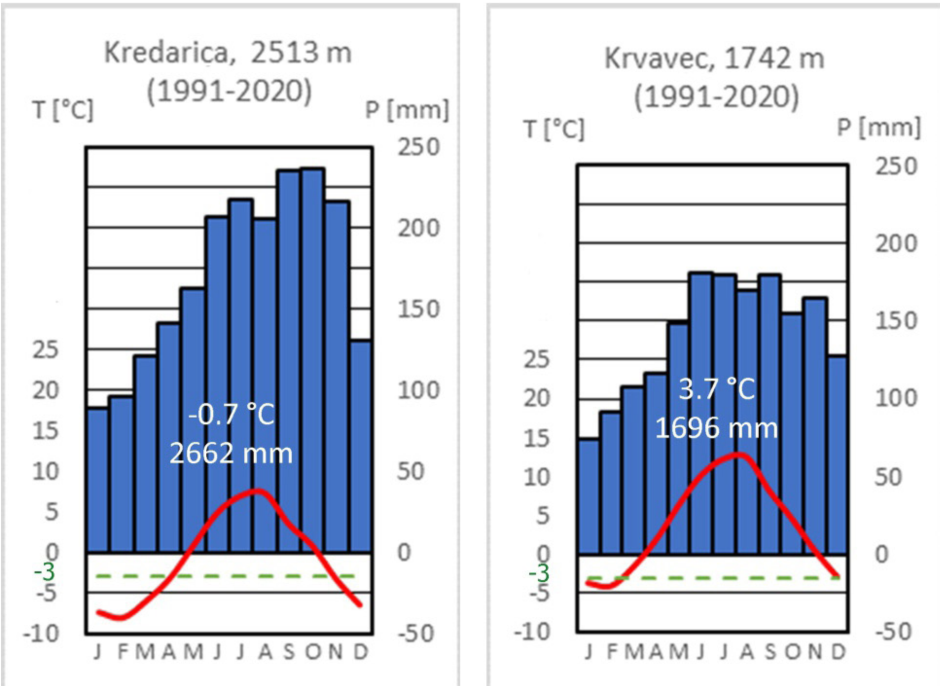


Table 6: Basic characteristics of a mountain climate.

<table>
<tr><td colspan="2">Mountain climate
- Average temperature of the coldest month below –3 °C (January isotherm –3 °C at about 1530 m)
- October warmer than April
- Average annual temperature below 6 °C
- Average annual temperature amplitude less than18 °C
- Annual amount of precipitation more than1600 mm (Pohorje 1400 to 1600 mm)
- Perhumid climate (L >160)</td></tr>
<tr><td>Higher mountain climate
(ET according to Köppen)
- Avg. temp. of the warmest month below 10 °C (July isotherm 10 °C at around 2200 m)
- Avg. annual temperature below 3 °C
- Annual amount of precipitation more than 2000 mm
- Moderate Mediterranean precipitation regime (MI over 10)</td><td>Lower mountain climate
(Dfcw‘ (x‘), Dfbw‘ (x‘) and Cfcw‘ (x‘) according to Köppen)
- 1 to 4 months with an average monthly temperature above10 °C
- Avg. annual temp. 3 to 6 °C
- Average annual amount of precipitation 1400 to 2000 mm
- moderate Mediterranean precipitation regime (MI >10); Pohorje moderate continental precipitation regime</td></tr>
</table>

A higher mountain climate is found along the highest ridges of the Julian and Kamnik-Savinja Alps, where the average temperature of the warmest month does not exceed 10 °C. Thus, in the highest and coldest areas (above 2400 m, sub-snow zone), where the mean annual temperatures are around or slightly below 0 °C, the vegetation is sparse and includes typical representatives of alpine flowers such as pink cinquefoil (*Potentilla nitida*), alpine forget-me-not (*Eritrichium nanum*) and similar. Between about 2000 and 2400 m, mean annual temperatures are a degree or two higher than in the sub-snow zone, which is enough for the alpine zone to appear. Grasses and perennial cushion plants such a various sedges (e.g. evergreen, rusty, hardy), mountain aven (*Dryas octopetala*), etc. thrive here. Lower down, a zone of cool-loving shrubs begins to appear. The most common is the dwarf mountain pine (*Pinus mugo*), while underneath it grows the hairy alpenrose (*Rhododendron hirsutum*), rhododendron *(Rhodothamnus chamaecistus*) and heather (*Erica carnea*) (Blatnik and Repe, 2012). Between the alpine zone and the tree line is the subalpine zone, which includes areas mostly between 1500 and 2000 m. Average annual temperatures are approximately between 4 and 2 °C. In this zone, it is still too cold for stands of forest to appear. Scattered larches (*Larix decidua*) and spruces (*Picea abies*) as well as mountain ash (*Sorbus aucuparia*) begin to appear mixed in with the mountain pine. The number of tree species increases with decreasing altitude, until they transition into forest stands with lush undergrowth. In addition to the mountain pine, the alpine honeysuckle (*Lonicera alpigena*), alpine clematis (*Clematis alpina*), spurge laurel (*Daphne mezereum*), etc. thrive in the shrub layer (Repe, 2017).

Lower down, below the tree line, where one to four months have an average temperature above 10 °C, up to an altitude of about 1200 m, is a lower mountain climate. This also extends to some mountain valleys and higher-lying karst depressions, where temperatures are similar to mountain ones mainly due to strong temperature inversions. With respect to natural vegetation, this area could be classified as a lower montane zone; spruce (*Picea abies*) is the predominant tree species, while beech (*Fagus sylvatic*a) is also common, while in lower parts of this area silver fir (*Abies alba*) and maples (e.g. the sycamore maple, *Acer pseudoplatanus*) grow, and higher up larch (*Larix decidua*). Beech associations (with the three-leaved anemone (*Anemono trifoliae-F.*), large white buttercup (*Ranunculo platanifoliae-F.*), *Homogyne sylvestris-F.* etc.) and natural spruce forest associations (with buckthorn *(Rhamno fallici*), alpine plantain (*Adenostylo glabrae-Piceetum*)) etc. are common. On sun-exposed slopes beech along with hop-hornbeam grows (Repe, 2019). In the past, in many places in the mountains a cultural landscape of mountain pastures could be seen up to the tree line, as the wet summers enable the lush growth of grass. In many places, this process anthropogenically lowered the natural tree line, which has been gradually rising in recent decades due to the abandonment of grazing as well as climate change.

Figure 13: Upper tree line on the southern slope of Golica (photo: D. Ogrin).

Submontane climate

The foothills of the Alps and most of the pre-Alpine hills and the Dinaric karst plateaus and hills have a submontane climate. This is a transitional climate between mountain and moderate continental on the eastern side, and mountain and moderate Mediterranean on the southwestern side of the Alpine-Dinaric barrier. Average January temperatures are mostly between 0 and –3 °C and July temperatures between 16 and 20 °C. Due to the location in the area of the Alpine-Dinaric barrier, the climate is wetter than average, with the least precipitation in winter. Snow cover is less reliable than in mountain climates due to lower elevations and higher temperatures. Precipitation and temperature conditions are the basis for dividing the submontane climate into very humid, found in the central, highest, coldest and wettest part of the barrier, and humid, found in the lower and slightly warmer areas on the continental and coastal sides of the barrier at the edge.

Due to the less favourable climatic, relief and soil conditions, areas of Slovenia with a submontane or lower mountain climate have a lot of forest. The entire area is noticeably dominated by beech forests, which on carbonate rocks typically form distinctive climate- and altitude-dependent belts. At the lowest altitudes, the already mentioned beech associations with haquetia and dead nettle occur. As the altitude increases, the proportion of conifers begins to increase, primarily fir (*Abies alba*), and higher still spruce (*Picea abies*). Thus, the high Dinaric karst plateaus are completely dominated by fir-beech forests (an association of beech and blue-eyed-Mary, *Omphalodo-Fagetum*), which gives way to an association with three-leaved anemone (*Anemono trifoliae-Fagetum*) in the direction of the Alps. In frost hollows of the Dinaric Karst, beech is first replaced by spruce and then dwarf mountain pine. Beech forests with hop-hornbeam (*Ostryo-Fagetum*) grow on sun-exposed slopes. On silicate rocks, acid-loving beech forests with chestnut and deer fern (*Blechno-Fagetum*) thrive where spruce, fir and red pine are abundantly mixed in (Gregorčič et al., 2022; Marinček, Čarni, 2002; Repe, 2020).

In areas with a submontane climate with favourable relief, soil and local climatic conditions, the natural landscape has been transformed by agriculture. In the lower elevated parts, there is a warm belt, which is conducive to growing fruit trees due to the lower risk of frost and less humid nights. Higher up, forests of the species already mentioned predominate, interspersed with meadows, which the relatively humid summers suit. The high moisture of the Western Pre-Alpine Hills, especially in autumn, is often reflected in extreme precipitation events, which can cause abundant torrential floods, and less destructive karst flooding in karst poljes. In Dinaric Karst areas in this type of climate, pronounced temperature inversions occur on the karst poljes, depressions. and other depressed landforms. For example, on clear mornings, the karst poljes often become true frost hollows, and the settlements in these places are the coldest populated areas in Slovenia (e.g. Babno Polje, Rakitna, Retje, Travnik) (Ogrin et al., 2006).

The occurrence of temperature inversions in populated karst poljes and depressions is also associated with the low self-cleaning capabilities of the air and increased pollution as a result of local emissions from households and traffic, especially in the colder half of the year (Glojek et al., 2018; 2020; 2022). Higher areas with this type of climate are moderately ventilated, but the lowlands lack any pronounced winds, with the exception of valleys in Alpine and pre-Alpine areas, where daily thermals occur with anticyclonal weather (katabatic and anabatic wind).

Figure 14: Climogram for very humid (Babno Polje) and humid (Lisca) submontane climate.

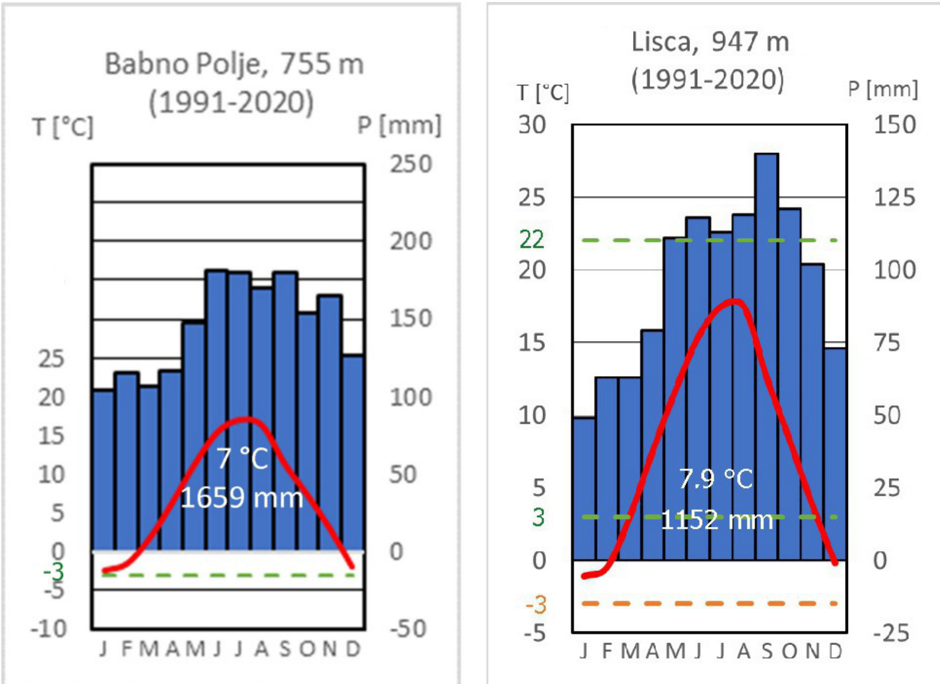


Table 7: Basic characteristics of a submontane climate.

<table>
<tr><td colspan="2">Submontane climate (Cfbw' and Cfbx' according to Köppen)
- Average January temperature 0 to −3 °C, average July temperature 16 to 20 °C, average annual temperature 6 to 9 °C
- Average annual temperature amplitude 18 to 20 °C
- October warmer than April
- Annual amount of precipitation more than 1400 mm
- Moderate Mediterranean precipitation regime (except for Pohorje and Kozjak with Košenjak)</td></tr>
<tr><td>Very humid submontane climate
- Perhumid climate (L >160)</td><td>Humid submontaneclimate
- Humid climate (L = 100 to 159)</td></tr>
</table>

Figure 15: A high amount of precipitation falls in mountain areas, including in Bohinj. The umbrella is therefore one of the symbols of these places (photo: D. Ogrin).

4 DISCUSSION

The climate classification of Slovenia for the period 1991–2020 is partly based on different criteria than all the previous ones, so a direct comparison with previous classifications is not possible. Although it partially preserves the naming of certain climate types, e.g. moderate continental climate, climate of lower and higher mountains, coastal and inland moderate Mediterranean climate, the criteria differ from past studies, which is a consequence of the general warming of the atmosphere and climate change. At the same time, it also eliminates certain climate types (e.g. the moderate continental climate of western and southern Slovenia and the climate of the lower mountains and intervening basins and valleys of northern Slovenia) and introduces new ones. The method on which the classification is based is also not comparable to climate classifications in neighbouring countries, as its purpose is to identify the climatic types of Slovenia by describing their characteristics and finding differences and similarities between Slovenian regions. Four large geographical units come together on the territory of Slovenia (Ogrin, Plut, 2009), which in turn leads to the great geographical diversity of Slovenian landscapes; this is also reflected in high abiotic diversity (geodiversity), in which climate types can also be included. Climate types are the result of established weather processes and their properties, which are the result of the action of other abiotic and biotic factors (geological composition, relief, water bodies, vegetation) and at the same time also influence and shape them.

The largest share of Slovenian territory is in the submontane climate type (46.4%), followed by moderate continental (40%), moderate Mediterranean (7.1%) and mountain climate (6.5%). The dominance of the submontane climate overlaps in large degree with the Pre-Alpine and Dinaric Karst regions, with the exception of the Ljubljana Basin and the lower parts of the Dinaric Karst regions. At the same time, it indicates the transition of climatic characteristics between mountain, moderate Mediterranean and moderate continental areas. The second most dominant climate type, the moderate continental climate, also indicates a transition between the mountain and submontane areas of Slovenia and the distinctly continental areas east of it. This climate type is also present in Croatia (Zaninović et al., 2008), in Bosnia and Herzegovina (Bosnia and..., 2023) and in Serbia (Republički hidrometeorološki..., 2023). The moderate Mediterranean climate is the result of a transition between the Mediterranean regions south of Slovenia and the regions in its interior. An understandable consequence of the marked transitional nature of Slovenia's climate is also seen in the fact that the mountain climate, which is not a transitional type, covers the smallest area of the climate types.

With regard to subtypes, the largest share of Slovenia (30%) has a very humid submontane climate. It is the only subtype that covers more than 20% of the area. It is followed by the moderate continental climate of northeastern Slovenia (19%) and the humid submontane climate (17%). More than 10% of the territory of Slovenia has the moderate continental climate of eastern and southeastern Slovenia (14%). Less than 10% has the moderate continental climate of central Slovenia (7%), either mountain (6.5 and 0.5%) or moderate Mediterranean (4.7 and 2.7%) subtypes of climate, respectively (Table 8). The smallest share has a higher mountain climate, which occupies only 0.5% of the surface of Slovenia, coinciding roughly with the territory above an elevation of about 2200 m.

With respect to population density by climate subtypes and types, the moderate continental type greatly stands out: almost three-quarters of the population of Slovenia (74.6%) live in areas with this climate type. Within this type, the moderate continental climate of central Slovenia is most prominent, where 31% of the population live (a density of 421 inhabitants/km2). A little over one-sixth (16.1%) of the population lives in areas with a submontane climate, and a little over a tenth (9.5%) in areas with a moderate Mediterranean climate, of which only a little under 3% live in the areas with the inland subtype. The contact of sea and land and the attractive climate of the coastal zone are the reason for the second highest population density among the climatic subtypes in Slovenia, which amounts to 277 inhabitants/km2. The area with a mountain climate area is practically devoid of population, as only 1‰ of Slovenia's population live here, and there are no inhabitants in areas with a higher mountain climate.

Table 8: Spatial and demographic representation of climate types in Slovenia.

Climate type	Average el. (m)	Area (km²)	Share of area (%)	No. of inhabitants	Share of pop.	Pop. density (inh./ km²)
Moderate continental	327	8111	40.0	1,516,291	74.4	187
Moderate continental of northeastern Slovenia	311	3824	18.9	511,722	25.1	134
Moderate continental of eastern and southeastern Slovenia	285	2786	13.7	372,479	18.3	134
Moderate continental of central Slovenia	384	1501	7.4	632,090	31	421
Moderate Mediterranean	245	1441	7.1	193,194	9.4	134
Coastal moderate Mediterranean	123	488	2.4	134,973	6.6	277
Inland moderate Mediterranean	367	953	4.7	58,221	2.9	61
Mountain climate	1734	1314	6.5	2516	0.1	1.9
Higher mountain	2096	102	0.5	0	0	0
Lower mountain	1372	1212	6.0	2516	0.1	2
Submontane climate	635	9404	46.4	327,114	16.1	35
Very humid submontane	788	6015	29.7	168,537	8.3	28
Humid submontane	517	3389	16.7	158,577	7.8	47

Demographic data are from 2016 (SURS, 2016).

5 CONCLUSION

From the 1930s to the end of the century, geographers prepared six climate classifications for the area of Slovenia. These have been methodologically improved and updated and also covered other time periods, but the trend of global warming was not taken into account. In 2009, Ogrin's classification was updated based on data for the period 1971–2000 (Ogrin, 2009), which preserved the criteria of the previous classification (D. Ogrin, 1996). Global warming is already reflected in this classification, as for example the spread of the moderate Mediterranean climate towards the interior of Slovenia, the shift of the climate of lower mountains to higher altitudes, the mitigation of the continental temperature regime due to the rise in winter temperatures, and in the case of precipitation, the shift of a moderate Mediterranean precipitation regime towards the east of the country. In 2017, a climate classification for the period 1981–2010 was prepared by meteorologists (Kozjek et al., 2017) using factor analysis and cluster analysis, and it was updated by calculating the measures of variability of the most important climatic elements for the period 1961–2011. In our research, we prepared a revised climate classification based on Ogrin's earlier classification that includes the last completed 30-year reference period (1991–2020), and methodologically improved it. The improved methodology, compared to Ogrin's previous classification, takes into account Lang's precipitation factor in describing humidity conditions, we have adapted Köppen's criteria of the precipitation regime and the Mediterranean index of precipitation, and we have also included differences in humidity between the warmer and colder halves of the year. The classification is also based on a higher density of point data, on data in a kilometre grid and more objective spatial interpolation.

More recent data reflect the current climate conditions resulting from climate change, which is manifested in positive temperature deviations in certain areas from the values that we have been used to. Changes are also evident in some other criteria, e.g. in terms of annual temperature amplitudes and the Mediterranean index. It turns out that the new classification cannot be based only on the expansion or contraction of existing climate types, but it is also necessary to introduce a new climate type, and some established climate types have disappeared. Greater spatial density of input data and more objective spatial interpolation also enable more precise demarcation of climate types, which, even after a basic generalization, still appear in less regular or more complex spatial forms (polygons). The main modifiers of climate and climate types in Slovenia remain altitude, relief and distance from the Adriatic Sea; geographical location in relation to the most frequent winds must also be considered.

Our research also confirmed the strongly transitional character of Slovenia's climate, as well as the high climatic variety, which is the result of the variability of the main climate modifiers. With the exception of the mountain climate, all climate types in Slovenia are transitional climate types; the area of the mountain climate covers only 6.5% of Slovenia's territory and is inhabited by only 1‰ of the population. The most spatially extensive climate type is the submontane climate, which covers 46% of Slovenia, and the most populated area is the moderate continental climate (75% of the population, 421 inhabitants/km2), which prevails in the largest and thus most densely populated lowlands of inner Slovenia. In terms of population density, the area covered by the coastal moderate Mediterranean climate stands out (277 preb./km2), more a result of the proximity of the sea than the favourable climate.

In our research we analysed the climate conditions for the last 30-year reference period, which provides the basis for a new interpretation of climate conditions in Slovenia, for which we must be aware that the dynamics of climate change dictate the adaptation of climate classifications faster than was necessary throughout most of the 20th century. Although the purpose of our research was not to compare the climate types of older classifications with the current ones, by analysing and processing the data of the last reference period, we obtained a good basis for the preparation of such studies.

Acknowledgments

The authors sincerely thank Renato Bertalanič from the Ministry of the Environment and Spatial Planning, ARSO, for his selfless help in preparing and obtaining climate data for the period 1991–2020.

The research was partly carried out within the framework of the research program Sustainable regional development of Slovenia (P6–0229), which is co-financed by Slovenian Research and Innovation Agency.

References

Ahrens, C. D., 2005. Essentials of meteorology, an invitation to the atmosphere. Michigan: Thomson Brooks/Cole.

ARSO [Agencija Republike Slovenije za okolje], 2021. Temperaturni in padavinski podatki za Slovenijo za obdobje 1991–2020. Ljubljana: Agencija Republike Slovenije za okolje.

Bertalanič, R., Demšar, M., Dolinar, M., Dvoršek, D., Nadbath, M., Pavčič, B., Roethel-Kovač, M., Vertačnik,G., Vičar, Z., 2010. Spremenljivost podnebja v Sloveniji. Ljubljana: MOP ARSO.

Blatnik, M., Repe, B., 2012. Vegetacijski pasovi na meliščih v slovenskih Alpah. Dela, 37, pp. 45–63. DOI: 10.4312/dela.37.45-63.

Bosnia and Herzegovina, Climate change knowledge portal, 2023. URL: https://climateknowledgeportal.worldbank.org/country/bosnia-and-herzegovina/climate--data-historical (accessed 5. 6. 2023).

Cui, D., Liang, S., Wang, D., Liu, Z., 2021. A 1 km global dataset of historical (1979–2013) and future (2020–2100) Köppen-Geiger climate classification and bioclimatic variables. Earth System Science Data, 13, pp. 5087–5114. DOI: 10.5194/essd-13-5087-2021.

Dolinar, M., 2016. Monthly gridded datasets for temperature and precipitation over Slovenia. Proceedings of GeoMLA – Geostatistics and Machine Learning, Applications in climate and environmental science. Beograd, Univerza v Beogradu, Gradbena fakulteta. URL: http://geomla.grf.bg.ac.rs/site_media/static/Proceedings%20of%20GeoMla%202016%20Conference.pdf (accessed 13. 5. 2023).

Dolinar, M., Vertačnik, G., 2010. Spremenljivost temperaturnih in padavinskih razmer v Sloveniji. V: Okolje se spreminja – Podnebna spremenljivost Slovenije in njen vpliv na vodno okolje. Ljubljana: MOP ARSO, pp. 37–40.

Dovečar, M., Ogrin, M., Sinjur, I., Vertačnik, G. 2009. Najnižja temperatura v Sloveniji. Geografski obzornik 56, 1/2, pp. 27–31.
Furlan, D., 1960. Klimatska razmejitev Slovenije. Geografski vestnik, 32, pp. 45–57.
Gams, I., 1972. Prispevek h klimatogeografski delitvi Slovenije. Geografski obzornik, 19-1, pp. 1–9.
Gams, I., 1996. Geografske značilnosti Slovenije. Ljubljana: Mladinska knjiga.
Geiger, R., Pohl, W., 1954. Eine neue Wandkarte der Klimagebiete der Erde. Erdkunde, 8, 1-4, pp. 58–61.
Glojek, K., Gregorič, A., Ogrin, M., 2018. Onesnaženost zraka s črnim ogljikom : študija primera iz Loškega Potoka = Black carbon air pollution : case study of Loški Potok. Dela 50, pp. 5 –43. DOI: 10.4312/dela.50.5-43.
Glojek, K., Gregorič, A., Močnik, G., Cuesta-Mosquera, A., Wiedensohler, A., Drinovec, L., Ogrin, M., 2020. Hidden black carbon air pollution in hilly rural areas: a case study of Dinaric depression. European Journal of Geography, 11, 2, pp. 105–122. DOI: 10.48088/ejg.k.glo.11.2.105.122.
Glojek, K., Močnik, G., Alas, H. D. C., Cuesta-Mosquera, A., Drinovec, L., Gregorič, A., Ogrin, M.,Weinhold, K.. Ježek, I., Rigler, M., Remškar, M., Markelj, M., 2022. The impact of temperature inversions on black carbon and particle mass concentrations in a mountainous area. Atmospheric chemistry and physics, 22, 8, pp. 5577–5601. DOI: 10.5194/acp-22-5577-2022.
Gregorčič, T., Rozman, A., Repe, B., 2022. Uporaba metode maksimalne entropije pri proučevanju potencialnega vpliva podnebnih sprememb na slovenske gozdove. Dela, 57, pp. 57–88. DOI: 10.4312/dela.57.57-88.
GURS, 2021. Digitalni model višin. Ljubljana: Geodetska uprava Republike Slovenije.
Henderson-Sellers, A., Robinson, P. J., 1999. Contemporary climatology. Harlow, Essex: Pearson Prentice Hall.
Ilešič, S., 1970. Klimatska območja Jugoslavije. Geografski obzornik, 17, pp. 4–10.
Kaligarič, M., 2004. Rastlinske združbe. V: Narava Slovenije, Ljubljana, Mladinska knjiga, pp. 183–197.
Koppany, G., Unger, J., 1992. Mediterranean climatic character in the annual march of precipitation. Acta Climatologica, 24-26, pp. 1–4, 24–26.
Köppen, W, 1936. Das geographische System der Klimate. Handbuch der Klimatologie, B. I., Teil C. Berlin.
Köppen, W., 1918. Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf. Petermanns Mitteilungen, 64, pp. 193–203, 243–248.
Kozjek, K., Dolinar, M., Skok, G., 2017. Objective climate classification of Slovenia. International Journal of Climatology, 37 (Supl. 1), pp. 848–860. DOI: 10.1002/joc.5042.
Kozjek, K., Dolinar, M., Vertačnik, G., 2016. Podnebni tipi Slovenije na podlagi podnebnih povprečij, trendov in spremenljivosti. Vetrnica, 9/16, pp. 79–90.
Kozjek, K., Dolinar, M., Vertačnik, G., 2016a. Climate types in Slovenia, based on climate normals, trends and variability. Proceedings of 16th EMS Annual meeting and 11th European conference on applied climatology, ECAC, Trieste.

Kutnar, L., Kobler, A., 2014: Possible impacts of global warming on forest tree species composition in Slovenia. V: Sustainable land management and climate changes: international conference on land conservation – LANDCON 1209, Beograd, 17.–21. september 2012 (prispevek na konferenci), pp. 107.
Marinček, L., Čarni, A., 2002. Komentar k vegetacijski karti gozdnih združb Slovenije v merilu 1:400.000. Ljubljana: Založba ZRC SAZU.
Melik, A., 1935. Slovenija – Geografski opis. Ljubljana: Slovenska matica.
Ogrin D., 2015: Long-term air temperature changes in Ljubljana (Slovenia) in comparison to Trieste (Italy) and Zagreb (Croatia). Moravian Geographical Reports 23, 3, pp. 17–26. DOI: 10.1515/mgr-2015-0014.
Ogrin, D., 1996. Podnebni tipi v Sloveniji. Geografski vestnik, 68, pp. 39–56.
Ogrin, D., 2003. Spreminjanje temperature zraka in padavin po letnih časih v Ljubljani in Trstu v obdobju 1851–2022. Dela, 20, pp. 115–131.
Ogrin, D., 2009. Podnebni tipi. V: Ogrin, D., Plut, D. Aplikativna fizična geografija Slovenije. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, pp. 88–91.
Ogrin, D., 2014. Tendence spreminjanja podnebja po 2. svetovni vojni na jugovzhodu Krasa. Dela, 41, pp. 81–100.
Ogrin, D., Ogrin, M., 2005. Predhodno poročilo o raziskovanju minimalnih temperatur v mraziščih pozimi 2004/2005. Dela, 23, pp. 221–233.
Ogrin, D., Plut, D., 2009. Aplikativna fizična geografija Slovenije. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani.
Ogrin, M. 2007. The minimum temperatures in the winter 2006/07 in Slovenian frost hollows and cold basins. Dela, 28, pp. 221–237.
Ogrin, M., Kozamernik, E., 2018. Horizontalni padavinski gradienti v alpskih dolinah severozahodne Slovenije/Horizontal precipitation gradients in alpine valleys of Northwestern Slovenia. Dela, 49, pp. 5–36. DOI: 10.4312/dela.49.5-36.
Ogrin, M., Kozamernik, E., 2020a. Vertical precpitation gradients: a case study of alpine valleys of Northwestern Slovenia. Theoretical and Applied Climatology, 140, 1-2, pp. 401–409. DOI: 10.1007/s00704-019-03051-z.
Ogrin, M., Kozamernik, E., 2020b. Padavinski gradienti v alpskih dolinah na primeru izbranih dolin Julijskih Alp. Vetrnica, 12-13, pp. 70–76.
Ogrin, M., Ortar., J., Sinjur, I. 2012. Topoklimatska pestrost Slovenije. Geografija v šoli, 21, pp. 4–13.
Ogrin, M., Sinjur, I., Ogrin, D., 2006. Minimalne temperature v slovenskih mraziščih pozimi 2005/2006. Geografski obzornik, 53, 2, pp. 4–12.
Ogrin, M., Vintar Mally, K. 2013. Primerjava poletne onesnaženosti zraka z dušikovim dioksidom v Ljubljani med letoma 2005 in 2013. Dela, 40, pp. 55–72. DOI: 10.4312/dela.40.4.55-72.
Ortar, J., 2008. Tipizacija in regionalizacija slovenskih mrazišč. Diplomsko delo. Ljubljana: Univerza v Ljubljani.

Peel, M. C., Finlayson, B. L., McMahon T. A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11, pp. 1633–1644.

Podnebne spremembe 2021, fizikalne osnove in stanja v Sloveniji, poročilo IPCC 2021, povzetek za odločevalce z dodanim vpisom stanja v Sloveniji, 2021. Ljubljana: ARSO, Urad za meteorologijo, hidrologijo in oceanografijo. URL: https://meteo.arso.gov.si/met/sl/climate/change/ (accessed: 11. 3. 2023).

Repe, B., 2012. Biogeografska pestrost Slovenske Istre. V: Ogrin, D. (ed.). Geografija stika Slovenske Istre in Tržaškega zaliva. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, pp. 177–192.

Repe, B., 2017. Izbrane pedo in fitogeografske značilnosti doline Kamniške Bistrice s členitvijo. V: Ogrin, D. (ed.). Kamniška Bistrica – geografska podoba gorske doline. Ljubljana– Znanstvena založba Filozofske fakultete Univerze v Ljubljani, pp. 21–44.

Repe, B., 2019. Izbrane pedo in fitogeografske značilnosti Jezerskega. V: Repe, B. (ed.). Fizična geografija Jezerskega z dolino Kokre. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, pp. 107–142.

Repe, B., 2020. Natural vegetation. V: Rogelj, B. (ed.). Geography of Slovenia. Ljubljana: Znanstvena založba Filozofske fakultete Univerze v Ljubljani, pp. 89–98.

Republički hidrometeorološki zavod, Osnovne klimatske karakteristike na teritoriji Srbije, 2023. URL: https://www.hidmet.gov.rs/latin/meteorologija/klimatologija_srbije.php (accessed 5. 6. 2023).

Strahler, A., 2013. Introducing physical geography. Hoboken: Wiley.

Strässer, M., 1998. Klimadiagramme zur Köppenschen Klimaklassifikation. Gotha: Kleth-Perthes.

Strle, D., Svetlin, D., Glojek, K., Kobal, M., Pogačnik, K., Ogrin, M, 2020. Meritve koncentracij črnega ogljika in dušikovega dioksida na Lavrici in v Kranju = Measurements of black carbon and nitrogen dioxide concentrations in Lavrica and Kranj. Dela, 54, pp. 5–52. DOI: 10.4312/dela.54.5-52.

Supan, A., 1921. Grundzüge der Physischen Erdkunde. Berlin, Leipzig: Vereinigung Wissenschaftlicher Verleger, Walter de Gruyter &Go.

SURS, 2016. 100 m mreža števila prebivalcev.

Svetlin, D., 2020. Analiza temperaturnih razmer v mraziščih Komne. Magistrsko delo. Ljubljana: Univerza v Ljubljani.

Šegota, T., Filipčić, A., 1996. Klimatologija za geografe. Zagreb: Školska knjiga.

Trošt, A., 2008. Mrazišča na Komni. Diplomsko delo. Ljubljana: Univerza v Ljubljani.

Vertačnik, G., Dolinar, M., Bertalanič, R., Klančar, M., Dvoršek, D., Nadbath, M., 2013. Podnebne značilnosti Slovenije: glavne značilnosti gibanja zraka v obdobju 1961–2011. Ljubljana: ARSO, Ministrstvo za kmetijstvo in okolje.

Vertačnik, G., Vičar, Z., Bertalanič, R., 2016. Podnebna spremenljivost Slovenije v obdobju 1961–2011, 2 Kontrola in homogenizacija podatkov. Ljubljana: Agencija RS za okolje.

Zaninović, K., Gajić-Čapka, M., Perčec Tadić, M. in sod., 2008: Klimatski atlas Hrvatske/Climate atlas of Croatia 1961–1990, 1971–2000. Zagreb: Državni hidrometeorološki zavod.

Žiberna, I., 1992. Izbrane numerične metode v klimatogeografiji. Geografija v šoli, 2, pp. 75–79.

Stanka Miklič*, Tajan Trobec**

SEZONSKE SPREMEMBE GLADINE CERKNIŠKEGA JEZERA V OBDOBJU 1961–2020

Izvirni znanstveni članek
COBISS 1.01
DOI: 10.4312/dela.59.91-150

Izvleček

V prispevku analiziramo letne spremembe najnižjih (Hnp), srednjih (Hs) in najvišjih (Hvp) letnih vodostajev Cerkniškega jezera v obdobju 1961–2020 ter jih skušamo povezati s spremembami lokalnega podnebja. Manjša količina padavin, višja temperatura in posledično večje izhlapevanje ter manjši vpliv snežnega zadržka se odražajo v spremenjenem odtoku s pojezerja, kar se zrcali v upadu letnih, pomladnih in poletnih Hs in Hvp, medtem ko so zimski in jesenski Hs in Hvp ostali na podobni ravni. Po drugi strani so Hnp razen pomladi v porastu, kar na letni ravni, poleti in jeseni (kolikor to dopušča nezanesljivost podatkov ob najnižjih vodostajih) verjetno lahko pripišemo umetnemu zadrževanja vode v jezeru, pozimi in pomladi pa podnebnim spremembam.

Ključne besede: hidrogeografija, podnebne spremembe, spreminjanje vodostaja, vodni režim jezera, Cerkniško jezero, Notranjsko podolje, Dinarski kras

*Notranjska cesta 37, 1380 Cerknica, SI-Slovenija
**Filozofska fakulteta, Univerza v Ljubljani, Oddelek za geografijo, Aškerčeva 2, SI-1000 Ljubljana, Slovenija
e-pošta: stanka.miklic11@gmail.com, tajan.trobec@ff.uni-lj.si
ORCID: 0000-0002-8784-4366 (T. Trobec)

1 UVOD

Podnebje vpliva na različne procese v okolju in mnoga področja človekovega delovanja. Njegovo spreminjanje je sicer povsem običajno, vendar je zaradi izpustov toplogrednih plinov hitrost spreminjanja podnebja v zadnjih desetletjih nesorazmerno velika (IPCC, 2022). Podnebne spremembe se kažejo v spremenjenih vrednostih pri številnih meteoroloških spremenljivkah, v Sloveniji med drugim v povišanju temperature zraka, spremembi količine, oblike in razporeditve padavin ter v zmanjšanju višine snežne odeje. Njihov vpliv se odraža na gospodarskih dejavnostih, kot so kmetijstvo, gozdarstvo, energetika, turizem, promet itd. (Vertačnik, Bertalanič, 2017), poleg gospodarstva pa so podnebnim spremembam močno podvržene tudi vode ter ekosistemi (Bertalanič in sod., 2018; Trobec, 2022). Jezerski ekosistemi so ključnega pomena za vodne in obvodne organizme ter najrazličnejše človekove potrebe, zaradi česar ima vsakršna sprememba v količini ali poslabšanje kakovosti jezerske vode potencialno široke ekološke in družbene posledice (George, 2010; Vincent, 2009).

V pričujočem prispevku smo za preučevanje vplivov podnebnih sprememb na hidrološke značilnosti voda izbrali Cerkniško jezero, ki se nahaja na kraškem Cerkniškem polju. Zaradi presihajočega režima je Cerkniško jezero v hidrološkem smislu že samo po sebi izjemno spremenljivo (Zhelezov in sod., 2011). Presihajoča kraška jezera imajo zaradi lege na stiku podzemnih in površinskih voda zelo kompleksno hidrologijo, saj na njihovo pojavljanje in višino vode vplivajo številni dejavniki, kot so količina padavin, taljenje snega, izhlapevanje, dotok površinske in podzemne vode, zaloge podzemne vode v kraškem vodonosniku in podzemni odtok (Kovačič, 2010; Mayaud in sod., 2019). Poleg naravnih dejavnikov pa na odtok in s tem gladino vode presihajočih kraških jezer lahko vplivajo tudi različni hidrotehnični posegi na vodotokih, še posebej v ponornem delu polj (zajezitve in namenske ojezeritve, širjenje ponorov ipd.) (Bonacci, 1987).

Pri pregledu literature smo naleteli na številne raziskave, ki preučujejo vpliv podnebnih sprememb na vodno bilanco jezer in količino vode v njih (na primer: Kayastha in sod., 2022; Lenters, Kratz, Bowser, 2005; Torabi Haghigi, Kløve, 2015; Van der Kamp, Keir, Evans, 2008; Wrzesiński, Ptak, 2016), malo pa je raziskav, ki naslavljajo neposredni vpliv podnebnih sprememb na spremembe vodostajev kraških presihajočih jezer (na primer: Morrissey in sod., 2021). Na Cerkniškem jezeru sta se s spreminjanjem vodostaja v povezavi s podnebnimi spremembami in antropogenimi posegi v režim odtoka ukvarjala Mikličeva (2021) in Blatnik s sodelavci (2024). Skupna ugotovitev je pozitiven in statistično značilen trend najnižjih letnih vodostajev (Hnp), medtem ko se zaradi nekoliko različnega obdobja preučevanja zaključki glede trenda srednjih (Hs) in najvišjih vodostajev (Hvp) razlikujejo. Preučeni so bili tudi vodna bilanca Cerkniškega jezera (Kovačič, 2010), vodni režim (Zhelezov in sod., 2011) in poplave (Kranjc, 1986).

V Sloveniji so bile na temo vpliva podnebnih sprememb na hidrološke značilnosti površinskih voda večinoma izdelane študije, ki se nanašajo na vodno bilanco (Andjelov in sod., 2021; Frantar, 2008), trende različnih karakterističnih pretokov na izbranih območjih (na primer: Hrvatin, Zorn, 2020; Kovačič, 2016) in spremembe rečnih pretočnih režimov (Frantar, Hrvatin, 2005). Primerjava vodne bilance Slovenije na ravni celotne države za obdobji 1961–1990 in 1991–2020 kaže na zmanjšanje višine odtoka (za 120 mm) in odtočnega količnika (za 3,5 %) kot posledice višjih temperatur in izhlapevanja ter manjše količine padavin (Andjelov in sod., 2021; Kolbezen, Pristov, 1998). Trendi pretokov večine slovenskih vodotokov kažejo na zmanjševanje srednjih in malih pretokov ter daljšanje obdobij z malimi pretoki, ki vodijo v hidrološko sušo, po drugi strani pa na pogostejše in izrazitejše velike pretoke (Kobold, Dolinar, Frantar, 2012). Pri rečnih pretočnih režimih je v Sloveniji kot posledica podnebnih sprememb pri primerjavi obdobij 1961–1990 in 1971–2000 opazno zmanjšanje pomladanskega in povečanje jesenskega pretočnega viška. Zmanjšalo se je število rečnih pretočnih režimov, kot tudi razlike med njimi (Frantar, Hrvatin, 2005).

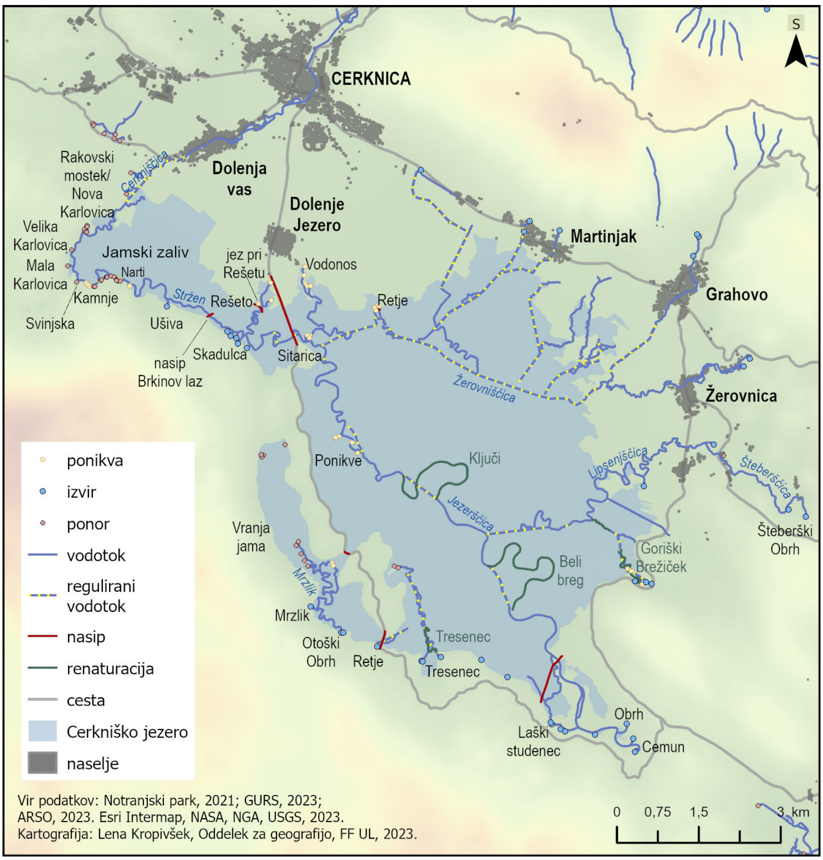
Glede na izsledke navedenih raziskav je moč sklepati, da se posledice podnebnih sprememb odražajo tudi na vodostaju Cerkniškega jezera. Namen pričujočega prispevka je preučiti spreminjanje povprečnega letnega in sezonskega vodostaja Cerkniškega jezera v 60-letnem obdobju 1961–2020 ter povleči morebitne vzporednice s podnebnimi spremembami. Za navedeno obdobje smo preučili in prikazali trende letnega in sezonskega spreminjanja temperature zraka, višine padavin in snežne odeje na območju Cerkniškega jezera in njegovega ožjega vodozbirnega zaledja ter trende spreminjanja letnih in sezonskih srednjih (Hs), najnižjih (Hnp) in najvišjih (Hvp) vodostajev jezera kot tudi najmanjših (Qnp), srednjih (Qs) in največjih (Qvk) pretokov največjega površinskega dotoka – Cerkniščice. Preučili smo tudi povezanost med izbranimi meteorološkimi in hidrološkimi spremenljivkami.

Poznavanje spreminjanja vodostaja Cerkniškega jezera je pomembno z vidika prihodnje dinamike njegovega presihanja in s tem ohranjanja že tako občutljivih, edinstvenih (ob)vodnih in podzemnih ekosistemov, značilnih za kraška polja (Bonacci, 2014; Gaberščik in sod., 2003; 2020). Pri Cerkniškem jezeru je to še toliko pomembneje, saj gre za svetovno znano presihajoče kraško jezero v osrčju Notranjskega regijskega parka, pomembno območje Nature 2000 in Ramsarske konvencije, pa tudi izjemno pestro območje z vidika geodiverzitete (Stepišnik, Ilc Klun, Repe, 2017). Hkrati je vprašanje spreminjanja vodostajev kot posledice podnebnih sprememb pomembno tudi zaradi uspešnega prilagajanja hidrološkim ekstremom, kot so poplave in suše, ter nadaljnjega gospodarskega razvoja širšega območja (kmetijstvo, turizem in druge dejavnosti v pojezerju).

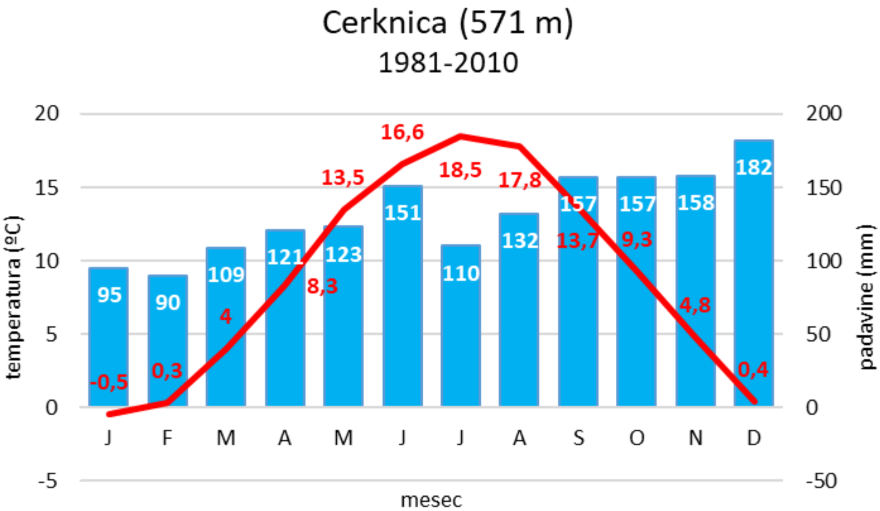
2 PREDSTAVITEV PREUČEVANEGA OBMOČJA

Cerkniško polje je s površino 38 km^2 največje kraško polje v Sloveniji (Ravbar in sod., 2021) ter osrednje polje v nizu hidrološko povezanih kraških polj Notranjskega podolja, ki je sestavni del porečja Ljubljanice (slika 1). Leži med višjim Loškim poljem na jugovzhodu in nižjim Planinskim poljem na severozahodu. Na jugozahodni strani ga obdajajo Javorniki, na severovzhodni pa Slivnica in Bloška planota. Dno polja leži na nadmorski višini okoli 550 m. Za Cerkniško polje je značilno zmernocelinsko podnebje zahodne in južne Slovenije (Ogrin, 1996). Na klimatološki postaji Dolenje Jezero je letna povprečna temperatura zraka v obdobju 1981–2010 znašala 8,9 °C (vrednost je interpolirana na podlagi vrednosti za klimatološko postajo v Postojni). V enakem obdobju je bilo na padavinski postaji v Cerknici v povprečju letno 1552 mm padavin (ARSO, 2022; slika 2).

Slika 1: Karta Cerkniškega polja.



Slika 2: Klimogram za meteorološko postajo Cerknica za obdobje 1981–2010.

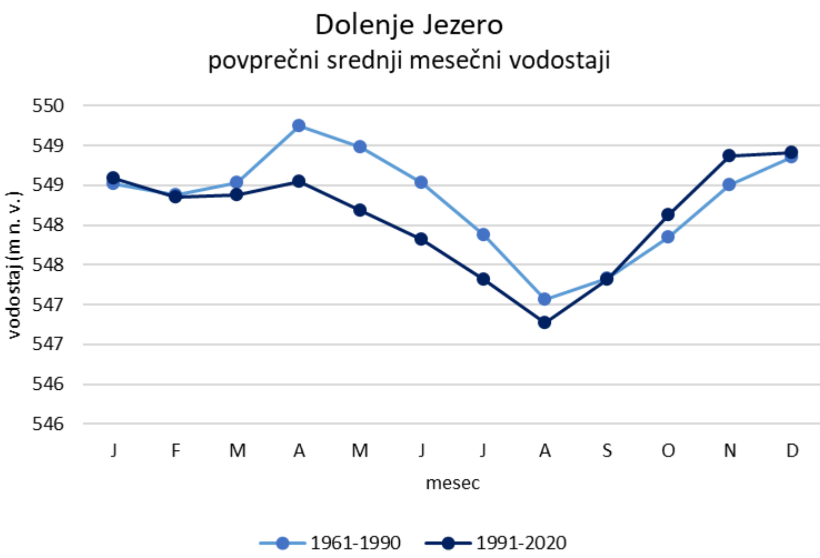


Vir podatkov: ARSO, 2022.

Cerkniško polje predstavlja kombiniran tip robnega in izvirno-ponorniškega polja (Gams, 1974), oziroma kombinacijo občasno ojezerjenega, prelivnega in pritočnega polja (Stepišnik, 2020). Hidrološko zaledje Cerkniškega polja je zelo raznoliko in obsežno, saj se na polje podzemno stekajo vode z Loškega polja in Blok (Kranjc, 1986), površinsko pa nanj doteka vodotok Cerkniščica. Površina zaledja znaša 475 km^2. Na polje doteka približno 80 % kraške in 15 % površinske vode, preostanek dotoka pa predstavlja padavinska voda s samega polja. Glavnina kraških vodotokov priteka z vzhodnega in jugovzhodnega obrobja polja. Največji vodotok na polju je Stržen, ki se na izviru imenuje Obrh. Na vzhodnem delu polja sta največja dotoka Žerovniščica in Šteberščica, na južni strani pa so večji izviri Laški studenec, Tresenec, Retje, Otoški obrh, Mrzlek, Vranja jama v Zadnjem kraju ter Skadulca in izvir v Ušivi Loki. Cerkniščica je edini daljši površinski nekraški dotok jezera, v katero se zlivajo vode z roba Otavske, Vidovske in Bloške planote (Kranjc, 1986). Odtok Cerkniškega jezera je sestavljen iz več požiralnih enot in je v celoti kraški. Najpomembnejši ponori so povezani s ponornim jamskim sistemom Velike in Male Karlovice ter Svinjske jame v severozahodnem delu polja, imenovanem Jamski zaliv, ki vodo večinoma odvajajo v smeri proti Rakovemu Škocjanu in Planinskemu polju (Gams, 1965; Petrič in sod., 2020). V osrednjem delu polja so številne ponikve (na primer Rešeto in Vodonos južno od vasi Dolenje Jezero), iz katerih se voda podzemno steka neposredno v izvire Ljubljanice (Gams, 1965). Najdlje se jezerska voda zadržuje v najnižjem delu polja, imenovanem Zadnji kraj, od koder ravno tako odteka v izvire Ljubljanice (Gams, 1965; Kranjc, 1986).

Do ojezeritve Cerkniškega polja pride, kadar dotok preseže vrednost odtoka in gladina vode zraste nad koto 547,4 m (vrednost 184 cm na vodomerni postaji Dolenje Jezero) (Kolbezen, 1998). Redna ojezeritev, definirana kot višina vode, ki je presežena vsaj 10 dni v letu znotraj referenčnega 30-letnega obdobja, pa je po novejših raziskavah opredeljena pri koti 550,3 m (vrednost 474 cm na vodomerni postaji Dolenje Jezero). Pri tej vrednosti voda prelije 21,84 km^2 veliko območje (Ravbar in sod., 2021). Jezero ima vodo v povprečju devet mesecev na leto. Polno je najpogosteje aprila, maja in decembra, prazno pa med avgustom in oktobrom (Kranjc, 2005). Za vodni režim jezera sta bila v referenčnem obdobju 1961–1990 značilna dva viška (aprila in decembra) in dva nižka (avgusta in februarja) (Kovačič, 2010). Po interpretaciji avtorja je bil aprilski višek deloma pogojen s taljenjem v višjih delih pojezerja med zimo akumuliranega snega, deloma z aktualnimi padavinami v obdobju še pred intenzivno rastno dobo. Decembrski višek je bil posledica kombinacije novembrskega viška padavin in hkratnega kraškega zadržka, ki je glavnino novembrskega odtoka s polja zamaknila v december. Avgustovski nižek je bil pogojen z intenzivnim izhlapevanjem, februarski pa s snežnim zadržkom. Iz priloženega grafikona (slika 3) je razvidno, da se je v naslednjem tridesetletnem obdobju (1991–2020) vodni režim jezera spremenil na račun občutno nižjih pomladanskih in poletnih vodostajev ter nekoliko višjih jesenskih vodostajev. V obdobju med 1961 in 2007 je vodni režim jezera za pet dekad analiziral Zhelezov s sodelavci (2011) ter pokazal na precejšnje razlike med posameznimi dekadami.

Slika 3: Hidrogram srednjih mesečnih vodostajev za vodomerno postajo Dolenje Jezero v obdobjih 1961–1990 in 1991–2020.



Vir podatkov: ARSO, 2022.

Cerkniško polje se nahaja v občini Cerknica. Naselja na Cerkniškem polju imajo, razen osrednjega naselja Cerknica, večinoma podeželski značaj. Z izjemo Dolenjega Jezera so se umaknila dosegu poplav (Smrekar, 2000). Leta 2020 je v njih prebivalo 6120 prebivalcev, od tega približno 2/3 v Cerknici (SURS, 2022). Za manjša naselja v občini je v zadnjih 50 letih značilen upad prebivalstva, v večjih naseljih z boljšimi možnostmi za razvoj različnih dejavnosti (Cerknica, Unec, Rakek, Martinjak in Grahovo) pa se število prebivalcev povečuje. Večina delovno aktivnega prebivalstva se še vedno zaposluje zunaj občine (Pustovrh Benda, 2015). Cerkniško jezero predstavlja turistični potencial širšega območja, ki pa je le deloma izkoriščen. Turistični obisk se sicer povečuje, a je večinoma vezan na enodnevne izletnike, ki kraje ob jezeru obiščejo predvsem v toplejšem delu leta (Lukan, 2017).

3 ANTROPOGENI POSEGI V ODTOČNI REŽIM NA CERKNIŠKEM JEZERU

Periodično pojavljanje Cerkniškega jezera so v preteklosti skušali uravnavati na različne načine, odvisno od zgodovinskih razmer in interesov, v katerih so pobude nastale. V agrarni dobi je bila prisotna ideja o njegovi izsušitvi oziroma zmanjšanju obsega in trajanja poplav zavoljo pridobivanja obdelovalnih površin, kasneje pa so prevladovale težnje po stalni ojezeritvi z namenom razvoja turizma in ribištva ter pridobivanja električne energije (Bidovec, 2007).

V imenu izsuševanja so do druge svetovne vojne znižali in očistili nekatere požiralnike, razširili in poglobili ponore Velika Karlovica (slika 4) in Mala Karlovica, Rakovski mostek, Svinjska jama, Kamnje in Narte, odstrelili nekaj sifonov, razširili in znižali podzemeljske struge ter postavili grablje na vhodu v obe Karlovici, uredili dotok v Svinjsko jamo, regulirali Stržen z nekaterimi pritoki ter z odvodnimi jarki uredili njegov odtok v bližnje ponikve in ponore. S temi ukrepi so omejili večje povodnji ter povzročili hitrejše odtekanje srednje visokih voda (Kranjc, 1986).

V želji po preprečitvi katastrofalnih poginov rib ob presihanju jezera so domačini leta 1946 zgradili manjši jez pred Rešetom (slika 5), ki je zadrževal nizke vode, da niso odtekle proti Rešetu. Uredili so tudi nasip Brkinov laz na Strženu v višini 200 cm na vodomerni postaji Dolenje Jezero, ki zajezuje odtok vode proti Jamskemu zalivu. Za ohranitev najnižjega vodostaja so leta 1956 poleg obnove jezu pred Rešetom (ponovno je bil obnovljen in povišan leta 1969) preuredili del Stržena in Žerovniščice ter zgradili več manjših zadrževalnikov pri Ponikvi, Retju in Sitarici (Kebe, 2011).

Konec šestdesetih let 20. stoletja so z namenom poskusne zajezitve ponorov zabetonirali vhod v Malo Karlovico, zazidali pet jamskih vhodov v Nartih, Veliko Karlovico pa pregradili z betonskim jezom s prelivom na višini 551 m (544 cm na vodomerni postaji Dolenje Jezero) ter jo z umetnim rovom povezali z Rakovskim mostkom (Novo Karlovico), kjer so na vhodu namestili železno zapornico. Na ta način so zmanjšali odtok pri srednjih in visokih vodah ter podaljšali poplave, ob sušah pa je jezero še vedno presihalo (Bidovec, 2007; Habič, 1974; Kranjc, 1986).

Slika 4: Velika Karlovica (foto: S. Miklič).

Slika 5: Jez pred Rešetom (foto: T. Trobec).

V letih, ki so sledila, so znižali pregrado pred Veliko Karlovico, odmašili nekaj ponorov ter obudili čiščenje in poglabljanje nekaterih strug. Konec osemdesetih in v začetku devetdesetih let 20. stoletja so preuredili objekt na Novi Karlovici, s čimer je postala glavni ponor za odtok vode iz Cerkniškega jezera s kapaciteto okoli 40 m^3/s (Pravilnik za obratovanje …, 2014). Leta 1992 so odstranili betonsko pregrado na vhodu v Malo Karlovico, po poplavah v letu 2000 pa za 60 cm znižali preliv pregrade na Veliki Karlovici, tako da se čeznjo prelivajo vode le, ko vodostaj na vodomerni postaji Dolenje Jezero doseže 500 cm (Kebe, 2011).

Leta 2015 so pričeli z izvajanjem pravilnika, ki predpisuje režim delovanja zapornice na Novi Karlovici z namenom ohranjanja ribjega življa, ki je v času drsti vezan na visoko zimsko in pomladansko vodo. Zapornica se zapre s 1. decembrom ter ostane zaprta vse do sredine ali konca maja (odvisno od vodostaja). Odpre se le v primeru, če višina vode na vodomerni postaji Dolenje Jezero preseže 470 cm in to le toliko, da vodostaj preneha naraščati (Pravilnik za obratovanje …, 2014). Pred letom 2015 z zapornico na Novi Karlovici niso upravljali, domneva pa se, da je bila večino časa odprta in redno čiščena (Tratnik, 2023).

Leta 2016 in 2018 so ponovno obnovili in nadvišali ribiški jez v Rešetu s prelivno višino, ki odgovarja 150 cm na vodomerni postaji Dolenje Jezero (Tratnik, 2023), s katerim v jezeru ob nizkem vodostaju ohranjajo vodo pri okvirni višini okoli 70 cm na vodomerni postaji Dolenje Jezero (Schein, 2020).

Med leti 2019 in 2021 je pod vodstvom Notranjskega regijskega parka potekala vzpostavitev prvotne struge Stržena v Ključih in Belem bregu ter v letu 2009 renaturacija zgornjih delov Goriškega Brežička in Tresenca, kar naj bi po pričakovanjih nekoliko upočasnilo odtok nizkih voda ter podaljšalo zastajanje vode v depresijah in vzpostavljenih rokavih vodotokov (Tratnik, 2023).

4 METODE DELA

Za preučevano območje smo za obdobje 1961–2020 analizirali povprečno letno in sezonsko višino padavin, višino snežne odeje ter skupno višino novega snega, povprečno letno in sezonsko temperaturo zraka, povprečne letne in sezonske najnižje (Hnp), srednje (Hs) in najvišje (Hvp) vodostaje Cerkniškega jezera ter najmanjše (Qnp), srednje (Qs) in največje (Qvk) letne pretoke Cerkniščice. Sezonske vrednosti se nanašajo na meteorološke letne čase, pri katerih trimesečje med decembrom in februarjem predstavlja zimo, trimesečje med marcem in majem pomlad, trimesečje med junijem in avgustom poletje ter trimesečje med septembrom in novembrom jesen.

Za izračun trendov spreminjanja padavin in snežne odeje na proučevanem območju smo uporabili mesečne višine padavin padavinske postaje Cerknica (ARSO, 2022), ki ima popoln niz. Glede na ta kriterij bi lahko v analizo vključili tudi postaji Šmarata in Nova vas na Blokah, a je preliminarna analiza pokazala veliko ujemanje v trendih in letni razporeditvi padavin med postajami, zaradi česar se za to na koncu nismo odločili. Pri izračunu in prikazu trenda povprečne dnevne temperature smo temperaturne podatke za klimatološko postajo Dolenje Jezero, ki je delovala le slabih deset let, interpolirali s temperaturnimi podatki klimatološke postaje Postojna, ki je najprimernejša bližnja postaja s homogeniziranim nizom podatkov. Pri interpolaciji smo naprej izračunali razliko v mesečni povprečni temperaturi zraka za skupno obdobje delovanja postaj (1969–1977) ter nato razliko prišteli nizu podatkov meteorološke postaje Postojna za obdobje 1961–2020. V raziskavi nismo posebej upoštevali evapotranspiracije, ki je sicer izračunana za Bloke in Babno Polje, ker gre za izvedeno (preračunano) in ne osnovno (merjeno) meteorološko spremenljivko. Pri analizi vodostajev Cerkniškega jezera smo uporabili mesečne podatke najnižjih, srednjih in najvišjih vodostajev na vodomerni postaji Dolenje Jezero, za analizo pretokov Cerkniščice pa mesečne pretoke vodomerne postaje Cerknica (ARSO, 2022).

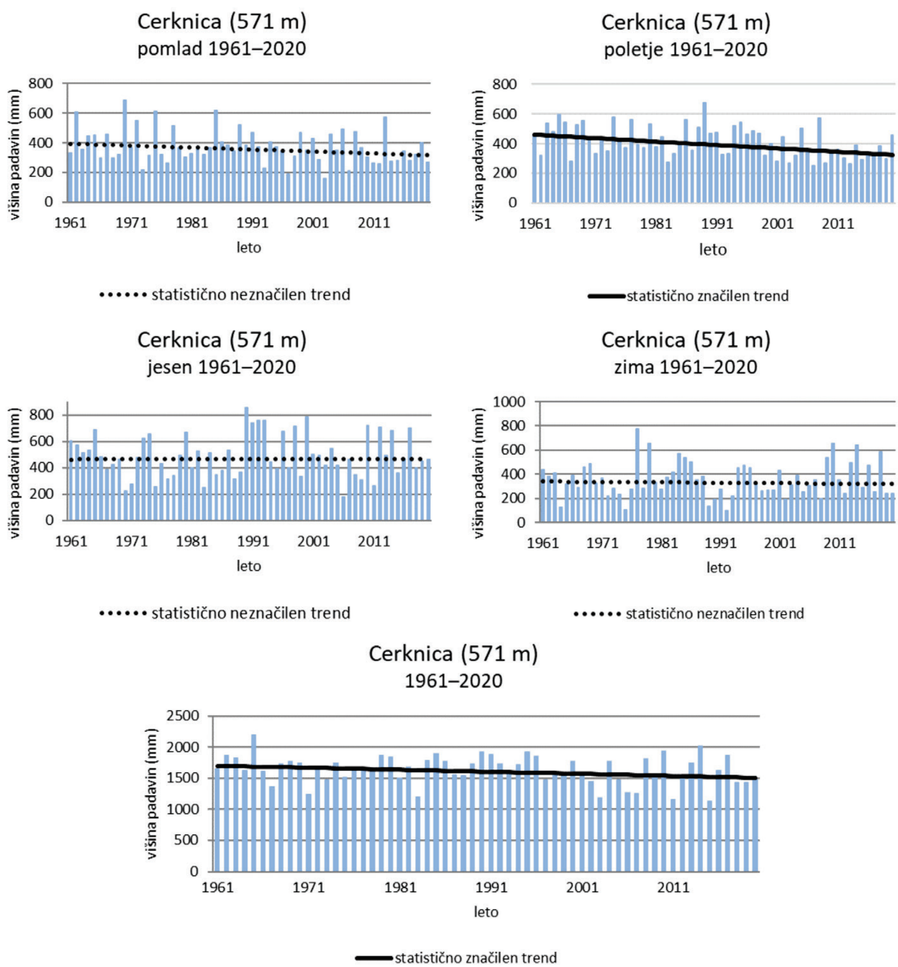
Trend spreminjanja temperature, višine padavin in snežne odeje, vodostajev in pretokov smo računali z Mann-Kendallovim statističnim testom in Senovim naklonom. Mann-Kendallov test nam v primeru prisotnosti trenda pokaže njegovo značilnost, Senov naklon pa vrednost. Mann-Kendallov test in Senov naklon smo izračunali v programu MS Excel, po predlogi MAKESENS (Makesens-application …, 2021). Povezanost med izbranimi meteorološkimi in hidrološkimi spremenljivkami smo ugotavljali s Spearmanovim koeficientom korelacije (ρ), kjer so podatki pred izračunom preoblikovani v range in zato manj občutljivi za izstopajoče vrednosti. Spearmanov koeficient korelacije za razliko od Pearsonovega tudi ne zahteva linearne povezanosti spremenljivk in normalne frekvenčne porazdelitve (Helsel in sod., 2020) ter je tako primernejši za analizo povezanosti med meteorološkimi in hidrološkimi spremenljivkami, ki predstavljajo vnose in iznose iz kraških sistemov (Kovačič, 2009).

5 REZULTATI

V obdobju 1961–2020 je bila na padavinski postaji Cerknica povprečna letna višina padavin 1629 mm. Zaznan je negativen trend, ki je statistično neznačilen ($\alpha \leq 5$ %) in znaša –33 mm/desetletje, kar pomeni, da se je količina padavin v preučevanem obdobju zmanjšala za 197 mm oziroma 11 %. Najbolj namočeno je bilo leto 1965, ko je padlo 2189 mm padavin, najmanj pa leto 2015 s 1125 mm padavin. Tudi sezonski trendi višine padavin so razen jeseni negativni. Pomladni linearni trend je statistično neznačilen in znaša –13 mm/desetletje, kar pomeni, da se je pomladanska količina padavin zmanjšala za 79 mm oziroma 20 %, povprečna pomladanska količina padavin v preučevanem obdobju pa je znašala 373 mm. Povprečna poletna količina padavin v preučevanem obdobju je znašala 413 mm. Poleti je upad padavin v primerjavi z ostalimi letnimi časi najbolj očiten, saj so se te zmanjšale za 30 % oziroma 139 mm. Linearni trend je v poletnem času statistično značilen ($\alpha \leq 5$ %) in znaša –23 mm/

desetletje. Povprečna višina padavin na padavinski postaji Cerknica je bila s 488 mm v preučevanem obdobju najvišja jeseni. Linearni trend jesenske višine padavin pa je z 0,4 mm/desetletje neznaten in statistično neznačilen. V jesenskem času se je količina padavin v primerjavi z ostalimi letnim časi povečala, a le za 0,5 % oziroma 2 mm. Povprečna zimska višina padavin je v preučevanem obdobju znašala 356 mm, kar kaže na primarni nižek padavin v zimskem času. Trend je statistično neznačilen in znaša –3 mm/desetletje. Pozimi so se tako padavine zmanjšale za 21 mm oziroma 6 % (slika 6).

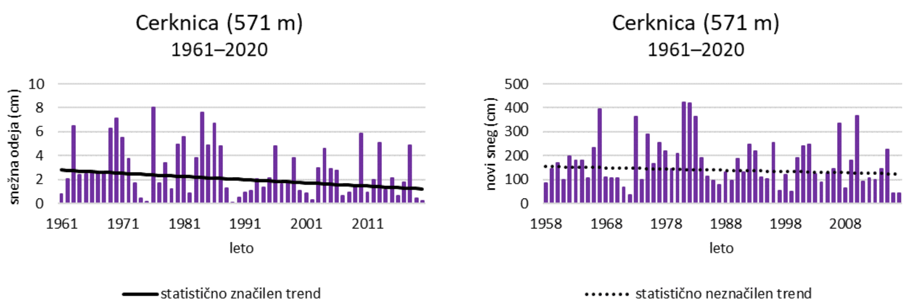
Slika 6: Časovni potek povprečne višine padavin v obdobju 1961–2020 na padavinski postaji Cerknica.



Vir podatkov: ARSO, 2022.

Pri analizi višine snega v obdobju 1961–2020 smo na padavinski postaji Cerknica analizirali dve spremenljivki: povprečno višino snežne odeje in skupno višino novega snega (slika 7). Povprečna višina snežne odeje v poljubnem obdobju ustreza aritmetični sredini vseh dnevnih vrednosti, tudi kadar snega ni (višina snežne odeje je tedaj 0 cm), skupna višina novega snega pa pomeni vsoto dnevnih vrednosti novega snega v izbranem časovnem obdobju (Vertačnik, Bertalanič, 2017). V preučevanem obdobju je bila najvišja povprečna višina snežne odeje leta 1976 (8 cm), najnižja pa leta 1989, ko je znašala 0,1 cm. Do leta 1986 se je vrednost nad 6 cm pojavila še petkrat (leta 1963, 1969, 1970, 1984 in 1986), kasneje pa ne več. Največja skupna višina novega snega je bila leta 1984, ko je znašala 421 cm, najmanjša pa leta 1975 (35 cm). Nad 350 cm je bila vrednost še v letih 1970, 1976, 1985, 1986 in 2013.

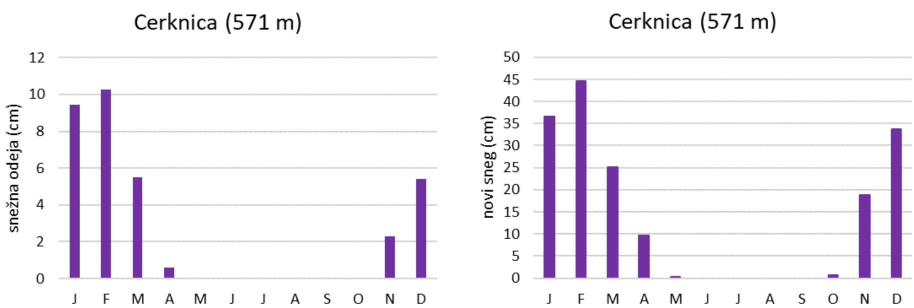
Slika 7: Časovni potek povprečne višine snežne odeje in višine novega snega v obdobju 1961–2020 na padavinski postaji Cerknica.



Vir podatkov: ARSO, 2022.

V preučevanem obdobju je bil na območju Cerkniškega polja najbolj snežen mesec februar (slika 8). Povprečna višina februarske snežne odeje je znašala 10,3 cm, povprečna skupna višina novega snega pa 45 cm. Glavnina novega snega (nad 25 cm na mesečni ravni) je v povprečju zapadla med decembrom in marcem. Povprečna višina snežne odeje na letni ravni je znašala 2,8 cm, skupna višina novega snega pa 170 cm. V preučevanem obdobju smo statistično značilen trend ($\alpha \leq 5$ %) zaznali za povprečno višino snežne odeje, ki znaša –0,26 cm/desetletje, kar pomeni zmanjšanje za 1,6 cm oziroma 57 %. Pri skupni višini novega snega je trend ravno tako negativen (–5 cm/desetletje), a ni statistično značilen. Na letni ravni se je v preučevanem obdobju količina novozapadlega snega zmanjšala za 31 cm oziroma 20 %.

Slika 8: Mesečna povprečna višina novega snega in snežne odeje na padavinski postaji Cerknica v obdobju 1961–2020.

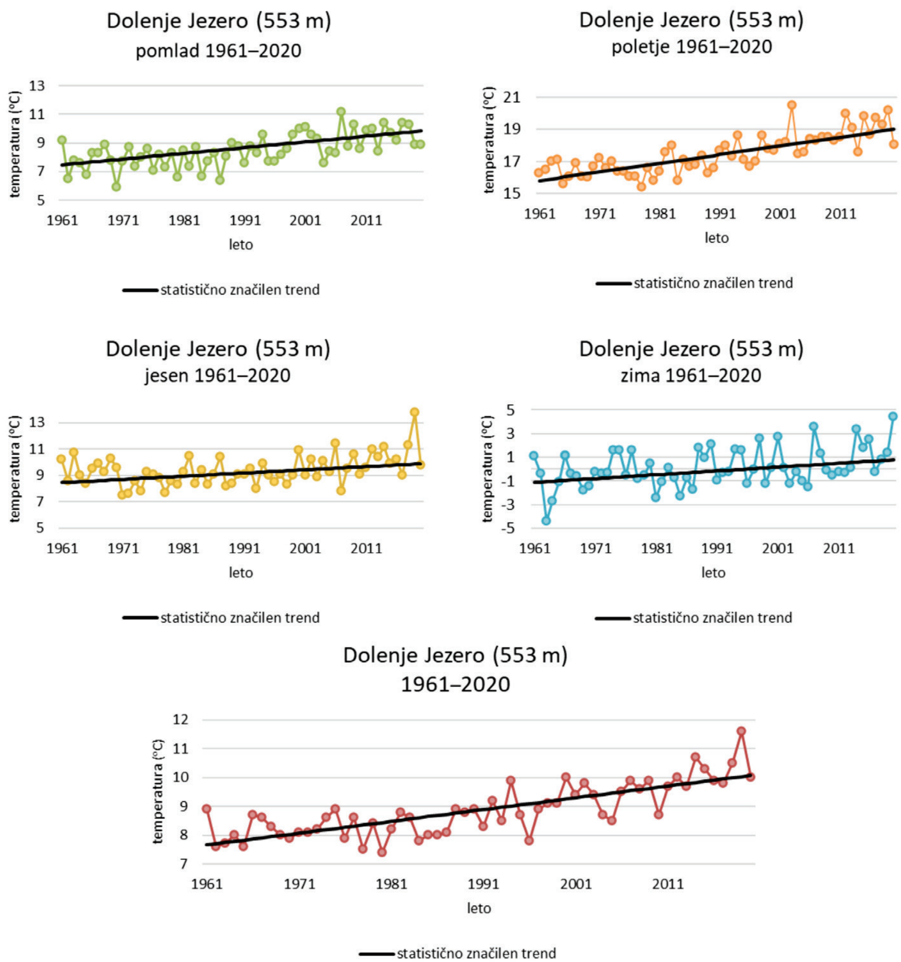


Vir podatkov: ARSO, 2022.

Povprečna letna temperatura zraka na klimatološki postaji Dolenje Jezero je bila v obdobju 1961–2020 8,9 °C. Najnižja letna povprečna temperatura zraka je bila izmerjena leta 1980, ko je znašala 7,4 °C, najtoplejše pa je bilo leto 2019 s povprečno temperaturo 11,6 °C. V preučevanem obdobju je zaznan pozitiven in statistično značilen trend (α ≤ 5 %), ki znaša 0,4 °C/desetletje, kar pomeni, da se je v preučevanem obdobju ozračje ogrelo za 2,5 °C. Za razliko od trendov povprečne višine padavin so trendi povprečne temperature zraka v vseh letnih časih pozitivni in statistično značilni (α ≤ 5 %). Največja stopnja ogrevanja je poleti, ko znaša linearni trend 0,5 °C/desetletje. V spomladanskem času znaša linearni trend povprečne temperature zraka 0,4 °C/desetletje, jeseni 0,2 °C/desetletje, pozimi pa 0,3 °C/desetletje. Poleti se je tako v povprečju ogrelo za 3,2 °C, jeseni za 1,5 °C, pozimi za 1,9 °C, pomladi pa za 2,3 °C (slika 9).

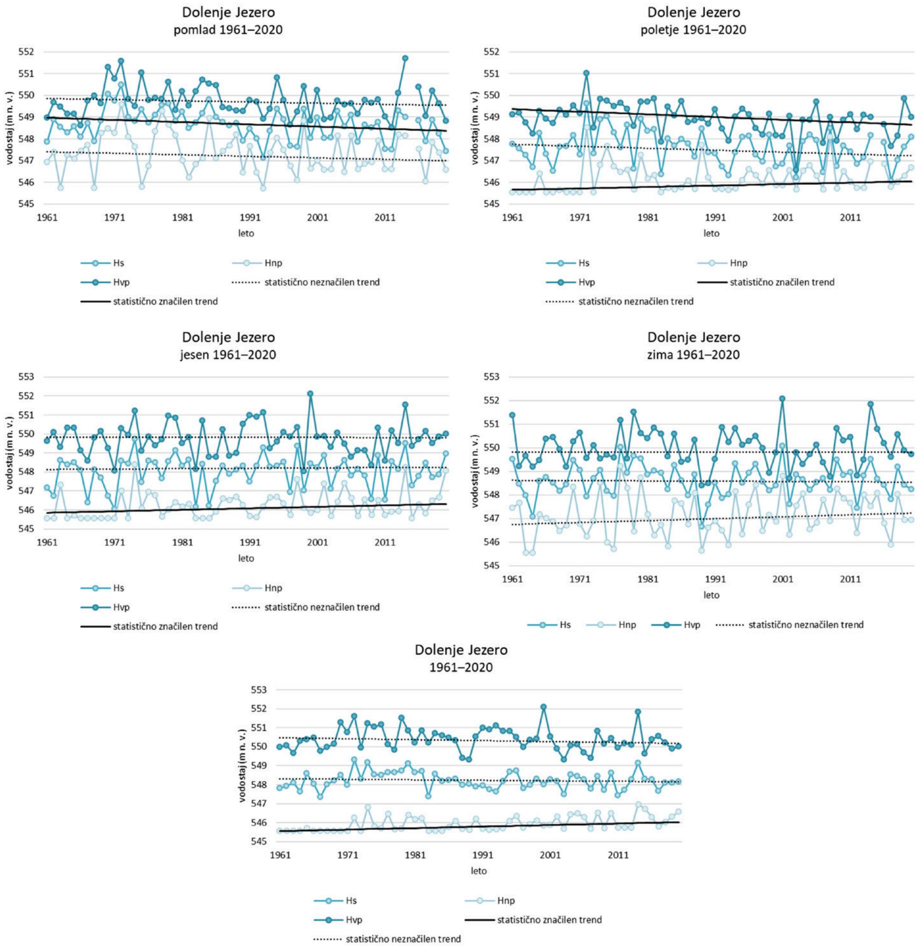
Različni vodostaji (Hnp, Hs in Hvp) so v preučevanem obdobju tako na letni ravni kot ob različnih letnih časih podvrženi različnim trendom in posledičnim spremembam v višini njihove gladine (slika 10, slika 11). Trenda najvišjih (Hvp) in srednjih (Hs) letnih vodostajev Cerkniškega jezera na vodomerni postaji Dolenje Jezero sta bila med letoma 1961 in 2020 negativna in statistično neznačilna, medtem ko je bil trend najnižjih letnih vodostajev (Hnp) pozitiven in statistično značilen (α ≤ 5 %). Glede na enačbo linearnega trenda se je v preučevanem obdobju najbolj zmanjšala višina Hvp (30 cm). Zmanjšanje Hs je znašalo 16 cm, povečanje Hnp pa 48 cm. Pomladi so bili trendi vodostajev negativni, a je bil statistično značilen (α ≤ 5 %) le trend za Hs, čigar zmanjšanje je v preučevanem obdobju znašalo 62 cm, kar je tudi največje zmanjšanje med vsemi sezonskimi Hs. Višina Hnp se je pomladi znižala za 42 cm, višina Hvp pa za 32 cm. V poletnem času sta bila trenda Hvp in Hs negativna, kjer je prvi tudi statistično značilen (α ≤ 5 %), trend Hnp pa pozitiven in ravno tako statistično značilen (α ≤ 5 %). Poleti je najbolj opazno zmanjšanje Hvp za 74 cm (največje zmanjšanje med vsemi sezonskimi Hvp), Hnp se je povečal za 40 cm, Hs pa zmanjšal za 54 cm. Jeseni je bil linearni trend Hs negativen in statistično neznačilen z zmanjšanjem za 12 cm v preučevanem obdobju, pri Hvp pa je bil trend neznaten. Trend jesenskega Hnp je bil pozitiven in statistično značilen (α ≤ 5 %), s povečanjem poletnih najnižjih vodostajev za 47 cm. V zimskem času sta bila trenda Hvp in Hs negativna ter statistično neznačilna, trend Hnp pa je bil pozitiven in prav tako statistično neznačilen. Največja sprememba je pri Hnp (povečanje za 49 cm), Hs se je znižal za 8 cm, Hvp pa je ostal praktično enak.

Slika 9: Časovni potek povprečne temperature zraka v obdobju 1961–2020 na klimatološki postaji Dolenje Jezero.



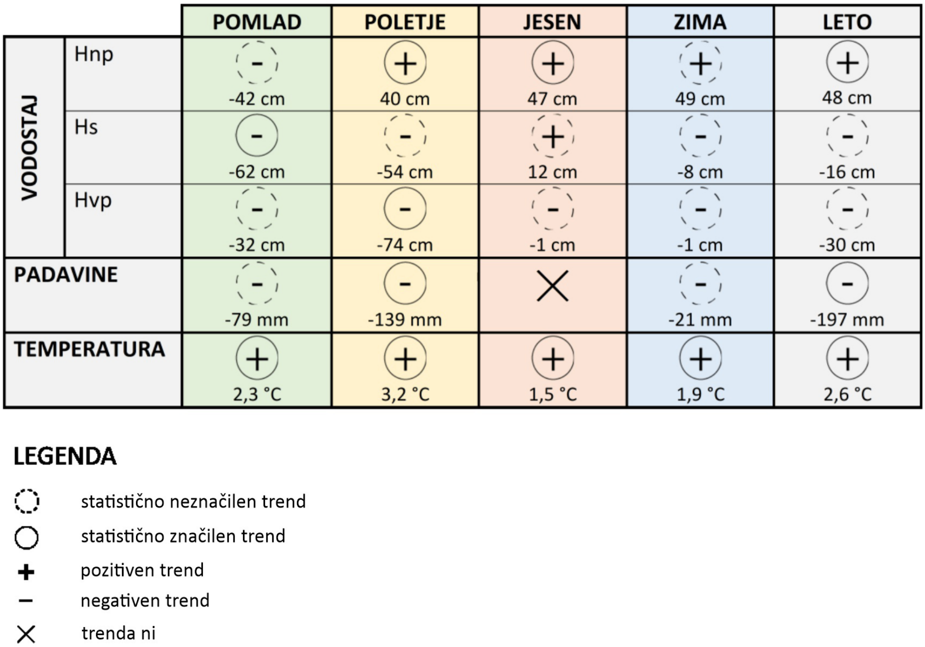
Vir podatkov: ARSO, 2022.

Slika 10: Časovni potek najnižjih, srednjih in najvišjih vodostajev v obdobju 1961–2020 na vodomerni postaji Dolenje Jezero.



Vir podatkov: ARSO, 2022.

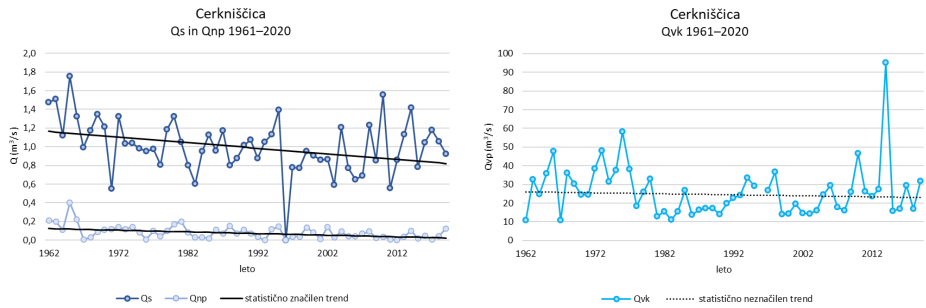
Slika 11: Sintezni prikaz trendov izbranih meteoroloških spremenljivk in vodostajev v obdobju 1961–2020 za padavinsko postajo Cerknica ter klimatološko in vodomerno postajo Dolenje Jezero.



Vir podatkov: ARSO, 2022.

Trendi letnih pretokov na Cerkniščici so bili v obdobju 1961–2020 negativni. Trenda Qnp in Qs sta statistično značilna ($\alpha \leq 5$ %), trend letnega Qvk pa ni statistično značilen. Zmanjšanje Qs je v preučevanem obdobju znašalo 0,32 m^3/s (28 %), zmanjšanje Qvk 3,17 m^3/s (12 %), vrednost Qnp pa se je zmanjšala za 0,09 m^3/s oziroma za 78 % (slika 12).

Slika 12: Časovni potek Qnp, Qs in Qvp v obdobju 1961–2020 na vodomerni postaji Cerknica.



Vir podatkov: ARSO, 2022.

Povezanost med vodostaji in izbranimi meteorološkimi spremenljivkami smo ugotavljali s Spearmanovim koeficientom korelacije (ρ) (preglednica 1). Povezanost med različnimi vodostaji (Hnp, Hs, Hvp) in temperaturo zraka je v večini primerov nizka (ρ je med ±0,20 in ±0,39), v nekaterih primerih celo neznatna (ρ je med ±0,01 in ±0,19), in ima v različnih letnih časih različen predznak. Največja negativna povezanost (srednja) je med poletnima Hs in Hvp s temperaturo zraka (ρ = –0,48 oz. –0,49), srednja povezanost pa je še med letnim Hnp in temperaturo zraka, le da je ta pozitivna (ρ = 0,41). Povezanosti letnih vodostajev s temperaturo zraka so glede na absolutne vrednosti precej različne in imajo tudi različen predznak (–0,30 < ρ < 0,41). Pomladi in poleti so povezanosti negativne in neznatne do srednje (–0,03 < ρ < –0,49), pozimi pozitivne in neznatne do nizke (–0,19 < ρ < 0,24), jeseni pa neznatne ter z različnim predznakom (–0,07 < ρ < 0,08).

Povezanost med različnimi vodostaji (Hnp, Hs, Hvp) in višino padavin je povsod pozitivna ter v povprečju višja od povezanosti med vodostaji in temperaturo zraka. V dobri polovici primerov je vsaj srednja (ρ je med 0,40 in 0,59), od tega v dveh primerih visoka (ρ je med 0,60 in 0,79) ter v enem primeru zelo visoka (ρ > 0,80). Največja povezanost se kaže jeseni med Hvp in višino padavin (ρ = 0,86). Srednja povezanost je med letnim Hvp in višino padavin (ρ = 0,52), med letnima Hs in Hnp ter višino padavin pa nizka (ρ = 0,39) oziroma neznatna (ρ = 0,01). Z izjemo letne ravni ter jeseni je med vsemi vodostaji najbolj izražena povezanost med Hs in višino padavin. Pomladi in poleti je ta srednja (ρ = 0,55 oz. 0,46), jeseni in pozimi pa visoka (ρ = 0,64 oz. 0,63). Neznatna povezanost je le med letnim ter jesenskim Hnp in višino padavin (ρ = 0,01 oz. 0,08).

Preglednica 1: Vrednosti Spearmanovega koeficienta korelacije (ρ) med vodostaji in temperaturo zraka ter višino padavin.

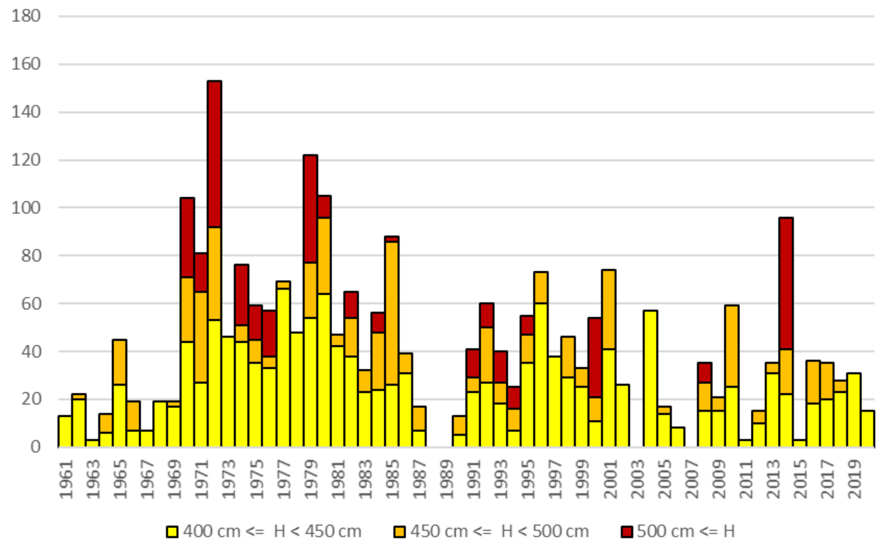
	Temperatura zraka	Višina padavin
Letni Hs	–0,30*	0,39*
Letni Hnp	0,41*	0,01
Letni Hvp	–0,17	0,52*
Pomladni Hs	–0,40*	0,55*
Pomladni Hnp	–0,33*	0,39*
Pomladni Hvp	–0,19	0,45*
Poletni Hs	–0,48*	0,46*
Poletni Hnp	–0,03	0,24*
Poletni Hvp	–0,49*	0,38*
Jesenski Hs	–0,07	0,64*
Jesenski Hnp	0,08	0,08
Jesenski Hvp	–0,05	0,86*
Zimski Hs	0,19	0,63*
Zimski Hnp	0,24*	0,40*
Zimski Hvp	0,21	0,46*

**Povezanost je statistično značilna* ($\alpha \leq 5$ %).

6 RAZPRAVA

Negativen trend srednjih in najvišjih vodostajev ter s tem zmanjšanje letnih Hs (16 cm) in Hvp (0,30 cm) Cerkniškega jezera v obdobju 1961–2020 verjetno lahko pripišemo predvsem 11-odstotnemu zmanjšanju letne količine padavin in porastu povprečne temperature zraka za 2,5 °C ter posledičnemu povečanju izhlapevanja. Slednjo domnevo posredno potrjujejo povezave vodostajev s padavinami in temperaturo, in sicer nizka povezanost med Hs in višino padavin (ρ = 0,39), srednja povezanost med Hvp in višino padavin (ρ = 0,52) ter nizka in neznatna negativna povezanost Hs in Hvp s temperaturo zraka (ρ = –0,30 oz. –0,17). Del znižanja srednjih in najvišjih vodostajev je morda povezan tudi s postopnim odstranjevanjem nekaterih ukrepov, s katerimi so konec šestdesetih let 20. stoletja izvedli poskusne ojezeritve (Kranjc, 1986), na primer odmašitev nekaterih ponorov, odstranitev pregrade na vhodu v Malo Karlovico, znižanje preliva pregrade pri veliki Karlovici, pa tudi obuditev čiščenja in poglabljanja nekaterih strug (Kebe, 2011). Kljub negativnemu trendu Hvp pa velja izpostaviti, da sta bila absolutno najvišja vodostaja dosežena ravno v drugem delu preučevanega obdobja, in sicer leta 2000 (654 cm) ter 2014 (628 cm), ko smo bili priča poplavam na širšem območju Slovenije (ARSO, 2014; Kovačič, Ravbar, 2010). Blatnik s sodelavci (2024), ob upoštevanju nekoliko daljšega niza podatkov (1956–2022), v nasprotju z nami ugotavlja rahel pozitiven trend Hvp. Razhajanje je posledica velike variabilnosti najvišjih letnih vodostajev, kjer lahko že majhne razlike v preučevanem nizu vplivajo na obrat trenda. Omenjena ekstremna vodostaja v letih 2000 in 2014 sovpadata z ugotovitvami o pogostejših in izrazitejših velikih pretokih pri nas kot posledici podnebnih sprememb (Kobold, Dolinar, Frantar, 2012) ter nakazujeta na realno možnost, da bomo v prihodnje na Cerkniškem jezeru, ne glede na trend Hvp, ob izjemni količini padavin lahko imeli pogosteje opravka tudi z izjemno visokimi vodami. Vseeno pa se gledano v splošnem število dni z najvišjimi vodostaji, na primer nad 400, 450 ali 500 cm, tudi če odmislimo obdobje poskusa stalne ojezeritve na prehodu iz šestdesetih v sedemdeseta leta 20. stoletja, na Cerkniškem jezeru zmanjšuje (Slika 13).

Slika 13: Število dni v letu z visokim vodostajem na vodomerni postaji Dolenje Jezero v obdobju 1961–2020.



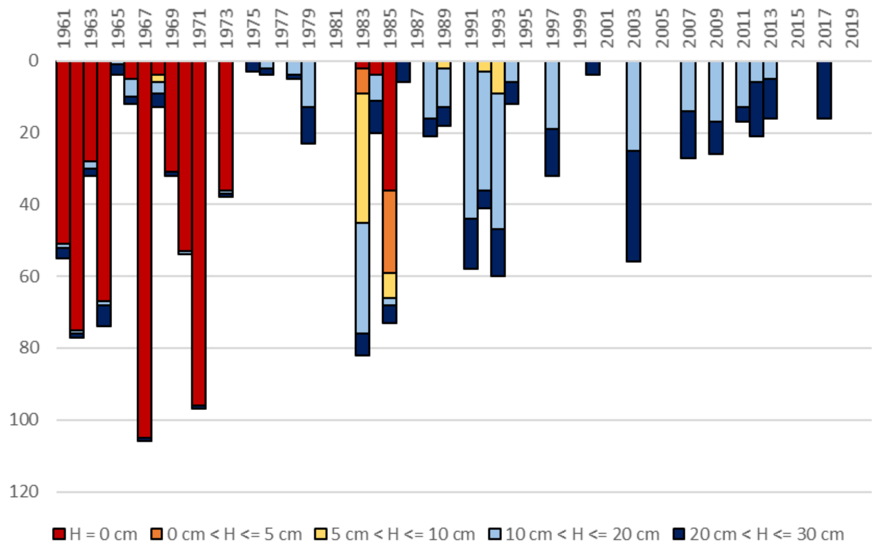
Vir podatkov: ARSO, 2022.

Za razliko od Hs in Hvp je trend Hnp pozitiven in statistično značilen ($\alpha \leq 5$ %), zaradi česar so najnižji letni vodostaji v porastu (povečanje za 48 cm). Kaže se odsotnost povezanosti letnega Hnp z višino padavin ($\rho = 0{,}01$) ter njegova srednja povezanost s temperaturo zraka ($\rho = 0{,}41$), pri čemer ima slednja obraten predznak od pričakovanega. Povečevanje najnižjih letnih vodostajev navkljub manjši količini padavin in višji temperaturi je verjetno pogojeno z antropogenimi posegi v odtok.

V tem primeru ima odločujoč vpliv jez pri Rešetu, za katerim zadržujejo vodo ob nizkih vodostajih z namenom ohranjanja ribjega življa. Vsi registrirani letni Hnp so bili namreč v preučevanem obdobju nižji od preliva jezu (150 cm na vodomerni postaji Dolenje Jezero). Jez pa je bil v preučevanem obdobju ob visoki vodi večkrat poškodovan, obnovljen ter v želji po večji količini zadržane vode tudi nadvišan (Schein, 2020; Tratnik, 2023), kar bi lahko pojasnilo naraščajoč trend Hnp. Zadrževanje vode ob najnižjih vodostajih pa verjetno ni edini razlog za povečanje Hnp. Domnevamo, da je slednji fenomen deloma tudi odraz načina merjenja vodostaja, ki na vodomerni postaji Dolenje Jezero ni naklonjen preučevanju najnižjih vrednosti. Pogled na priložen grafikon (slika 14) razkrije, da so od začetka delovanja postaje do leta 1974 zelo pogosto zabeležene vrednosti H = 0 cm (absolutna nadmorska višina 545,56 m), kar za kasnejše obdobje (z nekaj izjemami v začetku osemdesetih let 20. stoletja) ni več značilno. Od leta 1974 naprej se vse bolj poredko pojavljajo tudi vodostaji nižji od na primer 5, 10, 20 ali 30 cm, čeprav iz prakse vemo, da Stržen v sušnih obdobjih lahko presahne. Kot primer navajamo izjemno suho leto 2022, ko je bil kljub odsotnosti vode najnižji vodostaj uradno registriran pri H = 30 cm (ARSO, 2022), saj je bila v času meritve vodomerna letev s koto 0 vkopana v sediment na dnu struge (slika 15). Glede na veliko število registriranih vrednosti H = 0 cm v začetnem delu preučevanega obdobja je možno, da je bilo dno struge tedaj nižje in zato vodomerna letev s koto 0 ni bila vkopana v sediment. Povsem možno pa je tudi, da je opazovalec pred letom 1974 (takrat so namreč uvedli zvezni način beleženja vodostaja z limnigrafom) ob odsotnosti vode v strugi, ne glede na morebitno vkopanost vodomerne letve s koto 0 v sediment, vodostaj registriral pri H = 0 cm, kar zaradi samodejne registracije v kasnejšem obdobju ni bilo več mogoče. Uradne evidence o načinu registracije najnižjih vodostajev do leta 1974 ter o vkopanosti kote 0 v sediment ne obstajajo, zaradi česar se trenda letnega Hnp verjetno niti ne da zanesljivo interpretirati.

Pretočni podatki za edini večji nekraški dotok na Cerkniško polje – Cerkniščico – na vodomerni postaji Cerknica v enakem obdobju (1961–2020) glede na enačbo linearnega trenda kažejo na zmanjšanje srednjega letnega pretoka (Qs) in največjih letnih pretokov (Qvk) za 28 % oziroma 12 %, kar se sklada s spremembami Hs in Hvp Stržena na vodomerni postaji Dolenje Jezero. Za razliko od Hnp, ki se je v preučevanem obdobju povečal, pa so se na Cerkniščici najnižji letni pretoki (Qnp) zmanjšali, in to kar za 78 %. Slednje dejstvo je dodaten posredni dokaz, da povečanje najmanjših vodostajev Cerkniškega jezera ne more biti podnebno pogojeno, temveč je v ozadju drug dejavnik – najverjetneje antropogeni posegi v odtok.

Slika 14: Število dni z nizkim vodostajem na vodomerni postaji Dolenje Jezero v obdobju 1961–2020.



Vir podatkov: ARSO, 2022.

Pomladni Hs, Hnp in Hvp Cerkniškega jezera se zmanjšujejo (upad za 62 cm, 42 cm in 32 cm) skladno z vse manjšo spomladansko količino padavin (zmanjšanje za 20 %) in vse višjimi temperaturami (povečanje za 2,3 °C), ki vplivajo na večje izhlapevanje. Slednje se odraža tudi v srednji povezanosti med pomladnim Hs, Hnp in Hvp s padavinami ($0{,}39 < \rho < 0{,}55$) ter majhni negativni povezanosti s temperaturo ($-0{,}40 < \rho < -0{,}19$). Znaten upad pomladanskih vodostajev je razviden tudi ob primerjavi marčevskih, aprilskih in majskih povprečnih vodostajev obdobij 1961–1990 in 1991–2020 (slika 3). Zniževanje spomladanskih vodostajev verjetno lahko deloma pripišemo tudi manjšemu vplivu snežnega zadržka. Pri tem gre za kombinacijo manjšega deleža zimskih snežnih padavin, ki v določeni meri odtečejo šele spomladi, kot tudi vse manj izdatnih zimskih padavin (zmanjšanje za 6 %). Manjši delež snežnih padavin se kaže v 20-odstotnem zmanjšanju količine novozapadlega snega, 57-odstotno zmanjšanje povprečne višine snežne odeje pa nakazuje na hitrejše taljenje snega, ki posledično tudi s krajšim časovnim zamikom preide v odtok. Slednje ugotovitve se ujemajo z ugotovitvami o višini snežne odeje pri nas, saj se je ta v obdobju 1961–2011 na ravni države znižala za okoli 16 % na desetletje (Vertačnik, Bertalanič, 2017), slabitev snežnega zadržka pa se na številnih vodotokih kaže kot zmanjšanje spomladanskih pretokov (Frantar, Hrvatin, 2005). Pri vrednotenju vpliva snežnih padavin na vodostaj Cerkniškega jezera je treba izpostaviti, da smo zaradi odsotnosti višje ležečih padavinskih postaj analize izvedli na nižinski padavinski postaji Cerknica, ki ni reprezentativna za celotno pojezerje Cerkniškega jezera, saj se sneg v večjih količinah pojavlja šele v višjih legah.

Slika 15: Suha struga Stržena poleti 2022 (foto: T. Trobec).

Poletni Hs je v preučevanem obdobju upadel za 54 cm, kar je drugo največje zmanjšanje Hs za pomladanskim, poletni Hvp pa je upadel za 74 cm, kar je največje zmanjšanje med sezonskimi Hvp. Znaten upad poletnih vodostajev je razviden tudi ob primerjavi junijskih, julijskih in avgustovskih povprečnih vodostajev obdobij 1961–1990 in 1991–2020 (slika 3). Tolikšno zmanjšanje poletnih Hvp in Hs verjetno lahko pripišemo povečanemu izhlapevanju, ki je posledica segrevanja ozračja (poletno povečanje temperature za 3,2 °C je največje med vsemi letnimi časi), ter izrazito manjši količini padavin, ki je najbolj upadla ravno poleti (30 %). Izraženo domnevo potrjuje tudi srednja povezanost poletnih Hs in Hvp z višino padavin (ρ = 0,46 oz. 0,38) in s temperaturo zraka (ρ = –0,48 oz. –0,49), ki ima v tem letnem času pričakovan, negativen predznak. Kljub velikemu upadu poletnih padavin in višjim temperaturam pa je trend poletnih Hnp pozitiven (povečanje za 40 cm), zelo podoben pa je tudi trend jesenskih Hnp (povečanje za 47 cm). Glede na to, da se v preučevanem obdobju letni Hnp v 87 % pojavlja poleti ali jeseni (občasno tudi v obeh letnih časih hkrati), je iz že omenjenih metodoloških negotovosti pri registraciji najnižjih vodostajev (tako kot pri letnih Hnp) nezanesljiva tudi interpretacija trenda poletnih in jesenskih Hnp. Vseeno pa je pozitiven trend poletnih in jesenskih Hnp verjetno možno vsaj v določeni meri povezati z že omenjenim umetnim zadrževanjem vode ob nizkih vodostajih za jezom pri Rešetu. Velika večina poletnih in jesenskih Hnp (90 % oz. 88 %) je bila namreč v posameznih letih nižja od 150 cm na vodomerni postaji Dolenje Jezero, ki ustreza višini preliva nasipa. Domnevo o vplivu umetnega zadrževanja vode na najnižje poletne in jesenske vodostaje posredno potrjujejo tudi neznatna oziroma nizka povezanost poletnih in jesenskih Hnp z višino padavin (ρ = 0,24 oz. 0,08) ter neznatna povezanost s temperaturo zraka (ρ = –0,03 oz. 0,08), ki ima jeseni poleg tega obraten predznak od pričakovanega. Glede na linearni trend so bile jesenske spremembe Hs v preučevanem obdobju razmeroma majhne (povečanje za 12 cm), Hvp pa je ostal praktično enak. Majhne spremembe vodostajev so verjetno posledica neznatnih sprememb v jesenski količini padavin (povečanje za 0,5 %) ter sorazmerno skromnega povečanja jesenskih temperatur (povečanje za 1,5 °C; najmanj med vsemi letnimi časi). Domnevo posredno potrjuje tudi visoka do zelo visoka povezanost jesenskih Hs in Hvp s padavinami (ρ = 0,64 oz. 0,86), medtem ko je povezanost s temperaturo neznatna.

Pozimi je stanje glede trendov pri vodostajih podobno jesenskemu, saj se je zimski Hnp povečal (49 cm), Hs in Hvp pa nista bila podvržena večjim spremembam. Hs se je nekoliko zmanjšal (8 cm), medtem ko je Hvp ostal praktično enak. Na majhno spremembo povprečnega zimskega vodostaja kažejo tudi skoraj identične vrednosti decembrskih, januarskih in februarskih povprečnih vodostajev na vodomerni postaji Dolenje Jezero ob primerjavi obdobij 1961–1990 in 1991–2020 (slika 3). Majhnim spremembam v vodostajih verjetno botruje relativno majhna sprememba v zimski količini padavin (zmanjšanje za 6 %), kar se odraža tudi v srednji do visoki povezanosti zimskih Hs in Hvp s padavinami (ρ = 0,63 oz. 0,46). V preučevanem obdobju je bilo znatno tudi povečanje zimske temperature (1,9 °C), kar pa v tem letnem času zaradi siceršnjih nizkih temperatur nima pomembnega vpliva na povečano izhlapevanje in s tem na manjši odtok. Slednje se kaže tudi v povezanosti zimskih Hnp, Hs in Hvp s temperaturo ($0,19 < \rho < 0,23$), ki ima pozitiven predznak. Zimski Hs se na podobni ravni ohranja morda tudi zato, ker je upad zimskih padavin verjetno v določeni meri nadomeščen z njihovim hitrejšim odtokom, kot posledica že omenjenega slabenja vpliva snežnega zadržka (manjši delež zimskih snežnih padavin in hitrejše taljenje ter odtok novozapadlega snega zaradi višje temperature). Zmanjšan vpliv snežnega zadržka pa je verjetno tudi vzrok za povečanje zimskega Hnp.

Zgoraj je predstavljen vertikalni pregled sprememb analiziranih meteoroloških in hidroloških spremenljivk po letnih časih, v nadaljevanju pa podajamo še horizontalni pregled sprememb posameznih vodostajev (Hnp, Hs, Hvp) Cerkniškega jezera preko leta. Srednji vodostaj (Hs) se je v preučevanem obdobju 1961–2020 tako na letni ravni kot tudi na ravni letnih časov (razen jeseni, ko je prisotno majhno povečanje) zmanjšal, njegove spremembe pa sovpadajo z manjšo količino padavin in višjo temperaturo ter večjim izhlapevanjem. Zmanjšanje Hs je največje pomladi in poleti, ko so hkrati največje tudi spremembe v količini padavin in temperaturi. Upad je (razen pozimi in jeseni, ko praktično ni bilo sprememb) značilen tudi za največje vodostaje (Hvp). Tudi ti so se zaradi manjše količine padavin in višje temperature najbolj znižali pomladi in poleti. Znižanje pomladnih in poletnih Hs in Hvp pa je vsaj v manjši meri morda povezano tudi z že omenjeno postopno odstranitvijo nekaterih ukrepov, s katerimi so konec šestdesetih let 20. stoletja izvedli poskusno ojezeritev (Kebe, 2011; Kranjc, 1986). Za najnižje vodostaje (Hnp) je po drugi strani (razen pomladi) značilno povečanje, kar je v nasprotju z zaznanimi spremembami v količini padavin in temperaturi. Povečanje Hnp na letni ravni, kot tudi poleti in jeseni, ko so vodostaji praviloma najnižji, je (kolikor to dopušča že omenjena vprašljiva metodologija registracije najnižjih vodostajev) moč pojasniti z že omenjenim umetnim zadrževanjem vode ob nizkih vodostajih za jezom pri Rešetu (Schein, 2020; Tratnik, 2023). Zimski in pomladni Hnp pa so v splošnem višji od poletnih in jesenskih ter približno v polovici let preučevanega obdobja presegajo vrednost 150 cm na vodomerni postaji Dolenje Jezero, kar pomeni, da ima zadrževanje vode za jezom pri Rešetu nanje sorazmerno manjši vpliv kot poleti in jeseni. V dobri tretjini primerov presegajo tudi vrednost 200 cm, ko se vode Cerkniškega jezera prek nasipa Brkinov laz začno v večjih količinah prelivati proti Jamskemu zalivu (Habič, 1974; Tratnik, 2023) in tako znaten del vode prične ponirati v Karlovicah ter številnih drugih ponorih in ponikvah dolvodno od Rešeta. Glede na podobno razporeditev pojavljanja zimskih in pomladnih Hnp v odnosu do prelivnih višin jezu pri Rešetu in nasipa Brkinov laz sklepamo, da je vpliv antropogenih posegov na Hnp v obeh letnih časih podoben in je razlog za tolikšno razliko v trendu verjetno v večji meri posledica podnebnih sprememb. Zdi se, da je povečanje zimskih Hnp (49 cm) in hkratno zmanjšanje pomladnih Hnp (42 cm) morda posledica že omenjenega slabenja vpliva snežnega zadržka. Dodaten zimski dotok v jezero s tega naslova sicer ne vpliva na povečanje zimskega Hs, možno pa je, da v zapletenem kraškem sistemu napajanja Cerkniškega jezera vseeno vpliva na povečanje najnižjih vodostajev. Manko pomladnega dotoka v jezero zaradi manjšega vpliva snežnega zadržka pa je verjetno le še dodaten dejavnik že tako izdatnega znižanja pomladnih vodostajev (kot posledice že omenjene manjše količine padavin in višjih temperatur), kar se odraža tudi na poletnem Hnp.

Povezanost med letnimi in sezonskimi vodostaji (Hnp, Hs in Hvp) ter višino padavin oziroma temperaturo zraka je, še posebej pri temperaturi, kjer je med letom in med različnimi vodostaji nekonsistenten tudi predznak povezanosti, v splošnem razmeroma nizka. Vsaj srednja povezanost ($0,40 < \rho < 0,59$) je namreč izražena v tretjini primerov (10), visoka ($0,60 < \rho < 0,79$) v dveh primerih, zelo visoka ($\rho > 0,80$) pa le v enem primeru. Na nižjo povezanost verjetno vpliva več dejavnikov, ki so naravno in antropogeno pogojeni. Eden izmed njih je zagotovo kraški zadržek, zaradi katerega se vodostaj Cerkniškega jezera na padavine odziva z določenim zamikom, voda pa v jezeru ostane visoko še dolgo po njih. Blatnik in sodelavci (2024) so za obdobje 1954–2022 denimo ugotovili največjo povezanost med dnevnim vodostajem Cerkniškega jezera in vsoto predhodnih 45-dnevnih efektivnih padavin (padavine zmanjšane za evapotranspiracijo). Drugi razlog je metodološke narave, saj smo v pričujoči raziskavi izhajali iz realnih in ne efektivnih padavin. Tretji razlog pa so številni antropogeni posegi v odtok, ki so imeli v posameznih obdobjih pri različni višini vode različen vpliv (Blatnik in sod., 2024; Habič, 1974). Višja povezanost med vodostaji (Hnp, Hs in Hvp) in višino padavin v primerjavi s povezanostjo med vodostaji in temperaturo zraka tako na letni kot na sezonski ravni kaže na v splošnem večji vpliv padavin na vodostaj jezera. Nekoliko večja negativna povezanost med vodostaji in temperaturo zraka (ki pa je še vedno manjša od povezanosti med vodostaji in višino padavin) se kaže le pomladi in poleti, kar nakazuje na močneje izražen vpliv temperature na vodostaje predvsem v toplejšem delu leta, ko je v rastni dobi tudi izhlapevanje intenzivnejše.

7 SKLEP

Spreminjanje podnebja vpliva na spremenjen pretočni režim vodotokov in vodostaj nekaterih jezer. Za preučevanje vplivov spreminjanja podnebja smo si izbrali presihajoče Cerkniško jezero, ki je zaradi svojega kraškega značaja še toliko bolj občutljivo za vsakršne (tudi podnebne) spremembe. V prispevku smo preučili letne in sezonske spremembe vodostaja Cerkniškega jezera med letoma 1961 in 2020 ter poskušali najti povezave z lokalnim spreminjanjem podnebja. V ta namen smo na območju Cerkniškega polja in njegovega ožjega vodozbirnega zaledja analizirali letne in sezonske spremembe količine padavin, snežne odeje in temperature zraka, spremembe najnižjega (Hnp), srednjega (Hs) in najvišjega (Hvp) vodostaja Cerkniškega jezera ter trende najmanjših (Qnp), srednjih (Qs) in največjih (Qvk) pretokov Cerkniščice.

Analize meteoroloških in hidroloških spremenljivk nakazujejo na znatno spremenjeno vodno bilanco Cerkniškega jezera v preučevanem obdobju. Količina padavin se je na območju Cerkniškega polja zmanjšala za 11 % oziroma slabih 200 mm. Zmanjšanje je bilo najbolj izrazito poleti (30 %) in pomladi (20 %). Količina novozapadlega snega se je zmanjšala za 20 %, povprečna višina snežne odeje pa za 57 %. Temperatura zraka je narasla za 2,5 °C. Najbolj se je ogrelo poleti (3,2 °C) in pomladi (2,3 °C). V Cerkniškem jezeru je skozi leta prisotne vse manj vode, kar se kaže v zmanjšanju srednjega letnega vodostaja (Hs) za 16 cm. Glede na enačbo linearnega trenda se je najvišji vodostaj (Hvp) zmanjšal za 30 cm, najnižji (Hnp) pa povečal za 48 cm. Upad Hs in Hvp je povezan predvsem z nižjo količino padavin in višjo temperaturo zraka ter posledičnim povečanjem izhlapevanja, v manjši meri pa morda tudi s postopno odstranitvijo nekaterih antropogenih ukrepov za zadrževanje vode s konca šestdesetih let, s katerimi so tedaj zmanjšali odtok pri srednjih in visokih vodah ter podaljšali poplave. Povečanje Hnp pa je (kolikor to dopušča nezanesljivost podatkov ob najnižjih vodostajih) verjetno možno povezati z umetnim zadrževanjem vode v jezeru za večkrat obnovljenim in nadvišanim jezom v Rešetu v času najnižjih vodostajev, ki je namenjeno ohranjanju ribjih populacij.

Pomladni Hs, Hnp in Hvp Cerkniškega jezera so se izrazito zmanjšali (upad za 62 cm, 42 cm in 32 cm). Poleti je značilno zmanjšanje Hvp (74 cm) in Hs (54 cm), Hnp pa se je povečal za 40 cm. Jesenske spremembe so bolj kot ne omejene na povečanje Hnp za 47 cm, medtem ko so spremembe pri Hs razmeroma majhne (povečanje za 12 cm), Hvp pa je ostal praktično enak. Podobno je tudi pozimi, ko se je Hnp povečal za 49 cm, Hs in Hvp pa se skorajda nista spremenila. Sezonske spremembe vodostaja Cerkniškega jezera lahko v primeru Hs in Hvp, ki se znižujeta predvsem pomladi in poleti, v znatni meri povežemo z višjimi sezonskimi temperaturami in povečanim izhlapevanjem ter manjšo sezonsko količino padavin, deloma pa morda tudi z omenjeno postopno odstranitvijo nekaterih antropogenih ukrepov za zadrževanje visokih in srednjih voda s konca šestdesetih let. Za najnižje vodostaje (Hnp) je podobno kot na letni tudi na sezonski ravni (razen pomladi) značilno povečanje, kar je v nasprotju z zaznanimi spremembami v količini padavin in temperaturi. Povečanje poletnih in jesenskih Hnp (ki so navadno tudi najnižji vodostaji v letu) je tako kot v primeru letnih Hnp (kolikor to dopušča nezanesljivost podatkov ob najnižjih vodostajih) moč povezati z umetnim zadrževanjem vode za jezom v Rešetu v času najnižjih vodostajev. Spremembe pri zimskih in pomladnih Hnp (ki so znatno višji od poletnih in jesenskih Hnp in zato zadrževanju vode ob nizkih vodostajih podvrženi v manjši meri) pa verjetno lahko povežemo s podnebnimi spremembami in posledično vse manj izraženim snežnim zadržkom.

Kljub razmeroma nizki povezanosti letnih in sezonskih Hnp, Hs in Hvp z višino padavin in temperaturo zraka, kjer kvečjemu pri tretjini povezav lahko govorimo o vsaj srednji povezanosti ($0{,}40 < \rho < 0{,}59$), lahko zaključimo, da imajo ne glede na to podnebne spremembe odločujoč vpliv na spreminjanje vodostaja jezera – zlasti v primeru srednjega vodostaja (Hs) in največjih vodostajev (Hvp). Nizki vodostaji (Hnp) pa so bolj kot s podnebnimi spremembami pogojeni z antropogenimi posegi v odtok. Slednjih je bilo v preteklosti veliko in so bili včasih usmerjeni v pospeševanje odtoka, drugič v zadrževanje vode v jezeru. Njihov vpliv na vodostaj je zaradi pogosto nasprotujočih si učinkov, izmenjevanja vodnatih in sušnejših let pa tudi zaradi same presihajoče narave jezera praktično nemogoče povsem objektivno ovrednotiti.

Literatura in viri

Andjelov, M., Frantar, P., Pavlič, U., Rman, N., Souvent, P., 2021. Količinsko stanje podzemnih voda v Sloveniji. Ljubljana: ARSO.

ARSO [Agencija Republike Slovenije za okolje], 2014. Hidrološko poročilo o poplavah v dneh od 8. do 27. februarja 2014. URL: https://www.arso.gov.si/vode/poro%c4%8dila%20in%20publikacije/Porocilo%20poplave%208-27%20feb%202014%20splet.pdf (citirano 4. 8. 2022).

ARSO [Agencija Republike Slovenije za okolje], 2022. Meteorološki in hidrološki podatki. URL: https://www.arso.gov.si/ (citirano 16. 8. 2022)

Bertalanič, R. in sod., 2018: Ocena podnebnih sprememb v Sloveniji do konca 21. stoletja. Sintezno poročilo – prvi del. Ljubljana: ARSO.

Bidovec, M., 2007. Pretekli posegi na Cerkniškem jezeru. Novice Notranjskega regijskega parka, 1, 2, str. 2–7.

Blatnik, M., Gabrovšek, F., Ravbar, N., Frantar, P., Gill, L. W., 2024. Assessment of climatic and anthropogenic effects on flood dynamics in the Cerkniško Polje (SW Slovenia) based on a 70-year observation dataset. Journal of Hydrology: Regional Studies, 51 (*v tisku*).

Bonacci, O., 1987. Man's influence on the water regime in the karst terrains. V: Bonacci, O. (ur.). Karst hydrology: with special reference to the Dinaric karst. Berlin: Springer, str. 150–173.

Bonacci, O., 2014. Ecohydrology of karst poljes and their vulnerability. V: Sackl P., Durst, R., Kotrošan, D., Stumberger, B. (ur.). Dinaric karst poljes – floods for life. Radolfzell: EuroNatur, str. 25–37.

Frantar, P. (ur.), 2008. Vodna bilanca Slovenije 1971–2000. Ljubljana: Ministrstvo za okolje in prostor, Agencija Republike Slovenije za okolje.

Frantar, P., Hrvatin, M., 2005. Pretočni režimi v Sloveniji med letoma 1971 in 2000. Geografski vestnik, 77, 2, str. 115–127.

Gaberščik, A., Grašič, M., Abram, D., Zelnik, I., 2020. Water level fluctuations and air temperatures affect common reed habitus and productivity in an intermittent wetland ecosystem. Water 2020, 12, 10, str. 2806.

Gaberščik, A., Urbanc-Berčič, O., Kržič, N., Kosi, G., Brancelj, A., 2003. The intermittent Lake Cerknica: Various faces of the same ecosystem. Lakes & Reservoirs Research & Management, 8, 3–4, str. 159–168.

Gams, I. 1965. Aperçu sur l'hydrologie du karst Slovene et sus communications souterraines. Naše jame 7, 1–2, str. 51–60.
Gams, I. 1974. Kras v Sloveniji v prostoru in času. Ljubljana: Založba ZRC, ZRC SAZU.
George, G. (ur.), 2010. The impact of climate change on European lakes. Dordrecht, New York: Springer.
Habič, P., 1974. Tesnenje požiralnikov in presihanje Cerkniškega jezera. Acta carsologica, 6, str. 35–56.
Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Archfield, S. A., Gilroy, E. J., 2020. Statistical methods in water resources. Reston: U.S. Geological Survey. DOI: 10.3133/tm4a3.
Hrvatin, M., Zorn, M., 2020. Climate and hydrological changes in Slovenia's mountain regions between 1961 and 2018. Economic- and Ecohistory, 16, 1, str. 201–218.
IPCC, 2022. Climate Change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (ur.). Cambridge University Press (*v tisku*).
Kayastha, M. B., Ye, X., Huang, C., Xue, P., 2022. Future rise of the Great Lakes water levels under climate change. Journal of Hydrology, 612, B, str. 128–205.
Kebe, J., 2011. Cerkniško jezero in ljudje ob njem. Koper: Ognjišče.
Kobold, M., Dolinar, M., Frantar, P., 2012. Spremembe vodnega režima zaradi podnebnih sprememb in drugih antropogenih vplivov. I. kongres o vodah Slovenije, str. 7–22.
Kolbezen, M., 1998. Hidrografija. V: Gams, I., Vrišer, I. (ur.). Geografija Slovenije. Ljubljana: Slovenska matica, str. 139–172.
Kolbezen, M., Pristov, J., 1998. Površinski vodotoki in vodna bilanca Slovenije. Ljubljana: Ministrstvo za okolje in prostor, Hidrometeorološki zavod Republike Slovenije.
Kovačič, G., 2009. Hidrologija kraškega izvira Malenščica in njegovega hidrografskega zaledja. Doktorska disertacija. Koper: Univerza na Primorskem, Fakulteta za humanistične študije, 329 str.
Kovačič, G., 2010. An attempt towards an assessment of the Cerknica polje water balance. Acta carsologica, 39, 1, str. 39–50.
Kovačič, G., 2016. Trendi pretokov rek jadranskega povodja v Sloveniji brez Posočja. Geografski vestnik, 88, 2, str. 9–29.
Kovačič, G., Ravbar, N., 2010. Extreme hydrological events in karst areas of Slovenia, the case of the Unica River basin. Geodinamica Acta, 23, 1–3, str. 89–100.
Kranjc, A., 1986. Cerkniško jezero in njegove poplave. Acta geographica, 25, str. 75–123.
Kranjc, A., 2005. Kako nastaja in izginja Cerkniško jezero? »Jezero, ki izginja« – monografija o Cerkniškem jezeru. Kras: revija o Krasu in krasu, o ljudeh in njihovem ustvarjanju 70, str. 12–17.

Lenters, J. D., Kratz, T. K., Bowser, C. J., 2005. Effects of climate variability on lake evaporation: Results from a long-term energy budget study of Sparkling Lake, northern Wisconsin (USA), 308, 1–4, str. 168–195.

Life Stržen. 2019. URL: http://life.notranjski-park.si/sl/ (citirano 14. 10. 2019).

Lukan, A., 2017. Razvoj turizma v okolici Cerkniškega jezera. Ljubljana: Ekonomska fakulteta. URL: http://www.cek.ef.uni-lj.si/vps_diplome/lukan744.pdf (citirano 15. 9. 2022).

Makesens-application for trend calculation. 2021. URL: https://en.ilmatieteenlaitos.fi/makesens (citirano 13. 5. 2021).

Mayaud, C., Gabrovšek, F., Blatnik, M., Kogovšek, B., Petrič, M., Ravbar, N., 2019. Understanding flooding in poljes: A modelling perspective. Journal of Hydrology, 575, str. 874–889.

Miklič, S., 2021. Spreminjanje vodostaja Cerkniškega jezera v obdobju 1958–2019. Magistrsko delo. Ljubljana: Oddelek za Geografijo, Filozofska fakulteta, Univerza v Ljubljani.

Morrissey, P., Nolan, P., McCormack, T., Johnston, P., Naughton, O., Bhatnagar, S., Gill, L., 2021. Impacts of climate change on groundwater flooding and ecohydrology in lowland karst. Hydrology and Earth System Sciences, 25, str. 1923–1941. DOI: 10.5194/hess-25-1923-2021.

Občina Cerknica. URL: https://www.stat.si/obcine/sl/Municip/Index/18 (citirano 15. 9. 2022).

Ogrin, D., 1996. Podnebni tipi v Sloveniji. Geografski vestnik, 68, str. 39–56.

Perko, D., Orožen Adamič, M., (ur.), 1998. Slovenija. Pokrajine in ljudje. Ljubljana: Mladinska knjiga.

Petrič, M., Ravbar, N., Gostinčar, P., Krsnik, P., Gacin, M., 2020. Vzpostavitev prosto dostopne GIS zbirke rezultatov sledenj toka podzemne vode in možnosti njene uporabe. Geologija, 63, 2, str. 203–220.

Pravilnik za obratovanje in vzdrževanje zapornice Nova Karlovica na Cerkniškem polju. 2014. URL: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiRqeGSpNqCAxVXhP0HHSUPBswQFnoECBMQAQ&url=https%3A%2F%2Frdcerknica.si%2Fwp-content%2Fuploads%2F2021%2F12%2FPRAVILNIK-ZA-OBRATOVANJE-IN-VZDRZEVANJE-NOVA-KARLOVICA.pdf&usg=AOvVaw0Ru4c8SYzdPLsmEZSo9LwD&opi=89978449 (citirano, 22. 11. 2022).

Pustovrh Benda, M., 2015. Prikaz stanja prostora za območje občine Cerknica. URL: https://cerknica.eobcina.si/files/other/acts/31/9528Prikaz%20stanja%20prostora%202.pdf (citirano 19. 9. 2022).

Ravbar, N., Mayaud., C., Blatnik, M., Petrič, M. 2021: Determination of inundation areas within karst poljes and intermittent lakes for the purposes of ephemeral flood mapping. Hydrogeology Journal, 29, str. 213–228. DOI: 0.1007/s10040-020-02268-x.

Schein, T., 2020. Posegi na Cerkniškem jezeru (osebni vir, 8. 10. 2020). Cerknica.
Smrekar, A. 2000: Cerkniško polje kot primer poseljenega kraškega ranljivega območja. Geographica Slovenica, 33, 1, str. 117–156.
Spearmanov koeficient korelacije. URL: https://www.statistik.si/spearmanov-koeficient/ (citirano 12. 10. 2022).
Stepišnik, U., 2020. Kraška polja v Sloveniji. Dela, 53, str. 23–43. DOI: 10.4312/dela.53.23-43.
Stepišnik, U., Ilc Klun, M., Repe, B., 2017. Vrednotenje izobraževalnega potenciala geodiverzitete na primeru Cerkniškega polja. Dela, 47, str. 5–21.
SURS [Statistični urad Republike Slovenije], 2022. Prebivalstvo. URL: https://pxweb.stat.si/SiStat/sl/Podrocja/Index/100/prebivalstvo (citirano 15. 9. 2022).
Torabi Haghigi, A., Kløve, B., 2015. A sensitivity analysis of lake water level response to changes in climate and river regimes. Limnologica, 51, str. 118–130.
Tratnik, D., 2023. Posegi na Cerkniškem jezeru (osebni vir, 22. 11. 2023). Cerknica.
Trobec, T., 2022. Vpliv podnebnih sprememb na vode v Sloveniji. Geomix, 29, 2, str. 37–40.
Turk, J., Pipan, T., 2009. Cerkniško polje. URL: http://www.dedi.si/dediscina/9-cerknisko-polje (citirano 18. 2. 2022).
Van der Kamp, G., Keir, D., Evans, M. S., 2008. Long-term water level changes in closed-basin lakes of the Canadian prairies. Cannadian Water Resources Journal, 33, str. 23–38.
Vertačnik, G., Bertalanič, R., 2017. Podnebna spremenljivost Slovenije v obdobju 1961-2011. Značilnosti podnebja v Sloveniji. Ljubljana: Agencija Republike Slovenije za okolje .
Vincent, W. F., 2009. Effects of climate change on lakes. V: Likens, G. E. (ur.). Encyclopedia of Inland Waters. Elsevier, str. 55–60.
Wrzesiński, D., Ptak, M., 2016. Water level changes in Polish lake during 1976–2010. Journal of Geographical Sciences, 26, str. 83–101. DOI: 10.1007/s11442-016-1256-5.
Zhelezov, G., Varbanov, M., Germ, M., Gaberscik, A. 2011. Hydrological characteristics and related ecosystem services of Srebarna and Cerknica lakes. Problems of geography, 1–2, str. 107–118.

Stanka Mikič*, Tajan Trobec**

SEASONAL CHANGES IN THE CERKNICA LAKE LEVEL DURING THE PERIOD 1961–2020

Izvirni znanstveni članek
COBISS 1.01
DOI: 10.4312/dela.59.91-150

Abstract

In this article, we analyse the annual changes in the minimum (Hnp), mean (Hs) and maximum (Hvp) water levels of Cerknica Lake in the period 1961–2020 and try to relate them to changes in the local climate. Lower precipitation, higher temperatures and the resulting higher evaporation as well as a reduced influence of snow retention are reflected in the changing discharge from the lake basin, which is a cause of a decrease in annual, spring and summer Hs and Hvp, while winter and fall Hs and Hvp have remained at a similar level. On the other hand, Hnp increases, except in spring, which is on an annual basis, in summer and fall (as far as the unreliability of data at the lowest water levels allows) probably due to artificial retention of water in the lake, and in winter and spring due to climate change.

Keywords: hydrogeography, climate change, changing water levels, lake water regime, Cerknica Lake, the Notranjska valley system, Dinaric karst

*Notranjska cesta 37, SI-1380 Cerknica, Slovenia
**Department of Geography, Faculty of Arts, University of Ljubljana, Aškerčeva cesta 2, SI-1000 Ljubljana, Slovenia
e-pošta: stanka.miklic11@gmail.com, tajan.trobec@ff.uni-lj.si
ORCID: 0000-0002-8784-4366 (T. Trobec)

1 INTRODUCTION

Climate affects a wide range of environmental processes and many areas of human activity. Although climate change is a natural phenomenon, the pace of climate change has increased disproportionately in recent decades due to greenhouse gas emissions (IPCC, 2022). Climate change is reflected in changes in a number of meteorological variables, including in Slovenia an increase in air temperature, changes in the amount, form and distribution of precipitation and a decrease in snow cover. Its effects are reflected in economic activities such as agriculture and forestry, energy, tourism, transportation, etc. (Vertačnik, Bertalanič, 2017), and in addition to the economy, water bodies and ecosystems are also highly vulnerable to climate change (Bertalanič et al., 2018; Trobec, 2022). Lake ecosystems are of critical importance for aquatic and riparian organisms and for a variety of human needs, so any change in the quantity or degradation of lake water quality can potentially have far-reaching ecological and societal consequences (George, 2010; Vincent, 2009).

In the present paper, we have chosen Cerknica Lake in the karst area of Cerknica Polje to study the effects of climate change on the hydrological properties of its waters. Due to its intermittent regime, Cerknica Lake is naturally highly variable in hydrological terms (Zhelezov et al., 2011). Due to their location at the interface between groundwater and surface water, intermittent karst lakes have a very complex hydrology, as their occurrence and water levels are influenced by a number of factors such as precipitation, snowmelt, evaporation, surface and groundwater inflow, groundwater reserves in the karst aquifer and groundwater outflow (Kovačič, 2010; Mayaud et al., 2019). In addition to natural factors, the discharge and thus the water levels of the intermittent karst lakes can also be influenced by various hydraulic engineering interventions on the watercourses, especially in the sinking part of the poljes (damming and special impoundments, widening of ponors, etc.) (Bonacci, 1987).

In our literature review, we came across a number of studies that examine the effects of climate change on the water balance and water quantity of lakes (e.g. Kayastha et al., 2022; Lenters, Kratz, Bowser, 2005; Torabi Haghigi, Kløve, 2015; Van der Kamp, Keir, Evans, 2008; Wrzesiński, Ptak, 2016), but there are few studies looking at the direct effects of climate change on changes in water levels of intermittent karst lakes (e.g. Morrissey et al., 2021). In Cerknica Lake, the change in water levels associated with climate change and anthropogenic interventions in the discharge regime was investigated by Miklič (2021) and Blatnik et al. (2024). The overall result is a positive and statistically significant trend in annual minimum water levels (Hnp), while the conclusions regarding the trend in mean (Hs) and maximum water levels (Hvp) differ due to the slightly different study period. The water balance of Cerknica Lake (Kovačič, 2010), the water regime (Zhelezov et al., 2011) and flooding (Kranjc, 1986) were also investigated.

In Slovenia, studies on the effects of climate change on the hydrological properties of surface waters have been conducted mainly on the water balance (Andjelov et al., 2021; Frantar, 2008), trends in various characteristic discharges in selected areas (e.g. Hrvatin, Zorn, 2020; Kovačič, 2016) and changes in river discharge regimes (Frantar, Hrvatin, 2005). A comparison of Slovenia's water balance at the level of the entire country for the period 1961–1990 and 1991–2020 shows a decrease in runoff height (by 120 mm) and runoff coefficient (by 3.5%) as a result of higher temperatures and evaporation and lower precipitation (Andjelov et al., 2021; Kolbezen, Pristov, 1998). The discharge trends of most Slovenian watercourses show a decrease in medium and low discharges and an extension of periods with low discharges, leading to hydrological drought, while on the other hand high discharges are more frequent and more pronounced (Kobold, Dolinar, Frantar, 2012). Comparing the periods 1961–1990 and 1971–2000, a decrease in peak discharge in spring and an increase in fall can be observed in the discharge regimes of rivers in Slovenia as a result of climate change. The number of discharge regimes has decreased, as have the differences between them (Frantar, Hrvatin, 2005).

The results of the above-mentioned suggest that the effects of climate change are also reflected in the water level of Cerknica Lake. The aim of this article is to examine the fluctuations in the mean annual and seasonal water level of Cerknica Lake over the 60-year period 1961–2020 and to draw possible parallels with climate change. For this period, we examined and presented the trends of annual and seasonal changes in air temperature, precipitation and snow cover in the area of Cerknica Lake and its immediate catchment, as well as the trends of mean (Hs), minimum (Hnp) and maximum (Hvp) annual and seasonal water levels of the lake and the minimum (Qnp), mean (Qs) and maximum (Qvk) discharge of the largest surface tributary – the Cerkniščica River. We also investigated the correlation between selected meteorological and hydrological variables.

Knowledge of the fluctuations in the water level of Cerknica Lake is important for the future dynamics of its intermittency and thus for the preservation of the already fragile, unique (peri-)aquatic and subterranean ecosystems characteristic of karst poljes (Bonacci, 2014; Gaberščik et al., 2003; Gaberščik et al., 2020). This is all the more important for Cerknica Lake, a world-famous intermittent karst lake in the heart of the Notranjska Regional Park, an important Natura 2000 and Ramsar site and an exceptionally diverse area in terms of geodiversity (Stepišnik, Ilc Klun, Repe, 2017). At the same time, the issue of changing water levels due to climate change is also important for successful adaptation to hydrological extremes such as floods and droughts and for the further economic development of the wider area (agriculture, tourism and other activities in the lake area).

2 PRESENTATION OF THE STUDY AREA

With an area of 38 km^2, the Cerknica Polje is the largest karst polje in Slovenia (Ravbar et al., 2021) and the central karst polje in a series of hydrologically connected karst poljes of the Notranjska valley system, which is an integral part of the Ljubljanica river basin (Figure 1). It lies between the higher Loško Polje in the southeast and the lower Planinsko Polje in the northwest. It is surrounded by the Javorniki Mountains to the southwest and the Slivnica and Bloke Plateau to the northeast. The bottom of the polje lies at an altitude of around 550 metres. The Cerknica Polje is characterised by the temperate continental climate of western and southern Slovenia (Ogrin, 1996). At the Dolenje Jezero climatological station, the mean annual air temperature in the period 1981–2010 was 8.9 °C (interpolated value from the climatological station in Postojna). In the same period, the mean annual precipitation at the precipitation station in Cerknica was 1552 mm (ARSO, 2022; Fig. 2).

Figure 1: Map of the Cerknica polje.

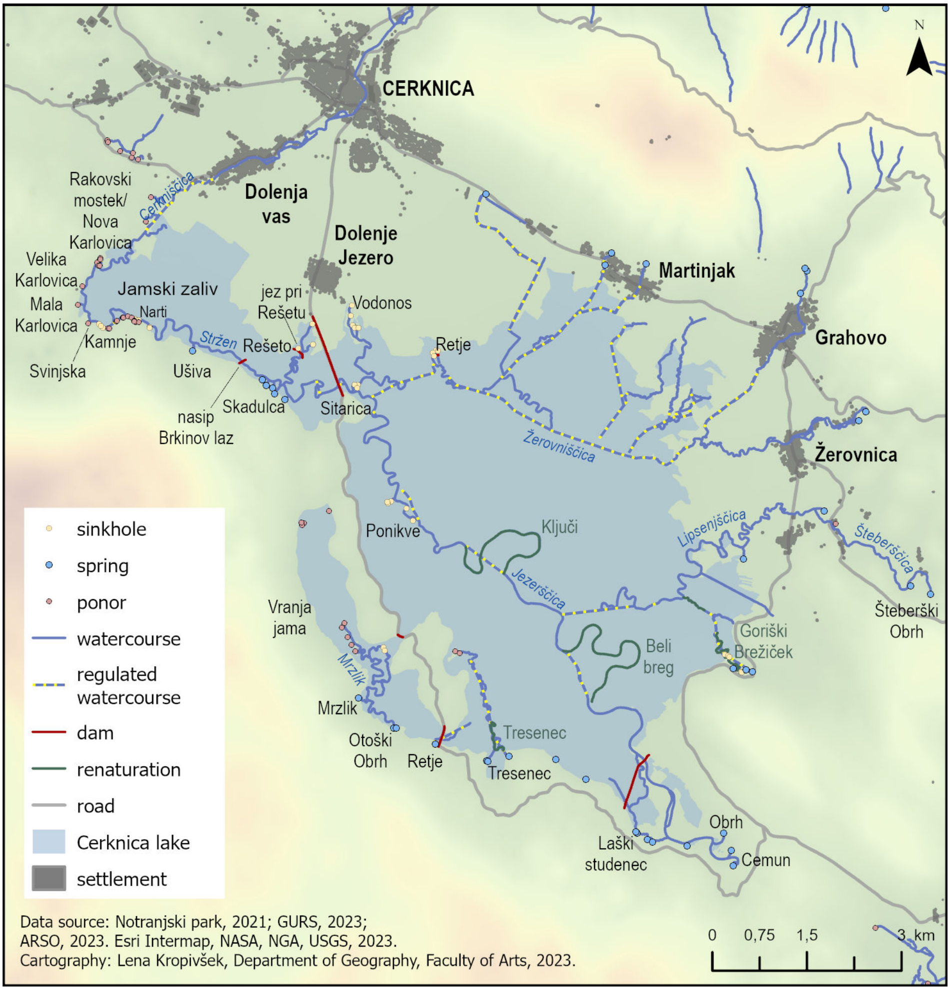
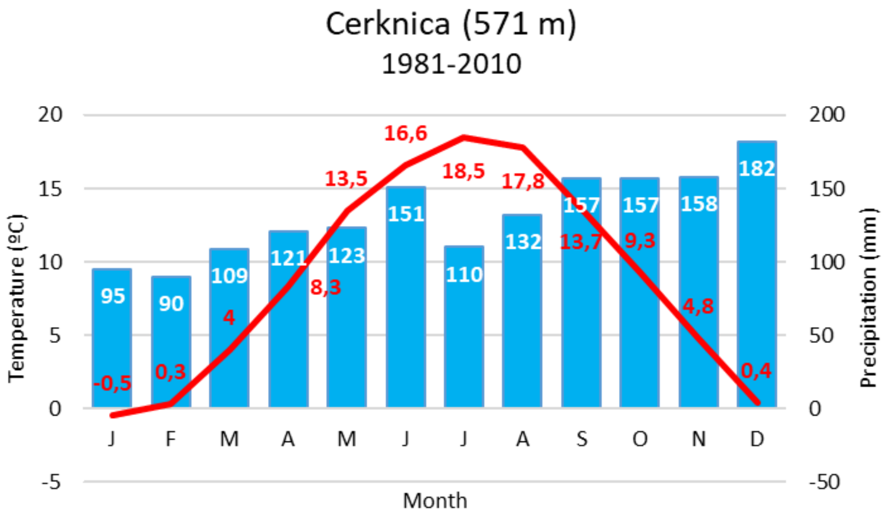


Figure 2: Climate diagram for the Cerknica meteorological station for the period 1981–2010.



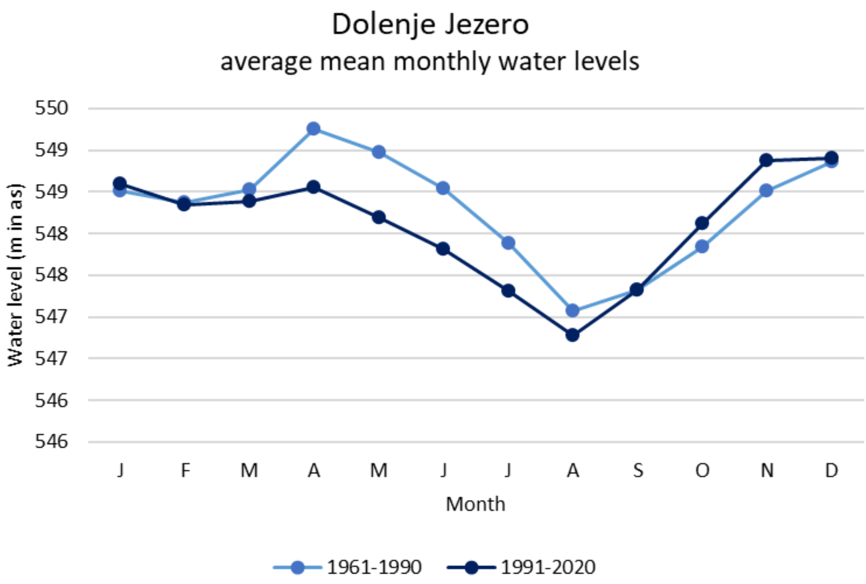
Source of the data: ARSO, 2022.

The Cerknica Polje is a combined type of border and spring-ponor polje (Gams, 1974) or a combination of inundated, overflow and inflow type polje (Stepišnik, 2020). The hydrological hinterland of the Cerknica polje is very diverse and extensive, with water from the Loško Polje and the Bloke Plateau flowing into the polje from underground (Kranjc, 1986) and the Cerkniščica River flowing into the polje from the surface. The catchment area of Cerknica Lake is 475 km^2. About 80 % of the area is fed by karst water and 15% by surface water, the rest comes from rainwater from the polje itself. Most of the karst watercourses flow from the eastern and south-eastern edges of the polje. The largest watercourse in the polje is the Stržen, which is called Obrh at its source. In the eastern part of the polje, the largest tributaries are Žerovniščica and Šteberščica, while on the southern side the larger springs are Laški Studenec, Tresenec, Retje, Otoški Obrh, Mrzlek, Vranja Jama v Zadnjem Kraju, Skadulca and the spring in Ušiva Loka. The Cerkniščica River is the only longer, non-karstic tributary of the lake, that receives water from the edge of the Otavska, Vidovska and Bloke plateaus (Kranjc, 1986). The outflow of Cerknica Lake consists of several outflow units and is entirely karstic. The most important ponors are connected to the Velika and Mala Karlovica cave system and the Svinjska Jama cave in the northwestern part of the polje, the so-called Jamski zaliv (Cave bay), which drain water mainly towards Rakov Škocjan and Planinsko Polje (Gams, 1965; Petrič et al., 2020). In the central part of the polje, there are numerous sinkholes (e.g. Rešeto and Vodonos south of the village of Dolenje Jezero), from which water flows underground directly into the springs of the Ljubljanica River (Gams, 1965). The lake water is retained the longest in the lowest part of the polje, the so-called Zadnji kraj, from where it also flows into the springs of the Ljubljanica (Gams, 1965; Kranjc, 1986).

Cerknica Lake begins to apear when the inflow exceeds the outflow and the water level rises above 547.4 m (184 cm at the Dolenje Jezero water gauging station) (Kolbezen, 1998). According to more recent studies, however, the regular lake level, defined as the water level that is exceeded on at least 10 days per year within a reference period of 30 years, is 550.3 m (value of 474 cm at the Dolenje Jezero gauging station). At this value, the water floods an area of 21.84 km^2 (Ravbar et al., 2021). The lake carries water for an average of nine months a year. The lake is most often full in April, May and December and empty between August and October (Kranjc, 2005). The water regime of the lake in the reference period 1961–1990 was characterised by two highs (April and December) and two lows (August and February) (Kovačič, 2010). According to the author's interpretation, the peak in April was partly due to snowmelt that had accumulated in the higher parts of the catchment during the winter and partly due to precipitation in the period preceding the intensive growing season. The peak in December was caused by a combination of the precipitation peak in November and a karst retention that shifted most of the November runoff from the polje to December. The low in August was due to heavy evaporation, while the low in February was due to snow retention. The attached graph (Figure 3) shows that the water regime of the lake changed in the following 30-year period (1991–2020) at the expense of significantly lower water levels in spring and summer and slightly higher water levels in fall. For the period 1961–2007, the lake's water regime was analysed for five decades by Zhelezov et al. (2011) and showed significant differences between the various decades.

Cerknica Polje is located in the municipality of Cerknica. The settlements in Cerknica Polje, with the exception of the central settlement of Cerknica, are predominantly rural. With the exception of Dolenje Jezero, they have withdrawn from the area of influence of the floods (Smrekar, 2005). In 2020, they had a population of 6120 inhabitants, of which about 2/3 lived in Cerknica (SURS, 2022). Smaller settlements in the municipality have been characterised by a decline in population over the last 50 years, while larger settlements with better opportunities for the development of various activities (Cerknica, Unec, Rakek, Martinjak and Grahovo) have seen an increase in population. The majority of the working population is still employed outside the municipality (Pustovrh Benda, 2015). Cerknica Lake represents the tourist potential of the wider area, which is only partially exploited. Tourist arrivals are increasing, but these are mainly day-trippers who visit the lake mainly in the warmer season (Lukan, 2017).

Figure 3: Hydrograph of mean monthly water levels at the Dolenje Jezero water gauging station for the periods 1961–1990 and 1991–2020.



Source of the data: ARSO, 2022.

3 ANTHROPOGENIC INTERVENTIONS IN THE DRAINAGE REGIME OF CERKNICA LAKE

The periodic occurrence of Cerknica Lake has been regulated in various ways in the past, depending on the historical situation and the interests that gave rise to the initiatives. In the agricultural era, there was the idea of draining the lake or reducing the volume and duration of flooding in favor of arable land, while later there was a tendency to permanently dam the lake in order to develop tourism, fishing and electricity generation (Bidovec, 2007).

In the name of drainage, some of the sinkholes were lowered and cleaned until the Second World War, Velika Karlovica (Fig. 4) and Mala Karlovica, Rakovski Mostek, Svinjska Jama cave, Kamnje and Narte ponors were widened and deepened, some siphons were blasted, underground channels were widened and lowered and screens were installed at the entrance to both Karlovicas, the inflow to Svinjska Jama cave was regulated, Stržen with some tributaries was regulated and its outflow into the nearby sinkholes and ponors was regulated by drainage ditches. These measures have limited major flooding and led to a faster discharge of medium-high water (Kranjc, 1986).

Figure 4: Velika Karlovica (photo: S. Miklič).

Figure 5: Dam in front of Rešeto (photo: T. Trobec).

To prevent a catastrophic fish kill when the lake dried up, the locals built a small dam in front of Rešeto in 1946 (Figure 5), which prevented the low water from flowing into Rešeto sinkhole. They also built the Brkinov Laz dam on Stržen at a height of 200 cm at the Dolenje Jezero water gauging station to stem the flow of water towards Jamski Zaliv. In order to maintain the lowest water level, in 1956, in addition to the reconstruction of the dam in front of Rešeto (which was rebuilt and raised in 1969), part of Stržen and Žerovniščica were regulated and several small reservoirs were built at Ponikva, Retje and Sitarica (Kebe, 2011).

At the end of the 1960s, the entrance to the Mala Karlovica was concreted to test the damming of ponors, five cave entrances were built in Narti and the Velika Karlovica was dammed with a concrete dam with an overflow at 551 m (544 cm at the Dolenje Jezero water gauging station), and connected by an artificial tunnel to the Rakovski Mostek (Nova Karlovica), where an iron sluice was installed at the entrance. In this way, the outflow at medium and high water levels was reduced and floods were prolonged, but the lake continued to dissapear in periods of drought (Bidovec, 2007; Habič, 1974; Kranjc, 1986).

In the following years, the barrier in front of Velika Karlovica was lowered, some of the ponors were relieved and the cleaning and dredging of some channels was resumed. In the late 1980s and early 1990s, the Nova Karlovica facility was rebuilt and became the main sink for the outflow of water from Cerknica Lake, with a capacity of around 40 m^3/s (Pravilnik za obratovanje …, 2014). In 1992, the concrete barrier at the entrance to Mala Karlovica was removed and after the floods of 2000, the overflow of the barrier at Velika Karlovica was lowered by 60 cm, so that water only flows over the barrier when the water level at the Dolenje Jezero water gauging station reaches 500 cm (Kebe, 2011).

In 2015, the implementation of a regulation prescribing the operating regime of the lock at Nova Karlovica began in order to protect the fish fauna, which is tied to high winter and spring water levels during spawning. The lock is closed on December 1st and remains closed until the middle or end of May (depending on the water level). It is only opened when the water level at the Dolenje Jezero gauging station exceeds 470 cm, and even then only until the water level stops rising (Pravilnik za obratovanje …, 2014). The lock in Nova Karlovica was not operated before 2015, but it is assumed that it was open most of the time and was cleaned regularly (Tratnik, 2023).

In 2016 and 2018, the fishing weir in Rešeto was rebuilt and upgraded with an overflow height of 150 cm at the Dolenje Jezero water gauging station (Tratnik, 2023), which keeps the water in the lake at an approximate height of about 70 cm at the Dolenje Jezero water gauging station during low water levels (Schein, 2020).

Between 2019 and 2021, under the management of the Notranjska Regional Park, the original channel of the Stržen in Ključi and Beli Breg was restored and in 2009 the upper parts of Goriški Brežiček and Tresenec were renaturated, which is expected to slightly slow down the outflow of low water and prolong the stagnation of water in the depressions and established arms of the watercourses (Tratnik, 2023).

4 METHODS

For the study area, we analysed the mean annual and seasonal precipitation, snow cover and total snow depth, mean annual and seasonal air temperature, mean annual and seasonal minimum (Hnp), mean (Hs) and maximum (Hvp) water level of Cerknica Lake, and minimum (Qnp), mean (Qs) and maximum (Qvk) annual discharge of the Cerkniščica River for the period 1961–2020. The seasonal values refer to the meteorological seasons, with the December–February quarter representing winter, the March–May quarter representing spring, the June–August quarter representing summer and the September–November quarter representing fall.

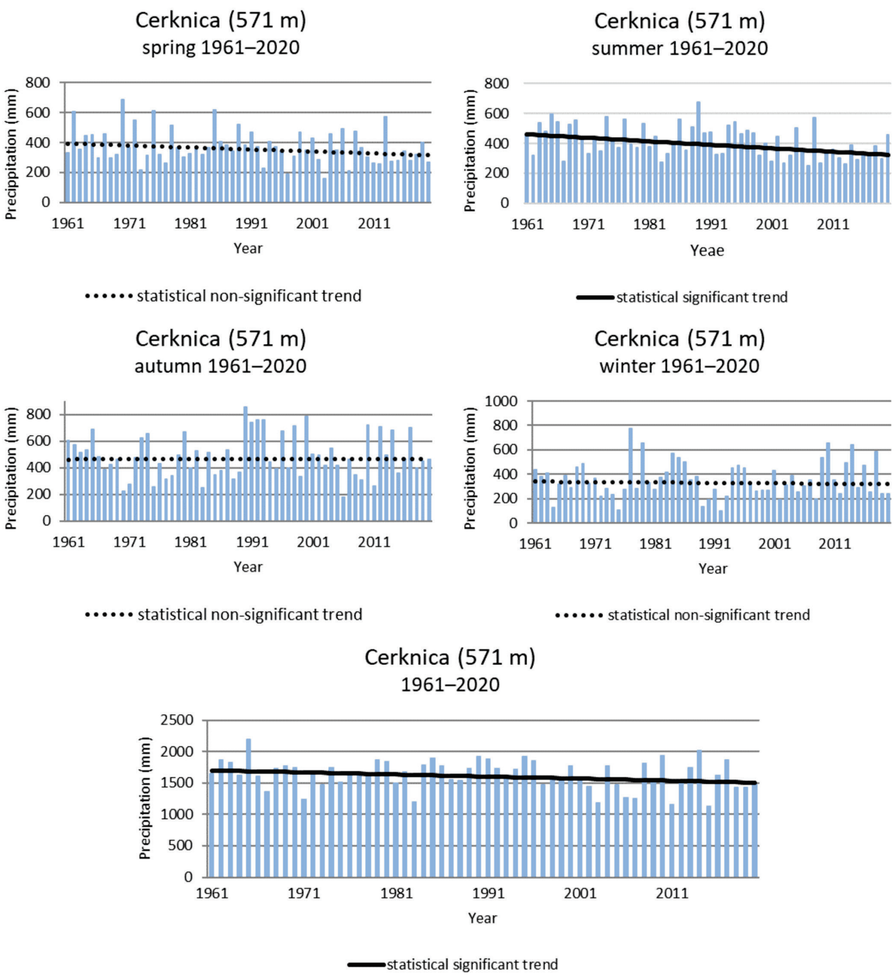
To calculate the trends in precipitation and snow cover in the study area, we used the monthly precipitation heights from the Cerknica precipitation station (ARSO, 2022), which has a complete set. According to this criterion, the Šmarata and Nova Vas na Blokah stations could also have been included in the analysis, but the preliminary analysis showed a high level of agreement in the trends and annual distribution of precipitation between the stations, which is why we ultimately decided against it. For the calculation and presentation of the trend of the average daily temperature, the temperature data from the climatological station Dolenje Jezero, which has only been in operation for less than ten years, were interpolated with the temperature data from the climatological station Postojna, which is the closest station with a homogenised data set. In the interpolation, we also calculated the difference in monthly mean air temperature for the entire period of operation of the stations (1969–1977) and then added the difference to the data set of the Postojna meteorological station for the period 1961–2020. In the study, we did not separately consider evapotranspiration, which is otherwise calculated for Bloke and Babno Polje, as it is a derived (calculated) and not a basic (measured) meteorological variable. For the analysis of the water levels of Cerknica Lake, we used the monthly data of minimum, mean and maximum water levels at the Dolenje Jezero gauging station, and for the analysis of the discharge of the Cerkniščica River, we used the monthly discharges at the Cerknica gauging station (ARSO, 2022).

The trend of temperature, precipitation and snow cover, water levels and discharges were calculated using the Mann-Kendall statistical test and Sen's slope. The Mann-Kendall test indicates the significance of the trend, if it exists, and the Sen's slope indicates the value. The Mann-Kendall test and Sen's slope were calculated in MS Excel using the MAKESENS template (Makesens-application ..., 2021). The correlation between the selected meteorological and hydrological variables was determined using the Spearman rank correlation coefficient (ρ), in which the data are converted into ranks before calculation and are therefore less sensitive to outliers. In contrast to the Pearson correlation coefficient, the Spearman correlation coefficient also assumes no linear correlation between the variables and a normal frequency distribution (Helsel et al., 2020) and is therefore more suitable for analysing the correlation between meteorological and hydrological variables, representing inputs and outputs of karst systems (Kovačič, 2009).

5 RESULTS

In the period 1961–2020, the average annual precipitation at the Cerknica precipitation station was 1629 mm. There is a negative trend, which is statistically significant ($\alpha \leq 5\%$), of –33 mm/decade, which means that precipitation decreased by 197 mm or 11% in the analysed period. The wettest year was 1965 with 2189 mm of precipitation and the driest year was 2015 with only 1125 mm of precipitation. With the exception of the fall, the seasonal trends in precipitation are also negative. The

Figure 6: Temporal course of average precipitation 1961–2020 at the Cerknica precipitation station.

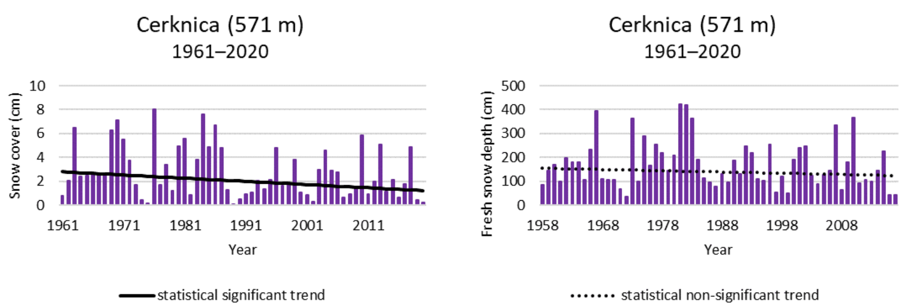


Source of the data: ARSO, 2022.

linear trend in spring is statistically insignificant at –13 mm/decade, which means that precipitation in spring has decreased by 79 mm or 20 %, while the average precipitation in spring during the analysed period was 373 mm. The average summer precipitation during the period studied was 413 mm. The decrease in summer precipitation is most pronounced compared to the other seasons, with a decrease of 30 % or 139 mm. The linear trend in summer is statistically significant (α ≤ 5%) and amounts to –23 mm/decade. The average amount of precipitation at the Cerknica precipitation station was highest in the fall at 488 mm during the study period. However, the linear trend in fall precipitation is insignificant and statistically insignificant at 0.4 mm/decade. Precipitation in the fall increased compared to the other seasons, but only by 0.5% or 2 mm. The average winter precipitation over the period studied was 356 mm, which indicates a primary decrease in winter precipitation. At –3 mm/decade, the trend is statistically insignificant. Winter precipitation therefore decreased by 21 mm or 6% (Figure 6).

Two variables were analysed for the snow depth 1961–2020 at the Cerknica precipitation station: the average snow cover and the total new snow depth (Figure 7). The average snow cover in a given period corresponds to the arithmetic mean of all daily values, even if there is no snow (snow cover is 0 cm), while the total snow depth is the sum of the daily values of new snow in the selected period (Vertačnik, Bertalanič, 2017). In the period studied, the highest average snow cover was in 1976 (8 cm) and the lowest in 1989 (0.1 cm). Until 1986, values above 6 cm occurred five more times (1963, 1969, 1970, 1984 and 1986), but no more after that. The highest total new snow depth was 421 cm in 1984 and the lowest in 1975 (35 cm). In 1970, 1976, 1985, 1986 and 2013, the value was over 350 cm.

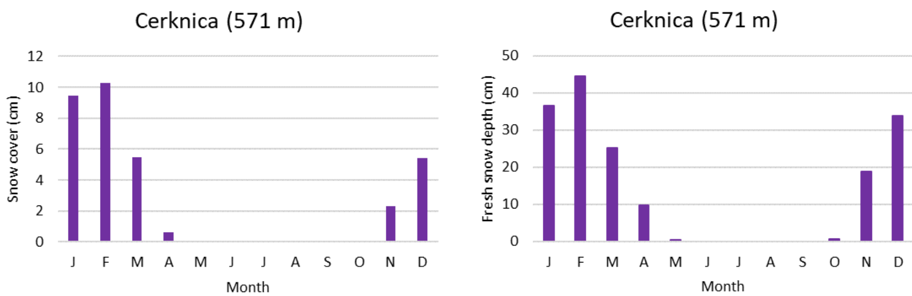
Figure 7: Temporal course of the average snow cover and new snow depth for the period 1961 – 2020 at the Cerknica precipitation station.



Source of the data: ARSO, 2022.

The snowiest month in the Cerknica Polje area during the study period was February (Figure 8). The average snow cover in February was 10.3 cm and the average total new snow depth was 45 cm. Most of the new snow (over 25 cm on a monthly basis) fell on average between December and March. The average annual snow depth was 2.8 cm and the total new snow depth was 170 cm. A statistically significant trend (α ≤ 5%) was observed for the average snow depth over the period studied, which amounted to –0.26 cm/decade, a decrease of 1.6 cm or 57%. For the total new snow depth, the trend is also negative (–5 cm/decade), but not statistically significant. On an annual basis, the amount of new snow fell by 31 cm or 20% in the period studied.

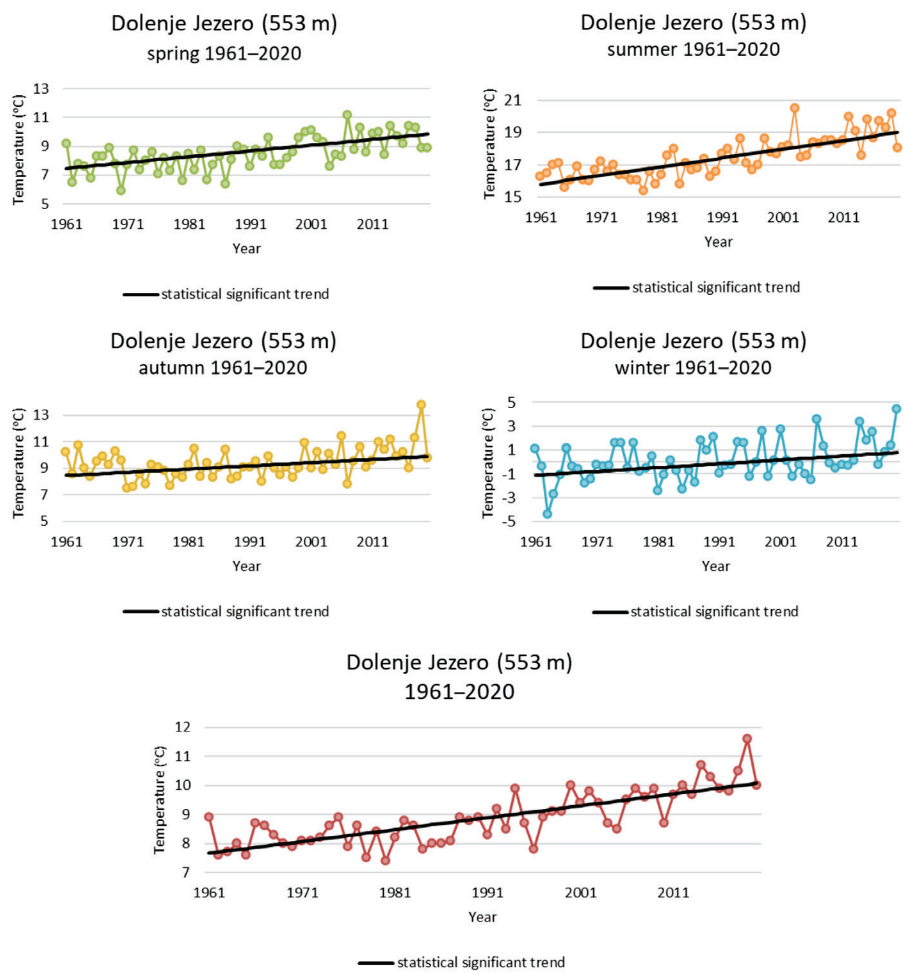
Figure 8: Monthly average amount of new snow and snow cover at the Cerknica precipitation station 1961–2020.



Source of the data: ARSO, 2022.

The average annual air temperature at the climatological station Dolenje Jezero in the period 1961–2020 was 8.9 °C. The lowest average annual air temperature was measured in 1980 with 7.4 °C, and the warmest year was 2019 with an average temperature of 11.6 °C. There is a positive and statistically significant trend (α ≤ 5%) of 0.4 °C/decade, which means that the atmosphere has warmed by 2.5 °C over the period studied. Unlike the trends in mean precipitation, the trends in mean air temperature are positive and statistically significant (α ≤ 5%) in all seasons. The warming rate is highest in summer, when the linear trend is 0.5 °C/decade. In spring, the linear trend of the mean air temperature is 0.4 °C/decade, in fall 0.2 °C/decade and in winter 0.3 °C/decade. In summer it warmed by an average of 3.2 °C, in fall by 1.5 °C, in winter by 1.9 °C and in spring by 2.3 °C (Figure 9).

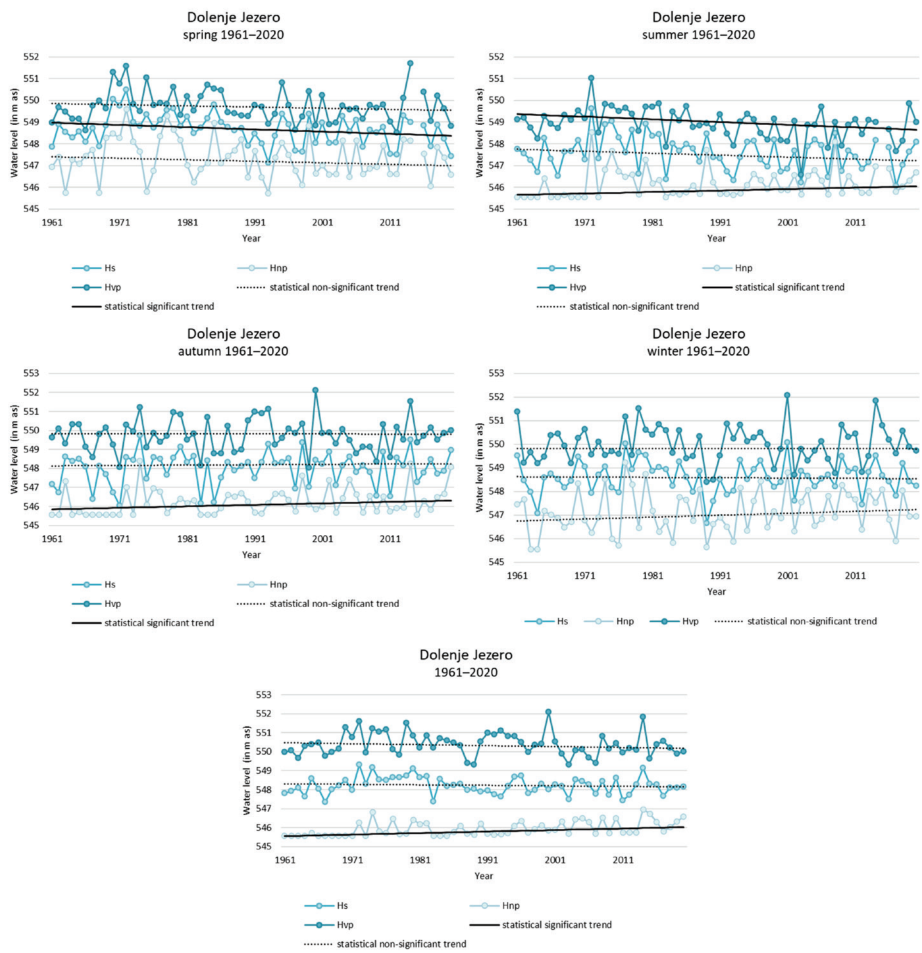
Figure 9: Temporal course of the average air temperature 1961 – 2020 at the Dolenje Jezero climatological station.



Source of the data: ARSO, 2022.

The different water levels (Hnp, Hs and Hvp) are subject to different trends and associated changes in their height both on an annual basis and at different times of the year during the study period (Figure 10, Figure 11). The trends of the highest (Hvp) and mean (Hs) annual water levels of Cerknica Lake at the Dolenje Jezero gauging station between 1961 and 2020 were negative and not statistically significant, while the trend of the lowest annual water levels (Hnp) was positive and statistically significant ($\alpha \leq 5\%$). According to the linear trend equation, Hvp decreased the most during the analysed period (30 cm). The decrease in Hs was 16 cm and the increase in Hnp was 48 cm. In spring, water level trends were negative, but only the trend for Hs was statistically significant (α ≤ 5%), with a decrease of 62 cm over the period studied, which was also the largest decrease among all seasonal Hs. In spring, Hnp decreased by 42 cm and Hvp by 32 cm. In summer, the trends of Hvp and Hs were negative, with the former also being statistically significant (α ≤ 5%), and the trend of Hnp was positive and also statistically significant (α ≤ 5%). In summer, the most significant decrease was 74 cm in Hvp (the largest decrease among all seasonal Hvp), while Hnp increased by 40 cm and

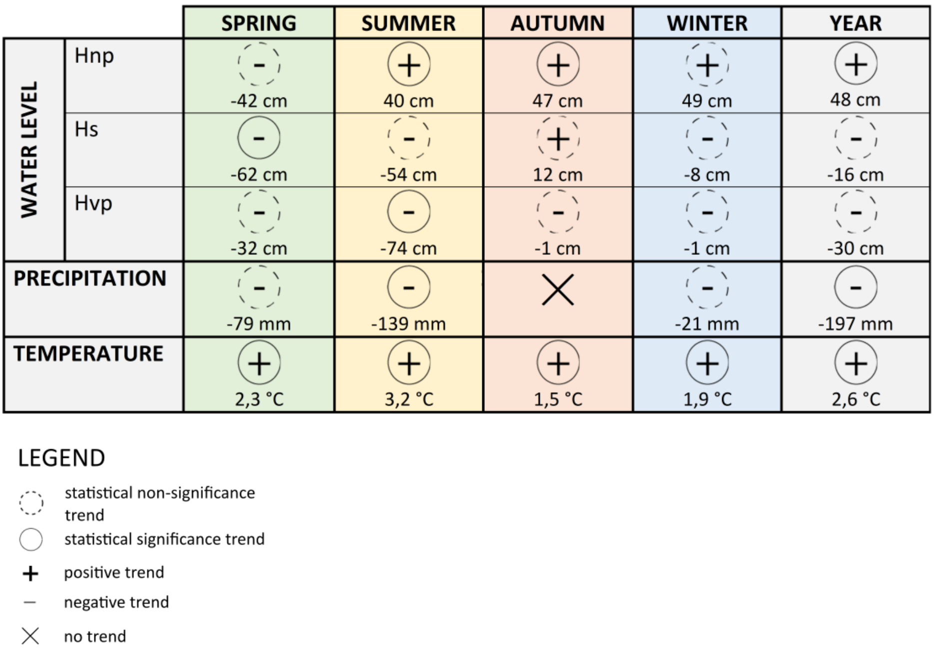
Figure 10: Temporal course of the lowest, average and highest water levels in the period 1961–2020 at the Dolenje Jezero water gauging station.



Source of the data: ARSO, 2022.

Hs decreased by 54 cm. In the fall, the linear trend of Hs was negative and statistically insignificant with a decrease of 12 cm over the period studied, while the trend for Hvp was insignificant. The fall trend for Hnp was positive and statistically significant ($\alpha \leq 5\%$), with a 47 cm increase in summer minimum water levels. In winter, the trends for Hvp and Hs were negative and not statistically significant, while the trend for Hnp was positive and also not statistically significant. The largest change was for Hnp (increase of 49 cm), Hs decreased by 8 cm and Hvp remained practically the same.

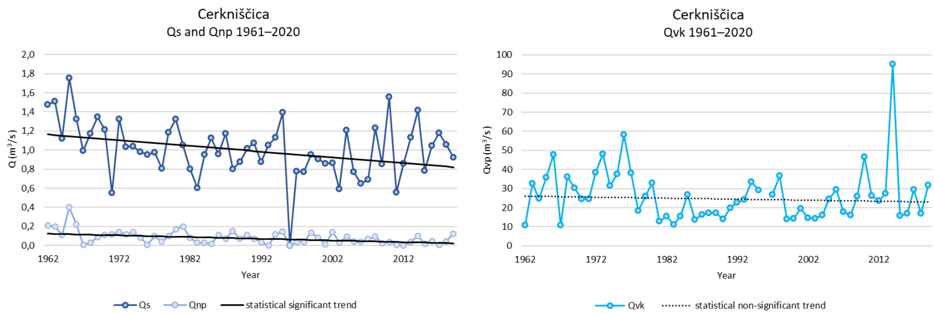
Figure 11: Synthesis of trends of selected meteorological variables and water levels in the period 1961–2020 for the precipitation station Cerknica and the climatological and water gauging station Dolenje Jezero.



Source of the data: ARSO, 2022.

The trends of annual discharges on the Cerkniščica River were negative in the period 1961–2020. The trends of Qnp and Qs are statistically significant ($\alpha \leq 5\%$), while the trend of annual Qvk is not statistically significant. The decrease in Qs over the period studied was 0.32 m^3/s (28%), the decrease in Qvk was 3.17 m^3/s (12%) and the decrease in Qnp was 0.09 m^3/s or 78% (Figure 12).

Figure 12: Temporal course of Qnp, Qs and Qvp in the period 1961–2020 at the Cerknica water gauging station.



Source of the data: ARSO, 2022.

The correlation between the water levels and the selected meteorological variables was determined using Spearman's rank correlation coefficient (ρ) (Table 1). The correlation between the different water levels (Hnp, Hs, Hvp) and air temperature is low in most cases (ρ between ±0.20 and ±0.39), in some cases even insignificant (ρ between ±0.01 and ±0.19) and has a different sign at different times of the year. The largest negative correlation (mean) is between Hs and Hvp in summer with air temperature (ρ = –0.48 and –0.49, respectively), and there is another mean correlation between Hnp in summer and air temperature, but it is positive (ρ = 0.41). The correlations of annual water levels with air temperature vary considerably in absolute value and also have different signs (–0.30 < ρ < 0.41). In spring and summer, the correlations are negative and insignificant to medium (–0.03 < ρ < –0.49), in winter positive and insignificant to low (–0.19 < ρ < 0.24) and in fall insignificant and with a different sign (–0.07 < ρ < 0.08).

The correlation between the different water levels (Hnp, Hs, Hvp) and precipitation is positive everywhere and on average higher than the correlation between water level and air temperature. In slightly more than half of the cases, it is at least medium (ρ between 0.40 and 0.59), of which two cases are high (ρ between 0.60 and 0.79) and one case is very high (ρ > 0.80). The highest correlation between Hvp and precipitation is in fall (ρ = 0.86). There is a medium correlation between annual Hvp and precipitation (ρ = 0.52) and a low correlation (ρ = 0.39) and an insignificant correlation (ρ = 0.01) between annual Hs and Hnp and precipitation. With the exception of the annual level and fall, the most pronounced correlation between all water levels is that between annual Hvp and precipitation. Hs and precipitation are most strongly correlated. In spring and summer it is medium (ρ = 0.55 and 0.46 respectively) and in fall and winter it is high (ρ = 0.64 and 0.63 respectively). There is only a low correlation between the annual and autumnal Hnp and the amount of precipitation (ρ = 0.01 and 0.08 respectively).

Table 1: Values of Spearman's rank correlation coefficient (ρ) between water levels and air temperature and precipitation.

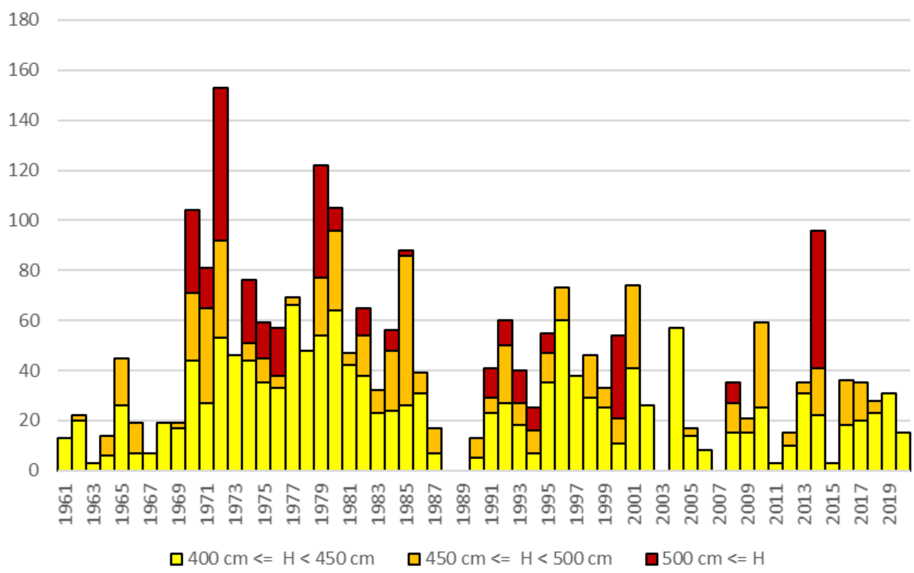
	Air temperature	Precipitation
Annual Hs	–0,30*	0,39*
Annual Hnp	0,41*	0,01
Annual Hvp	–0,17	0,52*
Spring Hs	–0,40*	0,55*
Spring Hnp	–0,33*	0,39*
Spring Hvp	–0,19	0,45*
Summer Hs	–0,48*	0,46*
Summer Hnp	–0,03	0,24*
Summer Hvp	–0,49*	0,38*
Fall Hs	–0,07	0,64*
Fall Hnp	0,08	0,08
Fall Hvp	–0,05	0,86*
Winter Hs	0,19	0,63*
Winter Hnp	0,24*	0,40*
Winter Hvp	0,21	0,46*

**The correlation is statistically significant (α ≤ 5%).*

6 DISCUSSION

The negative trend in mean and maximum water levels and thus the decrease in annual Hs (16 cm) and Hvp (0.30 cm) of Cerknica Lake in the period 1961–2020 is probably mainly due to a decrease in annual precipitation by 11% and an increase in mean air temperature by 2.5 °C, with a consequent increase in evaporation. The latter hypothesis is indirectly supported by the relationships of water levels to precipitation and temperature, namely the small correlation between Hs and precipitation (ρ = 0.39), the medium correlation between Hvp and precipitation (ρ = 0.52) and the small and insignificant negative correlation of Hs and Hvp to air temperature (ρ = –0.30 and –0.17, respectively). Part of the decline in mean water levels and peak water levels could also be related to the gradual removal of some measures taken in the late 1960s to implement the experimental impoundment (Kranjc, 1986), such as the release of some ponors, the removal of the barrier at the entrance to Mala Karlovica, the lowering of the overflow of the barrier at Velika Karlovica and the resumption of clearing and dredging of some of the river channels (Kebe, 2011). Despite the negative trend in Hvp, it is worth noting that the absolute highest water levels were reached in the second half of the study period, namely in 2000 (654 cm) and 2014 (628 cm), when floods occurred in a larger area of Slovenia (ARSO, 2014; Kovačič, Ravbar, 2010). Blatnik et al. (2024), who in contrast to us look at a somewhat longer data set (1956–2022), find a slightly positive trend in Hvp. The divergence is due to the high variability of annual maximum water levels, where even small differences in the investigated set can influence the reversal of the trend. The extreme water levels in 2000 and 2014 are consistent with the findings of more frequent and more pronounced flooding as a result of climate change (Kobold, Dolinar, Frantar, 2012) and indicate that there is a real possibility that we will experience more frequent extreme flooding at Cerknica Lake in the future, regardless of the trend in Hvp, when exceptional precipitation occurs. In general, however, the number of days with the highest water levels, e.g. above 400, 450 or 500 cm, is decreasing at Cerknica Lake, even if we exclude the period of attempted permanent management of the lake in the transition from the 1960s to the 1970s (Figure 13).

Figure 13: Number of days per year with high water levels at the Dolenje Jezero gauging station in the period 1961–2020.

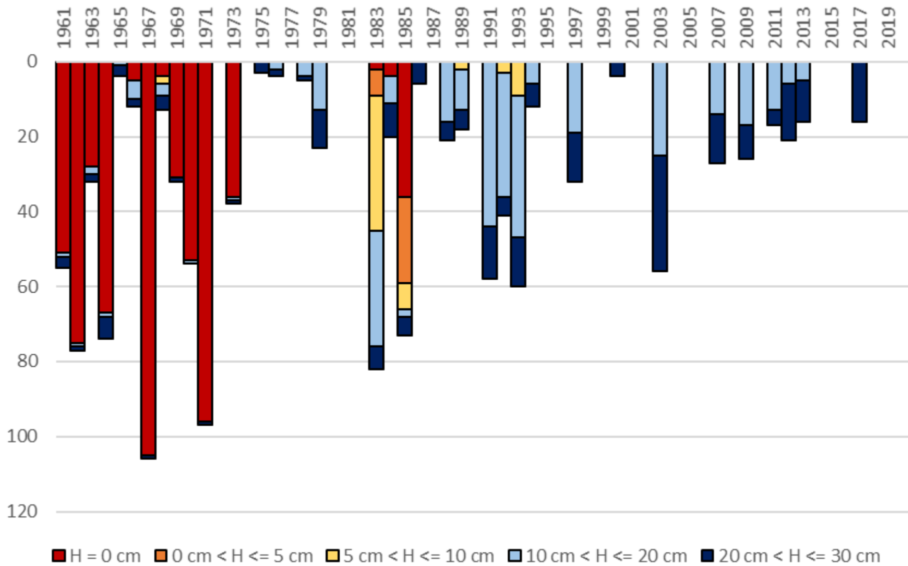


Source of the data: ARSO, 2022.

In contrast to Hs and Hvp, the trend of Hnp is positive and statistically significant ($\alpha \leq 5\%$), leading to an increase in the lowest annual water levels (increase of 48 cm). There is a lack of correlation of annual Hnp with rainfall ($\rho = 0.01$) and a moderate correlation with air temperature ($\rho = 0.41$), with the latter having the opposite sign to that expected. The increase in annual minimum water levels despite lower precipitation and higher temperature is probably due to anthropogenic interventions in outflow. In this case, the dam at Rešeto sinkhole, behind which water is held back at low water levels to protect fish, has a decisive influence. In fact, all annual Hnp recorded during the studied period were below the overflow of the dam (150 cm at the Dolenje Jezero water gauging station). However, the dam was damaged, rebuilt and raised several times during the study period to retain more water (Schein, 2020; Tratnik, 2023), which could explain the increasing trend in Hnp. However, water retention at the lowest water levels is probably not the only reason for the increase in Hnp. We suspect that the latter phenomenon is partly due to the way water levels are measured, which is unfavourable for studying the lowest values at the Dolenje Jezero gauging station. A look at the attached graph (Figure 14) shows that from the beginning of the station's operation until 1974, values of H = 0 cm (absolute height 545.56 m) were recorded very frequently, which is no longer typical for the later period (with some exceptions in the early 1980s). Since 1974, water levels of less than e.g. 5, 10, 20 or 30 cm have also become increasingly rare, although it is known from experience that the Stržen River can dry out during dry periods. For example, in the exceptionally dry year of 2022, despite the absence of water, the lowest water level was officially recorded at H = 30 cm (ARSO, 2022) because the water level bar with the value 0 cm was buried in the sediment at the bottom of the channel at the time of measurement (Figure 15). In view of the many recorded values of H = 0 cm at the beginning of the study period, it is possible that the bed of the channel was deeper at this time and the water level bar at 0 cm was therefore not buried in the sediment. It is also quite possible that before 1974 (when continuous recording of water levels with a limnigraph was introduced) the observer recorded the water level at H = 0 cm when there was no water in the channel, regardless of whether the water level gauge was buried in the sediment at 0 cm, which was no longer possible due to automatic recording in the later period. There are no official record of how the lowest water levels were recorded until 1974 and of the burial of the level at 0 cm in the sediment, so the trend in annual Hnp is unlikely to be reliably interpreted.

The discharge data for the only larger non-karstic tributary of the Cerknica polje – the Cerkniščica – at the Cerknica gauging station show, according to the linear trend equation, a decrease in mean annual discharge (Qs) and annual peak discharge (Qvk) by 28% and 12% respectively in the same period (1961–2020), which is consistent with the changes in Hs and Hvp of the Stržen at the Dolenje Jezero gauging station. In contrast to the increase in Hnp in the analysed period, the annual minimum discharge (Qnp) at Cerknica decreased by 78%. The latter fact is further indirect evidence that the increase in minimum water levels at Cerknica cannot be climatic, but is due to another factor – most likely an anthropogenic influence on the outflow.

Figure 14: Number of days with low water levels at the Dolenje Jezero water gauging station in the period 1961–2020.



Source of the data: ARSO, 2022.

Spring Hs, Hnp and Hvp of Cerknica Lake decrease (62 cm, 42 cm, 32 cm decrease), which is consistent with decreasing spring precipitation (20% decrease) and increasing temperatures (2.3 °C increase) affecting evaporation. The latter is also reflected in a medium correlation between Hs, Hnp and Hvp in spring with precipitation ($0.39 < \rho < 0.55$) and a small negative correlation with temperature ($-0.40 < \rho < -0.19$). The significant decline in water levels in spring also becomes clear when comparing the mean water levels in March, April and May for the periods 1961–1990 and 1991–2020 (Figure 3). The decline in water levels in spring is probably partly due to the reduced influence of snow retention. This is a combination of a lower proportion of snowfall in winter, which only partially runs off in spring, and less abundant winter precipitation (a 6% decrease). The lower proportion of snowfall is reflected in a 20% decrease in the amount of new snow, while the 57% decrease in average snowpack height indicates faster snowmelt, which consequently turns into runoff with a shorter time lag. The latter results are consistent with those on snowpack depth in Slovenia, which decreased by about 16% per decade at the national level between 1961 and 2011 (Vertačnik, Bertalanič, 2017), and the weakening of snow retention is reflected in a reduction of spring discharge in many watercourses (Frantar, Hrvatin, 2005). When assessing the impact of snowfall on the water level of Cerknica Lake, it should be noted that the analyses were carried out at the lowland precipitation station Cerknica, which is not representative of the entire catchment area of Cerknica Lake due to the lack of precipitation stations at higher altitudes, as snow only occurs in larger quantities at higher altitudes.

Figure 15: Dry riverbed of the Stržen in summer 2022 (photo: T. Trobec).

Summer Hs declined by 54 cm during the period studied, the second largest decline in Hs after spring, and summer Hvp declined by 74 cm, the largest decline among seasonal Hvp. The significant decline in summer water levels is also evident when comparing the mean water levels of June, July and August for the periods 1961–1990 and 1991–2020 (Figure 3). This decrease in summer Hvp and Hs can probably be attributed to the increased evaporation due to the warming of the atmosphere (the summer temperature increase of 3.2 °C is the highest of all seasons) and to the significant decrease in precipitation, which is most pronounced in summer (30%). This hypothesis is also supported by the mean correlation of Hs and Hvp in summer with precipitation ($\rho = 0.46$ and 0.38, respectively) and with air temperature ($\rho = -0.48$ and –0.49, respectively), which has the expected negative sign at this time of year. Despite the strong decrease in summer precipitation and warmer temperatures, the trend of summer Hnp is positive (increase of 40 cm) and the trend of autumn Hnp is very similar (increase of 47 cm). Considering that 87% of Hnp on an annual basis occurs in summer or autumn (and occasionally in both seasons simultaneously) during the studied period, the interpretation of the trend in summer and autumn Hnp is also unreliable (as in annual Hnp) due to the above-mentioned methodological uncertainties in the recording of minimum water levels. However, as mentioned above, the positive trend in summer and autumn Hnp can probably be linked, at least in part, to artificial water retention at low water levels behind the dam at Rešeto. Indeed, the vast majority of summer and autumn Hnp (90% and 88%, respectively) in individual years at the Dolenje Jezero gauge were below 150 cm, which corresponds to the overflow height of the dam. The hypothesis of the influence of artificial water retention on the lowest summer and autumn water levels is also indirectly confirmed by the insignificant and low correlation of summer and autumn Hnp with precipitation ($\rho = 0.24$ and 0.08, respectively) and the insignificant correlation with air temperature ($\rho = -0.03$ and 0.08, respectively), which is also inverse to that expected in autumn. According to the linear trend, the autumn changes in Hs were relatively small (12 cm increase) during the studied period, while Hvp remained practically the same. The small changes in water levels are probably due to the insignificant changes in autumn precipitation (0.5% increase) and the relatively modest increase in autumn temperatures (1.5 °C increase; the smallest of all seasons). This is indirectly supported by the high to very high correlation of Hs and Hvp in fall with precipitation ($\rho = 0.64$ and 0.86, respectively), while the correlation with temperature is insignificant.

In winter, the trend in water levels is similar to that in autumn, with Hnp rising in winter (49 cm) and Hs and Hvp experiencing no major changes. Hs has fallen slightly (8 cm), while Hvp has remained practically the same. The small change in the average water level in winter is also illustrated by the almost identical values of the average water levels in December, January and February at the Dolenje Jezero gauging station when comparing the periods 1961–1990 and 1991–2020 (Figure 3). The small changes in water levels are probably due to the relatively small change in winter precipitation

(6% decrease), which is also reflected in the medium to high correlation of Hs and Hvp in winter with precipitation (ρ = 0.63 and 0.46, respectively). There was also a significant increase in winter temperature (1.9 °C) over the period studied, but due to the otherwise low temperatures at this time of year, this has no significant effect on the increased evaporation and thus the lower runoff. The latter is also reflected in the correlation of winter Hnp, Hs and Hvp with temperature ($0.19 < \rho < 0.23$), which has a positive sign. Hs in winter remains at a similar level, possibly because the decrease in winter precipitation is compensated to some extent by faster runoff. This is a result of the already mentioned weaker effect of snow retention (less snowfall in winter and faster melting and runoff of newly fallen snow due to warmer temperatures). The reduced effect of snow retention is probably also the cause of the increase in winter Hnp.

Above is a vertical overview of the changes in the analysed meteorological and hydrological variables by season and below a horizontal overview of the changes in the individual water levels (Hnp, Hs, Hvp) of Cerknica Lake over the course of the year. The mean water level (Hs) has decreased in the period 1961–2020 both on an annual and seasonal level (with the exception of autumn, when a slight increase is recorded), and its changes coincide with lower precipitation, higher temperatures and higher evaporation. The decline in Hs is greatest in spring and summer, when changes in precipitation and temperature are also greatest. The maximum water levels (Hvp) also show a decline (except in winter and autumn, where there were practically no changes). Here too, the decline was greatest in spring and summer due to lower precipitation and higher temperatures. The decline in Hs and Hvp in spring and summer could also be related, at least to a small extent, to the aforementioned phasing out of some experimental damming measures in the late 1960s (Kebe, 2011; Kranjc, 1986). The lowest water levels (Hnp), on the other hand, are characterised by an increase (except in spring) that contrasts with the observed changes in precipitation and temperature. The increase in Hnp on an annual basis and in summer and autumn, when water levels are generally lowest, can be explained (as far as the above-mentioned questionable methodology for recording the lowest water levels allows) by the artificial water retention at low water levels behind the dam at Rešeto (Schein, 2020; Tratnik, 2023). However, the Hnp in winter and spring are generally higher than the Hnp in summer and autumn and exceed 150 cm at the Dolenje Jezero gauging station in about half of the years of the study period, which means that the water retention behind the dam at Rešeto has a relatively smaller influence on them than in summer and autumn. In a good third of cases, they also exceed 200 cm, when the water of Cerknica Lake begins to overflow in large quantities over the dam of Brkinov Laz towards Jamski Zaliv (Habič, 1974; Tratnik, 2023), and thus a significant part of the water in Karlovica and in many other ponors and sinkholes downstream of Rešeto begins to sink. Given the similar distribution of winter and spring Hnp occurrence in relation to the overflow heights of the dam at Rešeto and the Brkinov Laz dam, we conclude that the effects of anthropogenic interventions on Hnp are similar in both seasons and that the reason for this different trend is probably largely due to climate change. The increase in Hnp in winter (49 cm) and the simultaneous decrease in Hnp in spring (42 cm) may be due to the aforementioned weakening effect of snow retention. Although the additional winter inflow to the lake from this source has no influence on the increase in Hnp in winter, it may nevertheless influence the increase in minimum water levels in the complex karst recharge system of Cerknica Lake. However, the lack of spring inflow to the lake due to the reduced influence of snow retention is probably only an additional factor for the already abundant decrease in water levels in spring (as a result of the above-mentioned lower precipitation and higher temperatures), which is also reflected in the summer Hnp.

The correlation between annual and seasonal water levels (Hnp, Hs and Hvp) and precipitation or air temperature is generally relatively low, especially for temperature, where the sign of the correlation is also inconsistent between years and between different water levels. In one third of the cases (10) at least a medium correlation ($0.40 < \rho < 0.59$) is reported, in two cases a high correlation ($0.60 < \rho < 0.79$) and in only one case a very high correlation ($\rho > 0.80$). The lower correlation is probably influenced by several factors, both natural and anthropogenic. One of them is certainly the karst retention effect, which causes the water level of Cerknica Lake to react to precipitation with a certain delay and the water level in the lake remains high for a long time after precipitation. Blatnik et al. (2024), for example, found the highest correlation between the daily water level of Cerknica Lake and the sum of the preceding 45 days of effective precipitation (precipitation minus evapotranspiration) for the period 1954–2022. The second reason is methodological, as we used actual and not effective precipitation in the present study. The third reason is the numerous anthropogenic interventions in outflow, which had different effects at different times at different water levels (Blatnik et al., 2024; Habič, 1974). The higher correlation between water levels (Hnp, Hs and Hvp) and precipitation compared to the correlation between water levels and air temperature, both on an annual and seasonal basis, indicates a generally higher influence of precipitation on lake water levels. The slightly stronger negative correlation between water level and air temperature (which is still lower than the correlation between water level and precipitation) is only observed in spring and summer and indicates a stronger influence of temperature on water levels, especially in the warmer season when evaporation is also more intense during the growing season.

7 CONCLUSION

Climate change affects the discharge regime of watercourses and the water levels of lakes. We selected the intermittent Cerknica Lake to study the effects of climate change because its karstic nature makes it even more susceptible to any kind of change (including climate change). In this paper, we investigated the annual and seasonal changes in the water level of Cerknica Lake between 1961 and 2020 and tried to find correlations with local climate change. To this end, we analysed the annual and seasonal changes in precipitation, snow cover and air temperature, the changes in minimum (Hnp), mean (Hs) and maximum (Hvp) water levels of Cerknica Lake, and the trends in minimum (Qnp), mean (Qs) and maximum (Qvk) discharges of the Cerkniščica River in the area of Cerknica polje and its immediate catchment.

The analyses of meteorological and hydrological variables indicate a significant change in the water balance of Cerknica Lake during the period under study. The amount of precipitation in the area of Cerknica polje decreased by 11% or almost 200 mm. The decrease was most pronounced in summer (30%) and spring (20%). The amount of new snow fell by 20% and the average snow cover by 57%. The air temperature rose by 2.5 °C. It warmed the most in summer (3.2 °C) and spring (2.3 °C). Cerknica Lake has received less and less water over the years, which is reflected in a 16 cm decrease in the average annual water level (Hs). According to the linear trend equation, the maximum water level (Hvp) has fallen by 30 cm and the minimum water level (Hnp) has risen by 48 cm. The decrease in Hs and Hvp is mainly related to lower precipitation and higher air temperatures, which have led to an increase in evaporation, and to a lesser extent perhaps also to the phasing out of some anthropogenic water retention measures from the late 1960s, which at that time reduced runoff during mean and high water and led to prolonged flooding. However, the increase in Hnp (as far as the unreliability of the data at low water levels allows) can probably be linked to the artificial retention of water in the lake behind the repeatedly rebuilt and raised dam at Rešeto at low water levels, which is intended to preserve fish populations.

In spring, Hs, Hnp and Hvp of Cerknica Lake decreased significantly (62 cm, 42 cm, 32 cm). In summer, Hvp (74 cm) and Hs (54 cm) decreased and Hnp increased by 40 cm. In the fall, changes were limited to a 47 cm increase in Hnp, while changes in Hs were relatively small (12 cm increase) and Hvp remained virtually the same. In winter, Hnp also rose by 49 cm, while Hs and Hvp remained almost unchanged. The seasonal changes in the water level of Cerknica Lake in the case of Hs and Hvp, which decrease mainly in spring and summer, can be attributed to a considerable extent to the higher seasonal temperatures and increased evaporation as well as to the lower seasonal precipitation and partly perhaps also to the aforementioned phasing out of some of the anthropogenic high and medium water retention measures of the late 1960s. The lowest water levels (Hnp) show a seasonal increase (except in spring) that is similar to the annual increase, which contrasts with the observed changes in precipitation and temperature. The increase in Hnp in summer and autumn (which are usually also the lowest water levels of the year) can be linked to the artificial retention of water behind the Rešeto dam during the lowest water levels (as far as the unreliability of the data at the lowest water levels allows), as with the annual Hnp. However, the changes in Hnp in winter and spring (which are significantly higher than Hnp in summer and autumn and therefore less dependent on water retention at low water levels) can probably be linked to climate change and the associated decrease in snow retention.

Despite the relatively low correlation of annual and seasonal Hnp, Hs and Hvp with precipitation and air temperature, where at most one third of the relationships show at least a medium correlation ($0.40 < \rho < 0.59$), it can be concluded that climate change has a decisive influence on the changes in water level in the lake – especially for the mean water levels (Hs) and the maximum water levels (Hvp). Low water levels (Hnp) are more likely to be caused by anthropogenic interventions in the outflow than by climate change. The latter have been numerous in the past, sometimes with the aim of accelerating outflow, other times to retain water in the lake. Their impact on water level is difficult to assess objectively due to their often contradictory effects, the alternation between wet and dry years and the intermittent nature of the lake itself.

References

Andjelov, M., Frantar, P., Pavlič, U., Rman, N., Souvent, P., 2021. Količinsko stanje podzemnih voda v Sloveniji. Ljubljana: ARSO.

ARSO [Agencija Republike Slovenije za okolje], 2014. Hidrološko poročilo o poplavah v dneh od 8. do 27. februarja 2014. URL: https://www.arso.gov.si/vode/poro%c4%8dila%20in%20publikacije/Porocilo%20poplave%208-27%20feb%202014%20splet.pdf (accessed 04.08.2022).

ARSO [Agencija Republike Slovenije za okolje], 2022. Meteorološki in hidrološki podatki. URL: https://www.arso.gov.si/ (accessed 16.08.2022)

Bertalanič, R. et al., 2018: Ocena podnebnih sprememb v Sloveniji do konca 21. stoletja. Sintezno poročilo – prvi del. Ljubljana: ARSO.

Bidovec, M., 2007. Pretekli posegi na Cerkniškem jezeru. Novice Notranjskega regijskega parka, 1, 2, pp. 2–7.

Blatnik, M., Gabrovšek, F., Ravbar, N., Frantar, P., Gill, L. W., 2024. Assessment of climatic and anthropogenic effects on flood dynamics in the Cerkniško Polje (SW Slovenia) based on a 70-year observation dataset. Journal of Hydrology: Regional Studies, 51 (*in press*).

Bonacci, O., 1987. Man's influence on the water regime in the karst terrains. V: Bonacci, O. (ed.). Karst hydrology: with special reference to the Dinaric karst. Berlin: Springer, pp. 150–173.

Bonacci, O., 2014. Ecohydrology of karst poljes and their vulnerability. V: Sackl P., Durst, R., Kotrošan, D., Stumberger, B. (ed.). Dinaric karst poljes – floods for life. Radolfzell: EuroNatur, pp. 25–37.

Frantar, P. (ed.), 2008. Vodna bilanca Slovenije 1971–2000. Ljubljana: Ministrstvo za okolje in prostor, Agencija Republike Slovenije za okolje.

Frantar, P., Hrvatin, M., 2005. Pretočni režimi v Sloveniji med letoma 1971 in 2000. Geografski vestnik, 77, 2, pp. 115–127.

Gaberščik, A., Grašič, M., Abram, D., Zelnik, I., 2020. Water level fluctuations and air temperatures affect common reed habitus and productivity in an intermittent wetland ecosystem. Water 2020, 12, 10, pp. 2806.

Gaberščik, A., Urbanc-Berčič, O., Kržič, N., Kosi, G., Brancelj, A., 2003. The intermittent Lake Cerknica: Various faces of the same ecosystem. Lakes & Reservoirs Research & Management, 8, 3–4, pp. 159–168.

Gams, I. 1965. Aperçu sur l'hydrologie du karst Slovene et sus communications souterraines. Naše jame, 7, 1–2, pp. 51–60.

Gams, I. 1974. Kras v Sloveniji v prostoru in času. Ljubljana: Založba ZRC, ZRC SAZU.

George, G. (ed.), 2010. The impact of climate change on European lakes. Dordrecht, New York: Springer.

Habič, P., 1974. Tesnenje požiralnikov in presihanje Cerkniškega jezera. Acta carsologica, 6, pp. 35–56.

Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Archfield, S. A., Gilroy, E. J., 2020. Statistical methods in water resources. Reston: U.S. Geological Survey. DOI: 10.3133/tm4a3.

Hrvatin, M., Zorn, M., 2020. Climate and hydrological changes in Slovenia's mountain regions between 1961 and 2018. Economic- and Ecohistory 16, 1, pp. 201–218.

IPCC, 2022. Climate Change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.). Cambridge University Press (*in press*).

Kayastha, M. B., Ye, X., Huang, C., Xue, P., 2022. Future rise of the Great Lakes water levels under climate change. Journal of Hydrology, 612, B, pp. 128–205.

Kebe, J., 2011. Cerkniško jezero in ljudje ob njem. Koper: Ognjišče.

Kobold, M., Dolinar, M., Frantar, P., 2012. Spremembe vodnega režima zaradi podnebnih sprememb in drugih antropogenih vplivov. I. kongres o vodah Slovenije, pp. 7–22.

Kolbezen, M., 1998. Hidrografija. In: Gams, I., Vrišer, I. (ed.). Geografija Slovenije. Ljubljana: Slovenska matica, pp. 139–172.

Kolbezen, M., Pristov, J., 1998. Površinski vodotoki in vodna bilanca Slovenije. Ljubljana: Ministrstvo za okolje in prostor, Hidrometeorološki zavod Republike Slovenije.

Kovačič, G., 2009. Hidrologija kraškega izvira Malenščica in njegovega hidrografskega zaledja. Doctoral dissertation. Koper: Univerza na Primorskem, Fakulteta za humanistične študije.

Kovačič, G., 2010. An attempt towards an assessment of the Cerknica polje water balance. Acta carsologica, 39, 1, pp. 39–50.

Kovačič, G., 2016. Trendi pretokov rek jadranskega povodja v Sloveniji brez Posočja. Geografski vestnik, 88, 2, pp. 9–29.

Kovačič, G., Ravbar, N., 2010. Extreme hydrological events in karst areas of Slovenia, the case of the Unica River basin. Geodinamica Acta, 23, 1–3, pp. 89–100.

Kranjc, A., 1986. Cerkniško jezero in njegove poplave. Acta geographica, 25, pp. 75–123.

Kranjc, A., 2005. Kako nastaja in izginja Cerkniško jezero? »Jezero, ki izginja« – monografija o Cerkniškem jezeru. Kras: revija o Krasu in krasu, o ljudeh in njihovem ustvarjanju, 70, pp. 12–17.

Lenters, J. D., Kratz, T. K., Bowser, C. J., 2005. Effects of climate variability on lake evaporation: Results from a long-term energy budget study of Sparkling Lake, northern Wisconsin (USA), 308, 1–4, pp. 168–195.

Life Stržen. 2019. URL: http://life.notranjski-park.si/sl/ (accessed 14.10.2019).

Lukan, A., 2017. Razvoj turizma v okolici Cerkniškega jezera. Ljubljana: Ekonomska fakulteta. URL: http://www.cek.ef.uni-lj.si/vps_diplome/lukan744.pdf (accessed 15.09.2022).

Makesens-application for trend calculation. 2021. URL: https://en.ilmatieteenlaitos.fi/makesens (accessed 13.05.2021).

Mayaud, C., Gabrovšek, F., Blatnik, M., Kogovšek, B., Petrič, M., Ravbar, N., 2019. Understanding flooding in poljes: a modelling perspective. Journal of Hydrology, 575, pp. 874–889.

Miklič, S., 2021. Spreminjanje vodostaja Cerkniškega jezera v obdobju 1958–2019. Master's thesis. Oddelek za Geografijo, Filozofska fakulteta, Univerza v Ljubljani.

Morrissey, P., Nolan, P., McCormack, T., Johnston, P., Naughton, O., Bhatnagar, S., Gill, L., 2021. Impacts of climate change on groundwater flooding and ecohydrology in lowland karst. Hydrology and Earth System Sciences, 25, pp. 1923–1941. DOI: 10.5194/hess-25-1923-2021.

Občina Cerknica. URL: https://www.stat.si/obcine/sl/Municip/Index/18 (accessed 15.09.2022).

Ogrin, D., 1996. Podnebni tipi v Sloveniji. Geografski vestnik, 68, pp. 39–56.

Perko, D., Orožen Adamič, M. (eds.), 1998. Slovenija. Pokrajine in ljudje. Ljubljana: Mladinska knjiga.

Petrič, M., Ravbar, N., Gostinčar, P., Krsnik, P., Gacin, M., 2020. Vzpostavitev prosto dostopne GIS zbirke rezultatov sledenj toka podzemne vode in možnosti njene uporabe. Geologija, 63, 2, pp. 203–220.

Pravilnik za obratovanje in vzdrževanje zapornice Nova Karlovica na Cerkniškem polju. 2014. URL: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiRqeGSpNqCAxVXhP0HHSUPBswQFnoECBMQAQ&url=https%3A%2F%2Frdcerknica.si%2Fwp-content%2Fuploads%2F2021%2F12%2FPRAVILNIK-ZA-OBRATOVANJE-IN-VZDRZEVANJE--NOVA-KARLOVICA.pdf&usg=AOvVaw0Ru4c8SYzdPLsmEZSo9LwD&opi=89978449 (accessed 22.11.2022).

Pustovrh Benda, M., 2015. Prikaz stanja prostora za območje občine Cerknica. URL: https://cerknica.eobcina.si/files/other/acts/31/9528Prikaz%20stanja%20prostora%202.pdf (accessed 19.09.2022).

Ravbar, N., Mayaud., C., Blatnik, M., Petrič, M. 2021: Determination of inundation areas within karst poljes and intermittent lakes for the purposes of ephemeral flood mapping. Hydrogeology Journal, 29, pp. 213–228. DOI: 0.1007/s10040-020-02268-x.

Schein, T., 2020. Posegi na Cerkniškem jezeru (personal information, 8. 10. 2020). Cerknica.

Smrekar, A. 2000: Cerkniško polje kot primer poseljenega kraškega ranljivega območja. Geographica Slovenica, 33, 1, pp. 117–156.

Spearmanov koeficient korelacije. URL: https://www.statistik.si/spearmanov-koeficient/ (accessed 12.10.2022).

Stepišnik, U., 2020. Kraška polja v Sloveniji. Dela, 53, pp. 23–43. DOI: 10.4312/dela.53.23-43.

Stepišnik, U., Ilc Klun, M., Repe, B., 2017. Vrednotenje izobraževalnega potenciala geodiverzitete na primeru Cerkniškega polja. Dela, 47, pp. 5–21.

SURS [Statistični urad Republike Slovenije = Statistical Office of the Republic of Slovenia], 2022. Prebivalstvo. URL: https://pxweb.stat.si/SiStat/sl/Podrocja/Index/100/prebivalstvo (accessed 15.09.2022).

Torabi Haghigi, A., Kløve, B., 2015. A sensitivity analysis of lake water level response to changes in climate and river regimes. Limnologica, 51, pp. 118–130.

Tratnik, D., 2023. Posegi na Cerkniškem jezeru (personal information, 22.11.2023). Cerknica.

Trobec, T., 2022. Vpliv podnebnih sprememb na vode v Sloveniji. Geomix, 29, 2, pp. 37–40.

Turk, J., Pipan, T., 2009. Cerkniško polje. URL: http://www.dedi.si/dediscina/9-cerknisko-polje (accessed 18.02.2022).

Van der Kamp, G., Keir, D., Evans, M. S., 2008. Long-term water level changes in closed-basin lakes of the Canadian prairies. Cannadian Water Resources Journal, 33, pp. 23–38.

Vertačnik, G., Bertalanič, R., 2017. Podnebna spremenljivost Slovenije v obdobju 1961-2011. Značilnosti podnebja v Sloveniji. Ljubljana: Agencija Republike Slovenije za okolje .

Vincent, W. F., 2009. Effects of climate change on lakes. In: Likens, G. E. (ed.). Encyclopedia of Inland Waters. Elsevier, pp. 55–60.

Wrzesiński, D., Ptak, M., 2016. Water level changes in Polish lake during 1976–2010. Journal of Geographical Sciences, 26, pp. 83–101. DOI: 10.1007/s11442-016-1256-5.

Zhelezov, G., Varbanov, M., Germ, M., Gaberscik, A. 2011. Hydrological characteristics and related ecosystem services of Srebarna and Cerknica lakes. Problems of geography, 1–2, pp. 107–118.

Blaž Repe*, Tina Pavlin*

SUBAQUEOUS SOIL SEQUENCE IN MARINE WATERS OF THE STRUNJAN BAY

Izvirni znanstveni članek
COBISS 1.01
DOI: 10.4312/dela.59.151-177

Abstract

Soil research focuses mainly on soils on land, but the process of soil formation also takes place in shallow waters. Subaqueous soils form below the water surface, mainly on the bottom of shallow, stagnant waters such as bogs, swamps, lakes, and shoals in the sea. Three subaquatic soil profiles were investigated in the Strunjan Bay to study them in detail. The sites for the soil investigation were selected after observing the movement of seawater and thus its possible influence on subaquatic soils. All the soils studied are permanently and year-round under water. Therefore, all soil samples were collected under water using drainage pipes and by excavation. The samples were slowly drained in the pipes to prevent mixing of the material and to keep the horizons as intact as possible. Visual observations and standard analyses were carried out in the laboratory according to the identified horizons. During the investigation, we found that apart from water properties and movement, most soil-forming factors can be considered constant, so we investigated and presented a soil hydrosequence. According to the WRB classification, the subaqueous soils in the waters of the Strunjan Bay were divided into the reference groups Gleysols and Leptosols.

Keywords: soil geography, subaqueous soils, soil forming factors, WRB soil classification, the Strunjan Bay, Slovenia

* Department of Geography, Faculty of Arts, University of Ljubljana, Aškerčeva cesta 2, SI-1000 Ljubljana, Slovenia
e-mail: blaz.repe@ff.uni-lj.si, tinkara.pavlin@gmail.com
ORCID: 0000-0002-5530-4840 (B. Repe)

GENETSKO ZAPOREDJE PODVODNIH PRSTI V STRUNJANSKEM ZALIVU

Izvleček

Raziskovanje prsti se v glavnem osredotoča predvsem na prsti na kopnem, vendar se pedogenetski procesi nastajanja prsti pojavljajo tudi v plitvih vodah. Podvodne prsti nastajajo pod vodno gladino, predvsem na dnu plitvih, stoječih voda, kot so barja, močvirja, jezera in morske plitvine. V Strunjanskem zalivu smo proučevali tri podvodne profile prsti z namenom, da bi jih podrobneje raziskali in predstavili. Lokacije za raziskavo prsti so bila izbrane glede na opazovanje gibanja morske vode in posledično njenega možnega vpliva na podvodne prsti. Vse proučevane prsti so stalno in vse leto pod vodo, zato so bili vsi vzorci tal zbrani pod vodo z drenažnimi cevmi in s pomočjo izkopa. Vzorce smo počasi izsušili v samih ceveh in s tem preprečili mešanje gradiva in ohranitev horizontov. V laboratoriju smo opravili vizualna opazovanja in standardne analize za vsakega od prepoznanih horizontov. Med raziskavo smo ugotovili, da lahko poleg lastnosti vode in njenega gibanja večino pedogenetskih dejavnikov smatramo za konstantne, zato smo proučili in predstavili pedogenetsko hidrosekvenco prsti. Podvodne prsti pod vodo Strunjanskega zaliva so bile po mednarodni WRB klasifikaciji prepoznane in uvrščene v referenčni skupini *Gleysols* in *Leptosols*.

Ključne besede: geografija prsti, podvodne prsti, pedogenetski dejavniki, WRB klasifikacija, Strunjanski zaliv, Slovenija

1 INTRODUCTION

Soil is an unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants (Gregorich et al., 2001). When we think of soils, we generally think of soils on land. Agricultural soils in particular are usually found on land, but soils also occur in shallow waters. Subaqueous soils form below the water table, especially at the bottom of shallow standing waters, e.g. in bogs, swamps and lakes (Bufon et al., 2005) and are very poorly studied. There are several reasons for this. Research (especially soil sampling) is extremely difficult, these soils have little economic value, and there are differing opinions as to whether this material is soil at all. Although some researchers (Goldschmidt, 1958; Kubiëna, 1953; Mückenhausen 1965) recognised this underwater material as soils as early as the middle of the last century, most researchers (geologists, biologists) consider them to be merely underwater sediments (Demas et al., 1996). The pioneering study of underwater material in the Maryland area (Demas, 1998) led to a change in definitions in soil taxonomy in 1999 (Payne, Turenne, 2009). The International WRB

Classification included subaqueous soils with the definition that *any material within 2 m from the Earth's surface that is in contact with the atmosphere, with the exclusion of living organisms, areas with continuous ice not covered by other material, and water bodies deeper than 2 m* (IUSS Working Group WRB, 2006).

In 1972 Folger (1972) described the primary factors that influence the composition and distribution of estuarine sediments. Together, therefore, the factors of Jenny and Folger form a (new) equation (Balduff, 2007):

$$p_e = f(p, cl, o, t, B, F, W, E) + H$$

in which subaqueous soils (p_s) are a function (*f*) soil forming factors: climate (*cl*), organisms (*o*), bathymetry (*B*), waterflow properties (*F*), parent material (*p*), time (*t*), chemical properties of water (*W*) and extreme events (*E*). The latter two factors were added later (Balduff, 2007) and human (*H*) influences were added separately. By examining the soils and the forming factors, we aimed to determine a hydrosequence. A soil hydrosequence refers to a series or sequence of soils arranged in a specific order, typically associated with variations in moisture content, drainage patterns and other hydrological factors. These sequences are often found in landscapes where water availability varies, such as wetlands, floodplains, or coastal regions. Soils within a hydrosequence have different characteristics and properties that are influenced by their location in the landscape and their relationship to water movement and availability. Typically, a hydrosequence includes soils adapted to different levels of water saturation, from well-drained soils in higher elevations or drier areas to poorly drained or waterlogged soils in lower elevations or wetter areas (Lin, 2012).

The main goal of the research was to investigate the soils on a certain location (the Strunjan Bay) at the Slovenian coast that are permanently under water, their inventory, and describe a soil hydrosequence.

1.1 A brief introduction to the classification of subaqueous soils

The sediments deposited in the water were mainly studied by geologists and biologists. The first initiative that some of the material was also the subject of pedology appeared in 1862, when von Post proposed the terms "*gyttja*" and "*dy*", which are still used today (von Post, 1862, cited in Demas, 1998). Research continued 100 years later. Kubiëna (1953) included subaqueous soils in his classification of European soils and divided them into two categories: 1. young soils that are constantly flooded with water and do not form peat, and 2. young subaqueous soils that form peat. Mückenhousen (1965) contributed to the classification of German soils by identifying subaqueous soils as sub hydric and dividing them into four groups (protopedon, gyttja, sapropel and dy). Soil Taxonomy of subaqueous soils includes specific taxa within Entisols and Histosols, such as "Wassents" and "Wassists" (Soil Survey Staff, 2010). The latest version of the WRB classification (Repe, 2018) does not have a special subaqueous group but defines it with specific material and qualifiers within Histosols, Technosols, Cryosols, Leptosols, Gleysols, Arenosols and Fluvisols. Among others, there are certain diagnostic features such as horizons (anthraquic, histic, hydragric), properties (gleyic, stagnic), materials (fluvic, limnic, organic) that indicate the possible presence of subaqueous soils. There are also some qualifiers directly (Floatic, Subaquatic, Tidalic) or indirectly (Fibric, Hemic, Sapric) associated with subaquatic soils (IUSS Working Group WRB, 2022). Subaqueous soils were included in the Yugoslav classification (Antić et al., 1982; Škorić, 1977) as subaquatic or subhydric, which was also adopted by the Slovenian classification (Prus, 2000; Repe, 2010), but without any serious research (Repe, Pristovšek, 2022; Repe, Pristovšek, Pavlin, 2019).

Figure 1: Research area of the Strunjan Bay.

2 METHODS

For the study, we chose subaqueous soils along the coast of the Slovenian Sea. We were looking for an accumulative, lagoonal coastal type (Bat et al., 2003; Radinja, 1990), which is constantly submerged and has different seawater influences, to study the soil hydrosequence. This means that three sites were selected in the waters of the Strunjan Bay (Strunjanski zaliv) (Figure 1).

2.1 Research area, soil forming factors and processes

The selected area of the Strunjan Landscape Park covers 428.6 ha and 4 km of the shore of the Gulf of Trieste. The park includes the Strunjan peninsula from Simon's Bay (Simonov zaliv) to the mouth of the Strunjan – Roja river, including a 200-metre-long strip of sea and the inner part of the Strunjan Bay. The Strunjan peninsula is located in the flysch landscape on the Slovenian coast. Flysch is a mechanically quite unstable rock, so the cliff areas are exposed to strong lateral processes. Large boulders and coarse material quickly accumulate directly on the coast and underwater, so the chances of soil formation are very low. Fine material is carried away by sea currents or waves, or accumulates under boulders. A large part of the Strunjan Bay consists of salt marshes that continue into the Strunjan Valley. The geomorphology of the Strunjan Peninsula is largely determined by geological features. The predominant material is flysch from the Eocene, generally consisting of alternating layers of lapis and sandstone. The lack of resistance of the rocks emphasises mechanical and chemical weathering). An important element of the park is the Stjuža, the only marine lagoon on the Slovenian coast. More than 200 years ago, this lagoon was an open bay, which was then closed by a dike. This cut off the direct connection to the sea. Today, the only connection to the sea is via a channel (Hoyer et al., 1986). It is divided into the Great Lagoon and the Transitional Lagoon (DOPPS, 2018). Since it is closed, the name Stjuža also derives from the Italian word *chiusa* – closed. The water movement is tidal, there are no waves or currents in the lagoon (Hoyer et al., 1986).

According to the Köppen climate classification, the coastal zone up to an altitude of 350 m is classified as a temperate warm-humid climate with hot summers (Cfa). Compared to the Mediterranean climate (Cs), there is more precipitation distributed more evenly throughout the year, less pronounced dryness in summer and generally lower temperatures throughout the year. In the coastal zone there is a so-called temperate Mediterranean coastal climate (locally known as the climate of the olive tree, Olea europaea) or sub-Mediterranean climate (Ogrin, 1993; 1996; 2012).

Shallowness is an important feature of the Slovenian Sea (Bat et al., 2003; Ogrin, Plut, 2009; Radinja, 1990). The Gulf of Trieste descends rapidly and irregularly along the Slovenian coast. Sea water temperatures in the Gulf of Trieste typically reach their lowest point in February (8–9 °C) and their highest point in August (about 24 °C).

Therefore, the average annual amplitude is 15–16 °C. The average annual water temperature is about 16 °C, 2–3 °C higher than the average annual air temperature. The sea never freezes over. The Gulf of Trieste has a salinity of 37–38‰, which is higher than in the oceans. The salinity varies according to the seasons and the freshwater inflow into the bay. During the rainy season, the salinity of the water at the mouths of rivers and streams can fall below 20‰ (Kolbezen, 1998; Ogrin, Plut, 2009). The Slovenian Sea is characterised by high turbidity (poor transparency) due to its muddy and fine sandy bottom, shallow water depth, and high nutrient and plankton load. Many dead particles and transitions between water layers with different temperatures and salinities also contribute to higher turbidity and poorer visibility in the lower layers. Typical visibility at the surface is 6–8 m (Ogrin, Plut, 2009). The currents in the Gulf of Trieste are rather weak and already turn mostly to the west along the southern coast of Istria. The current that reaches the Gulf of Trieste flows north and northwest along the Slovenian coast before returning to the southern Adriatic along the Italian coast. The speed of the current is generally no more than 1.5 km/h. The tidal range off the Slovenian coast is a mixed type, with two tides alternating on a lunar day (24 hours and 50 minutes). The average tidal range is 66 cm in Koper and 88 cm in the Gulf of Trieste. Very high waves with destructive force are generated by strong local winds (especially storms) (Maček, Žabkar, Ušeničnik, 2002). The Stjuža lagoon hosts salt-loving (halophytic) vegetation that has developed on a silty substrate, mainly due to salinity, water availability, the soil type itself and microtopography. The halophytic and brackish vegetation started to develop when the bay was closed with dykes and the lagoon was created. Due to changes in hydrological dynamics, sediment deposition and anthropogenic influences, the vegetation cover has expanded throughout the area (Šajna, Kaligarič, 2005). Most of the Stjuža is covered by seagrass, namely *Cymodocea nodosa*, and there is also some *Zostera marina*. The waters of the Stjuža are home to a variety of animal species, mainly shrimps. These are swimming species of decapod crustaceans that play a very important role in the food web of the lagoon ecosystem. In the mud, one of the most abundant species is *Upogebia littoralis*, known to the locals as "*škaradobola*". This crustacean lives in small vertical tunnels in the mud bottom (Lipej, 2004) and is responsible for the vertical mixing of the bottom material (Figure 2).

Like terrestrial soils, subaqueous soils are also subject to pedogenesis. In fieldwork we have the following processes:

- Translocation of material within the soil profile: Diffusion is an important process where the entry of oxygen from seawater into the soil causes the surface horizons to become coated with iron oxides and take on a brown colour. In the case of impermeable cover by dead vegetation, this influx is stopped, and reduction takes place (grey and blackish hues). Bioturbation is also important, where organisms (marine worms and crabs) move organic material mainly downwards, up to half a metre into the bottom profile.

- Transformation of material: Mineral material is transformed very little under anaerobic conditions. As a result, larger, sandy particles are abundant in our subaqueous soils. Organic material is subject to anaerobic microbial decay processes that prevent oxygen from reaching the soils. The putrefaction processes lead to sulphidisation (anaerobic formation of iron sulphide compounds (FeS, Fe_3S_4, FeS_2) (Demas, Rabenhorst, 1999) and the release of gases (H_2S) with a distinctly unpleasant odour.
- Inputs of pedogenesis. These are mainly mineral (weathered rock debris carried in by terrestrial waters) and biogenic substances. Of the latter, organic matter is the most important and contributes significantly to the high proportions of poorly weathered organic matter. Biogenic matter also includes fine shell particles, which contribute to the higher $CaCO_3$ content. The mineral and organic fractions are mixed by seawater movement and often overlap at the surface.
- Outputs of pedogenesis. The most common output in subaqueous soils is related to subaqueous erosion, where wave action and currents carry material from surface horizons to deeper areas of the seabed. Another important output in subaqueous soils is the decomposition of organic material.

Figure 2: Animal (crab) burrow that enables vertical movement of oxygen and soil material (photo: B. Repe).

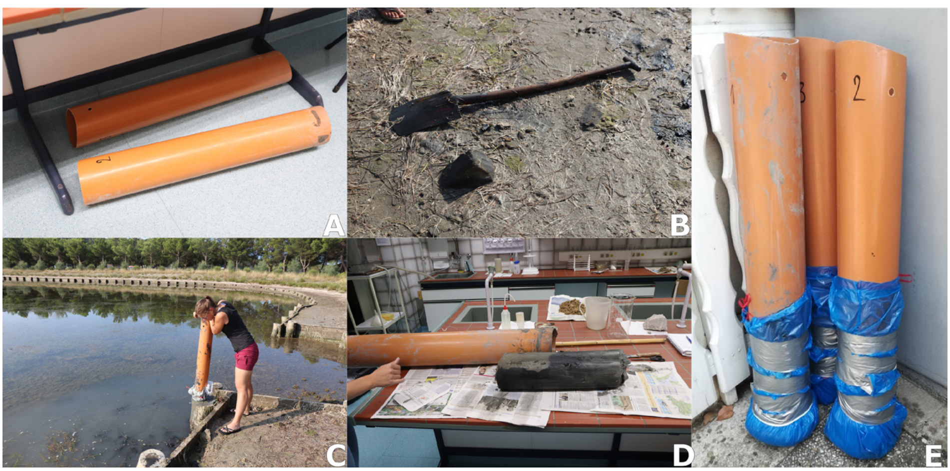
2.2 Soil sampling and analysis

For our investigation we selected three different sites in the Strunjan Landscape Park. The first soil sample was taken in the Stjuža lagoon, the second in the transition area – the channel between Stjuža and the seashore – and the last on the seashore of the Strunjan Bay.

We used sewage pipes with a diameter of 16 cm and a length of 1 m. We drilled holes in the upper part of the pipes and put a metal rod through them to facilitate pushing the pipe into the soil as deep as possible. Under water we excavated the area around the inserted pipe. Then the pipes with the samples were carefully and slowly lifted out of the water, taking care that the soil did not slip out of the pipe. The lower (opened) parts of the pipes were tightly sealed with plastic bags and held together with cable ties and tape. We drilled tiny holes in the bags so that the water could slowly seep away without disturbing the structure of the profile. In this way, the samples were dried outdoors for a month and in the laboratory at room temperature for a week. Later, the samples were pushed out of the pipes, cut lengthwise and the horizons for each sample were determined. An extremely unpleasant odour (rotten eggs) was present. As expected, the odour was most intense in the first sample, only faintly perceptible in the second sample and odourless in the third sample. The dried samples from each horizon were then crushed and sieved and prepared for laboratory analysis. A standard soil analysis was carried out for each horizon of each sample. Electrical conductivity was also measured, and the percentage of shells estimated.

The soil samples were collected in August 2018 and the laboratory analysis was carried out in October 2018. As the processes of formation and change in soil properties

Figure 3: Soil sampling. A) Sewage pipes for taking soil samples; B) Spade for excavating pipes containing samples; C) Soil sampling; D) Extracting the sample from the pipe; E) Drying of soil samples (photos A–D: B. Repe; photo E: T. Pavlin).



are often measured over a period of at least several decades, it is unlikely that the situation investigated to date has changed significantly. An exception could be major human intervention, which was not detected last year (2022).

3 RESULTS

Based on the field observations and measurements as well as the laboratory analyses (Tables 1, 2 and 3), we described the profiles (determining the diagnostic horizons, properties and materials as well as all qualifiers) and finally gave a full name of the soil according to the WRB classification (IUSS Working Group WRB, 2022).

Table 1: Horizon designations and the results of the field measurements and laboratory analysis for the sample No. 1, the Stjuža lagoon.

HOR	DEP	SHEL	COLM	COLD	Sa	Si	Cl	TEXT
C	0,2–0	/	/	2,5Y 5/2	/	/	/	sand
$2H_aC_{r1}$	0–9	1	N1,5/0	5Y 5/2	37,3	47,3	15,4	loam
$2H_aC_{r2}$	9–21	5	N2/0	5Y 5/1	33,3	44,2	22,5	loam
$3AC_{r1}$	21–28	1+	7,5GY 2/1	5Y 5/1	34	51,5	14,5	silt loam
$3AC_{r2}$	29–46	15	5GY 2/1	5Y 5/1	22,7	54,8	22,5	silt loam
$3AC_{r3}$	46–	10	2,5GY 3/1	5Y 5/1	16,5	48,5	35	silt clay loam

HOR	pH	OM	$CaCO_3$	Ece	H	S	CEC	V
C	/	/	33,96	/	/	/	/	/
$2H_aC_{r1}$	6,89	19,23	47,21	7,97	1	50	50,65	98,72
$2H_aC_{r2}$	6,95	20,43	42,24	13,13	2	50	51,3	97,47
$3AC_{r1}$	7,36	22,01	35,61	16,08	1	50	50,65	98,72
$3AC_{r2}$	7,17	18,28	43,07	8,72	2	50	51,3	97,47
$3AC_{r3}$	7,32	15,33	27,33	12,91	2	50	51,3	97,47

HOR – horizon name; DEP – horizon depth; SHEL – % of biogenic shells; COLM – colour in wet state; COLD – colour in dry state; Sa – % of sand fraction; Si – % of silt fraction; Cl – % of clay fraction; TEXT – texture class; pH – PH value; OM – % of organic matter; $CaCO_3$ – % of free calcium carbonate; Ece – electric conductivity (dS/m); H – hydrolytic acidity (mekv); S – sum of all basic cations (mekv); CEC – cation exchange capacity (mekv/ 100g); V – base saturation (%).

Table 2: Horizon designations and the results of the field measurements and laboratory analysis for the sample No. 2, the channel to the Stjuža lagoon.

HOR	DEP	SHEL	COLM	COLD	Sa	Si	Cl	TEXT
C	3–0	/	5Y 3/2	5Y 5/2	31,7	51,8	16,5	silt loam
C_gA_{h1}	0–4	1	5Y 3/1	5Y 5/1	29,2	49,9	20,9	loam
C_gA_{h2}	4–7	1	5Y 2/2	5Y 5/1	34,8	43,4	21,8	loam
C_{r1}	7–15	5+	5Y 2/2	7,5Y 5/1	46,3	39,2	14,5	loam
C_{r2}	15–25	3+	5Y 2/2	5Y 5/1	42	41,7	16,3	loam
C_{r3}	25–	10	5Y 2/2	5Y 5/1	38,6	44,9	16,5	loam

HOR	pH	OM	$CaCO_3$	Ece	H	S	CEC	V
C	7,18	16,63	35,41	28,6	3	50	51,95	96,25
C_gA_{h1}	7,2	16,59	31,4	25,2	2	50	51,3	97,47
C_gA_{h2}	7,49	16,69	38,83	20,3	2	50	51,3	97,47
C_{r1}	6,95	16,89	40,49	12,92	2	50	51,3	97,47
C_{r2}	7,18	17,32	42,96	11,7	3	50	51,95	96,25
C_{r3}	7,09	16,1	45,44	9,53	2	50	51,3	97,47

HOR – horizon name; DEP – horizon depth; SHEL – % of biogenic shells; COLM – colour in wet state; COLD – colour in dry state; Sa – % of sand fraction; Si – % of silt fraction; Cl – % of clay fraction; TEXT – texture class; pH – PH value; OM – % of organic matter; $CaCO_3$ – % of free calcium carbonate; Ece – electric conductivity (dS/m); H – hydrolytic acidity (mekv); S – sum of all basic cations (mekv); CEC – cation exchange capacity (mekv/100g); V – base saturation (%).

Table 3: Horizon designations and the results of the field measurements and laboratory analysis for the sample No.3, seashore of the Strunjan Bay.

HOR	DEP	SHEL	COLM	COLD	Sa	Si	Cl	TEXT
O_i	1–0	/	/	5Y 5/2	87,5	5,7	6,8	loamy sand
AC	0–4	/	2,5Y 3/3	2,5Y 5/2	93,9	1,4	4,7	sand
C_g	4–7	3	5Y 3/2	2,5Y 5/2	88,4	5,2	6,4	loamy sand
C_r	7–9	/	5Y 3/3	5Y 5/2	90,6	1,8	7,6	sand
O_eC_{r1}	9–9,5	/	5Y 2/1	5Y 5/2	/	/	/	/
O_eC_{r2}	9,5–	/	5Y 3/1	5Y 5/2	87,2	7,1	5,7	loamy sand

HOR	pH	OM	$CaCO_3$	Ece	H	S	CEC	V
O_i	7,87	/	75,37	6,5	/	/	/	/
AC	7,04	11,56	70,4	18,52	1	50	50,65	98,72
C_g	8,07	15,3	67,91	1,395	1	50	50,65	98,72
C_r	8,01	16,06	59,63	0,0115	1	50	50,65	98,72
O_eC_{r1}	7,9	/	72,05	$8{,}87x10^{-3}$	/	/	/	/
O_eC_{r2}	7,79	12,94	62,11	$8{,}23x10^{-3}$	1	50	50,65	98,72

HOR – horizon name; DEP – horizon depth; SHEL – % of biogenic shells; COLM – colour in wet state; COLD – colour in dry state; Sa – % of sand fraction; Si – % of silt fraction; Cl – % of clay fraction; TEXT – texture class; pH – PH value; OM – % of organic matter; $CaCO_3$ – % of free calcium carbonate; Ece – electric conductivity (dS/m); H – hydrolytic acidity (mekv); S – sum of all basic cations (mekv); CEC – cation exchange capacity (mekv/100g); V – base saturation (%).

Site No. 1, the Stjuža Lagoon

Figure 4: Sampling site 1 (photo: B. Repe).

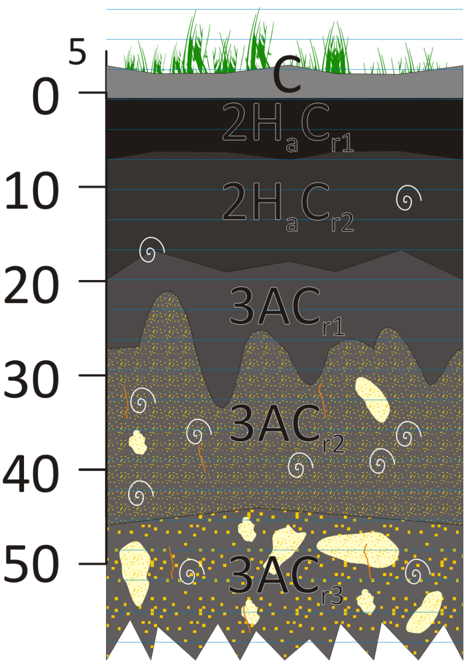
Site description: Location: NW part of the Stjuža Lagoon, N45°31'53.0", E13°36'10.4". Parent material: alluvial silt sediment of the flysch origin. Water conditions: permanently saturated with water, protected from wind, waves and currents; slow vertical tidal movement of water. Vegetation: *Cymodocea nodosa*, *Zostera marina.* Human influences: artificial formation of the lagoon by dike, possible illegal liquid waste deposits – sewage.

Diagnostic horizons: mollic (structure not massive or hard when dry, more than 0.6% organic carbon and more than parent material, moist colour value is lower than 3, base saturation is higher than 50%, it is more than 20 cm thick), salic (electric conductivity is higher than 15 dS/m, the product of ECe in thickness is higher than 450, it is more than 15 cm thick).

Diagnostic properties: gleyic (has reductimorphic colours (N), more than 5% of the oximorphic mottles around root channels).

Diagnostic materials: calcaric (strong effervescence (more than 50% of $CaCO_3$), structure is not disrupted, no concretions, nodules, coatings etc. present), limnic (material partly deposited by water, partly from aquatic plants), mineral (soil properties are dominated by mineral components), hyposulfidic (extreme odour, high pH value, does not cause acidification).

Figure 5: Soil profile 1.



Reference soil group: GLEYSOL (a layer is more than 25 cm thick and starts less than 40 cm from surface, it has gleyic properties throughout, it has reducing conditions in every sublayer).

Principal qualifiers: Subaquatic (permanently under water), Mollic (has a mollic horizon), Calcaric (has a calcaric material throughout), ~~Hypereutric~~ (because of Calcaric, Eutric is redundant).

Supplementary qualifiers: Loamic (dominant loamic texture), Humic (more than 1% of organic carbon), Limnic (has limnic material), Salic (has a salic horizon and ECe more than 30 dS/m), Sodic (does not have a natric horizon and has more than 15% of Na; not confirmed, but most probably), Hyposulfidic (has hyposulfidic material more than 15 cm thick and starting less than 100 cm from the soil surface).

Figure 6: Soil sample 1 (photo: B. Repe).

Complete WRB name: Calcaric Mollic Subaquatic GLEYSOL (Loamic, Humic, Salic, Sodic, Hyposulfidic).

Site No. 2, channel to the Stjuža Lagoon

Figure 7: Sampling site 2 (photo: B. Repe).

Site description: Location: middle section of channel leading from the Strunjan Bay to the SW part of the Stjuža Lagoon, N45°31'41.9", E13°36'16.2". Parent material: alluvial silt and sandy sediment of the flysch origin. Water conditions: permanently saturated with water, protected from wind, waves and currents; slow vertical tidal movement of water; according to the tide, slow lateral movement of water in and out of the lagoon). Vegetation: *Cymodocea nodosa*, *Sarcocornetea fruticose*, *Salicornia europaea*. Human influences: artificial formation of the channel by dike, local port for very small boats.

Diagnostic horizons: mollic (structure not massive or hard when dry, more than 0.6% organic carbon and more than parent material, moist colour value is lower than 3, base saturation is higher than 50%, it is more than 20 cm thick), salic (electric conductivity is higher than 15 dS/m, the product of ECe in thickness is higher than 450, it is more than 15 cm thick).

Diagnostic properties: gleyic (has reductimorphic colours (N), more than 5% of the oximorphic mottles around root channels), stagnic (mottles of reducti- and oxymorphic).

Diagnostic materials: calcaric (strong effervescence (more than 50% of $CaCO_3$), structure is not disrupted, no concretions, nodules, coatings etc. present), mineral (soil properties are dominated by mineral components).

Reference soil group: GLEYSOL (a layer is more than 25 cm thick and starts less than 40 cm from surface, it has gleyic properties throughout, it has reducing conditions in every sublayer).

Principal qualifiers: Subaquatic (permanently under water), Mollic (has a mollic horizon), Oxygleyic (within 100 cm soil does not meets diagnostic criterion 1 of the gleyic properties), Calcaric (has a calcaric material throughout), ~~Hypereutric~~ (because of Calcaric, Eutric is redundant).

Supplementary qualifiers: Loamic (dominant loamic texture), Humic (more than 1% of organic carbon), Limnic (has limnic material), Salic (has a salic horizon and ECe more than 30 dS/m), Sodic (does not have a natric horizon and has more than 15% of Na; not confirmed, but most probably).

Figure 8: Soil profile 2.

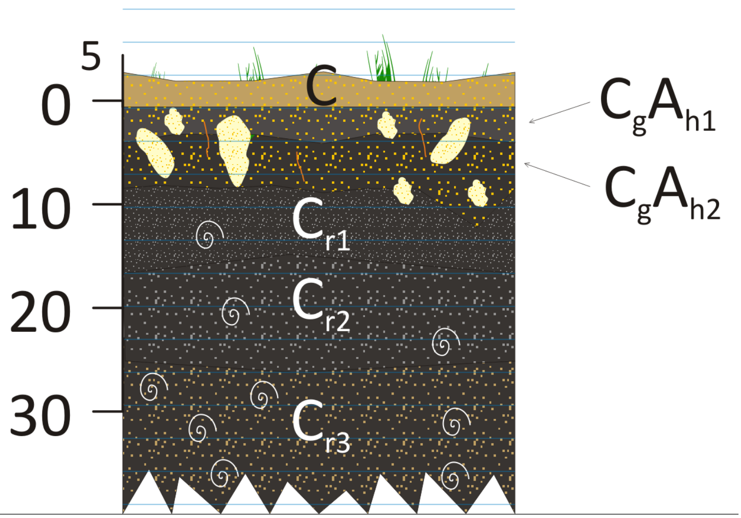
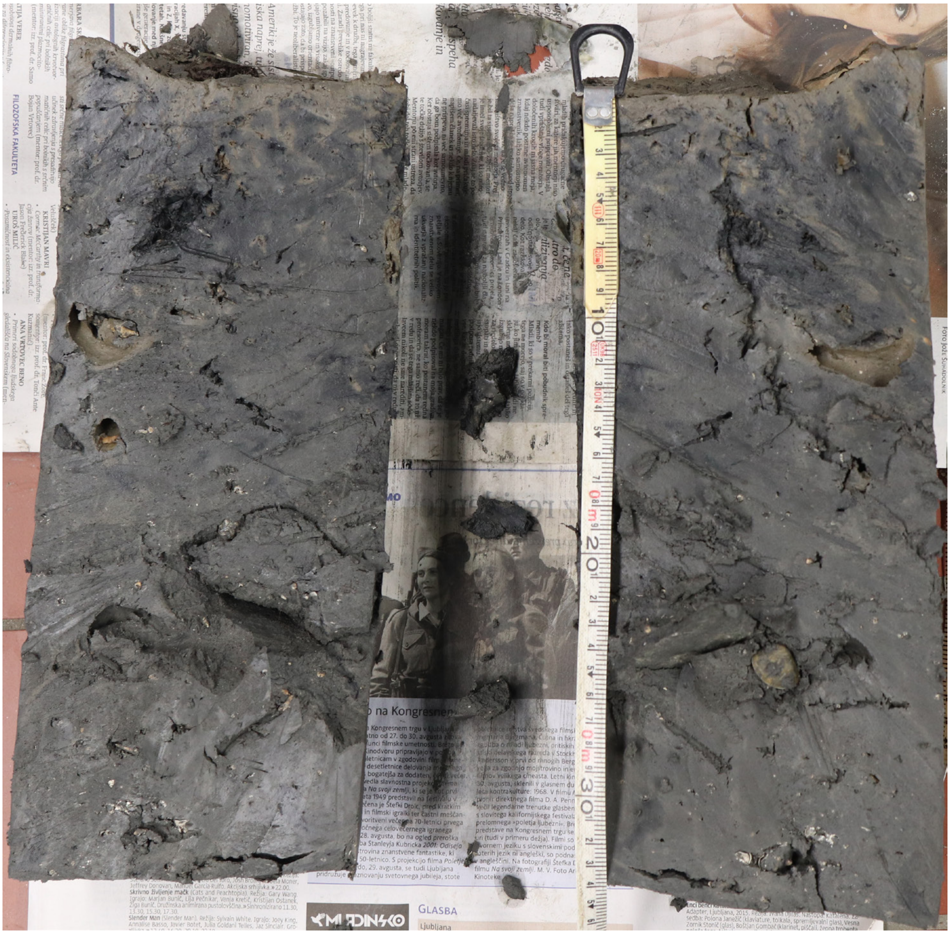


Figure 9: Soil sample 2 (photo: B. Repe).



Complete WRB name: Calcaric Oxygleyic Mollic Subaquatic GLEYSOL (Loamic, Humic, Salic, Sodic).

Site No. 3, seashore of the Strunjan Bay

Figure 10: Sampling site 3 (photo: B. Repe).

Site description: Location: E part of the Strunjan Bay, seashore, N45°31'41.6", E13°36'12.2". Parent material: alluvial sandy sediment over large of the flysch origin, covering large flysch blocks and boulders. Water conditions: permanently saturated with water; active movement of water by wind, waves, currents, and tide. Vegetation: *Cymodocea nodosa*. Human influences: bank of the shore and swimming resort.

Diagnostic horizons: /

Diagnostic properties: continuous rock (hard rock that cannot be penetrated by tools), gleyic (has reductimorphic colours (N), more than 5% of the oximorphic mottles around root channels).

Diagnostic materials: calcaric (strong effervescence (more than 50% of $CaCO_3$), structure is not disrupted, no concretions, nodules, coatings etc. present), fluvial (material of marine origin and has visible strata with alternating organic matter content).

Reference soil group: LEPTOSOL (has a *continuous rock* starting less than 25 cm from the soil surface).

Principal qualifiers: Lithic (has continuous rock less 10 cm from the soil surface), Subaquatic (permanently under water), Calcaric (has a calcaric material throughout), ~~Hypereutric~~ (because of Calcaric, Eutric is redundant).

Supplementary qualifiers: Akrofluvic (has fluvic material, but they are less than 25 cm thick), Arenic (dominant sandy texture), Ochric (more than 0.2% of organic carbon in the upper 10 cm), Limnic (has limnic material).

Figure 11: Soil profile 3.

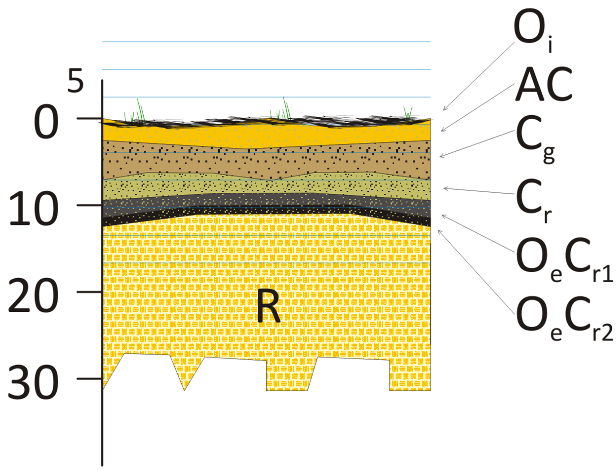


Figure 12: Soil sample 3 (photo: B. Repe).

Complete WRB name: Calcaric Subaquatic Lithic Leptosol (Akrofluvic, Arenic, Ochric).

According to old classifications, the first soil sample would be classified as sapropel, the second as gyttja and the third with properties between protopedon and gyttja (Mückenhausen, 1965).

4 DISCUSSION

The study of subaqueous soils is not a new field of research in soil science. However, the research is still quite rare for two main reasons. Rarely do these studies have application value (e.g., the mapping and analysis of Dutch polder soils prior to dam construction) (Demas et al., 1996), and the research is even more demanding and expensive than it already is. During our work, similar problems arose. Fieldwork, especially underwater sampling, proved to be very time-consuming, tedious, and demanding. As no professional and expensive field equipment was available, we were forced to improvise, which made the work even more difficult. Nevertheless, we managed to get all the results, successfully named the soils, and thus came to some important conclusions. On the other hand, the knowledge gained, and information collected has very limited application value.

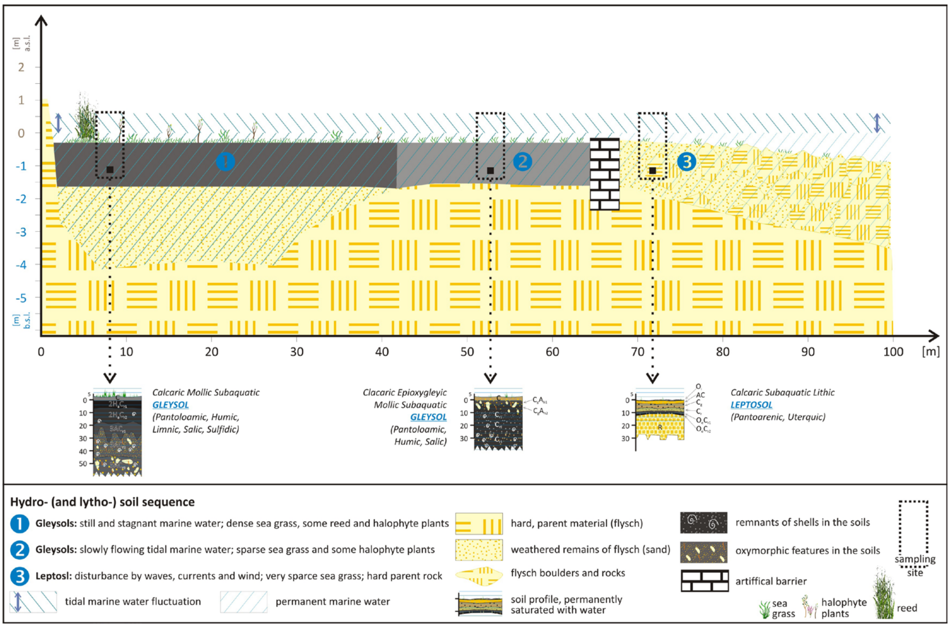
In a study carried out in the Gulf of St Bartholomew (Repe, Pristovšek, 2011), a soil hydrosequence was established referring to the intertidal zone, the time of inundation with seawater or the time when the soil was exposed to air. In fact, the hydrosequence showed a correlation between soil properties and distance from the coastline. Consequently, in simplified terms, the soil groups followed the following sequence: Solonchaks (land, with saline groundwater) – Histosols (intermittent flooding with seawater at low tide, the flooding duration is shorter than the duration of air exposure) – Gleysols (intermittent flooding with seawater at high tide, the flooding duration is longer than the duration of air exposure) – Arenosols (permanent water flooding). It should be noted that the thickness of the sandy flysch sediment is so great that the hard parent rock does not come to the surface). This is then related to the predominant vegetation, with mainly reeds (*Phragmites sp.)* growing on the shore, mainly salt-loving vegetation (*Salicornia europaea, Arthrocnemum glaucum, Crithmum maritimum, Limonium angustifolium, Juncus maritimus*) in the intertidal zone, and Neptune grass (*Cymodocea nodosa*) in the permanently flooded zone.

We have once again examined the hydrosequence in the waters of Strunjan Bay. The surface is flat, the parent substrate is flysch, the climate is sub-Mediterranean, the plants are dominated by seagrasses and the soils are all young and influenced by recent soil formation processes. However, this hydrosequence differs to some extent from the previous one. The main difference is that this time all sites are permanently under water and never in contact with atmospheric air. As a result, the vegetation is also submerged, with seagrasses dominating at all sites.

Figure 13: Coarse biogenic and sandy flysch material (photo: B. Repe).

The main difference between the three selected sites in this study is the effect of the sea water. At the first site (the Stjuža lagoon), the seawater is practically stagnant. Only depending on the tides is there a daily vertical fluctuation of the seawater level. The site is completely protected from external influences such as wind, waves or currents. As a result, all organic residues end up on the soil surface, where they slowly decompose anaerobically. The organic layer completely prevents the oxygen dissolved in the water from reaching the soil, so that the soil is heavily gleyed, the material completely reduced and grey in colour. The material is heavily transformed to a depth that can be sampled. The organic material is sulphidised and sulphur compounds are present, resulting in an unpleasant odour. Wastewater discharged or dumped into the lagoon is most likely a contributing factor. At the second site (artificial channel to the lagoon), seawater flows slowly in and out of the lagoon every day in accordance with the tides. The soil is also protected from external influences. The water flow is not turbulent and therefore does not cause displacement (inflow or erosion) of material or mixing of material in the upper horizons. The main process is still reduction and gleying. The main difference from site 1 is that the soils are flooded daily with fresh, oxygenated water, which can be seen in the brownish mottles (oxidation) in an otherwise predominantly grey soil matrix. The soils are highly altered up to a depth of 35 cm, after which coarser biogenic material occurs (Figure 13). There is no decay due to the decomposition by oxygen and consequently little odour. The biggest difference is at the third site (the shore of the Strunjan Bay), which is completely exposed to the action of waves, currents and wind and therefore shows intense displacement of mineral and organic material. The tides do not play a role. Another difference is that the very shallow soil is underlain by hard flysch bedrock, as the finer material is continuously carried away by seawater. The surface of the soil is covered with poorly weathered seagrass remains, followed by coarse, sandy, poorly altered mineral material that is gleyed only in the lower part. This is followed by a new organic layer (not a horizon!), another gleyed layer and then a thin layer of unaltered flysch sand lying directly on the hard flysch bedrock. The soil is young, poorly developed, and shallow. The texture of the first two samples is predominantly loamy, with an organic horizon present in both samples and the humus is mollic. The third soil is distinctly sandy, organic matter is in ochric form. All three samples are calcaric (above average free carbonate content), all are naturally saline, and the reaction is high (on average the pH is above 7 or even above 8). The base saturation is close to 100%.

Figure 14: Schematic soil hydro sequence of the Strunjan Bay.



Despite the modest number of samples, it can be concluded that the submarine soils of the Slovenian shallow coastal sea are quite similar, with the expected dominance of Gleysols. The closer the soils are to the coast, the more organic material is present and the stronger the gleying process. As the distance from the coast increases, the strength of the gleying decreases, while the proportion of sand fraction increases. At a point between 50 and 100 m from the coast (depending on the width of the submarine shelf), Arenosols begin to appear. At a still undetermined distance from the coastline, but certainly at a depth of more than three metres, only unaltered, flyschy, sandy material appears (Figure 14).

In order to obtain a complete overview of the soil types of the Slovenian offshore seabed, it would be necessary to investigate the areas below the cliffs, where the rocky seabed predominates, and shallow soils are very likely to prevail in the cracks between the boulders. In any case, the places where rivers flow into the sea should also be investigated, as the water there is less saline and the input of material from the coast is greater.

The continuation and completion of research on the underwater soils of the Slovenian coast will provide a comprehensive pedological and geographical overview of an area about which we know very little. And, more importantly, it will add one of the last pieces of the mosaic that is still missing to fully understand the ecological conditions for underwater flora and fauna to thrive. This in turn will provide a scientific basis for understanding and adequately protecting this fragile and unique habitat in Slovenia.

References

Antić, M., Jović, N., Avdalovič, V., 1982. Pedologija. Beograd: Naučna knjiga.

Balduff, D. M., 2007. Pedogenesis, inventory, and utilization of subaqueous soils in Chincoteague Bay, Maryland. College Park: University of Maryland, College Park.

Bat, M., Beltram, G., Cegnar, T., Dobnikar-Tehovnik, M., Grbović, J., Krajnc, M., Mihorko, P., Rejec Brancelj, I., Remec-Rekar, Š., Uhan, J., Bat, M., Frantar, P., Komavec, T., Marolt, D., Ulaga, Florjana., Robič, M., Brancelj, A., Makovec, T., Uhan, J., 2003. Vodno bogastvo Slovenije. Ljubljana: Ministrstvo za okolje, prostor in energijo, Agencija Republike Slovenije za okolje.

Bufon, M., Černe, A., Gams, I., Jeršič, M., Jurinčič, I., Jurgec, P., Kladnik, D., Kokole, V., Komac, B., Krevs, M., Kunaver, J., Lovrenčak, F., Natek, M., Ogorelec, B., Orožen Adamič, M., Pavšek, M., Perko, D., Plut, D., Radinja, D., Ravbar, M., 2005. Geografski terminološki slovar. Ljubljana: Založba ZRC SAZU.

Demas, G. P., 1998. Subaqueous Soils of Sinepuxent Bay, Maryland. College Park: University of Maryland, College Park.

Demas, G. P., Rabenhorst, M. C., 1999. Subaqueous soils pedogenesis in a submersed environment. Soil Science Society of America Journal, 63, 5, pp. 1250–1257. DOI: 10.2136/sssaj1999.6351250x

Demas, G. P., Rabenhorst, M. C., Stevenson, J. C., 1996. Subaqueous soils: A pedological approach to the study of shallow-water habitats. Estuaries, 19, 2, pp. 229–237. DOI: 10.2307/1352228.

DOPPS, 2018. Strunjanske soline. URL: https://www.ptice.si/ptice-in-ljudje/opazovanje-ptic/kam-na-izlet/strunjanske-soline/ (accessed 24.10.2023).

Folger, D. W., 1972. Characteristics of estuarine sediments of the United States. Professional Papers, 742, pp. 1–94. DOI: 10.3133/PP742.
Goldschmidt, V. M., 1958. Geochemistry. Oxford: Clarendon Press.
Gregorich, E. G., Turchenek, L. W., Carter, M. R., Angers, D. A. (eds.)., 2001. Soil and environmental science dictionary. Boca Raton, etc.: CRC Press.
Hoyer, S. A., Križan, B., Ravnik, M., Tomšič, D., 1986. Strunjan: naravna in kulturna dediščina. Varstvo spomenikov, 28, pp. 61–87.
IUSS Working Group WRB, 2006. World reference base for soil resources. Rome: FAO.
IUSS Working Group WRB, 2022. World reference base for soil resources. International soil classification system for naming soils and creating legends for soil maps. 4th edition. International Union of Soil Sciences (IUSS).
Kolbezen, M., 1998. Hydrography. In: Gams, I., Vrišer, I. (ed.). Geografija Slovenije. Ljubljana: Slovenska matica, pp. 139–172.
Kubiëna, W. L., 1953. The soils of Europe (illustrated diagnosis and systematics): with keys and descriptions for easy identification of the most important soil formations of Europe with consideration of the most frequent synonyms. London: Thomas Murby & Co.
Lin, H., 2012. Understanding soil architecture and its functional manifestation across scales. Hydropedology: Synergistic Integration of Soil Science and Hydrology, pp. 41–74. DOI: 10.1016/B978-0-12-386941-8.00002-2.
Lipej, L., 2004. Življenje v lagunah. Slovenija. Svet, 1, 7, p. 58.
Maček, J., Žabkar, A., Ušeničnik, B., 2002. Nesreče in varstvo pred njimi. Ljubljana: Uprava RS za zaščito in reševanje Ministrstva za obrambo.
Mückenhausen, E., 1965. The soil classification system ot the Federal Republic of Germany. Pedologie (Special Issue), 3, pp. 57–74.
Ogrin, D., 1993. (Sub)mediteransko podnebje v Sloveniji. Časopis za kritiko znanosti, 21, 158/159, pp. 25–34.
Ogrin, D., 1996. Podnebni tipi v Sloveniji. Geografski vestnik, 68, 1-2, pp. 39–56.
Ogrin, D., 2012. Uvod v oceanografske razmere Tržaškega zaliva. In: Ogrin. D. (ed.). Geografija stika Slovenske Istre in Tržaškega zaliva. Ljubljana: Znanstvena založba Filozofske fakultete, pp. 107–114.
Ogrin, D., Plut, D., 2009. Aplikativna fizična geografija Slovenije (1. natis). Ljubljana: Znanstvena založba Filozofske fakultete.
Payne, M. K., Turenne, J., 2009. Mapping the "new frontier" of soil survey: Rhode Island's MapCoast Partnership. Soil Horizons, 50, 3, 86–89. DOI: 10.2136/sh2009.3.0086.
Prus, T., 2000. Klasifikacija tal Slovenije – študijsko gradivo. Ljubljana: Center za pedologijo in varstvo okolja.
Radinja, D., 1990. Pokrajinske značilnosti Tržaškega zaliva in Koprskega Primorja: pomorske in obmorske poteze obeh pokrajin na sedanji stopnji antropogene

preobrazbe. In: Primorje: zbornik 15. zborovanja slovenskih geografov, Portorož, 24. - 27. oktobra 1990. Ljubljana: Zveza geografskih društev Slovenije, pp. 7–12.

Repe, B., 2010. Recognition of the Slovenian soil classification types. Dela, 34, pp. 143–166. DOI: 10.4312/dela.34.8.

Repe, B., 2018. Mednarodni klasifikacijski sistem za poimenovanje tal in izdelavo legend na zemljevidih tal 2014 (posodobitev 2015) (1. izd.). Ljubljana: Znanstvena založba Filozofske fakultete; Rim: Food and Agriculture Organization of the United Nations.

Repe, B., Pristovšek, A., 2011. Geografski prispevek k poznavanju subakvalnih prsti ob Slovenski obali. In: Četrti Melikovi dnevi: Geografski vidiki upravljanja z morjem in zaledjem, Koper, 10.–11. junij 2011. Koper: Univerza na Primorskem, Znanstveno-raziskovalno središče, pp. 51–52.

Repe, B., Pristovšek, A., 2022. Marine tidal/subaqueous soil sequence at the coast of Slovenia. In: Świtoniak, M., Charzyński, P. (eds.). Soil Sequence Atlas V, 1st ed., Vol. 5. Toruń: Nicolaus Copernicus University, pp. 135–155.

Repe, B., Pristovšek, A., Pavlin, T., 2019. Pedološki prispevek k poznavanju muljastega dna slovenske obale. Strokovna in Znanstvena Predavanja PDS, 47. URL: http://bit.ly/2HiAC4Z (accessed 10.10.2023).

Šajna, N., Kaligarič, M., 2005. Vegetation of the Stjuža coastal lagoon in Strunjan landscape park (Slovenia): a draft history, mapping and nature-conservancy evaluation. Annales, 15, 1, pp. 79–90.

Škorić, A., 1977. Tipovi naših tala. Zagreb: Liber.

Soil Survey Staff, 2010. Keys to soil taxonomy (11th ed.). Washington, D.C.: Natural Resources Conservation Service (U.S.), Agriculture Dept. (U.S.), Soil Survey Division.

GENETSKO ZAPOREDJE PODVODNIH PRSTI V STRUNJANSKEM ZALIVU

Povzetek

Glavni cilj raziskave je bil proučiti prsti na izbrani lokaciji (Strunjanski zaliv) na slovenski obali, ki so stalno pod vodo, ustrezno opisati in poimenovati prsti ter opisati hidrosekvenco. Za ugotavljanje hidrosekvence prsti smo iskali akumulacijski, lagunski obalni tip, ki je stalno potopljen in ima različne vplive morske vode. Posledično smo izbrali tri lokacije v vodah Strunjanskega zaliva. Prvi vzorec prsti je bil opisan v laguni Stjuža, drugi na prehodnem območju – kanalu med Stjužo in morsko obalo, in zadnji na morski obali Strunjanskega zaliva. Za vzorčenje smo uporabili kanalizacijske cevi premera 16 cm in dolžine 1 m. V zgornji del cevi smo izvrtali luknje, skozi katere smo vstavili kovinsko palico, da smo cev potisnili kolikor je mogoče globoko v prst. Pod vodo smo izkopali območje okoli vstavljene cevi. Nato smo cevi z vzorci previdno in počasi dvignili iz vode, pri čemer smo pazili, da vzorec ni zdrsnil iz cevi. Spodnje (odprte) dele cevi smo tesno zaprli s plastičnimi vrečkami in jih povezali z vezicami in lepilnim trakom. V vrečke smo izvrtali majhne luknjice, da je lahko voda počasi odtekala, ne da bi se pri tem porušila zgradba profila. Na ta način smo vzorce en mesec sušili na prostem in en teden v laboratoriju pri sobni temperaturi. Kasneje smo vzorce potisnili iz cevi, jih vzdolžno razrezali in za vsak vzorec določili horizonte. Ob izpostavljenosti zraku se je pojavil izjemno neprijeten vonj (po gnilih jajcih). Kot je bilo pričakovati, je bil vonj najintenzivnejši v prvem vzorcu, v drugem vzorcu je bil le rahlo zaznaven, tretji vzorec je bil brez vonja. Posušene vzorce iz vsakega horizonta smo nato zdrobili in presejali ter jih pripravili za laboratorijsko analizo. Za vsak horizont vsakega vzorca je bila opravljena standardna analiza tal. Izmerjena je bila tudi električna prevodnost in ocenjen odstotek školjčnih lupin. Vzorci prsti so bili odvzeti avgusta 2018, laboratorijske analize pa so bile opravljene oktobra 2018.

V raziskavi, ki je bila opravljena v zalivu Sv. Jerneja (Repe, Pristovšek, 2011; 2022), smo ugotovili hidrosekvenco, ki se je nanašala na bibavični pas, čas zalitosti z morsko vodo oziroma čas, ko so bile prsti izpostavljene zraku. Dejansko je hidrosekvenca kazala na povezavo med lastnostmi prsti in oddaljenostjo od obalne linije. Posledično so si poenostavljeno skupine prsti sledile v naslednjem zaporedju: *Solonchaks* (kopno, s slano podtalnico) – *Histosols* (občasna zalitost z morsko vodo ob plimi, obdobje zalitosti je krajše od obdobja izpostavljenosti z zrakom) – *Gleysols* (občasna zalitost z morsko vodo ob plimi, obdobje zalitosti je daljše od obdobja izpostavljenosti z zrakom) – *Arenosols* (stalna zalitost z vodo). Ob tem je treba povedati, da je debelina peščenega flišnega sedimenta takšne debeline, da trda matična kamnina ne pride blizu površja. Na to se nato navezuje tudi prevladujoče rastlinstvo, kjer na obali uspeva predvsem trstičje (*Phragmites* sp.), v pasu plime in oseke predvsem slanoljubno rastlinstvo (*Salicornia europaea*, *Arthrocnemum glaucum*, *Crithmum maritimum*,

Limonium angustifolium, *Juncus maritimus*), v stalno zalitem delu pa morska trava (*Cymodocea nodosa*). Tudi tokrat smo v vodah Strunjanskega zaliva proučevali hidrosekvenco. Površje je povsod uravnano, matična podlaga flišnata, podnebje submediteransko, med rastlinami prevladujejo morske trave, vse prsti so mlade, podvržene recentnim procesom. Se pa tokratna hidrosekvenca od prejšnje do določene mere razlikuje (zaporedje tipov prsti ni povsem identično). Najpomembnejši vzrok za to razliko je, da so tokrat vse lokacije stalno pod vodo in nikoli ne pride do stika z atmosferskim zrakom. Posledično je tudi rastlinstvo podvodno, na vseh lokacijah prevladujejo morske trave.

Med tremi izbranimi lokacijami je glavna razlika v delovanju morske vode. Na prvi lokaciji (laguna Stjuža) morska voda praktično miruje. Le v skladu s plimo in oseko se pojavlja dnevno, vertikalno nihanje gladine morske vode. Lokacija je povsem zaščitena pred zunanjimi vplivi vetra, valov ali morskih tokov. Posledično vse odmrlo gradivo konča na površini prsti, kjer počasi anaerobno gnije. Organska plast povsem prepreči dostop v vodi raztopljenega kisika, zato so prsti močno oglejene, gradivo povsem reducirano in sive barve. Gradivo je močno preoblikovano do globine, do koder je bilo mogoče odvzeti vzorec. Organska snov se sulfidizira, zato so prisotne žveplove spojine in posledično neprijeten vonj. Zelo verjetno k temu prispevajo tudi odplake, ki so bile speljane v laguno. Na drugi lokaciji (umetni kanal v Stjužo) morska voda dnevno, v skladu z delovanjem plime in oseke počasi teče enkrat v laguno in nato spet izven nje. Prsti so prav tako zaščitene pred zunanjimi vplivi. Vodni tok ni turbulenten, zato ne povzroča premeščanja (dotok ali erozija) gradiva niti mešanja gradiva zgornjih horizontov. Glavni proces je še vedno redukcija in oglejevanje. Bistvena razlika z lokacijo št. 1 je, da dnevno prsti preliva sveža, s kisikom bogata voda, kar je moč opaziti v procesih oksidacije, ki se marmorirano pojavlja v rjavkastih odtenkih, v sicer pretežno sivemu matriksu. Prsti so močno preoblikovane do globine 35 cm, potem pa se že pojavlja bolj grobo in skeletno gradivo. Zaradi kisika ne prihaja do gnitja, neprijeten vonj je komajda zaznaven. Največja razlika pa je na tretji lokaciji (obala Strunjanskega zaliva). Lokacija je povsem izpostavljena delovanju valov, morskih tokov in vetru, zato se pojavlja intenzivno premeščanje mineralnega in organskega gradiva. Plimovanje ne igra nobene vloge. Dodatna razlika je, da se plitvo pod površjem pojavlja trda flišna podlaga, saj drobno gradivo sproti odnaša morska voda. Površino prsti prekrivajo slabo prepereli ostanki morske trave, čemur sledi grobo, peščeno, slabo preoblikovano mineralno gradivo, ki je oglejeno šele v spodnjem delu. Temu sledi nov organski sloj, ponovno oglejen sloj in nato tanek sloj nepreoblikovanega flišnega peska, ki leži neposredno na trdi flišni podlagi. Prsti so mlade, slabo razvite in plitve. Tekstura prvih dveh vzorcev je prevladujoče meljnata, pri obeh se pojavi organski horizont, humusni je moličen. Tretje prsti so izrazito peščene, organska snov nastopa v ohrični obliki. Vsi trije vzorci so kalkarični (nadpovprečna količina prostih karbonatov), vsi so seveda slani, reakcija je visoka (v povprečju nad 7 ali celo nad 8). Zasičenost z bazami je blizu 100 %.

Kljub skromnemu številu vzorcev lahko vseeno zaključimo, da so si podvodne prsti slovenskega plitvega obalnega dna precej podobne, saj prevladujejo glejsoli. Glede na pedogenetske dejavnike jih upravičeno lahko pričakujemo tudi drugod, vendar bomo morali to še potrditi. Bližje ko se prsti nahajajo obali, več je organskega gradiva in hkrati močnejši je proces oglejevanja. Z oddaljevanjem od obalne črte se moč oglejevanja zmanjšuje, obenem pa se povečuje delež peščene frakcije. Med 50 in 100 m stran od obale (odvisno od širine podvodne morske police) se začno pojavljati arenosoli. Vsekakor pa se globlje od treh metrov pojavlja le še nepreoblikovano, flišno, peščeno gradivo. Za popolno pedološko sliko slovenskega priobalnega dna bi bilo treba proučiti še območja pod klifi, kjer prevladuje kamnito dno in prevladujejo zelo verjetno plitve prsti, v razpokah med skalnimi bloki. Vsekakor pa bi bilo treba proučiti tudi mesta, kjer se reke izlivajo v morje, saj je voda manj slana, dotok gradiva z obale pa večji.

Z nadaljevanjem in zaključkom raziskovanja podvodnih prsti slovenske obale bomo dobili celovit pedološki in geografski pregled območja, o katerem vemo izjemno malo. Še pomembneje je, da bomo z zaključkom dodali enega zadnjih kamnov v mozaiku naravnih dejavnikov, ki še manjkajo, da bomo lahko v celoti razumeli ekološke razmere za uspevanje podvodnega rastlinstva, pa tudi živalstva. To pa bo dalo znanstveno podlago za razumevanje in ustrezno varovanje krhkega ter v Sloveniji edinstvenega življenjskega okolja.

Tatjana Resnik Planinc*, Sašo Stefanovski*

CHOOSING TO STUDY GEOGRAPHY AND THE CAREER ASPIRATIONS OF FUTURE GRADUATES AND POSTGRADUATES

Izvirni znanstveni članek
COBISS 1.01
DOI: 10.4312/dela.59.179-211

Abstract

Several factors are bound to influence a young person's decision to study a particular study programme, including his or her interests and commitment, abilities and skills, career prospects, family expectations, social pressure and peer influence, the information and advice available to him or her and financial constraints. To find out what factors contribute to adolescents' decision to study geography and the career aspirations of future graduates and postgraduates, a survey was conducted in 2017 and 2020 at the Department of Geography, Faculty of Arts, University of Ljubljana involving a total of 155 students in their first year of the first cycle and the first and the second year of the second cycle. The results will be of great help in the further development of the geography study, as knowledge of the factors influencing their decisions to study, as well as their career aspirations and expectations, will allow us to understand the low enrolment figures in geography studies in recent years (which are not comparable to those of the past in all three Slovenian departments of geography) and to find potential solutions or ways to improve the current situation.

Keywords: geography studies, career aspirations, decision to study, Slovenia

*University of Ljubljana, Faculty of Arts, Department of Geography, Aškerčeva 2, SI-1000 Ljubljana, Slovenia
e-mail: tatjana.resnikplaninc@ff.uni-lj.si, saso.stefanovski@ff.uni-lj.si
ORCID: 0000-0002-5042-347X (T. Resnik Planinc), 0000-0002-7822-451X (S. Stefanovski)

ODLOČITEV ZA ŠTUDIJ GEOGRAFIJE TER POKLICNE ASPIRACIJE BODOČIH DIPLOMANTOV IN MAGISTRANTOV

Izvleček

Na odločitev mladostnika za določen študij zagotovo vplivajo številni dejavniki, med katerimi lahko izpostavimo predvsem njegove interese in predanost nečemu, sposobnosti in veščine, karierne možnosti, družinska pričakovanja, socialni pritisk in vpliv vrstnikov, informacije, ki so mu na voljo, in svetovanje, ki ga je deležen, ter finančne omejitve. Z namenom ugotoviti, kaj vse botruje odločitvi mladostnikov za študij geografije in kakšne so poklicne aspiracije bodočih diplomantov in magistrantov, smo leta 2017 in 2020 na Oddelku za geografijo FF UL izvedli raziskavo, v kateri je skupno sodelovalo 155 študentov prvih letnikov prve in druge stopnje ter drugih letnikov druge stopnje. Rezultati nam bodo v veliko pomoč pri nadaljnjem razvoju študija geografije, saj nam poznavanje dejavnikov, ki vplivajo na njihove odločitve za študij, ter njihovih poklicnih želja in pričakovanj omogoča razumeti nizke številke vpisa na študij geografije v zadnjih letih (ki na vseh treh slovenskih oddelkih za geografijo niso primerljive s preteklimi) ter poiskati potencialne rešitve oziroma pot k izboljšanju trenutne situacije.

Ključne besede: študij geografije, poklicne aspiracije, odločitev za študij, Slovenija

1 INTRODUCTION

In recent times, Slovenian university geography departments have been grappling with a significant decline in student enrolment in geography programmes. Notably, the Department of Geography at the Faculty of Arts, University of Ljubljana, which used to implement entrance exams in the past, has now shifted away from this practice, reflecting a broader trend. This phenomenon is not unique to Slovenia and has been a subject of discussion in numerous countries for several decades, as noted by scholars like Gibson (2007) and Head and Rutherford (2021). The prevailing sentiment among these departments is that they are satisfied if they can attract sufficient students to fill the available slots, prompting them to continuously ponder the underlying causes of this situation and explore strategies to reverse this unfavourable trend.

Many scholars argue that higher education institutions across the globe have become targets of various neoliberal and globalizing processes. These processes, as identified by authors such as Barcan (2013), Lewis (2011), Olssen and Peters (2005), Shore and Taitz (2012), and Dufty-Jones (2017), encompass factors such as the massification of student numbers, the internationalization of higher education as a global commodity, and the adoption of accountability practices intended to demonstrate a "return on investment" to governing bodies within universities. Collins and Lewis (2016) even suggest that these processes are part of a multifaceted agenda that includes the destruction of higher education. This agenda fundamentally transforms the traditional academic landscape, shifting it away from principles of community and collegiality and placing it under the governance of market forces and competition, as noted by Berg and Roche (1997, cited in Dufty-Jones, 2017).

However, it is essential to acknowledge that these processes are inherently complex, and it would be unwise to simplify them into a narrative of mere "decline" (Gibson, 2007). The challenges faced by geography departments and universities as a whole are multifaceted, and they require a nuanced and thoughtful approach to address the evolving landscape of higher education.

Can the exploration of the reasons for embarking on a career in geography offer a potential solution to the enigma described earlier? While it is widely acknowledged that "there has never been a more important time to use geographical knowledge and skills to pursue a career," as articulated on the UK Geographical Association website, a fundamental question lingers: Can we effectively convey to the younger generation that in the 21st century, comprehension and resolution of the myriad changes and challenges confronting Slovenia and the world hinge on geography?

Despite our resolute belief that geography, by bridging the realms of the natural and the human, the local and the global, while addressing crucial matters such as climate change, energy security, migration, and urbanization, equips us to strategize for a sustainable future, it remains essential to persuade them that geography unfurls a diverse spectrum of opportunities for their forthcoming employment and career paths.

2 THEORETICAL BACKGROUND

A multitude of factors come into play when young individuals contemplate their choices of particular study programmes. These factors include their personal interests and dedication, their aptitudes and competence, the perceived career prospects, familial expectations, societal pressures, peer influence, the availability of information and guidance, and, not insignificantly, financial constraints (Brooks, 2003; Eidimtas, Juceviciene, 2014; Piróg, 2018).

Adolescents typically opt for a course of study that resonates with their passions, hobbies, and commitments. When they harbour a genuine interest and enthusiasm for a subject, they are inclined to select a programme that allows them to explore and cultivate that interest. Concurrently, they often choose fields where their demonstrated abilities and skills align. Academic performance in a particular subject or domain during their prior schooling can significantly sway their choice to further pursue studies in that area.

The potential career opportunities arising from a specific course of study often feature prominently in their decision-making process. They embark on research to ascertain the available career options, job prospects, and avenues for career advancement within their chosen field. Equally impactful is the influence of their familial environment and their parents' expectations, which sometimes guide their choice of study in alignment with their family's desires.

Social and peer pressures can exert an additional layer of influence, albeit adolescents also stand to benefit significantly from well-informed decisions. Quality information about diverse study programmes, career trajectories, and the future of a particular field can markedly impact their choices. Advice from career counsellors, mentors, educators, and industry experts proves invaluable in facilitating informed decision-making. The awareness and understanding of the geographer profession within Slovenia are limited, leading to a common misconception among young individuals that their career options within geography are primarily confined to teaching in educational institutions.

Internationally, the discourse predominantly centres on the implementation of effective student recruitment procedures and strategies (Croot, 1999; Estaville et al., 2006; Hill et al., 2008; Piróg, 2018). However, in Slovenia, there exists a crucial need for empirical research to substantiate our assumptions regarding the perception of geography as a career choice in comparison to other academic disciplines. Presently, we lack scientific evidence to either validate or disprove the commonly asserted notion that young individuals favour subjects like chemistry, physics, biology, mathematics, and the like, over geography when pursuing professional success.

Recent deliberations within academic circles have even leaned toward the perspective that geography tends to be chosen by students who were unable to secure admission into more highly regarded programmes, such as computer and information science, medicine, biochemistry, or pharmacy. Consequently, the scope of geography is often perceived as primarily limited to careers in education or as a field of applied inquiry. It's worth noting that today, job opportunities for geography graduates are indisputably abundant, as affirmed by data from the Zavod RS za zaposlovanje (Slovenian Employment Service, 2023) and the Statistical Office of the Republic of Slovenia (2023).

As Kubiatko et al. (2012) emphasize, comprehending the perceptions of a subject is a fundamental facet of educational research. While studies investigating the perceptions of geography among students at various academic levels have been conducted in numerous countries (Fatima, 2016), the motivations behind choosing geography as a university major remain a relatively underexplored area (Solem et al., 2013; Piróg, 2018). Additionally, it's important to highlight another unique aspect associated with the study of geography: there exists a prevailing perception among young individuals and the general public that geography is primarily pursued by those aspiring to become geography teachers, often due to a lack of awareness regarding the broader career prospects that a geography degree can unlock.

Following a student's selection of a specific study programme, additional influential variables begin to exert their impact. Simultaneously, evaluating study programmes necessitates an understanding of various student aspects, including their engagement levels, acquired competence, career awareness, and for those, enrolled in teaching degree programmes, perceptions of the teaching profession. Milsom and Coughlin (2015) propose that student satisfaction or dissatisfaction with a study programme stems from introspection regarding self-discovered information and career insights. On the other hand, the adjustment to academic life significantly influences student success, underscoring the imperative to explore how diverse motivational and behavioural factors impact this adjustment and, consequently, academic achievement (van Rooij et al., 2018).

Upon entry into higher education, students bring forth specific personal traits and skills that undergo transformation and potential challenges within the new educational milieu. Successful adaptation to this environment, encompassing positive interactions with instructors and peers, as well as the management of heightened complexity within learning materials, dictates a student's contentment with their inaugural academic experience. Moreover, it directly affects their academic performance and progression to subsequent academic years (Astin, 1999; Pascarella, Terenzini, 2005; Sevinç, Gizir, 2014). Lowe and Cook (2003) observed that a notable percentage, approximately 20 to 30%, of university students encounter significant hurdles in acclimatizing to higher education, leading many to discontinue their studies or perform below their potential. In light of these observations, academic adjustment emerges as a pivotal aspect warranting investigation concerning student success (van Rooij et al., 2018).

3 METHODOLOGICAL FRAMEWORK OF THE STUDY

This research paper investigates the motivations behind the selection of geography as a field of study and explores the career aspirations of prospective graduates and postgraduates enrolled at the Department of Geography, Faculty of Arts, University of Ljubljana in response to the aforementioned key issues.

The study comprises five distinct sections. The initial segment compiles fundamental information about the students, delving into the primary factors influencing their choice of the geography study programme, and assesses their overall satisfaction with the academic pursuit. The second part concentrates on the skills and competence acquired during their years of study. In the third section, students' perspectives regarding their potential roles as geography teachers, the compensation they anticipate, and the level of respect accorded to educators in our society are examined. The fourth section explores the aspirations students hold after completing their education, while the concluding section gauges their contentment with the chosen study programme and evaluates their financial circumstances.

Data was gathered through a structured questionnaire administered in 2017 and 2020, involving a total of 155 students in their first year of the first cycle (bachelor's degree programme), and the first and second years of the second cycle (master's degree programme). This study employed a quantitative-empirical approach, employing an online survey as the data collection instrument. Subsequently, the gathered data was subjected to statistical analysis using Excel and SPSS 26. Various statistical tests such as the Pearson Chi-Square test, Symmetric Measures test, Phi Coefficient, Cramer's V, and Contingency Coefficient were employed to assess the significance and strength of correlations within the dataset.

In summary, this research seeks to provide valuable insights into the dynamics of geography education and the aspirations of geography students at the University of Ljubljana, shedding light on their motivations, skills development, career prospects, and overall satisfaction with their academic journey.

The survey encompassed a total of thirty-seven questions, comprising closed and semi-closed (short answer) queries. It is important to note that not all of these questions are incorporated into this study. In both years, all students in the first year of their first cycle and the first and second years of their second cycle were invited to partake in the survey, which was administered both orally and through e-classrooms. Importantly, all questions were optional, which may explain variations in the number of responses for each individual question.

The primary objectives of the research revolved around addressing the following key inquiries:

1. What motivated students to select geography as their field of study?
2. To what extent are students satisfied with their higher geography education?
3. What skills and competence do students acquire during their geography studies?
4. What is the students' perception of the teaching profession?
5. What are the career aspirations of the students?
6. How familiar are students with job opportunities, employer expectations, and requirements?
7. What strategies will students employ in their job search?
8. How would students decide if they were to choose their course of study again?

This comprehensive survey aimed to illuminate various facets of students' academic experiences, career aspirations, and future prospects in the field of geography.

Structurally, the questionnaire was organized into six distinct domains of inquiry, encompassing a combination of closed, mixed, and open-ended responses. These areas of investigation were designed to probe:

1. The extent of participants' awareness regarding the role and significance of geography in society.
2. The perceived importance of geography as an academic discipline within the contemporary education system.

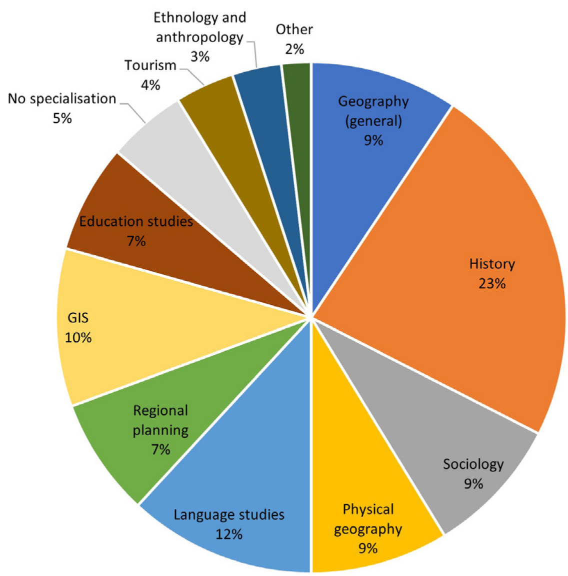
3. The allocation of geography hours in the weekly curriculum.
4. The participants' perceptions concerning the potential for a successful career pathway through the pursuit of geography studies.
5. An exploration of the employment opportunities available in the labour market for graduates and postgraduates in geography.
6. Identifying potential strategies to enhance the public perception of geography within society.

Additionally, the questionnaire included sections for capturing socio-demographic data, such as gender, age, and place of residence, to offer a comprehensive perspective on the participants' backgrounds and viewpoints.

4 RESULTS

A total of 194 geography students responded to the online survey, but as mentioned earlier, not all of them answered all questions. Therefore, only 155 respondents who answered the questionnaire in full were included in the analysis. 83 of the students were female, and 72 were male. The average age of the respondents was 22.4 years. Most of the respondents were undergraduate students (84). The majority (62%) of the students were double majors, while the others were single majors.

Figure 1: Geography students' specialisation (single majors) or study programme beside Geography (double majors).

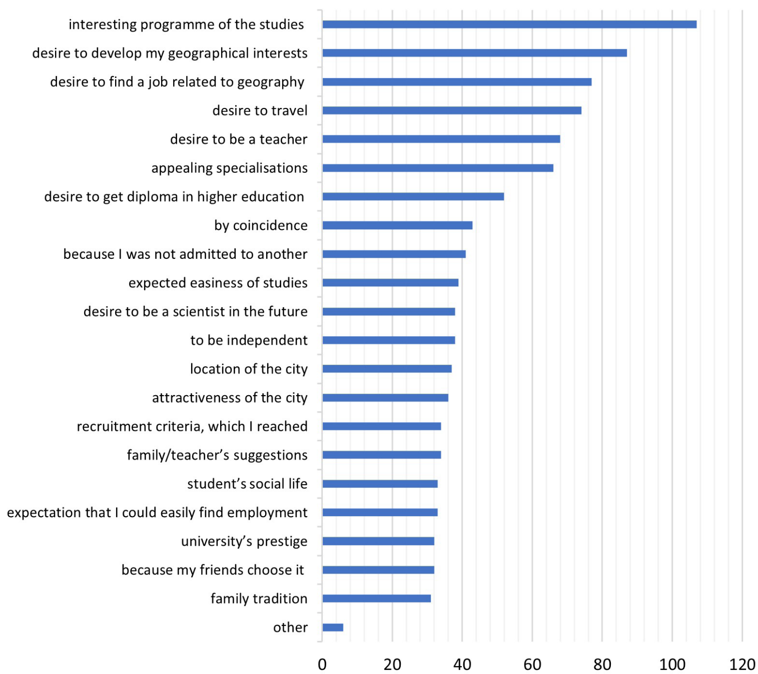


When asked to indicate their preferred specialisation (Figure 1) the responses of students studying two programmes (geography plus e.g., history, sociology, foreign language etc.) were mostly related to their second field of study. Their preferred specialisation is history (23%), which is also the most common combination of double majors. Various language studies (e.g., Spanish, English, Slovenian…) ranked second (12%), and sociology ranked third (9%). The responses of students with a single major were more diverse. At the undergraduate level, students have only general geography subjects, most of which are obligatory. When they enrol in the second cycle, they choose the modules they prefer. Most responses were related to GIS (10%), which is a strength of students with a single major. Physical geography was second (9%), and regional planning was third (7%).

Main reasons for choosing geography study programme

The respondents were asked to give three main reasons for choosing to study geography. The three reasons chosen were ranked by the students from most important to least important. The Figure 2 shows only the number of times the reason was mentioned, not the importance of each reason.

Figure 2: Main reasons for choosing geography study programme.



The most important reason is the interesting study programme, which received 55 first place votes and a total of 107 votes. Because the survey did not request explanations for the provided reason, we lack insight into the origins of their knowledge about the study programme (e.g. getting to know the studies during their schooling). The desire to develop my geographical interests came in second. 47 students chose it as the most important reason, and 40 chose it as the second or third reason. Appealing specialisations was the third most popular first place answer (27), but overall, it is in fifth place because it was not often selected as a second (26) or third option (13). Overall, the third most popular reason was the desire to find a job related to geography, which received 25 first-place votes. Nonetheless, the rationales underlying students' decisions to pursue geography studies prompt some concern. Notably, there exists a significant inclination towards a desire for travel, which can inadvertently link the study of geography with tourism-focused travel, leading to subsequent disillusionment. Moreover, reasons expressed such as 'random chance', 'simplicity of the programme', 'attraction to the urban environment' (presumably Ljubljana), and 'peer influence' are puzzling due to their lack of substantive justification and failure to meet professional standards.

Level of satisfaction with studying geography

There are several students who studied for several years and then abandoned their studies. The respondents were asked if they had ever thought of dropping out of their studies (Figure 3). Most of them (58%) have never thought about dropping out of their studies, while 24% have done so once. 18% have even considered it several times. Most of them had problems with one or two geography subjects in the first year of study or found that the geography course did not meet their expectations.

Figure 3: Level of tendency to stop studying geography.

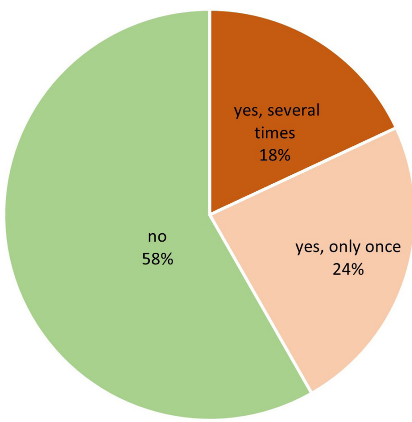
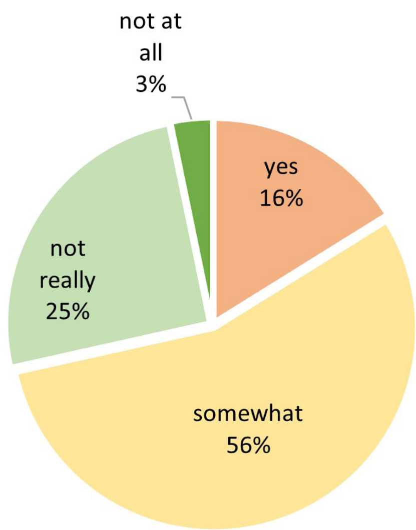


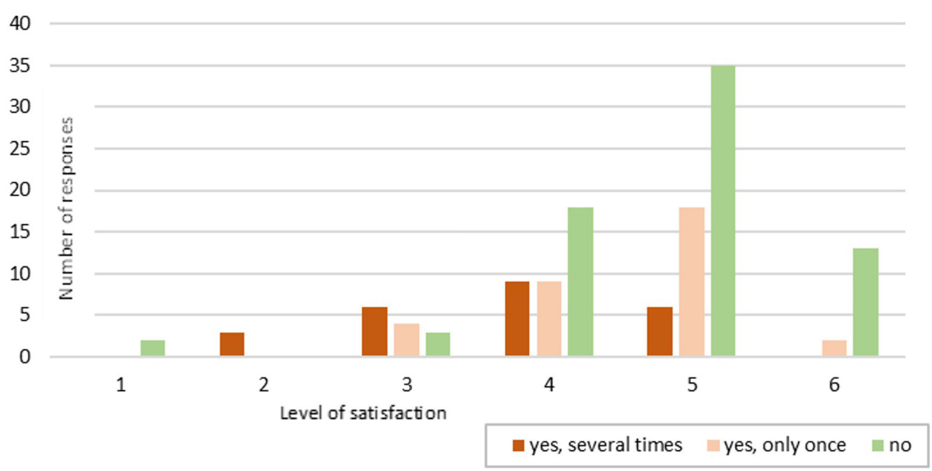
Figure 4: Level of difficulty of studying geography.



A portion of the students perceives geography as excessively scientific and rigorous. This sentiment is underscored by the data presented in Figure 4, revealing that merely a quarter of students do not regard the geography programme as challenging. Specifically, 16% view the study of geography as arduous, while a significant majority, comprising 56%, consider it to be somewhat demanding. Among these students, there are instances where individuals who briefly contemplated abandoning their studies at the first cycle level encountered doubts when considering pursuing further education in geography at the second cycle level.

Figure 5 shows a connection between the level of satisfaction and consideration of giving up on their studies. It is clearly visible that most students, that never considered dropping out, are also satisfied with their studies. Even students who were thinking of dropping out are somewhat satisfied with the study although they are rarely fully satisfied.

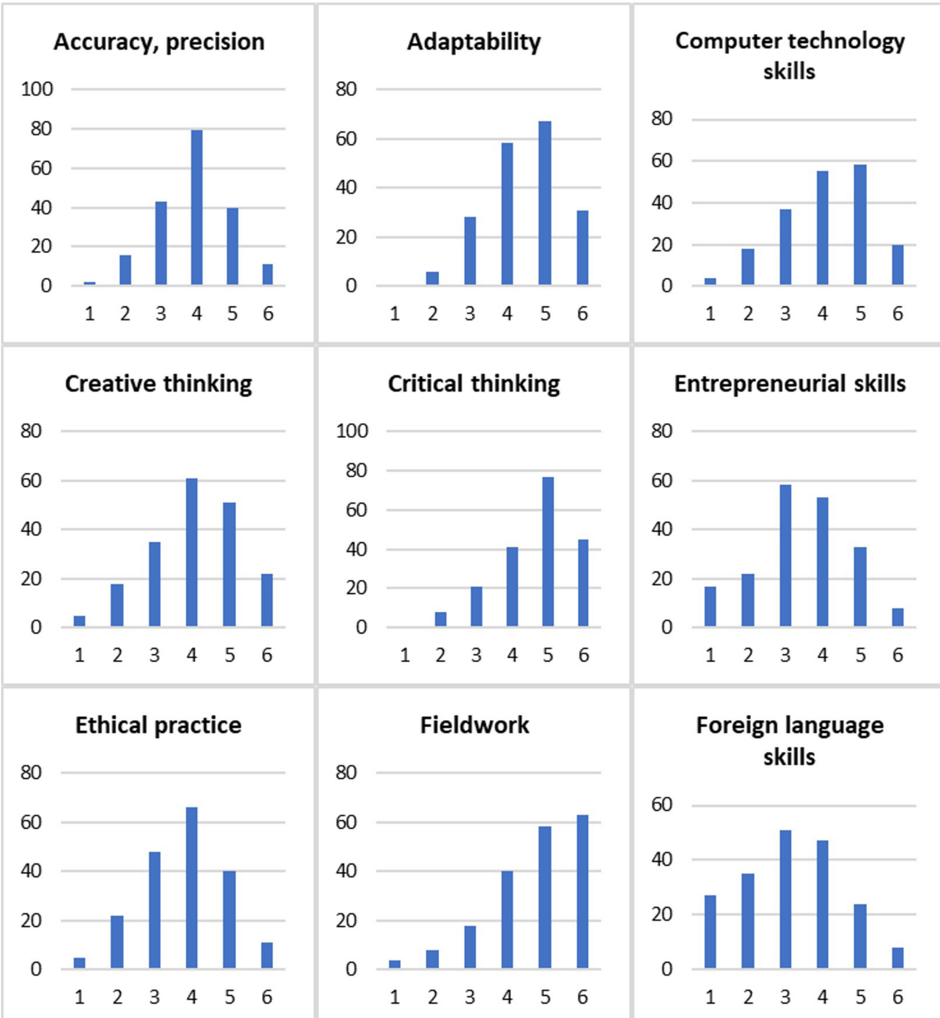
Figure 5: Level of satisfaction from 1 to 6 in choosing to study geography in connection with tendency to stop studying geography.



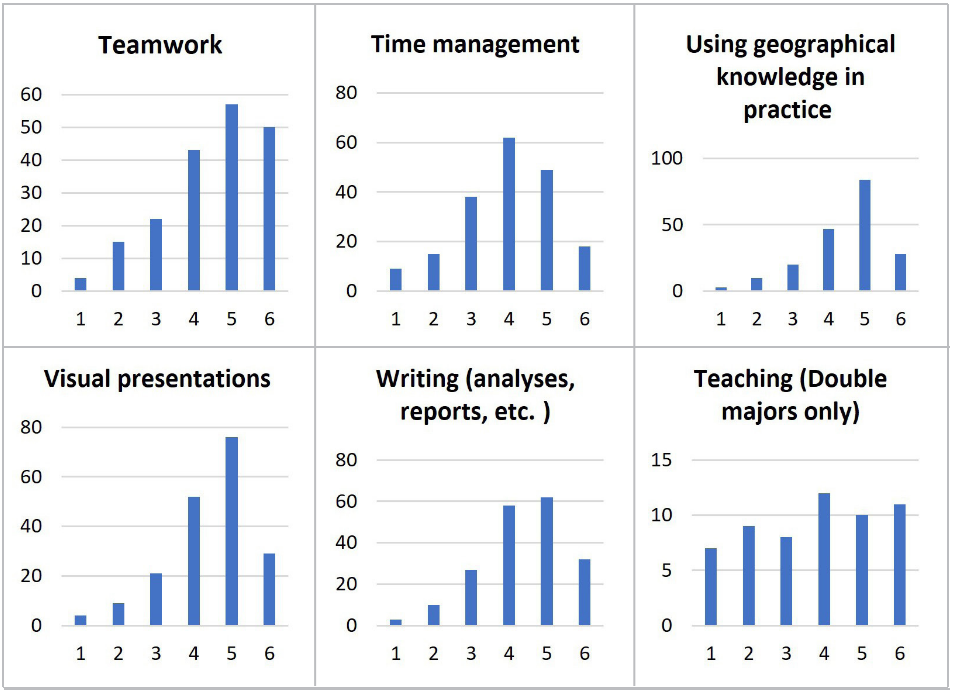
Skills and competence

Students were tasked with assessing the proficiency levels of various skills and competence acquired throughout their geography studies on a scale of 1–6 (1 being the lowest and 6 being the highest), as illustrated in Figure 6.

Figure 6: The skills and competence acquired in the course of studying geography.




Information management
80
60
40
20
0
1 2 3 4 5 6
Intercultural skills
60
50
40
30
20
10
0
1 2 3 4 5 6
Interpersonal communication
80
60
40
20
0
1 2 3 4 5 6
Problem solving
80
60
40
20
0
1 2 3 4 5 6
Project management
80
60
40
20
0
1 2 3 4 5 6
Project management (planning)
80
60
40
20
0
1 2 3 4 5 6
Public speaking
60
50
40
30
20
10
0
1 2 3 4 5 6
Qualitative skills
80
60
40
20
0
1 2 3 4 5 6
Quantitative skills
80
60
40
20
0
1 2 3 4 5 6
Relationship building skills
80
60
40
20
0
1 2 3 4 5 6
Research planning
80
60
40
20
0
1 2 3 4 5 6
Self-awareness
60
50
40
30
20
10
0
1 2 3 4 5 6

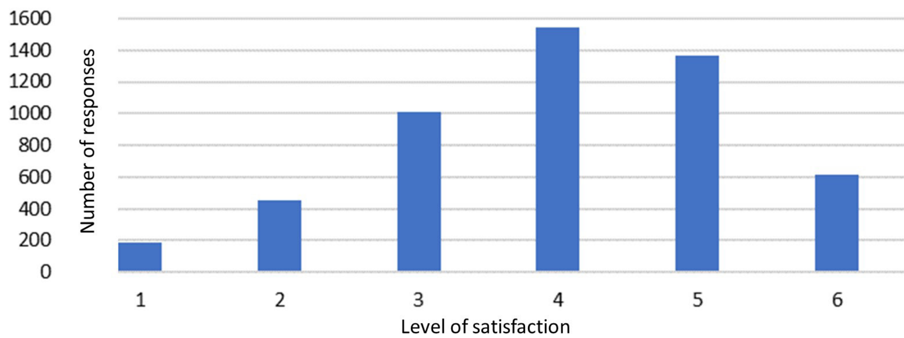


The majority of these skills and competence garnered ratings at levels 4 or 5. Unsurprisingly, fieldwork received the highest rating at level 6, aligning with the expectation since most geography courses necessitate at least one day of fieldwork per semester. Courses with a greater focus on fieldwork, such as "Physical geography of karst," entail several days of practical fieldwork. The second highest-rated competence was the application of geographic knowledge in real-world contexts. Other competence, including public speaking, teamwork, visual presentations, writing, critical thinking, and adaptability, also emerged as highly ranked.

It is essential to note that the teaching results presented pertain exclusively to double major students who earn a geography teaching certificate upon completing their second cycle. These findings reveal a diverse range of responses concerning the acquisition of teaching-related skills and competence. Notably, the lowest-rated skills and competence include foreign language proficiency and entrepreneurial skills.

Figure 7 provides a comprehensive overview of the collective skills and competence acquired during the course of their studies. On average, these proficiencies are rated at level 4, with level 5 being the second most frequently observed rating. This suggests that students believe they have made progress in enhancing their skills and competence through their geography education, although there is a prevailing sentiment that further improvements are both possible and desirable.

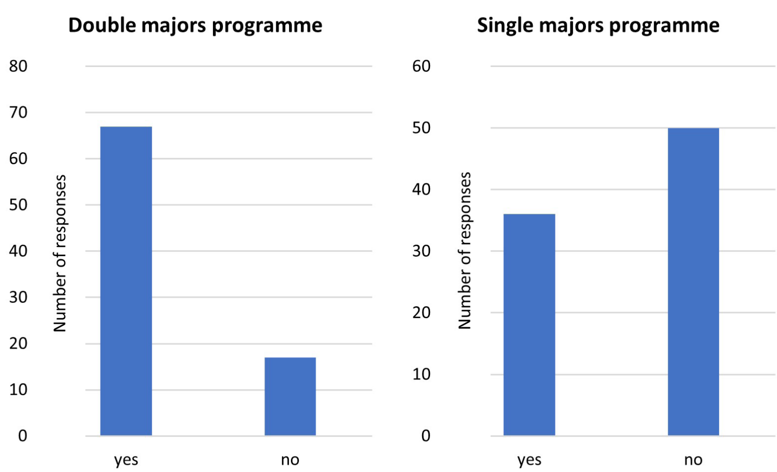
Figure 7: The sum of all skills and competence acquired while studying geography.



To be or not to be a teacher?

Given the absence of prior research in Slovenia regarding the awareness of potential career prospects associated with a geography degree, beyond the well-established teaching profession, our study sought to investigate this unexplored area. Additionally, our research aimed to delve into the aspirations of prospective geography teachers. To achieve this, we inquired whether students, including both single-subject and double-subject students, harboured an interest in pursuing a career as geography teachers. It's worth noting that double-subject students typically engage in the study of two subjects to fulfil the requirements for obtaining a teaching certificate.

Figure 8: Aspiration to work in the teaching profession.

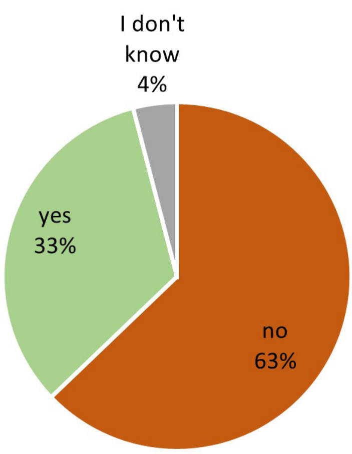


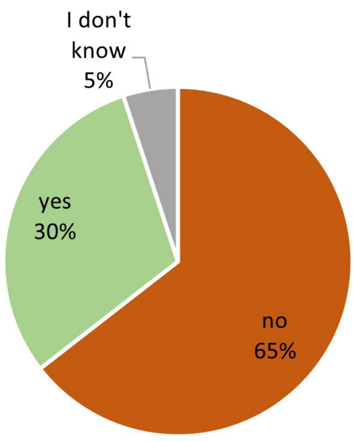
Evidently, a significant proportion of students aspire to pursue a career as educators. Many have expressed their preference for the study of geography with the intent of becoming teachers, driven by a genuine passion for working with children and sharing knowledge. Notably, approximately 20% of the double-subject students who participated in our survey harbour no inclination toward teaching; their choice of a double-subject programme primarily stems from their desire to study two different subjects rather than seeking a teaching qualification. In contrast, single-subject students, who do not automatically receive a teaching degree upon completing their second cycle, exhibit a substantial interest in the teaching profession, with 42% expressing the desire to become geography teachers one day. This underscores the importance of considering the inclusion of a single-subject pedagogical degree programme.

Over the past few decades, there has been a noticeable decline in the reputation of the teaching profession, as mirrored in the responses of the survey participants. Students have articulated concerns about the inadequacy of teachers' salaries in relation to the demands of the profession. While some acknowledge a lack of specific knowledge regarding the average salaries of educators, there is a prevailing perception that teachers are generally underpaid. In addition, a significant portion of the students share the belief that teachers no longer receive the level of respect they deserve, and that the teaching profession has lost some of the prestige it once enjoyed.

Students were also asked about their thoughts on teacher's salary and respect for teachers in society (Figure 9).

Figure 9: Opinion on the appropriateness of teachers' salaries and on respect for teachers in society.





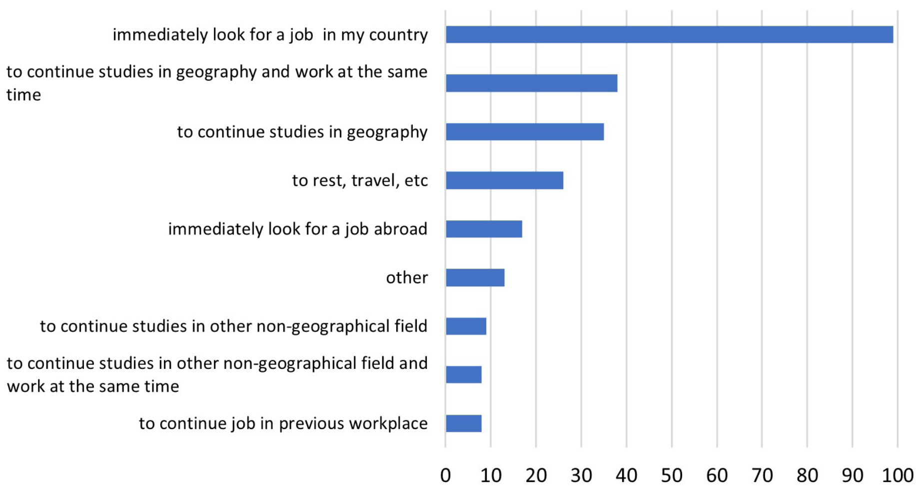
Although the respect for a profession is not solely determined by salary we nevertheless measured the correlation between their thoughts on teacher's salary and respect. We calculated the Pearson Chi-Square test, which shows the significance of correlation. We removed the categories "I don't know". The correlation values indicate that a correlation exists, since the significance values are less than 0.05. We can except the Chi-Square test since 0 cells have an expected count less than 5.

The Symmetric Measures test which indicates whether the correlation is strong and the Phi Coefficient which is used only for 2x2 tables were also done. The values are between –1 and 1, where 0 indicates a weak correlation. Since the value is 0.576, we can assume that the existing correlation is somewhat strong. This is also indicated by Cramer's V and Contingency Coefficient values.

Students' career aspirations

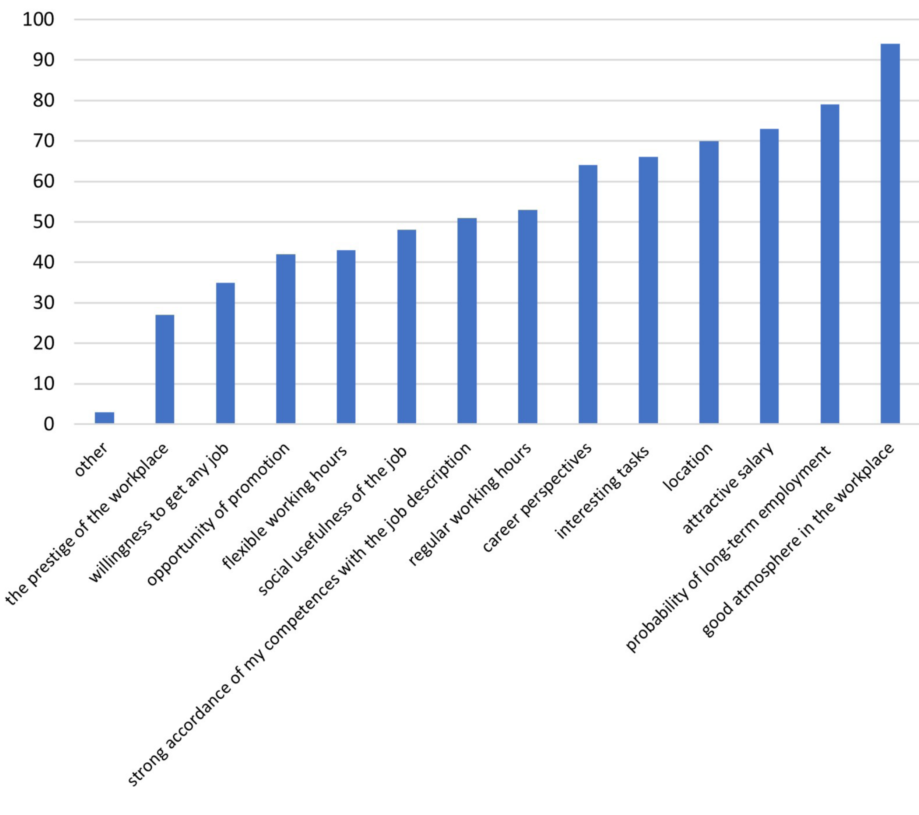
Regarding their future aspirations and plans (Figure 10) the majority of respondents will immediately look for a job in Slovenia. The undergraduate students will continue their geography studies, and some of them will work at the same time. A small percentage of students (4%) already have a job where they will continue to work after graduation. About 9% of students will continue their studies in subjects other than geography. 9% of students will look for a job abroad, while 14% will take time off to relax or travel.

Figure 10: Students' plans after graduation.



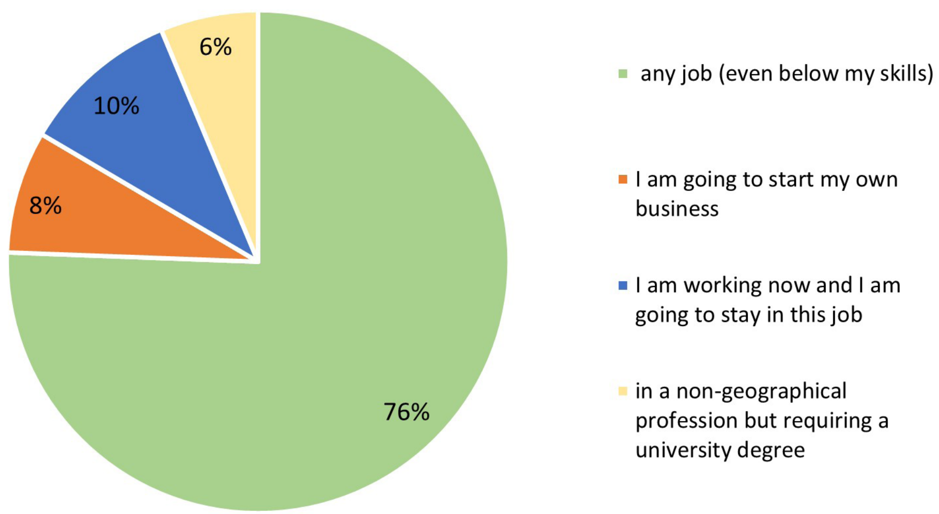
The respondents were then asked to rank up to 3 criteria they would use when choosing a job after graduation. The Figure 11 shows only how often the criterion was selected, but not how important each criterion is. Good atmosphere in the workplace got the most first-place votes (36) and ranked first when all votes were counted (94). Probability of long-term employment came in second in first-place votes (35) and overall (79). Interesting tasks received the third highest number of first placed votes (34) but ranked fifth overall (66). The third highest overall criterion is an attractive salary (73), but it received only 16 first-place votes, suggesting that while an attractive salary is very important in the job search, it is rarely the most important factor. Flexible working hours (10), opportunity of promotion (6), and job prestige (5) accounted for the lowest number of first placed votes. Willingness to accept any job was also ranked as one of the least important criteria (35 total votes).

Figure 11: What to consider when looking for a job.



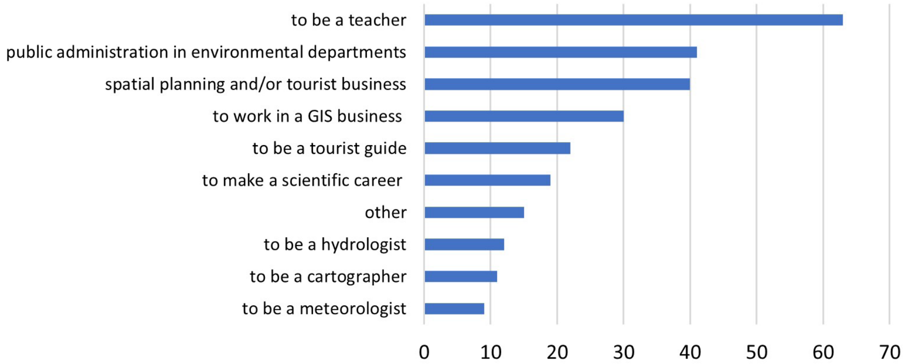
Although willingness to take any job was ranked as one of the least important criteria in the post-graduation job search, Figure 12 shows that geography students are willing to take any job, even if it is below their skills/competence level. Three-quarters of respondents are willing to take any job as their first job. 10% of students already have a job in which they will continue to work after graduation. 8% plan to start their own business. These businesses will be in GIS, tourism, agriculture, fashion and sports. 6% will graduate only to obtain a diploma in higher education and work in a non-geographic area that requires a university education.

Figure 12: Students' plans after graduation.



Students were presented with a list of professions and were tasked with indicating whether they would actively seek employment in those respective fields. The data reveals that 38% of the students expressed an interest in pursuing a career in education, while 25% expressed a desire to work in the environmental departments of public administration. Furthermore, 24% of the students expressed a preference for working in tourism and/or companies specializing in spatial planning. Conversely, professions such as meteorology, cartography, and hydrology appear to be the least favoured, implying a lower inclination among students to seek specialized roles in these fields, as indicated in Figure 13.

Figure 13: Professions in which students would seek employment.



Employers and young people's approach to finding a job

Students were requested to identify the criteria they believed employers consider when evaluating job applicants. They were allowed to select up to three criteria that they deemed most crucial in the hiring process. The Figure 14 indicates the frequency with which each criterion was chosen but does not provide insights into the relative importance of each. Notably, the most chosen criterion was previous work experience, garnering 60 first-place selections and a total of 119 votes. A diploma in higher education emerged as the second most frequently chosen criterion, earning 50 first-place votes and a total of 90 votes. Surprisingly, the personality of the candidate, while receiving only 23 first-place votes, ranked equally with the diploma in higher education in terms of total votes, accumulating 90 votes. Geographical skills were rated as the third most important attribute, earning 37 first-place votes and ranking fourth in terms of total votes with 82 selections.

Students and recent graduates take different approaches to job search. Respondents were asked to rank three approaches to job search. The chart again shows the total number of votes (Figure 15). Direct contact with the employer (visit or phone call) was the most common approach, with 94 first-place votes and 138 total votes. Personal or professional contact was second in first place votes (33) and second in total (94). Public employment agencies ranked third (83) and gained 25 first place votes.

Figure 14: What students think employers pay most attention to when recruiting.

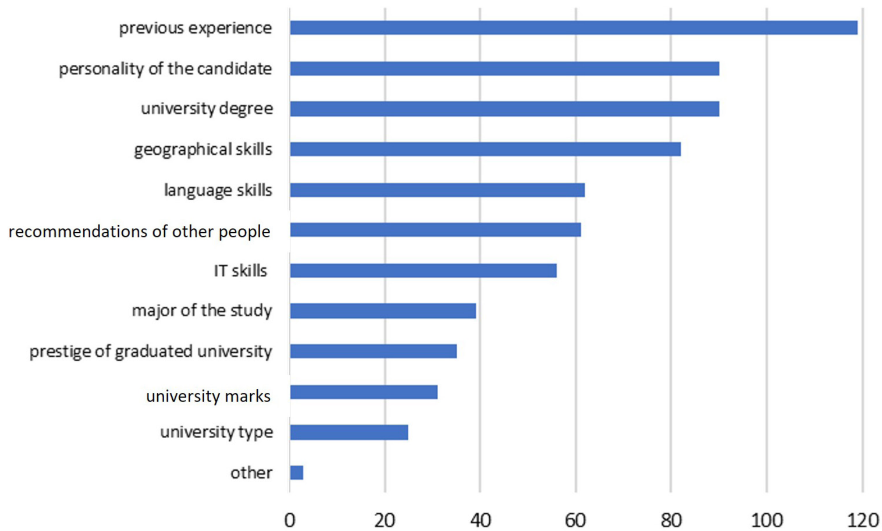
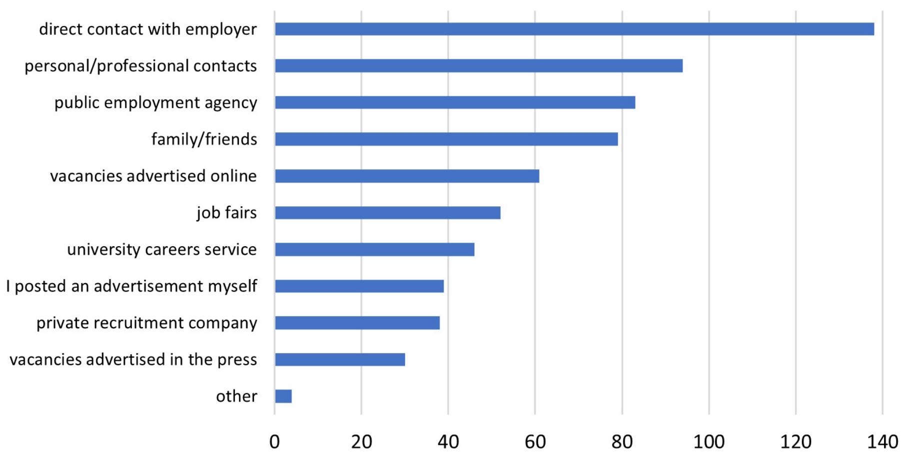
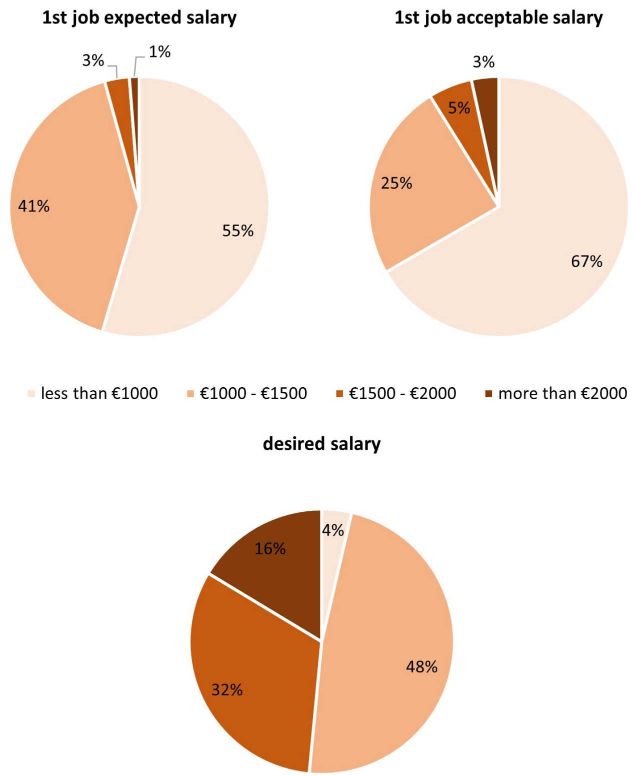


Figure 15: Ways of finding a job.



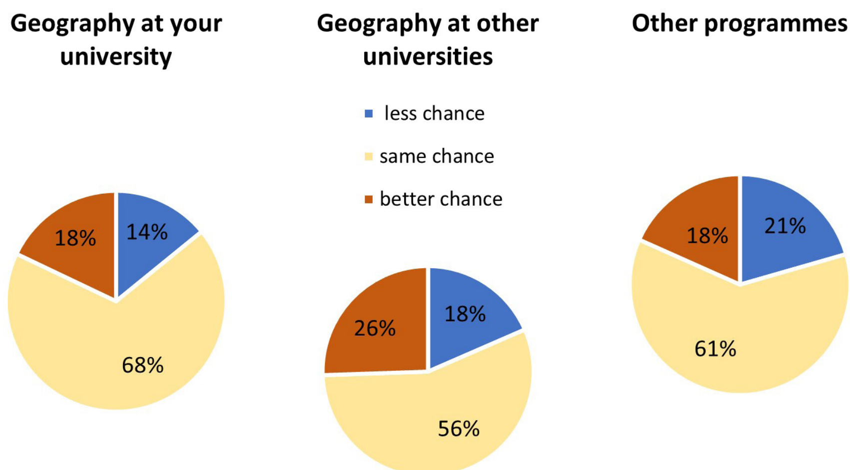
Survey participants were requested to provide estimations of their anticipated first salary, the minimum acceptable salary for their initial job, and their desired income, all measured in euros. This survey was conducted in both 2017 and 2020, with values adjusted to account for a 10% inflation rate. It's noteworthy that the average net salary in Slovenia stands at €1417.69 as of 2023 (according to SURS). The pie charts illuminate the expectations of respondents regarding their first salary, revealing that the majority anticipate receiving compensation below the national average. Specifically, more than half foresee earning less than €1000, with only 4% anticipating a starting salary exceeding €1500. Interestingly, a significant portion, approximately two-thirds of the participants, indicate a willingness to accept a salary below €1000 for their initial employment. About 25% express contentment with a salary in the range of €1000 to €1500, while 8% insist on a job that offers a compensation exceeding €1500. The landscape shifts when considering income aspirations, as a mere 4% aspire to earn €1000 or less. Approximately half aim to achieve earnings between €1000 and €1500, one-third set their sights on an income ranging from €1500 to €2000, and 16% harbour ambitions of earning more than that.

Figure 16: Students' expectations regarding their earnings.



Students estimated their chances of finding a job compared to other graduates. About two-thirds of the students believe that they have the same chances of finding a job compared to graduates of the same university. Only 18% believe they have a better chance. When students were asked to compare themselves to graduates from other universities, the number of students who believe they have better chances increased to 26%. The "less chance" category also increased by about 4%. About half believe that opportunities are equal and that it does not matter which university the graduate comes from. Compared to other majors, the number of students who believe they have lower opportunities exceeds the number of students who believe they have higher opportunities by 3%. 61% of all students believe they have the same employment opportunities as graduates of other programmes.

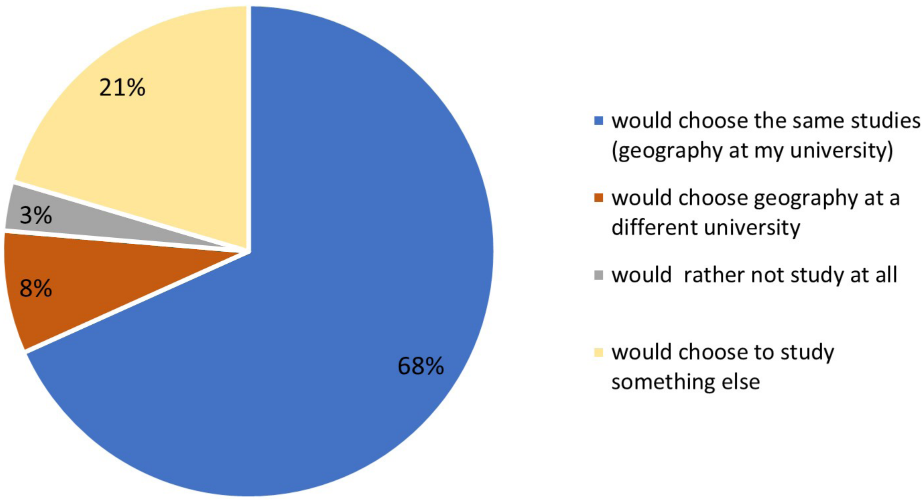
Figure 17: Students' estimation to find a job in comparison to other graduates.



If students were to decide again ...

The results show that students are generally satisfied with their studies. 68% of students would not change their choice of study. Surprisingly, 21% would choose a completely different course of study. In most cases, their subject of study would still be related to geography (e.g., tourism or geology) or computer science, or they would change from a double major to a single major, or vice versa. 8% would continue to study geography, just not in Ljubljana. Only 3% would prefer not to study at all.

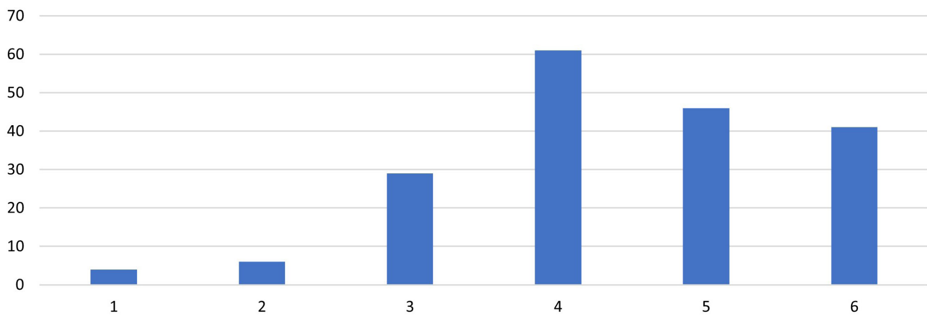
Figure 18: The decision for a study programme if students were to do it again.



Students were also invited to share their perspectives on how to enhance their programme and make it more valuable. The most frequent suggestions centred on increasing opportunities for fieldwork and hands-on experiences. Students expressed a desire for a broader range of subjects related to Geographic Information Systems (GIS) and a preference for curricula that are more application oriented.

Moreover, students generally held a positive view of studying geography and would readily recommend it to aspiring young learners. A substantial 33% of students rated their recommendation at level 4, while a significant 79% fell within the range of level 4 to level 6 (Figure 19). They found the programme exceptionally engaging, practically applicable to daily life, and highlighted its unique ability to provide a wide perspective not found in other disciplines. They would encourage young people who have a passion for traveling, exploring the world, immersing themselves in diverse cultures, and spending time outdoors to pursue geography studies. In their view, studying geography fosters a deeper comprehension of the surrounding world. Only a minority, constituting 5%, leaned towards level 1 or level 2, indicating a somewhat moderate level of interest. The primary concern expressed by this group was the limited job opportunities for geographers, rather than the subject's intrinsic appeal.

Figure 19: To study or not to study geography – students' choice.

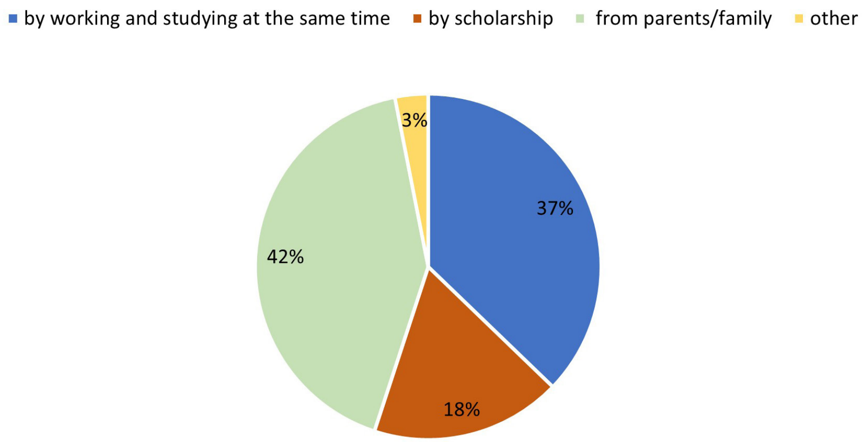


We analysed the correlation between students who were satisfied with the selection of their study and if they would also recommend it to young people. For this purpose, we calculated the Pearson Chi-Square test, which shows the significance of correlation. Because of small number of cases in some categories, we merged the first three categories into one, Level 4 was its own category, while levels 5 and 6 were also merged. There is an existing correlation between satisfaction and advising young people to study geography, as the Asymptotic Significance is below the 0.05 threshold. Less than 20% of cells have an expected count less than 5, which is necessary if we want to accept the Chi-Square test. The symmetric measures test shows the strength of the correlation between variables, the greater the value, the stronger the correlation. Values are on a scale from 0 to 1, where 1 indicates a very strong correlation. The values of Cramer's V and Contingency Coefficient show that the correlation is somewhat strong and significant.

While public education in Slovenia is offered without tuition fees, there are still financial implications associated with pursuing higher education. Students hailing from locations outside Ljubljana and its vicinity often find themselves responsible for covering housing expenses throughout the academic year. Geography students, in particular, face higher costs compared to the average student in Ljubljana due to the essential component of fieldwork in their curriculum. Fieldwork stands out as one of the most critical skills acquired in the study of geography, as highlighted earlier, and students overwhelmingly perceive it as such. Although fieldwork is mandatory for all geography students, it necessitates an added financial commitment.

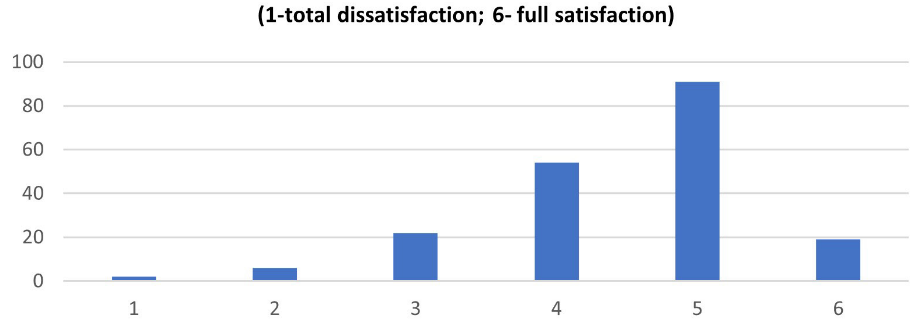
To meet these supplementary expenses (Figure 20), students predominantly rely on financial support from their families, constituting 42% of the source of funding. Approximately 37% of students adopt a dual approach, balancing work commitments alongside their studies to manage their costs. Furthermore, 18% of students receive scholarships to alleviate the financial burden associated with their education.

Figure 20: Covering subsistence cost during study.



In summary, students generally express a notable level of contentment with their choice of pursuing a geography major, as indicated in Figure 21. The average satisfaction rating stands at 4.5, with a significant 41% of students opting for level 5, while only 9% report being entirely satisfied with their choice. Notably, a mere 1% expressed complete dissatisfaction with the study of geography but did not provide specific feedback.

Figure 21: Students' satisfaction with their choice of study.



5 DISCUSSION

The data provided paints a compelling picture of the factors that influence students' decisions regarding their academic pursuits and future career aspirations. It is evident that the study programme itself plays a pivotal role in shaping their choices, with 55 first-place votes and a total of 107 votes highlighting its significance. The desire to nurture geographical interests closely follows as the second most important factor, with 47 students regarding it as their primary motivation. This suggests that a stimulating and engaging curriculum is a key driver of student satisfaction and persistence in their studies.

Furthermore, the data underscores the strong correlation between students' satisfaction with their studies and their intentions to persist. Even those students who contemplated dropping out appear to be somewhat satisfied with their academic experiences, emphasizing the value of a fulfilling education in retaining students. But nevertheless, the fact that 21% of students would opt for an entirely different course of study is concerning. This percentage is notably high and warrants further investigation.

The assessment of skills and competence acquired during the geography programme reveals an overall high level of competence, with fieldwork, a core component of geography courses, rating at the highest level. This not only reaffirms the programme's effectiveness but also underscores the practicality of the curriculum in preparing students for real-world applications.

The data on teaching skills and competence highlights the diversity of responses, with some skills rating higher than others. Notably, foreign language and entrepreneurial skills appear to be areas where students feel less prepared, indicating potential areas for improvement in the curriculum.

In terms of future aspirations, the majority of students express a desire to stay in Slovenia, with a significant portion planning to seek employment immediately. This speaks to the programme's perceived value in the local job market and the importance of geographic education in students' career prospects.

Lastly, when it comes to factors influencing students' job choices, a positive workplace atmosphere, the prospect of long-term employment, and interesting tasks emerge as top priorities. An attractive salary is deemed important but rarely the primary factor in job selection, indicating that students prioritize job satisfaction and work environment alongside financial considerations. But although the esteem for a profession is not exclusively dictated by salary, findings substantiate a correlation between teacher remuneration and the level of respect accorded to the teaching vocation.

In sum, this data underscores the importance of a stimulating curriculum, practical skill development, and favourable work conditions in shaping students' academic and career decisions. It also highlights the challenges facing the teaching profession, suggesting a need for improvements in salary and prestige to attract and retain quality educators.

The provided data sheds light on the priorities and expectations of geography students in terms of their career prospects and job choices. It is noteworthy that flexible working hours, opportunities for promotion, and job prestige received the fewest first-place votes, indicating that these factors may not be the primary drivers in their job search. Moreover, the willingness of geography students to accept any job, even if it is below their skill and competence level, is a significant finding. A substantial 75% of respondents express their willingness to take any job as their first job, potentially reflecting the competitive job market or the flexibility of geography graduates to adapt to different roles.

The data also offers insights into the specific career paths that geography students aspire to pursue. A significant proportion expresses interest in teaching jobs, public administration roles in environmental departments, and positions in tourism companies. These preferences align with the knowledge and skills acquired during their geography studies, underlining the programme's relevance to their career aspirations. But it is also concerning that a significant number of students perceive geography as merely a tool for understanding the world during travel, rather than recognizing its potential for a professional career. It seems they have not fully grasped the diverse opportunities available through the study and application of geography.

Regarding the attributes that matter most in their job search, previous experience tops the list, followed closely by a diploma in higher education. This suggests that practical experience and educational qualifications hold great importance for these students. Personality is also considered a significant factor, indicating the importance of soft skills in the job market.

The data on salary expectations is particularly revealing. The majority of students expect a starting salary below €1000, with only a small fraction anticipating a higher income. This data implies that geography students may have relatively modest salary expectations upon entering the job market, possibly influenced by a perceived lack of high-paying job opportunities in their field.

Furthermore, the findings regarding students' views on job prospects and their commitment to their chosen field of study are crucial. A majority of students believe they have an average chance of finding a job compared to graduates of the same university, suggesting a realistic perspective on their future employment. The fact that 68% would not change their choice of study is indicative of their dedication to geography, while the 21% who would opt for a different course of study may reflect a degree of uncertainty or the desire for alternative career opportunities.

Lastly, the data highlights the financial challenges faced by geography students, particularly those who are not from the Ljubljana area. The need to pay for housing during the year together with the fieldwork costs can significantly increase their overall costs.

In summary, this data provides valuable insights into the mindset and priorities of geography students as they navigate their academic and career paths. It underscores their adaptability, strong preference for relevant work experience, and potentially modest salary expectations, all of which have implications for educators, employers, and policymakers in the field of geography education and employment. The results will be of great help for the further development of geography study programmes at our faculty, as the knowledge of the factors influencing young people's decisions to study, as well as their career aspirations and expectations, will allow us to understand the low enrolment figures in geography study programmes in recent years and to find potential solutions or a way to improve the current situation.

6 CONCLUSIONS

In the dynamic field of education in Slovenia, where change has been the only constant, it is essential to recognize that not every change is inherently desirable. As Huber aptly noted, the direction of change requires collective agreement, and active participation is crucial to shape the change that aligns with our educational goals (Huber, 2011). One of the pressing challenges that this data highlights is the need to challenge the misconception that geography lacks identity and is merely a repository of general knowledge about the world's facts and features, as suggested by Israr-ud--Din (1991). To ensure the relevance of geography as a science subject, it is imperative to keep its curricula up to date with the ever-evolving scientific landscape, as pointed out by Khan (1991). This is especially crucial as geographers possess specialized skills in areas such as surveying, cartography, GIS, and environmental protection, which have not been fully utilized, leading to unemployment among geography graduates.

The decline in the number of students studying geography is a concerning trend, particularly in an era where global issues like climate change and biodiversity demand geographical perspectives. Understanding the demographics of geography students is a vital step in revitalizing the discipline and changing perceptions of its value. The data presented, encompassing a range of quantitative sources, suggests that there is hope for a resurgence in geography study in Slovenia. This also calls for proactive engagement with potential employers, as comprehending their expectations enables continual improvements to the study curriculum.

In conclusion, it is evident that the field of geography is at a critical juncture, where active efforts are needed to reshape perceptions and promote its importance. The challenge for the broader community of professional geographers is to collaboratively work towards improving the current situation. By dispelling misconceptions about geography and advocating for its relevance in addressing pressing global challenges, geography can regain its identity and secure its position as a vital discipline in the realm of education and beyond.

References

Astin, A., 1999. Student involvement: a developmental theory for higher education. Journal of College Student Development, 40, 5, pp. 518–529.

Barcan, R., 2013. Academic life and labour in the new university: Hope and other choices. Farnham: Ashgate.

Berg, L., Roche, M., 1997. Market metaphors, neo-liberalism and the construction of academic landscapes in Aotearoa/New Zealand. Journal of Geography in Higher Education, 21, 2, pp. 147–161.

Brooks, R., 2003. Young people's higher education choices: The role of family and friends. British Journal of Sociology of Education, 24, 3, pp. 283–297.

Collins, F., Lewis, N., 2016. New Zealand universities: the prospects and pitfalls of globalizing higher education. In: Collins, C., Lee, M., Hawkins, J., Neubauer, D. (eds.). The Palgrave handbook of Asia Pacific higher education. New York: Palgrave Macmillan, pp. 597–613.

Croot, D., 1999. Student recruitment and the geography of undergraduate geographers in England and Wales. Journal of Geography in Higher Education, 23, 1, pp. 21–47, DOI: 10.1080/03098269985588.

Davidson, J., Jones, C., Johnson, M., Yildiz, D., Prahalad, V., 2023. Renewing the purpose of geography education: Eco-anxiety, powerful knowledge, and pathways for transformation. DOI: 10.1111/1745-5871.12603.

Dufty-Jones, R., 2017. The career aspirations and expectations of geography doctoral students: establishing academic subjectivities within a shifting landscape. Geographical Research, 56, 2, pp. 126–138. DOI: 10.1111/1745-5871.12270.

Eidimtas, A., Juceviciene, P., 2014. Factors influencing school-leavers decision to enrol in higher education. Procedia – Social and Behavioural Sciences, 116, pp. 3983–3988. DOI: 10.1016/j.sbspro.2014.01.877.

Estaville, L., Brown, B., Caldwell, S., 2006. Geography undergraduate program assessment. Journal of Geography, 105, pp. 239–248. DOI: 10.1080/00221340608978693.

Fatıma, M., 2016. Perceptions of geography as a discipline among students of different academic levels in Pakistan. RIGEO, 6, 1, pp. 67–85. URL: https://files.eric.ed.gov/fulltext/EJ1158097.pdf (accessed 18.10.2023).

Gibson, C., 2007. Geography in higher education in Australia. Journal of Geography in Higher Education, 31, 1, pp. 97–119.

Head, L., Rutherford, I., 2021. The state of geography in Australian universities. Transactions of the Institute of British Geographers, n/a(n/a). DOI: 10.1111/tran.12456.

Hill, J., Woodland, W., Atterton, G., 2008. A case study of activities to enhance undergraduate recruitment into geography. Planet, 19, 1, pp. 21–25. DOI: 10.11120/plan.2008.00190021.

Huber, S. G., 2011. The impact of professional development: A theoretical model for empirical research, evaluation, planning and conducting training and development

programmes. Professional Development in Education, 37, 5, pp. 837–853. DOI: 10.1080/19415257.2011.616102.
Israr-ud-Din, 1991. The case of geography in Pakistan. Paper presented at the National Seminar on Progress of geography in Pakistan, Baragalli, Pakistan.
Khan, R. S. Z., 1991. Inaugural Address. Paper presented at the National Seminar on Progress of geography in Pakistan, Baragalli Pakistan.
Kubiatko, M., Janko, T., Mrazkova, K., 2012. Czech student attitudes towards geography. Journal of Geography, 111, 2, pp. 65–75. DOI:10.1080/00221341.2011.594904.
Lewis, N., 2011. Political projects and micro-practices of globalising education: building an international education industry in New Zealand. Globalisation, Societies and Education, 9, 2, pp. 225–246.
Lowe, H., Cook, A., 2003. Mind the gap: are students prepared for higher education? Journal of Further and Higher Education, 27, 1, pp. 53–76.
Milsom, A., Coughlin, J., 2015. Satisfaction with college major: A grounded theory study. NACADA Journal, 35, 2, pp. 5–14. DOI:10.12930/NACADA-14-026.
Olssen, M., Peters, M., 2005. Neoliberalism, higher education and the knowledge economy: from free market to knowledge capitalism. Journal of Education Policy, 20, 3, pp. 313–345.
Pascarella, E., Terenzini, P. T., 2005. How college affects students. A third decade of research. San Francisco: Jossey-Bass.
Piróg, D., 2018. To study or not to study geography? The changing motivations behind choosing geography degree programmes by Polish students in the years 1995–2015. Geoforum, 94, pp. 63–71. DOI: 10.1016/j.geoforum.2018.06.013.
Sevinç, S., Gizir, C. A., 2014. Factors negatively affecting university adjustment from the views of first-year university students: the case of Mersin University. Educational Sciences: Theory & Practice, 14, 4, pp. 1301–1308.
Shore, C., Taitz, M., 2012. Who 'owns' the university? Institutional autonomy and academic freedom in an age of knowledge capitalism. Globalisation, Societies and Education, 10, 2, pp. 201–219. DOI: 10.1080/14767724.2012.677707.
Slovenian Employment Service (Zavod RS za zaposlovanje). URL: https://www.ess.gov.si/iskalci-zaposlitve/#/ (accessed 10.09.2023).
Solem, M., Kollasch, A., Lee, J., 2013. Career goals, pathways and competencies of geography graduate students in the USA. Journal of Geography in Higher Education, 37, 1, pp. 92–116. DOI: 10.1080/03098265.2012.729563.
Statistical Office of the Republic of Slovenia. URL: https://www.stat.si/statweb/AboutUs/Recruitment (accessed 10.09.2023).
van Rooij, E. C. M., Jansen, E. P. W. A., van de Grift, W. J. C. M., 2018. First-year university students' academic success: the importance of academic adjustment. European Journal of Psychology of Education, 33, pp. 749–767. DOI: 10.1007/s10212-017-0347-8.

ODLOČITEV ZA ŠTUDIJ GEOGRAFIJE TER POKLICNE ASPIRACIJE BODOČIH DIPLOMANTOV IN MAGISTRANTOV

Povzetek

Na odločitev mladostnika za določen študij zagotovo vplivajo številni dejavniki, med katerimi lahko izpostavimo predvsem njegove interese in predanost nečemu, sposobnosti in veščine, karierne možnosti, družinska pričakovanja, socialni pritisk in vpliv vrstnikov, informacije, ki so mu na voljo, in svetovanje, ki ga je deležen, ter, nazadnje, finančne omejitve. Z namenom ugotoviti, kaj vse botruje odločitvi mladostnikov za študij geografije in kakšne so poklicne aspiracije bodočih diplomantov in magistrantov, smo leta 2017 in 2020 na Oddelku za geografijo FF UL izvedli raziskavo, v kateri je skupno sodelovalo 155 študentov prvih letnikov prve in druge stopnje ter drugih letnikov druge stopnje.

Pridobljeni podatki izkazujejo prepričljiv nabor dejavnikov, ki vplivajo na odločitve študentov glede njihovega študijskega udejstvovanja in prihodnjih poklicnih prizadevanj. Očitno je, da ima sam študijski program ključno vlogo pri njihovi izbiri, saj je njegov pomen poudarilo 55 sodelujočih, ki ga je umestilo na prvo mesto, skupno pa ga je omenilo 107 sodelujočih. Želja po razvijanju geografskih interesov je na drugem mestu po pomembnosti, saj jo je 47 študentov označilo za glavno motivacijo. To kaže, da je spodbuden in zanimiv študijski program ključni dejavnik zadovoljstva študentov in njihove vztrajnosti pri študiju. Poleg tega podatki kažejo, da obstaja močna povezava med zadovoljstvom študentov s študijem in njihovimi nameni, da bodo vztrajali. Zdi se, da so celo tisti študenti, ki so razmišljali o prekinitvi študija, vsaj deloma zadovoljni s svojimi študijskimi izkušnjami, kar poudarja vrednost izpolnjujočega izobraževanja pri ohranjanju študentov. Kljub temu pa je zaskrbljujoče dejstvo, da bi se 21 % študentov odločilo za povsem drugačen študij. Ker je delež izrazito visok, bi tovrstno težnjo študentov kazalo natančneje nasloviti.

Ocena spretnosti in kompetenc, pridobljenih med študijem geografije, kaže na splošno visoko raven pridobljenih kompetenc, pri čemer je terensko delo, ki je med osrednjimi deli študijskega programa, ocenjeno na najvišji ravni. To ne samo potrjuje učinkovitost programa, ampak tudi poudarja ustreznost programa pri pripravi študentov na profesionalno pot. Med spretnostmi in kompetencami, ki jih študenti ne dosegajo v zadovoljivi meri, izstopajo tuji jeziki in podjetniške spretnosti oz. kompetence, kar bi v prihodnosti kazalo izboljšati.

Kar zadeva želje in pričakovanja za prihodnost, si večina študentov želi ostati v Sloveniji, velik del pa jih namerava takoj poiskati zaposlitev, kar potrjuje zaznano vrednost programa na domačem trgu dela in pomen geografskega izobraževanja za poklicne možnosti študentov. Med dejavniki, ki vplivajo na izbiro zaposlitve študentov, se kot najpomembnejše prioritete pojavljajo pozitivno vzdušje na delovnem mestu,

možnost dolgoročne zaposlitve in zanimive naloge. Privlačna plača se zdi pomemben, vendar redko glavni dejavnik pri izbiri zaposlitve, kar kaže na to, da študenti poleg finančnih vidikov dajejo prednost zadovoljstvu pri delu in delovnemu okolju. Čeprav spoštovanja poklica ne narekuje izključno plača, pa ugotovitve na področju šolstva potrjujejo povezavo med plačo učiteljev in stopnjo spoštovanja učiteljskega poklica.

Če povzamemo, rezultati raziskave poudarjajo pomen spodbudnega študijskega programa, razvoja praktičnih spretnosti in ugodnih delovnih pogojev pri oblikovanju akademskih in poklicnih odločitev učencev. Opozarjajo tudi na izzive, s katerimi se sooča učiteljski poklic, in nakazujejo potrebo po izboljšanju plač in ugleda za privabljanje in ohranjanje kakovostnih učiteljev.

Rezultati osvetljujejo prednostne naloge visokošolskega študija geografije in pričakovanja študentov geografije glede njihovih poklicnih možnosti in izbire zaposlitve. Omeniti velja, da so prožen delovni čas, možnosti napredovanja in prestiž delovnega mesta prejeli najmanj glasov na prvem mestu, kar kaže na to, da ti dejavniki morda niso ključni pri njihovem iskanju zaposlitve. Poleg tega je pomembna ugotovitev tudi pripravljenost študentov geografije, da sprejmejo katero koli delo, tudi če je pod njihovo ravnjo znanja in kompetenc. Kar 75 % anketirancev izraža pripravljenost sprejeti katero koli delo kot svojo prvo zaposlitev, kar lahko odraža konkurenčni trg dela ali pripravljenost diplomantov oz. magistrantov geografije, da se prilagodijo različnim vlogam.

Podatki ponujajo tudi vpogled v specifične poklicne poti, ki si jih želijo opravljati študenti geografije. Velik delež jih izraža zanimanje za pedagoški poklic, delovna mesta v javni upravi na okoljskih oddelkih in delovna mesta v turističnih podjetjih. Te želje se ujemajo z znanjem in spretnostmi, ki so jih pridobili med študijem geografije, kar poudarja pomen programa za njihove poklicne želje. Zaskrbljujoče pa je tudi dejstvo, da precejšnje število študentov dojema geografijo zgolj kot orodje za razumevanje sveta med potovanjem, ne pa da bi prepoznali njen potencial za poklicno kariero. Zdi se, da niso v celoti dojeli različnih priložnosti, ki jih ponuja geografija.

Omenimo še lastnosti, ki so po mnenju sodelujočih najpomembnejše pri iskanju zaposlitve. Na vrhu seznama so predhodne izkušnje, takoj za njimi pa je visokošolska diploma, zato lahko sklepamo, da imajo praktične izkušnje in izobrazba za te študente velik pomen. Kot pomemben dejavnik izstopa tudi osebnost posameznika, kar kaže na pomen mehkih veščin na trgu dela. Tudi podatki o pričakovanih plačah so zelo zgovorni. Večina študentov pričakuje začetno plačo pod 1000 EUR, le majhen del pa pričakuje višji dohodek, kar bi bila lahko posledica razmeroma skromnih pričakovanj študentov geografije ob vstopu na trg dela.

Poleg tega so ključne ugotovitve o stališčih študentov glede zaposlitvenih možnosti in njihove zavezanosti izbranemu študijskemu področju. Večina študentov meni, da imajo v primerjavi z diplomanti oz. magistranti iste univerze povprečne možnosti, da najdejo zaposlitev, kar kaže na realističen pogled na njihovo prihodnjo zaposlitev. Dejstvo, da 68 % študentov ne bi spremenilo svoje izbire študija, kaže na njihovo predanost geografiji, medtem ko 21 % študentov, ki bi se odločili za drugačno študijsko smer, morda odraža stopnjo negotovosti ali željo po alternativnih poklicnih možnostih.

V raziskavi so bili izpostavljeni tudi finančni izzivi, s katerimi se soočajo študenti geografije, zlasti tisti, ki niso iz okolice Ljubljane, saj najemnina skupaj s stroški terenskega dela lahko znatno poveča njihove skupne stroške.

Če povzamemo, pridobljeni podatki zagotavljajo dragocen vpogled v miselnost in razmišljanje študentov geografije, ko krmarijo po svoji študijski in (bodoči) poklicni poti. Poudarjajo njihovo prilagodljivost, veliko naklonjenost ustreznim delovnim izkušnjam in potencialno skromna pričakovanja glede plač, kar vse vpliva na izobraževalce, delodajalce in oblikovalce politike na področju geografskega izobraževanja in zaposlovanja. Rezultati bodo v veliko pomoč pri nadaljnjem razvoju študijskih programov geografije na naši fakulteti, saj nam bo poznavanje dejavnikov, ki vplivajo na odločitev mladih za študij, ter njihovih poklicnih želja in pričakovanj omogočilo razumeti nizke številke vpisa na študijske programe geografije v zadnjih letih in najti morebitne rešitve oziroma način za izboljšanje trenutnega stanja.

Na dinamičnem področju izobraževanja v Sloveniji in širše, kjer so spremembe edina stalnica, se je treba zavedati, da vsaka sprememba ni sama po sebi zaželena. Kot je posrečeno zapisal Huber, je za smer sprememb potreben skupen dogovor, aktivna udeležba pa je ključna za oblikovanje sprememb, ki so skladne z našimi izobraževalnimi cilji (Huber, 2011). Upadanje števila študentov, ki študirajo geografijo, je zaskrbljujoč trend, zlasti v času, ko globalna vprašanja, kot so na primer podnebne spremembe in biotska raznovrstnost, zahtevajo geografsko perspektivo. Predstavljeni podatki, ki zajemajo vrsto kvantitativnih virov, kažejo, da obstaja upanje za ponovno oživitev študija geografije v Sloveniji. To zahteva tudi proaktivno sodelovanje s potencialnimi delodajalci, saj tudi razumevanje njihovih pričakovanj omogoča nenehno izboljševanje študijskega programa.

Zaključimo lahko, da je področje geografije na kritični točki, kjer so potrebna aktivna prizadevanja za preoblikovanje dojemanja in promocijo njenega pomena. Izziv za širšo skupnost poklicnih geografov je, da si s skupnimi močmi prizadevajo za izboljšanje trenutnega stanja. Z odpravljanjem napačnih predstav o geografiji in zagovarjanjem njenega pomena pri reševanju perečih globalnih izzivov lahko geografija ponovno pridobi svojo identiteto in si zagotovi položaj pomembne discipline na področju izobraževanja in širše.

NAVODILA AVTORJEM ZA PRIPRAVO PRISPEVKOV V ZNANSTVENI REVIJI DELA

1. Znanstvena revija DELA je periodična publikacija Oddelka za geografijo Filozofske fakultete Univerze v Ljubljani. Izhaja od leta 1985. Namenjena je predstavitvi znanstvenih in strokovnih dosežkov z vseh področij geografije in sorodnih strok. Od leta 2000 izhaja dvakrat letno v tiskani in elektronski obliki (https://journals.uni-lj.si/Dela). Revija je uvrščena v mednarodne baze (Scopus, CGP – Current Geographical Publications, DOAJ, ERIH PLUS, GEOBASE, Central and Eastern European Academic Source, GeoRef) in ima mednarodni uredniški odbor.

2. V prvem delu so objavljeni znanstveni članki (1.01 in 1.02 po kategorizaciji COBISS). V drugem delu se objavljajo informativni prispevki v rubriki POROČILA, in sicer biografski prispevki (obletnice, nekrologi), predstavitve geografskih monografij in revij, pomembnejše geografske prireditve in drugi dogodki idr.

3. Znanstveni in strokovni članki so lahko objavljeni v treh jezikovnih različicah: dvojezično slovensko-angleško, samo v slovenskem jeziku, samo v angleškem jeziku. Prispevki morajo imeti naslednje sestavine:
- naslov članka;
- ime in priimek avtorja/avtorjev;
- avtorjev poštni naslov (npr. Oddelek za geografijo Filozofske fakultete Univerze v Ljubljani, Aškerčeva cesta 2, SI-1000 Ljubljana);
- avtorjev elektronski naslov;
- ORCID (če ga avtor ima);
- izvleček (skupaj s presledki do 500 znakov);
- ključne besede (do 8 besed);
- besedilo članka (skupaj s presledki do 30.000 znakov; v primeru daljših prispevkov naj se avtor predhodno posvetuje z urednikom);
- v primeru enojezičnih člankov tudi povzetek/summary v drugem jeziku (skupaj s presledki od 5000 do 8000 znakov) ter prevod izvlečka in ključnih besed v drugi jezik;
- ime prevajalca.

4. Članek naj ima naslove poglavij in naslove podpoglavij, označene z arabskimi številkami v obliki desetiške klasifikacije (npr. 1 Uvod, 2 Metode, 3 Rezultati in razprava, 4 Sklep, Literatura in viri ipd.). Razdelitev članka na poglavja je obvezna, podpoglavja naj avtor uporabi le izjemoma.

5. Avtorji naj prispevke pošljejo v digitalni obliki v formatih *.doc, *.docx ali *.odt. Digitalni zapis besedila naj bo povsem enostaven, brez slogov in drugega zapletenega oblikovanja, brez deljenja besed, podčrtavanja in podobnega. Avtorji naj označijo le krepki in ležeči tisk. Besedilo naj bo v celoti izpisano z malimi tiskanimi črkami (velja tudi za naslove in podnaslove, razen velikih začetnic), brez nepotrebnih krajšav, okrajšav in kratic.

6. Zemljevidi, grafične priloge in fotografije morajo upoštevati največjo velikost v objavljenem delu, to je 125 x 180 mm. Rastrski formati (*.tiff ali *.jpg) morajo biti oddani v digitalni obliki z ločljivostjo najmanj 300 pik na palec (dpi). Zemljevidi in druge grafične priloge v vektorski obliki (*.ai, *.pdf, *.cdr) morajo vsebovati fonte, večje od 6 pt. Grafikoni morajo biti izdelani s programom Excel ali sorodnim programom (avtorji jih oddajo skupaj s podatki v izvorni datoteki, npr. Excelovi preglednici). Če avtorji ne morejo oddati prispevkov in grafičnih prilog v navedenih oblikah, naj se predhodno posvetujejo z urednikom. Za grafične priloge, za katere avtorji nimajo avtorskih pravic, morajo priložiti fotokopijo dovoljenja za objavo, ki so ga pridobili od lastnika avtorskih pravic.

7. Avtorji so dolžni upoštevati način citiranja v članku ter oblikovanje seznama virov in literature, preglednic in ostalega grafičnega gradiva, kot je to navedeno v podrobnejših navodilih za pripravo člankov na povezavi https://journals.uni-lj.si/Dela/about/submissions. Za dela, ki jih je avtor uporabil v elektronski obliki, naj poleg bibliografskih podatkov navede še elektronski naslov, na katerem je delo dostopno bralcem, in datum citiranja. Za znanstvene članke s številko DOI avtorji navedejo DOI številko.

8. Znanstveni članki bodo recenzirani. Recenzentski postopek je praviloma anonimen, opravita ga dva kompetentna recenzenta. Recenzenta prejmeta članek brez navedbe avtorja članka, avtor članka pa prejme recenzentove pripombe brez navedbe recenzentovega imena. Če recenziji ne zahtevata popravka ali dopolnitve članka, se avtorju članka recenzij ne pošlje. Uredniški odbor lahko na predlog recenzentov zavrne objavo prispevka.

9. Avtorji, ki želijo, da se njihov članek objavi v reviji, se strinjajo z naslednjimi pogoji:

- Pisci besedila z imenom in priimkom avtorstva potrjujejo, da so avtorji oddanega članka, ki bo predvidoma izšel v reviji DELA v okviru Znanstvene založbe Filozofske fakultete Univerze v Ljubljani (Univerza v Ljubljani, Filozofska fakulteta, Aškerčeva 2, 1000 Ljubljana). O likovno-grafični in tehnični opremi dela ter o pogojih njegovega trženja odloča založnik.
- Avtorji jamčijo, da je delo njihova avtorska stvaritev, da na njem ne obstajajo pravice tretjih oseb in da z njim niso kršene kakšne druge pravice. V primeru zahtevkov tretjih oseb se avtorji zavezujejo, da bodo varovali interese založnika ter mu povrnili škodo in stroške.

- Avtorji obdržijo materialne avtorske pravice ter založniku priznajo pravico do prve izdaje članka z licenco Creative Commons Attribution-ShareAlike 4.0 International License (priznanje avtorstva in deljenje pod istimi pogoji). To pomeni, da se lahko besedilo, slike, grafi in druge sestavine dela prosto distribuirajo, reproducirajo, uporabljajo, priobčujejo javnosti in predelujejo, pod pogojem, da se jasno in vidno navede avtorja in naslov tega dela in da se v primeru spremembe, preoblikovanja ali uporabe tega dela v svojem delu, lahko predelava distribuira le pod licenco, ki je enaka tej.
- Avtorji lahko sklenejo dodatne ločene pogodbene dogovore za neizključno distribucijo različice dela, objavljene v reviji (npr. oddaja v institucionalni repozitorij ali objava v knjigi), z navedbo, da je bilo delo prvič objavljeno v tej reviji.
- Pred postopkom pošiljanja ali med njim lahko avtorji delo objavijo na spletu (npr. v institucionalnih repozitorijih ali na svojih spletnih straneh), k čemur jih tudi spodbujamo, saj lahko to prispeva k plodnim izmenjavam ter hitrejšemu in obsežnejšemu navajanju objavljenega dela.

10. Avtor sam poskrbi za jezikovno ustreznost svojega besedila in prevoda (vključno z izvlečkom, ključnimi besedami in povzetkom članka). Če je besedilo jezikovno neustrezno, ga uredništvo vrne avtorju, ki mora poskrbeti za lektorski pregled besedila. Če obseg avtorskega dela ni v skladu z navodili za objavo, avtor dovoljuje izdajatelju, da ga po svoji presoji ustrezno prilagodi.

11. Izdajatelj poskrbi, da bodo vsi prispevki s pozitivno recenzijo objavljeni, če bo imel zagotovljena sredstva za tisk. O razporeditvi prispevkov odloča uredniški odbor. Vsakemu avtorju pripada en brezplačen tiskan izvod publikacije.

12. Avtorji naj prispevke pošljejo na elektronski naslov *dela_geo@ff.uni-lj.si* ali pa oddajo na spletni strani revije (https://journals.uni-lj.si/Dela/login).

INSTRUCTIONS FOR AUTHORS PREPARING ARTICLES FOR THE SCIENTIFIC JOURNAL – DELA

1. The scientific journal DELA is a periodical publication of the Department of Geography, Faculty of Arts, University of Ljubljana. It has been published since 1985. It is dedicated to presenting scientific and technical achievements in all fields of geography and related disciplines. Since 2000 it has been published twice yearly in print and electronic form (https://journals.uni-lj.si/Dela). The magazine is included in the international databases (Scopus, CGP – Current Geographical Publications, DOAJ, ERIH PLUS, GEOBASE, Central and Eastern European Academic Source, GeoRef) and has an international Editorial Board.

2. Published in the first part are scientific articles (1.01 and 1.02 by COBISS categorisation). Published in the second part are informative articles categorised as REPORTS as well as biographical contributions (anniversaries, obituaries), reviews of geographical monographs and journals, major events in the field of geography and other events, etc.

3. Scientific articles may be published in one of three language configurations: bilingual Slovene-English, entirely in Slovene or entirely in English

Articles must have the following components:

- Article title;
- Name and surname of author/authors;
- Author's address (eg. Department of Geography, Faculty of Arts, University of Ljubljana, Aškerčeva cesta 2, 1000 Ljubljana, Slovenia);
- Author's email;
- Author's ORCID (if available);
- Abstract (up to 500 characters with spaces);
- Keywords (up to eight);
- Article text (up to 30,000 characters with spaces; for longer articles authors should consult with the editor before submitting);
- In cases of articles written in one language, these must also include a summary in the other language (between 5,000 and 8,000 characters with spaces) and translations of the abstract and keywords;
- Name of translator.

4. The article should have chapter headings and subheadings identified with Arabic numerals in the form of decimal classification (e.g. 1 Introduction, 2 Methods, 3 Results and discussion, 4 Conclusion, References etc.). Structuring the article in chapters is mandatory, authors may use sub-chapters only in exceptional cases.

5. Authors should submit their articles as digital copies – format may be *.doc, *.docx or or *.odt. The digital version of the text should be completely clean, without styles and other sophisticated design, without line break hyphenation nor underlining, and so forth. Authors may mark using only bold and italic text. The text should be written entirely in lowercase (including in the title and subtitle, with the exception of capitalised words) without unnecessary contractions, acronyms and abbreviations.

6. Maps and other graphic materials must conform to the format of the journal. Fullpage figures need to be sized 125 x 170 mm, while smaller figures are restricted to a maximum width of 125 mm. Font size must be at least 6pt. All graphic materials must be submitted as individual files (i.e. not as part of the file with the text). Graphics (maps, etc.) should be in AI, CDR, PDF, TIFF or JPG file formats. Those in raster formats (e.g. *.tiff or *.jpg) must have a resolution of at least 300 dots per inch (dpi). Charts must be prepared in Excel or a similar programme (authors should submit them together with the data in the source file, e.g. Excel spreadsheet). If authors are unable to submit articles and graphic materials in the mentioned forms, they should consult with the editor. If an author is not the copyright holder of graphic materials then they must attach a photocopy of the approval for publication, which they have obtained from the copyright owner.

7. In articles authors are obliged to comply with the citation style and produce a reference list, tables and other graphic materials, as outlined in the detailed guidelines for the preparation of articles – available at https://journals.uni-lj.si/Dela/about/submissions. In instances where the author used electronic resources, in addition to the bibliographic details they should also provide a URL where readers can access the resources, and note the date it was accessed. For scientific articles with a DOI number, authors should provide the DOI number.

8. Scientific and professional articles will be peer reviewed. The peer-review process is anonymous, carried out by two competent reviewers. Reviewers receive an article without the author's name being revealed, the author of the article receives the reviewer's comments, without being given any reviewers' names. If reviewers do not demand corrections or amendments be made to the article, the reviewers do not send the author the reviewed article. Based on recommendations from the reviewers the Editorial Board may refuse to publish the article.

9. Authors wishing to have their article published in the journal agree to the following conditions:

- Listed authors (name and surname) confirm that they are the authors of the submitted article, intended for publication in the journal DELA, a publication of the Ljubljana University Press, Faculty of Arts [Znanstvena založba Filozofske fakultete Univerze v Ljubljani] (University of Ljubljana, Faculty of Arts, Aškerčeva 2, 1000 Ljubljana). Decisions concerning graphic design and technical production of the work and the conditions of its marketing are at the discretion of the publisher.

- Authors guarantee that the work is their own original composition, that no third parties have rights to the work, and that the article does not violate any other rights. In the case of third-party claims authors undertake to protect the interests of the publisher and cover the publisher's damages and costs.
- Authors retain copyright and recognise the publisher's right of first publication; the article will be licensed under a Creative Commons Attribution-ShareAlike 4.0 International License (attribution of authorship and shared authorship are covered by the same conditions). This means that text, pictures, graphs and other components of the work can be freely distributed, reproduced, used, communicated to the public and processed, provided that author's name and the article title are clearly and prominently indicated, and that in cases where changes or modifications are made or the work is used in other work, it can be distributed only under a license identical to this one.
- Authors may enter into additional separate contractual arrangements for non-exclusive distribution of the version of the work, published in the journal (e.g. submit it to an institutional repository or publish it in a book), with an acknowledgement that the work was first published in this journal.
- Before the submission process or during it authors can publish work on the internet (e.g. in institutional repositories or on their own websites), which we also encourage, as this can contribute to a fruitful exchange as well as rapid and widespread referencing of the published work.

10. Authors themselves ensure that the language used in their text is appropriate and that acceptable translations are provided (including of the abstract, keywords and summary of the article). If the language is inappropriate the Editorial Board will return it to the author, who must arrange for a professional proofreader to review the text. If the author's work is not in accordance with the instructions for publication, the author allows the publisher at their discretion to make appropriate adjustments.

11. The publisher shall ensure that all articles that are positively reviewed are published, provided it has funds available for printing. The sequence of articles is decided by the Editorial Board. Each author is entitled to one free copy of the printed publication.

12. Authors should send their articles to e-mail address *dela_geo@ff.uni-lj.si* or upload them to the journal's website (https://journals.uni-lj.si/Dela/login).

DELA 59
Oddelek za geografijo, Filozofska fakulteta Univerze v Ljubljani
Department of Geography, Faculty of Arts, University of Ljubljana

Založnik – Published by
Založba Univerze v Ljubljani

Izdajatelj – Issued by
Znanstvena založba Filozofske fakultete Univerze v Ljubljani;
Oddelek za geografijo, Filozofska fakulteta Univerze v Ljubljani

Za založbo – For the Publisher
Gregor Majdič, rektor Univerze v Ljubljani

Za izdajatelja – For the Issuer
Mojca Schlamberger Brezar, dekanja Filozofske fakultete

Upravnik – Editorial Secretary
Nejc Bobovnik

Naročila – Orders
Oddelek za geografijo, Filozofska fakulteta
Aškerčeva 2, p.p. 580, SI-1001 Ljubljana, Slovenija
e-mail: nejc.bobovnik@ff.uni-lj.si

Cena – Price
15 €

Fotografija na naslovnici/Cover photo:

Po ravninah in dolinah z zmerno celinskim podnebjem na vzhodu Slovenije so pogosti temperaturni obrati, zato sadijo vinsko trto in druge toplotno zahtevnejše kulture na prisoje toplega pasu. Na sliki je jutranja inverzijska megla na območju Bistrice ob Sotli (foto: D. Ogrin).

In the plains and valleys with a temperate continental climate in eastern Slovenia, temperature inversions occur frequently, which is why vines and other heat-loving plants are planted in the thermal belt on slopes exposed to the sun. The picture shows the morning inversion fog in the area of Bistrica ob Sotli (photo: D. Ogrin).