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MOGUĆNOST MODELIRANJA KLIMATSKOG RIZIKA INDEKSIMA

PREGLEDNI RAD

Apstrakt

U radu se analizira mogućnost primene indeksa u cilju kvantifikovanja različitih klimatskih varijabli. Prikazana je metodologija izračunavanja i osnovne karakteristike najznačajnijih vremenskih indeksa, kao što su temperaturni, indeksi padavina (SPI), decile i kvantile indeksi. Pored pomenutih indeksa, koji se uslovno mogu svrstati u jednostavnije, u radu je izvršena analiza kompozitnih indeksa, razvijenih na kompleksnoj osnovi, kao što su Gaj Karpenter indeks ili RMS indeks. Kompleksni indeksi su u upotrebi tek poslednjih nekoliko godina. Na osnovu analize postojećih indeksa i njihove praktične upotrebe, zaključuje se da vremenski indeks, pored transparentnosti, proverljivosti i objektivnosti, kako bi bio praktično primenljiv, mora biti u korelaciji sa efektima koje uzrokuje vremenska varijabla. Takođe, rad upućuje na zaključak da klimatski indeksi mogu biti prihvatljiva alternativa i osnova ugovora o indeksnom osiguranju, u slučaju nedostatka istorijskih podataka o štetama i nemogućnosti modeliranja katastrofalnih klimatskih događaja na drugi način. Izračunavanje indeksa prikazano je i kroz konkretne primere.

Ključne reči: *osiguranje, klimatski rizik, vremenski indeksi, suša, temperatura vazduha*

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I. Uvod

Na finansijskom tržištu SAD devedesetih godina prošlog veka razvijeni su vremenski derivati, kao odgovor na rastuću potrebu zaštite kompanija energetskog sektora od gubitaka usled ostvarenja vremenskih rizika. Ugovori su bili zasnovani na vremenskom indeksu i štitili su energetske kompanije od gubitaka usled toplih zimskih i hladnih letnjih meseci. Pozitivna iskustva u korišćenju vremenskih derivata podstakla su i delatnost osiguranja da u svoju ponudu uvrstiti ugovore zasnovane na vremenskim indeksima.

Američka akademija aktuara (*The American Academy of Actuaries*) formirala je radnu grupu u cilju sagledavanja mogućnosti i uslova pod kojima bi osiguravači mogli da pružaju osiguranje zasnovano na indeksu. Materijal radne grupe Američke akademije aktuara bio je od presudnog značaja za dalji razvoj i praktičnu primenu osiguranja zasnovanog na indeksu (*The American Academy of Actuaries* (1999.)). Te usluge su iskazivale potencijal za praktičnu primenu u pružanju zaštite sektoru poljoprivrede od klimatskih rizika, na šta su naročito ukazivali brojni autori, kao što su McCarthy N. (2003.) ili Alderman H. i Haque T. (2007.). Iskustva u praktičnoj primeni osiguranja zasnovanog na indeksu u Brazilu, Meksiku, Indiji, Etiopiji, ali i drugim državama, sublimirana su u istraživanju koje je sprovedeno u okviru Međunarodnog instituta za istraživanje klime i društva, Univerziteta Kolumbija (Hellmuth M.E., Osgood D. E., Hess U., Moorhead A. and Bhojwani H. (eds) 2009.). Jedan broj autora ukazivao je i na mogućnost razvoja novih usluga osiguranja, koje bi pružale zaštitu usled klimatskih promena, a bile bi zasnovane na indeksima, kao što su Weinhofer G. i Busch T. (2013.). Međutim, s vremenom su te usluge počele da iskazuju određene praktične nedostatke, od kojih je svakako najveći rizik baze, odnosno da se može dogoditi situacija da osiguranik ne pretrpi štetu a da mu bude isplaćena odšteta i suprotno. Ovom, ali i drugim rizicima koje ove usluge sa sobom nose u stručnoj literaturi se trenutno poklanja velika pažnja. O riziku baze su pisali Elabeda G., Bellemareb M. F., Cartera M. R. i Guirkingerc C. (2013.).

Vremenski indeksi, metodologija njihovog kreiranja, karakteristike i iskustva u njihovom praktičnom korišćenju predmet su ovog rada. Cilj rada je da se analizom osnovnih karakteristika i metodologije izrade ispita mogućnost njihovog eventualnog korišćenja na području Srbije.

II. Vremenski indeksi, pojam i karakteristike

Prirodni katastrofalni događaji i dalje čine najveće uzročnike šteta na imovini. U toku 2021. godine, od 280 milijardi USD ukupno zabeleženih katastrofalnih šteta, prirodne katastrofe su u 306 događaja uzrokovale ukupnu štetu od 270 milijardi

USD.[4] Trećina svetske populacije je izložena riziku od poplava, koje čine 47% ukupnih hidroloških katastrofalnih događaja. Oluje, za razliku od poplava, beleže daleko manje učešće u ukupnom broju zabeleženih nesreća, međutim, oko 40% smrtnih slučajeva uzrokovanih hidrološkim katastrofama odnosi se na oluje.[5]

Kako bi osiguravači bili u mogućnosti da odrede premije za svakog potencijalnog osiguranika, ili određene grupe osiguranika, moraju biti u mogućnosti da identifikuju, kvantifikuju ili bar delimično ocene verovatnoću pojavljivanja događaja i potencijalne štete. Uopšteno, u cilju predviđanja, a potom i savladavanja posledica realizacije neželjenog događaja neophodno je da rizik ima određene karakteristike koje ga čine pogodnim za statističku obradu. Modeliranje katastrofalnih klimatskih rizika je kompleksan proces, čiji uspeh prevashodno zavisi od dostupnosti i kvaliteta kvantitativnih i kvalitativnih inputa, koji na najbolji način reflektuju obeležja prirodne pojave. Pored tradicionalnih usluga, delatnost osiguranja je kao odgovor na vremenske i klimatske rizike osmislila nove sofisticirane usluge, među kojima prednjači osiguranje zasnovano na indeksu. U osnovi svakog ugovora o indeksnom osiguranju nalazi se vremenski indeks, koji predstavlja relativni pokazatelj odstupanja klimatskih varijabli od izabrane referentne tačke u referentnoj meteorološkoj stanici.

Univerzalna klasifikacija Centra za istraživanje epidemiologije katastrofa (*Centre for Research on the Epidemiology of Disasters*) sve vremenske katastrofalne događaje, prema vrsti hazarda, razvrstava u tri grupe. U meteorološke događaje, uzrokovane kratkotrajnim atmosferskim i vremenskim uslovima, koji mogu trajati od nekoliko minuta do nekoliko dana, ubrajaju se ekstremne temperature, magla i oluje. Pod ekstremnim temperaturama se podrazumevaju hladni talasi, topli talasi i teški zimski uslovi (sneg, led i mraz), dok se oluje dele na tropske, supertropske i konvektivne oluje (kišne, grmljavinske, peščane, mećave, tornada i sl). Hidrološke, uzrokovane pojavom, kretanjem i naletima površinskih i potpovršinskih slatkih i slanih voda, obuhvataju poplave, klizišta i talase. Poplave mogu biti primorske, rečne, bujične i poplave uzrokovane pojavom leda u vodotoku. U klimatološke, uzrokovane dugotrajnim atmosferskim procesima, svrstavaju se suša, topljenje glečera i požari.[6]

Kod procene i eventualnog modeliranja direktnih šteta prouzrokovanih katastrofalnim vremenskim događajima jedan od realnih problema predstavlja činjenica da su podaci o štetama nedostupni, pogotovo u slabo razvijenim zemljama. Pored inicijalnog prepoznavanja i identifikovanja negativnog uticaja određenog vremenskog fenomena na poslovanje ili imovinu, od suštinske je važnosti da se

[4] Swiss Re, Natural catastrophes in 2021: the floodgates are open *Sigma*, No 1/2022, Swiss Re Institute, Zurich, 2022, str. 3.

[5] UNSIDR, *Economic Losses, Poverty and Disasters 1998-2017*, 2017., str. 11 (14.01.2023), *https://www.unisdr.org/2016/iddr/CRED_Economic%20Losses_10oct_final.pdf.*

[6] Ranke U., *Natural Disaster Risk Management: Geosciences and Social Responsibility*, Springer, 2015., str. 55 i 56.

prepoznata klimatska varijabla može meriti. S razvitkom meteorologije, uz sofisticiranije i kompjuterizovane merne instrumente, stvorila se mogućnost korišćenja sve šire lepeze vremenskih varijabli na osnovu kojih je moguće kreirati usluge osiguranja. Za razliku od samih početaka, kada je promena temperature bila jedini vremenski fenomen od koga je finansijsko tržište pružalo zaštitu, sada je moguće obezbediti zaštitu od gotovo svih vremenskih varijabli.

Važno je ukratko prokomentarisati razliku između merenja efikasnosti tradicionalnih vrsta osiguranja i osiguranja zasnovanog na indeksu. Naime, kod tradicionalnih vrsta osiguranja na bazi učestalosti i intenziteta neželjene pojave i do tada zabeleženih šteta kreiraju se modeli na osnovu kojih se vrši procena osnovnih elemenata ugovora o osiguranju i projektovanih gubitaka. Statistike se koriste kao polazne vrednosti i daju osnovu za meru očekivanih rezultata transfera rizika. Indeks, koji se nalazi u osnovi usluga indeksnog osiguranja, mora biti u korelaciji s prinosima, ukoliko se govori o poljoprivredi, ili s prihodima osiguranika. U suprotnom, neće biti dobra osnova za kreiranje osiguravajuće usluge. Činjenica je da isplata po tim ugovorima ne zavisi od visine prouzrokovane štete, već od odstupanja ostvarenih vrednosti indeksa u odnosu na referentne. Iz pomenutih razloga u cilju procene efikasnosti indeksnog osiguranja u obzir se moraju uzeti i svi drugi bitni elementi, kao što su funkcija isplate, pokrivenost područja mernim stanicama ili udaljenost konkretne lokacije od referentne merne stanice.

Da bi indeks bio pogodna osnova, mora da ispuni nekoliko dodatnih uslova koji utiču na nivo pouzdanosti, odnosno na to da indeks bude od poverenja, pouzdan, da nije podložan ljudskoj manipulaciji, pri čemu rizik merenja indeksa mora biti nizak.[7] Javno dostupna merenja vremenskih prilika u najvećoj meri ispunjavaju te uslove. U slučaju indeksa vremenskih prilika, merne jedinice trebalo bi da pružaju smislene informacije o stanju vremenske varijable tokom perioda ugovora i često ih definišu potrebe tržišnih učesnika. Indeksi često predstavljaju kumulativne mere padavina, ili temperature tokom određenog perioda. U nekim primenama, prosečne vrednosti padavina ili temperatura koriste se umesto kumulativnih merenja. Nove tehnološke inovacije, među kojima su i sofisticirani satelitski prikazi iz kojih se zatim mogu izvući podaci o vremenu u visokoj rezoluciji i niska cena stanica za praćenje vremena koje se mogu instalirati na mnogim lokacijama, proširiće broj oblasti gde je moguće meriti vremenske varijable, kao i vrste merljivih varijabli.[8]

Indeks bi trebalo da bude relativno lako razumljiv i konceptualno jednostavan. Osim čisto statističkih mera, indeks i proces nadoknade gubitka u osnovi treba da imaju razumno zajedničku uzročnost. Drugim rečima, nivo gubitaka i vrednost

[7] Hess U., „Weather index insurance for coping with risks in agricultural production", in Motha R.P, Sivakumar M. V. K., *Managing Weather and Climate Risks in Agriculture*, Springer Berlin Heidelberg, 2007., str. 382.
[8] Ibid, str. 384.

indeksa treba da imaju zajedničke uzročne faktore. Važno je da vremenski okvir za promenu vrednosti indeksa bude konzistentan s nastankom procesa gubitka. Drugim rečima, i uopštenije gledano, vrednost indeksa ne bi trebalo da značajno zaostaje za pojavom gubitaka. Umesto toga, indeks bi u suštini trebalo da reaguje na gubitke onda kada se ovi pojave.[9] Takođe, indeks ne bi trebalo da bude izvor moralnog hazarda. Moralni hazard se odnosi na mogućnost povećanja prijavljenih gubitaka od strane osiguranika kako bi se povećala odšteta. Taj potencijal ne postoji ukoliko se okidač zasniva na plaćenim gubicima, jer bi korist od bilo kakvog oprosta duga bila neutralisana dodatnim isplatama gubitaka. S druge strane, postoji malo potencijala za moralni hazard u ugovorima zasnovanim na indeksu. Dakle, sa stanovišta smanjenja moralnog hazarda, poželjno je da indeks bude što je moguće šire postavljen.

Poželjno je i da se indeks može modelirati na osnovu izloženosti, ili na osnovu istorijske baze podataka. Treba imati na umu da opsežni istorijski podaci možda neće biti dostupni za nedavno razvijene indekse, ali indeks koji se pokaže korisnim ohrabriće prikupljanje relevantnih informacija. Pored testiranja u praksi, otvaranje novih tržišta i usluga osiguranja svakako bi doprinelo i razvoju okvira za procenu efektivnosti indeksa. Od presudne važnosti je da podaci potrebni za konstrukciju indeksa ne podležu manipulaciji. U zavisnosti od mere u kojoj se indeks sastoji od podataka iz nekoliko izvora, manipulacija jednim izvorom podataka ne bi trebalo da dovede do značajne manipulacije ukupnim indeksom. U meri u kojoj je to moguće, podaci koji čine indeks treba da budu proverljivi. Međunarodno udruženje supervizora osiguranja ukazuje na naročito obraćanje pažnje na indekse razvijene od strane jedne kompanije, ili koji se zasnivaju samo na jednom izvoru. Pomenuti indeksi trebalo bi da zahtevaju veću pažnju osiguranika i nadzornih organa, kako bi se zaštitili od moguće manipulacije.[10]

III. Temperaturni indeksi

Temperaturni indeksi, koji su prvi razvijeni, i dalje su najzastupljenija vrsta vremenskih indeksa, što je sasvim razumljivo imajući u vidu sveprisutan uticaj varijacija u temperaturi na gotovo sve privredne aktivnosti. Takođe, vremenska i prostorna zastupljenost meteoroloških kapaciteta i dostignuća meteorološke nauke ukazuju na najkonzistentniji pristup u izučavanju upravo ove vremenske varijable.

9 Kako bi se otklonile eventualne posledice loše definisanog indeksa, Međunarodno udruženje supervizora osiguranja (*The International Association of Insurance Supervisors*) predlaže postojanje arbitraže, koja bi dodatno uticala na kredibilitet indeksa. 12) IAIS, „Issues Paper on Index Based Insurances“, *Particularly in Inclusive Insurance Markets*, International Association of Insurance Supervisors, 2018., str. 19 *https://www.iaisweb.org/uploads/2022/01/180618-Issues-Paper-on-Index-based-Insurances-particularly-in-Inclusive-Insurance-Markets.pdf* (29.12.2022).

10 Ibid, str. 32.

Najpoznatiji temperaturni indeksi jesu indeksi koji izražavaju kumulativne varijacije dnevnih temperatura vazduha tokom posmatranog perioda u odnosu na referentnih 18°C ili 65°F i u skladu sa nazivima na engleskom jeziku označeni su međunarodno priznatim oznakama HDD (*Heating degree days - HDD*) i CDD (*Cooling degree days - CDD*).

HDD indeks se koristi tokom zimskog perioda i računa se pomoću formule:

$$HDD = maks\{0, (T_{ref} - T_{pros})\} \tag{1}$$

gde je

T_{ref} – referentna temperatura,

T_{pros} – prosečna temperatura.

Prosečna temperatura se izračunava prema formuli:

$$T_{pros} = \frac{T_{maks} + T_{min}}{2} \tag{2}$$

gde je,

T_{maks} – maksimalna dnevna temperatura,

T_{min} – minimalna dnevna temperatura.[11]

Referentna temperatura je unapred izabrana vrednost. U Evropi se izražava po Celzijusovoj skali i iznosi 18°C, dok se na području Amerike izražava u farenhajtima i iznosi 65°F. Indeks ne može uzimati negativne vrednosti. U tabelama 1 i 2 dat je primer izračunavanja HDD indeksa.

Tabela 1. Primer izračunavanja HDD indeksa / hladnije vreme

Referentna temperatura (A)	**18°C**	**18°C**	**18°C**	**18°C**	**18°C**	**18°C**	**18°C**	**kumulativ**
Maksimalna temperatura	14°C	16°C	15°C	12°C	10°C	12°C	15°C	/
Minimalna temperatura	12°C	10°C	9°C	6°C	6°C	8°C	11°C	/
Prosečna temperatura (B)	13°C	13°C	12°C	9°C	8°C	10°C	13°C	/
HDD (A-B)	**5**	**5**	**6**	**9**	**10**	**8**	**5**	**48**

Izvor: sopstvena kalkulacija

[11] Asseldonk M.A., Insurance against weather risk: Use of heating degree-days from non-local stations for weather derivatives, *Theoretical and Applied Climatology*, 74 (2003)., 2003., str. 138.

Tabela 2. Primer izračunavanja HDD indeksa / toplije vreme

Referentna temperatura (A)	18°C	18°C	18°C	18°C	18°C	18°C	18°C	kumulativ
Maksimalna temperatura	20°C	19°C	21°C	18°C	22°C	18°C	17°C	/
Minimalna temperatura	18°C	17°C	15°C	16°C	18°C	16°C	15°C	/
Prosečna temperatura (B)	19°C	18°C	18°C	17°C	20°C	17°C	16°C	/
HDD (A-B)	0	0	0	1	0	1	2	4

Izvor: sopstvena kalkulacija

Kao što se može videti na osnovu tabela 1 i 2, veća vrednost HDD indeksa ukazuje na nižu temperaturu vazduha u posmatranom periodu i obrnuto. Na osnovu rezultata prethodnog hipotetičkog primera, možemo videti da HDD indeksu od 48 korelira prosečna temperatura vazduha na nedeljnom nivou od 11,14°C, dok u drugom slučaju vrednosti HDD indeksa od 4 korelira prosečna nedeljna temperatura vazduha od 17,85°C. Situacija u drugom slučaju može izazvati ozbiljne štetne posledice po industriju energije, jer će toplije vreme tokom zimskog perioda voditi manjoj potrošnji toplotne energije.

CDD indeks se koristi tokom letnjeg perioda i računa se prema formuli:

$$CDD = maks\{0, (T_{pros} - T_{ref})\} \quad (3)$$

gde je

T_{pros} – prosečna temperatura,

T_{ref} – referentna temperatura.[12]

Veće vrednost CDD indeksa ukazuju na višu temperaturu vazduha od prosečne i suprotno. Takođe, kao i prethodni, CDD indeks ne može uzimati negativne vrednosti. Temperaturni indeksi se koriste i mere najčešće za tačno određeni period. Na primer, za kreiranje usluga osiguranja za potrebe poljoprivrede koristiće se kumulativni CDD indeks za vreme žetve ili HDD za vreme setve. U Tabeli 3 prikazan je način izračunavanja CDD indeksa.

Tabela 3. Izračunavanje CDD indeksa

Referentna temperatura (A)	18°C	18°C	18°C	18°C	18°C	18°C	18°C	kumulativ
Maksimalna temperatura	25°C	26°C	28°C	18°C	22°C	25°C	27°C	/
Minimalna temperatura	15°C	16°C	14°C	16°C	12°C	11°C	15°C	/
Prosečna temperatura (B)	20°C	21°C	22°C	17°C	17°C	18°C	21°C	/
CDD (B-A)	2	3	4	0	0	0	3	12

Izvor: sopstveni prikaz

12 Ibid, str. 139.

IV. Drugi vremenski indeksi

Istraživanju fenomena suše, koji sa katastrofalnim posledicama pogađa veliki broj zemalja, u poslednjih nekoliko decenija posvećena je posebna pažnja. Sveobuhvatan pristup u izučavanju suše razvijen je u Brazilu, gde se pored Nacionalne naučne akademije ovim fenomenom svakodnevno bavi nekoliko nacionalnih institucija uključujući Nacionalni institut za svemirska istraživanja (*National Institute for Space Research – INPE*), Nacionalni institut za meteorologiju (*National Institute of Meteorology – INMET*) i Nacionalni centar za praćenje i rano upozoravanje na prirodne katastrofe.[13] Pomenute institucije su se bavile procenom suše uz pomoć standardizovanog indeksa padavina (SPI indeksa), predstavljajući rezultate koji omogućavaju korišćenje informacija za predviđanje i ublažavanje negativnih posledica.

Standardizovani indeks padavina (SPI), koji je predložio američki naučnik Tomas Mek Ki (Thomas McKee), odgovara broju standardnih devijacija, gde je posmatrana količina padavina van klimatoloških proseka u toku određenog vremenskog raspona. Za kreiranje SPI pripremaju se setovi podataka o padavinama za *m* meseci, pri čemu se smatra da je najpogodniji period posmatranja najmanje 30 godina. Potom se od setova podataka kreiraju proseci za *i* meseci, pri čemu *i* uzima vrednosti 3, 6, 12, 24 i 48 meseci. Svaki novi set podataka o padavinama poredi se s prethodnim periodom. Period suša ima svoju potvrdu kada je vrednost indeksa u kontinuitetu manja od -1. Kada je vremenska skala mala (npr. 1, 2 ili 3 meseca), SPI se često pomera iznad ili ispod nule, posmatrajući meteorološki režim suše. S porastom prosečne skale (npr. 12–24 meseca), SPI slabije reaguje na promene padavina posmatrajući hidrološki režim suše. Dobijene vrednosti indeksa mogu se porediti sa serijama iz drugih područja, međutim, može se ustanoviti i određena veza između raspona vrednosti SPI i kvalitativne procene padavina posmatrane tokom određenog vremenskog raspona. Međunarodni centar za istraživanje klime i društva Univerziteta Kolumbija utvrdio je najučestaliju vezu indeksa i padavina, koju možemo videti u Tabeli 4.

Tabela 4. Veza između vrednosti SPI indeksa i klimatskih kategorija

SPI vrednosti	Kategorije
SPI > 2	Ekstremno vlažno
1.50< SPI<1.99	Dosta vlažno
1.00< SPI <1.49	Umereno vlažno
-0.99<SPI< 0.99	Skoro normalno

[13] U prvim decenijama ovog veka Brazil je pogodilo nekoliko katastrofalnih vremenskih događaja prouzrokovanih sušom. Suša je u periodu 2012–2016. godine pogodila teritoriju nastanjenu sa oko 33,4 miliona ljudi i prouzrokovala štetu od 30 milijardi USD. 17). Marengo J. A, at all, „Climatic characteristics of the 2010–2016 drought in the semiarid Northeast Brazil region“, *Annals of the Brazilian Academy of Sciences*, 2018., str. 1975.

SPI vrednosti	Kategorije
-1.00>SPI> – 1.49	Umereno suvo
-1.50>SPI> – 1.99	Ozbiljno suvo
SPI <-2.00	Ekstremno suvo

Izvor: Brunini O., at all, „Coping Strategies with Agrometheorological Risk and Uncertainties for Drought Examples in Brasil", in Motha R.P, Sivakumar M. V. K., Managing Weather and Climate Risks in Agriculture, Springer, Berlin Heidelberg, 2007., str. 286.

Empirijska istraživanja ustanovila su da funkcija raspodele verovatnoće padavina odgovara gama raspodeli,[14] kojoj odgovara sledeća funkcija gustine:

$$g(x) = \frac{1}{\beta^{\alpha} G(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}}, \quad \text{za } x>0 \tag{4}$$

gde je
α – parametar oblika,
β – parametar veličine,
x – količina padavina,
G(α) – gama funkcija definisana izrazom

$$G(\alpha)=\int_0^{\infty} y^{\alpha-1} e^{-y} dy. \tag{5}$$

Funkcija gustine verovatnoće gama raspodele daje različite forme na osnovu varijacija α. Vrednosti tog parametra koje su manje od 1 pokazuju jaku asimetričnu distribuciju (eksponencijalan oblik) sa g(x) koja je beskonačna kada x dostigne 0. Kada je α=0 funkcija presreće vertikalnu osu u β za x=0. Porast parametra smanjuje asimetrični stepen distribucije. Vrednosti za α koje su veće od 1 rezultiraju funkciji gustine nadesno sa maksimalnom vrednošću u β* (α-1). Porast parametra β smanjuje visinu funkciji gustine i smanjuje verovatnoću pojave modalne vrednosti. Slično tako, kako se gustina sabija nalevo (smanjenje veličine β), i visina funkcije postaje veća, a mogućnost pojave modalne vrednosti raste.

Upravo zbog toga, varijacije α i β u državi pokazuju koje su oblasti s najvećim stepenom asimetričnosti u vremenskoj distribuciji padavina (neregularnost količine padavina). Uzimajući u obzir suše, nepravilnosti povezane sa uslovima okruženja u svakoj oblasti, te regije su pod najvećim rizikom da budu predmet meteoroloških suša.[15]

Jedan od najvažnijih koraka u pravilnom sagledavanju pojave suše jeste kalkulacija padavina. Klimatološki adekvatni uslovi (**P**) mogu se shvatiti kao količina

[14] McKee T. B., Doesken N. J., Kleist J., 1993.,„The relationship of drought frequency and duration to time scales", Eighth Conference on Applied Climatology, 17-22 January 1993, Anaheim, California, (24.01.2023), *http://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf.*
[15] Brunini O., at all, 2007., str. 287.

mesečnih padavina neophodna za određenu oblast kako bi ona ostala pod normalnim klimatskim uslovima. Taj parametar je izračunao i opisao Vejn Palmer (Wayne Palmer). Za računanje mesečnih anomalija u vodenom prilivu (d), padavine posmatrane u mesecu (P_i) upoređuju se sa adekvatnim klimatološkim uslovima **P** u istom periodu:

$$d = P_i - \mathbf{P} \tag{6}$$

Pošto je Palmer razvio standardizovan indeks na osnovu poređenja podataka s različitih lokacija u bilo kom periodu, za njegovu konkretnu primenu prilikom analize podataka na određenoj lokaciji neophodno je da bude standardizovan na regionalnoj bazi. U tom cilju, Palmer je razvio faktor klimatološke kategorizacije označen slovom K

$$K = 17{,}67 \frac{K^1}{\sum_{i=1}^{12} D K^1} \tag{7}$$

gde je

$$K^1 = 1{,}5 \log_{10}\left[\frac{T+2{,}8}{D}\right] + 0{,}5 \tag{8}$$

T – odnos potrošnje i zaliha vode u regionu,
D – mesečni prosek apsolutnih vrednosti za d.

Palmer je predložio sledeću vezu indeksa, padavina i suše.

Tabela 5. Veza između Palmerovog indeksa i kategorija suše

Palmerov indeks	Kategorije
≥ 3.00	Ekstremno vlažno
2.00< a< 2.99	Ozbiljno vlažno
1.00 <a <1.99	Umereno vlažno
0.51< a< 0.99	Malo vlažno
0.50 >a >-0.50	Blizu normalnog
-0.51 >a> -0.99	Početak suše
-1.00 >a >-1.99	Umerena suša
-2.00 >a>-2.99	Ozbiljna suša
≤-3.00	Ekstremna suša

Izvor: Brunini O., at all, 2007., str. 288.

U jednom broju zemalja, kao što je to slučaj u Australiji, prilikom procene stepena suše koristi se metod decile. Decile metod se sastoji najpre iz organizacije u rastućem poretku, a potom i klasifikacije istorijskih podataka o padavinama akumuliranim u određenom periodu, uglavnom 1, 3, 6, 12 ili više meseci, na 10 intervala jednake frekvencije. Tako da verovatnoća pojave u bilo kom intervalu iznosi 10%. Ti intervali su nazvani decile i numerisani su brojevima od 1 do 10. *N* je broj registrovanih istorijskih posmatranja. Prvi decile sadrži n_1 n_1 najmanjih vrednosti za padavine, gde $n_1 n_1$ odgovara celom broju (*N* /10). Drugi decile sadrži sledeće vrednosti ($n_2 n_2$ & $n_1 n_1$), gde je $n_2 n_2$ = (*N* /20) itd. Nakon toga, kategorija će odgovarati svakoj decili, odnosno, deskriptivnom konceptu količine padavina u kome će decile biti grupisane. To znači da bi više od jedne decile moglo biti povezano sa istom kategorijom. Ukoliko se svaka kategorija označi određenom bojom, mogu se iscrtati mape koje pokazuju količinu padavina, proveravajući tako za svaku tačku vrednost količine padavina posmatranu tokom određenog perioda i iscrtavajući tačku na mapi s bojom koja je povezana s kategorijom. Metodologija korišćenja klasifikacije količine padavina po metodu decila prikazana je u Tabeli 6.

Tabela 6. Klasifikacija prema decile metodu

<table>
<tr><th rowspan="2">Decile</th><th>Originalno postavljena klasifikacija</th><th>Klasifikacija usvojena u Australiji</th><th colspan="2">Klasifikacija usvojena od strane INMET-a (Brazil)</th></tr>
<tr><th>Kategorija</th><th>Kategorija</th><th>Kategorija</th><th>Indeks</th></tr>
<tr><td rowspan="2">1</td><td rowspan="3">Mnogo ispod normalnog</td><td>Najniža</td><td rowspan="2">Ekstremno ispod normalnog</td><td rowspan="2">-3</td></tr>
<tr><td>Dosta ispod proseka</td></tr>
<tr><td>2</td><td rowspan="2">Ispod proseka</td><td>Ispod normalnog</td><td>-2</td></tr>
<tr><td>3</td><td rowspan="2">Ispod normalnog</td><td>Malo ispod normalnog</td><td>-1</td></tr>
<tr><td>4</td><td rowspan="4">Prosečna</td><td rowspan="4">Normalna</td><td>0</td></tr>
<tr><td>5</td><td rowspan="2">Blizu normalnog</td><td>1</td></tr>
<tr><td>6</td><td>2</td></tr>
<tr><td>7</td><td rowspan="2">Iznad normalnog</td><td>3</td></tr>
<tr><td>8</td><td rowspan="2">Iznad proseka</td><td>Malo iznad proseka</td><td>1</td></tr>
<tr><td>9</td><td rowspan="3">Mnogo iznad normalnog</td><td>Iznad proseka</td><td>2</td></tr>
<tr><td rowspan="2">10</td><td>Dosta iznad proseka</td><td rowspan="2">Ekstremno iznad proseka</td><td rowspan="2">3</td></tr>
<tr><td>Najviša</td></tr>
</table>

Izvor: Brunini O., at all, 2007., str. 289.

Kao što se može videti u Tabeli 6, pored opšte klasifikacije, australijski biro za meteorologiju i Nacionalni institut za meteorologiju Brazila (INMET) izvršili su određene modifikacije i usvojili sopstvene klasifikacije, prikazane u drugoj i trećoj koloni tabele, a koje su povezane s numeričkim indeksom čiji je raspon između -3 i 3 za svaku kategoriju. Po uzoru na decile metod, kvartile metod se sastoji iz klasifikacije akumulirane količine padavina tokom određenog perioda (vremenska skala) *X*, u pet kategorija, što se može videti u Tabeli 7.

Tabela 7. Klasifikacija padavina po kvantile metodu

Nivo padavina	Povezana verovatnoća	Kategorije (posmatrane padavine)
Kvantil 1	15%	Veoma suvo
Kvantil 2	20%	Suvo
Kvantil 3	30%	Normalno
Kvantil 4	20%	Vlažno
Kvantil 5	15%	Veoma vlažno

Izvor: Brunini O., at all, 2007., str. 290.

Prvi kvantil, 0≤X≤Q_1, gde je Q_1 takav da je verovatnoća P(X≤ Q_1)=0.15

Drugi kvantil, Q_1<X≤ Q_2, gde je Q_2 takav da je verovatnoća P (X≤Q_2)=0.35

Treći kvantil, Q_2 <X≤Q_3, gde je Q_3 takav da je verovatnoća P (X≤Q_3)=0.65

Četvrti kvantil, Q_3 <X≤Q_4, gde je Q_4 takav da je verovatnoća P (X≤Q_4)=0.85

Peti kvantil, X >Q_4.

Isto kao i kod SPI indeksa, za određivanje vrednosti Q_i, *i*=1,...,5, model verovatnoće je prilagođen (normalna gama raspodela) istorijskim podacima u periodu posmatranja. *X* je količina padavina za određeni period, dok je F(x) funkcija gustine, koja je prilagođena istorijskim vrednostima za X, dok je F_1F_1 prilagođena inverznoj F funkciji, tako da je:

$$Q_1 = F^1 (0.15),\ Q_2 = F^1(0.35),\ Q_3 = F^1(0.65) \text{ i } Q_4 = F^1 (0.85).$$

Svaki od pet opisanih kvantila povezan je s kvalitativnom klasifikacijom iz Tabele 7. Kao i kod drugih modela, određeni period je 1, 3, 6, 12 ili više meseci.[16]

Sa izuzetkom Palmerovog indeksa, suština goreopisanih metoda je ista i njihovi rezultati će se razlikovati jedino u smislu postojanja određenih varijacija

[16] Brunini O., at all, 2007., str. 290.

u kategorizaciji vremenske pojave, u ovom slučaju suše. U cilju identifikovanja, a potom i što realističnijeg utvrđivanja uzročno-posledične veze između vremenske pojave i konkretne prouzrokovane štete, postojeći, tradicionalni meteorološki indeksi su dopunjeni. Bitno je spomenuti da fenomen suše može biti određen u odnosu na meteorološke, hidrološke, agronomske i socioekonomske aspekte. Međutim, sa agronomskog gledišta, svako upravljanje i prognoziranje mora biti zasnovano na metodama koje uključuju agronomiju i agrometeorološko znanje. U tom smislu, razvijeni su kompozitni vremenski indeksi, kao što su evapotranspiracioni standardizovani indeks, indeks vlage, indeks uticaja vode na rod i indeks razvijanja roda kao funkcije vlažnosti.

Indeks Ko (IndexCo) je najeminentnija svetska kompanija koja se bavi kreiranjem indeksa za potrebe delatnosti osiguranja i finansijskog tržišta u širem smislu. Indeks katastrofe *Gaj Karpenter* (Guy Carpenter Catastrophe Index), koji je u vlasništvu kompanije „Indeks Ko“, oblikovan je za merenje iznosa osigurane štete na kućama u SAD od atmosferskih opasnosti kao što su uragani, tornada, oluje, gradovi i zamrzavanje. Indeks je iskazan kao koeficijent štete prema vrednosti, odnosno kao koeficijent osiguranih šteta prema osiguranoj vrednosti. Indeks se objavljuje za svih 50 država i distrikt Kolumbiju, dok se za Teksas objavljuje u posebnom procesu. Indeks se može prilagoditi gotovo svim područjima u SAD. Izračunava se na osnovu konkretnog događaja i na agregatnoj osnovi. U slučaju izračunavanja na osnovu konkretnog događaja, indeks meri štetu najvećeg katastrofalnog vremenskog događaja koji je pogodio određenu lokaciju u određenom vremenskom rasponu. U slučaju izračunavanja na agregatnoj osnovi, indeks meri ukupnu štetu od određene vrste vremenske katastrofe u određenom vremenskom rasponu.

Indeks je namenjen kreiranju usluga osiguranja stambenih objekata, pri čemu je važno napomenuti da te usluge ne mogu obuhvatati i zaštitu od drugih opasnosti, kao što su poplave, vetar, munje ili zemljotres. Najdetaljnija i najpogodnija izveštajna jedinica potrebna za kreiranje indeksa na nivou je poštanskog broja ili grupe poštanskih brojeva sastavljenih tako da pokrivaju veću geografsku oblast i tako formiraju verodostojnu izveštajnu oblast. Indeks se zatim može agregirati na bilo kojem drugom višem nivou. Da bi se poštanski broj kvalifikovao kao izveštajna jedinica, mora imati najmanje 1.000 naseljenih stambenih jedinica i najmanje četiri osiguravajuće kuće koje pokrivaju područje i učestvuju u osiguranju pomenutih stambenih jedinica, pri čemu svaka od njih mora obezbeđivati podatke o najmanje deset kuća sa minimum 700.000 USD osigurane stambene vrednosti. Ukoliko je potrebno kreirati indeks, a poštanski broj nije kvalifikovan kao izveštajna jedinica, u cilju kreiranja adekvatnog indeksa pomenuti poštanski broj se grupiše zajedno sa drugim poštanskim brojevima sve dok se ne kreira područje koje se može kvalifikovati kao izveštajna jedinica. Kada se definiše izveštajna jedinica, indeks se izračunava tako što se saberu vrednosti LTV racija (štete u odnosu na vrednost) svih osiguravajućih kuća sa izabranog područja i taj broj se potom podeli sa brojem kompanija. Indeks se objavljuje za naredna dva šestomesečna perioda.

RMS indeks poredi model katastrofe u odnosu na potencijalnu izloženost delatnosti. Kada su svi parametri katastrofalnog događaja poznati nakon katastrofe, kao što su centralni pritisak, brzina kretanja i radijus maksimalnog vetra i sl, unose se u model katastrofe da bi se odredio gubitak generisan modelom. Gubici generisani modelom za opasnosti poput uragana, tajfuna, ciklona i zemljotresa mogu se izračunati za događaje koji se dešavaju širom sveta. Gubici generisani modelima dele se sa 100 miliona dolara i zaokružuju na najbliži celi broj da bi se dobila vrednost indeksa. Indeks je dostupan i na bazi događaja i na agregatnoj osnovi.

Prag pojave (Rihterove skale) za zemljotrese varira od 5.0 do 7.0 po regionima. Prag događaja za uragane je Safir-Simpson kategorija 1 ili više. Gubici generisani modelom mogu se prijaviti na nivou područja poštanskog broja za različite periode. Konačne vrednosti indeksa dostupne su 28 dana nakon događaja.

Svake godine, „Svis Re" (Swiss Re), Švajcarsko reosiguravajuće društvo, objavljuje časopis *Sigmu* posvećen prirodnim katastrofama i katastrofama izazvanim ljudskim delovanjem. Na osnovu pomenutih podataka, razvijen je sigma indeks. U početku nije bio oblikovan da bude indeks, međutim, kao takav se može koristiti na finansijskom tržištu u transakcijama sa derivatima. Prirodne katastrofe uključuju poplave, oluje, zemljotrese (uključujući potrese morskog dna i cunami), suše, požare koji zahvataju rastinje (uključujući toplotne udare), hladnoću, mraz i druge (uključujući grad i lavine). Katastrofe izazvane ljudskim delovanjem uključuju velike požare, eksplozije, katastrofe u vazduhoplovstvu, katastrofe brodova, katastrofe na putevima/železnicama, nesreće u rudarstvu, propadanje gradnje/mostova i razno (uključujući terorizam). Indeks se najčešće koristi za međunarodnu sekjuritizaciju. „Svis Re" je objavio tabele sa velikim gubicima od 1970. godine. Izvori podataka su dnevne novine, Služba za imovinska potraživanja, periodične publikacije primarnog osiguranja i reosiguranja, stručne publikacije, kao i izveštaji primarnih osiguravajućih i reosiguravajućih društava.

V. Zaključak

Razumevanje složene prirode izloženosti i ranjivosti preduslov je za utvrđivanje kako vremenske prilike i klimatski događaji doprinose pojavama katastrofa, kao i za osmišljavanje i sprovođenje delotvornih strategija za adaptaciju i upravljanje rizicima od katastrofa. Prethodna iskustva sa klimatskim ekstremima doprinose razumevanju delotvornog upravljanja rizicima od katastrofa, kao i usvajanju pristupa za upravljanje ovim rizicima. Jačina uticaja klimatskih ekstrema u velikoj meri zavisi od nivoa izloženosti i ranjivosti prema tim ekstremima. Tendencije izloženosti i ranjivosti glavni su pokretači promena kada su u pitanju rizici od katastrofa. Razumevanje složene prirode izloženosti i ranjivosti preduslov je za utvrđivanje kako vremenske prilike i klimatski događaji doprinose pojavama katastrofa, kao i za osmišljavanje i sprovođenje delotvornih strategija za adaptaciju i upravljanje rizicima od katastrofa.

Jedan od najinovativnijih odgovora na sverastuću pretnju od klimatskih rizika jesu usluge indeksnog osiguranja. Preduslov njihove primene je svakako mogućnost modeliranja određene vremenske varijable indeksima. Sublimirajući osnovne kvalitativne karakteristike koje bi indeksi trebalo da imaju, mogu se uočiti potencijalne protivrečnosti, odnosno međusobno isključujući zahtevi. Jasno je da će teško koji indeks zadovoljiti svaku karakteristiku u meri u kojoj se može porediti. Prema tome, dobar indeks često podrazumeva kompromis između više različitih karakteristika.

Nedostatak delotvornih tržišnih mehanizama zaštite od vremenskih rizika u Srbiji moraće da bude nadomešten, pre svega imajući u vidu štete prouzrokovane poplavama. Dok sa tehničkog aspekta, u vidu postojanja mreže mernih stanica Republičkog hidrometeorološkog zavoda postoje mogućnosti kreiranja vremenskih indeksa, pre svih temperaturnih i padavina, Zakon o osiguranju ne predviđa postojanje ovakve vrste usluga osiguranja. Na osnovu praktične primene ovog modela, pre svega u Latinskoj i Severnoj Americi, jasno se mogu uočiti njegove brojne prednosti i koristi, koje bi imale pozitivne efekte na ekonomiju Srbije.

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CLIMATE RISK MODELING POSSIBILITY WITH INDEXES

REVIEW ARTICLE

Abstract

The paper includes the analyzes of a possibility of applying the index to quantify different climate variables. The calculation methodology was presented as well as the standard features of the most important weather indices such as temperature, precipitation (SPI), decile and quantile indices. In addition to the mentioned indices that can be conditionally classified as simpler, the paper analyzes composite indices, developed on a complex basis, such as the Guy Carpenter index or the RMS index. The complex indices have only been in use for the past few years. Based on the analysis of current indices and their practical use, it is concluded that the weather index, in order to be applicable in practice, has to be correlated with the effects caused by the weather variable (in addition to its transparency, verifiability and objectivity). The paper leads to the conclusion that climate indices can form an acceptable alternative and the merits of an insurance contract with index clause, in the case of a lack of historical data on damages and impossibility of modelling catastrophe climate events in another way. The calculation of the index is shown in particular examples.

Key words: *insurance, climate risk, weather indices, drought, air temperature*

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I. Introduction

Weather derivatives were developed in the US financial market in the 1990s, as a response to the growing need to protect companies in the energy sector against losses occurred form weather risks. The contracts were based on a weather index and protected energy companies against losses due to warm winter and cold summer months. Positive experience in the use of weather derivatives encouraged the insurance industry to include contracts based on weather indices in their offer.

The American Academy of Actuaries formed a working group with the aim of considering the possibilities and conditions under which insurers could provide index-based insurance coverage. The material developed by the working group of the American Academy of Actuaries was of crucial significance for further development and practical application of index-based insurance (The American Academy of Actuaries (1999)). Those services showed potential for the practical implementation in providing protection to the agricultural sector against climate risks, the fact that was specially pointed out by numerous authors such as McCarthy N. (2003) or Alderman H. and Haque T. (2007). Experience in the practical implementation of index-based insurance in Brazil, Mexico, India, Ethiopia and other countries were sublimated in research conducted within the International Institute for Climate and Society Research, Columbia University (Hellmuth ME, Osgood DE, Hess U., Moorhead A. and Bhojwani H. (eds) 2009.). A number of authors such as Weinhofer G. and Busch T. (2013) also indicated the possibility of developing new insurance services, which would provide protection against climate change and would be based on indices. However, as time passed, such services began to reveal certain practical shortcomings, the risk of the base being identified as the largest, deeming a possible situation where the insured would be indemnified for the damage which he had not sustained and vice versa. This, as well as other risks inherent to such new insurance services, are currently receiving a lot of attention in the professional literature. Elabeda G., Bellemareb MF., Cartera M. R and Guirkingerz C. (2013) wrote about the risk of the base.

Weather indices, the methodology of their development, characteristics and experiences in their practical application are the subject-matter of this paper. The goal of the paper is to test the possibilities of their possible application within the territory of Serbia by analyzing their basic characteristics and methodology.

II. Weather Indices, Concept and Characteristics

The nat-cat events continue to be the major cause of property damage. During the year 2021, natural catastrophes caused a total damage of 270 billion USD in 306 events, out of the 280 billion USD of total recorded catastrophe damages.[4]

[4] Swiss Re, Natural catastrophes in 2021: the floodgates are open *Sigma*, No 1 /2022, Swiss Re Institute, Zurich, 2022, p. 3.

A third of the world's population is exposed to the risk of floods, which account for 47% of total hydrological catastrophe events. Storms, unlike floods, have a much smaller share in the total number of recorded accidents; However, about 40% of deaths caused by hydrological catastrophes relate to the storms.[5]

In order for insurers to be able to establish premiums for any one potential policyholder, or certain groups of policyholders, they must be able to identify, quantify or at least partially assess the probability of occurrence of loss events and potential damages. In general, in order to predict and then overcome the consequences of the occurrence of an adverse event, it is necessary that the risk has certain features that make it suitable for statistical processing. Modelling catastrophe climate risks is a complex procedure, the success of which primarily depends on the availability and quality of quantitative and qualitative inputs that best reflect the characteristics of the natural phenomenon. In addition to traditional services, the insurance industry has developed new sophisticated services in response to weather and climate risks, among which the index-based insurance is leading the way. A weather index is at the base of every index-based insurance contract, being a relative indicator of the deviation of climate variables from the selected reference point in the reference weather forecast station.

The universal classification of the Center for Research on the Epidemiology of Catastrophes classifies all weather catastrophe events according to the type of hazard into three groups. Meteorological events caused by short-term atmospheric and weather conditions which can last from a few minutes to a few days, include extreme temperatures, fog and storms. Extreme temperatures mean cold waves, heat waves and severe winter conditions (snow, ice and frost), while storms are divided into tropical, supertropical and convective storms (rain, thunderstorms, sandstorms, blizzards, tornadoes, etc.). The hydrological ones, caused by the appearance, movement and surges of surface and subsurface fresh and salt water include floods, landslides and waves. Floods can be coastal, river, torrential and floods caused by the emergence of ice in the watercourse. The climate events caused by long-term atmospheric processes includes drought, melting glaciers and fires.[6]

One of the actual problems that occur when assessing and eventually modelling direct losses occasioned by the cat weather events is the fact that loss data is unavailable, especially in the emerging countries. In addition to the initial recognition and identification of the negative impact of a certain weather phenomenon on business or property, it is essential that the recognized climate variable can be measured. With the development of meteorology, along with more sophisticated and computerized measuring instruments, it became possible to use an ever wider

[5] UNSIDR, *Economic Losses, Poverty and Disasters 1998-2017* , 2017, p. 11 (14.01.2023) *https://www.unisdr.org/2016/iddr/CRED_Economic%20Losses_10oct_final.pdf.*

[6] Ranke U., *Natural Disaster Risk Management: Geosciences and Social Responsibility*, Springer, 2015, p. 55 and 56.

range of weather variables on the basis of which it is possible to develop the insurance services. Unlike the very beginnings, when temperature change was the only weather phenomenon against which the financial market provided protection, it is now possible to provide protection against almost all weather variables.

It is relevant to briefly comment on the difference between measuring the effectiveness of traditional types of insurance and index-based insurance. Namely, in the case of traditional types of insurance, models are created based on the frequency and intensity of adverse occurrences and the historical damage records and, based on such models, the basic elements of the insurance contract and projected losses are assessed. Statistics are used as starting values and provide a basis for measuring the expected results of risk transfer. The index, which is the basis of index-based insurance services, must be correlated with yields (if we are talking about agriculture) or with the Insured's profit. Otherwise, it will not form a sound basis for developing an insurance service. The fact is that the payment under such contracts does not depend on the level of the caused loss but on the deviation of the achieved values of the index compared to the reference values. For the aforementioned reasons, in order to evaluate the effectiveness of index insurance, all other important elements must be taken into account, such as the payment function, coverage of the area by measuring stations or the distance of a specific site from the reference measuring station.

In order for the index to be a suitable basis, it must meet several additional conditions that affect the level of reliability, i.e. for the index to be trustworthy, reliable, not subject to human manipulation, whereas the risk of measuring the index must be low.[7] Publicly available measurements of weather meet the above specified requirements to the greatest extent. In the case of weather indices, the units of measurement should provide meaningful information about the condition of the weather variable during the contractual period and are often defined by the needs of market participants. Indices often represent cumulative measures of precipitation or temperature over a specific time period. In some applications, average precipitation or temperature values are used instead of cumulative measurements. New technological innovations, including sophisticated satellite images from which high-resolution weather data can subsequently be extracted and low-cost weather stations installable in many locations, will expand the number of areas where weather variables can be measured, as well as types of measurable variables.[8]

The index should be relatively easy to understand and conceptually simple. Apart from purely statistical measures, the index and the loss recovery procedure should basically have a reasonable common causality. In other words, the level of losses and the value of the index should have common causal factors. It is important that the time frame for changing the value of the index be consistent with the onset

[7] Hess U., "Weather index insurance for coping with risks in agricultural production", in Motha RP, Sivakumar M. V. K., *Managing Weather and Climate Risks in Agriculture*, Springer, Berlin Heidelberg, 2007, p. 382.
[8] Ibid, p. 384.

of the loss process. In other words, and more generally, the value of the index should not significantly lag behind the occurrence of losses. Instead, the index should essentially react to losses as soon as they occur.[9] Likewise, the index should not be a source of moral hazard. Moral hazard refers to the possibility of increasing reported losses by the Insured in order to increase the indemnity. Such potential does not exist if the trigger is based on paid losses, as the benefit of any debt forgiveness would be offset by additional loss payments. On the other hand, there is a small potential for moral hazard in index-based contracts. Therefore, from the point of view of reducing moral hazard, it is desirable that the index be set as widely as possible.

It is also desirable that the index can be modelled based on exposure or based on a historical database. It should be noted that extensive historical data might not be available for recently developed indices, but an index that proves useful will encourage the collection of relevant information. In addition to the testing in practice, the opening of new markets and insurance services would certainly contribute to the development of a framework for assessing the index the efficiency. It is of crucial importance that the data required for the construction of the index are not subject to manipulation. Depending on the extent to which the index consists of data derived from several sources, manipulation of one data source should not result in significant manipulation of the overall index. To the extent possible, the data that make up the index should be verifiable. The International Association of Insurance Supervisors suggests paying particular attention to indices developed by one company, or based on one source only. The mentioned indexes should require greater attention from the Insured and supervisory authorities, in order to protect themselves against possible manipulation.[10]

III. Temperature Indices

Temperature indices, which were the first ones to be developed, are still the most common type of weather indices, which is quite understandable given the ubiquitous influence of temperature variations on almost all economic activities. Likewise, the temporal and spatial representation of meteorological capacities and the achievements of meteorological science indicate the most consistent approach in the study of this particular weather variable.

The most well-known temperature indices are indices that express the cumulative variations of daily air temperatures during the observed period compared

[9] In order to eliminate the possible consequences of a poorly defined index, the International Association of Insurance Supervisors proposes the existence of arbitration, which would additionally affect the credibility of the index. 12). IAIS, "Issues Paper on Index Based Insurances", *Particularly in Inclusive Insurance Markets*, International Association of Insurance Supervisors, 2018, p. 19, *https://www.iaisweb.org/uploads/2022/01/180618-Issues-Paper-on-Index-based-Insurances-particularly-in-Inclusive-Insurance-Markets.pdf* (29.12.2022).

[10] Ibid, p. 32.

to the reference 18°C or 65°F and, in accordance with the names in English, they are marked by the internationally recognized designations HDD (Heating degree days - HDD) and CDD (Cooling degree days – CDD).

The HDD index is used during the winter period and is calculated using the following formula:

$$HDD = maks\{0, (T_{ref} - T_{pros})\} \tag{1}$$

wherein

T_{ref} – reference temperature,

T_{pros} – average temperature.

The average temperature is calculated according to the formula:

$$T_{pros} = \frac{T_{maks} + T_{min}}{2} \tag{2}$$

wherein,

T_{maks} – maximum daily temperature,

T_{min} – minimum daily temperature.[11]

The reference temperature is a preselected value. In Europe, it is expressed on the Celsius scale and equals 18°C, while in America it is expressed in the Fahrenheit and equals 65°F. The index cannot take on the negative values. Tables 1 and 2 below show an example of HDD index calculation.

Table 1 Example of calculation of HDD index / colder weather

Reference temperature (A)	**18°C**	**18°C**	**18°C**	**18°C**	**18°C**	**18°C**	**18°C**	**cumulative**
Maximum temperature	14°C	16°C	15°C	12°C	10°C	12°C	15°C	**/**
Minimum temperature	12°C	10°C	9°C	6°C	6°C	8°C	11°C	**/**
Average temperature (B)	13°C	13°C	12°C	9°C	8°C	10°C	13°C	**/**
HDD (AB)	**5**	**5**	**6**	**9**	**10**	**8**	**5**	**48**

Source: author's calculation

[11] Asseldonk M. A., Insurance against weather risk: Use of heating degree-days from non-local stations for weather derivatives, *Theoretical and Applied Climatology* , 74 (2003)., 2003., p.138.

Table 2 Example of calculation of HDD index / warmer weather

Reference temperature (A)	18°C	18°C	18°C	18°C	18°C	18°C	18°C	cumulative
Maximum temperature	20°C	19°C	21°C	18°C	22°C	18°C	17°C	/
Minimum temperature	18°C	17°C	15°C	16°C	18°C	16°C	15°C	/
Average temperature (B)	19°C	18°C	18°C	17°C	20°C	17°C	16°C	/
HDD (AB)	**0**	**0**	**0**	**1**	**0**	**1**	**2**	**4**

Source: author's calculation

As can be seen on the basis of tables 1 and 2, a higher value of the HDD index indicates a lower air temperature in the observed period and vice versa. Based on the results of the previous hypothetical example, we can see that an HDD index of 48 correlates with an average weekly air temperature of 11.14°C, while in the second case, an HDD index value of 4 correlates with an average weekly air temperature of 17.85°C. The situation in the second case can cause serious adverse consequences for the energy industry, because warmer weather during the winter period will lead to lower consumption of heat energy.

The CDD index is used during the summer period and is calculated according to the formula:

$$CDD = maks\{0, (T_{pros} - T_{ref})\} \tag{3}$$

wherein

T_{pros} – average temperature,

T_{ref} – reference temperature.[12]

A higher value of the CDD index indicates a higher than average air temperature and vice versa. Moreover, like the previous one, the CDD index also cannot take negative values. The temperature indices are used and measured most often for a specific period. For example, the cumulative CDD index for harvest time or HDD for sowing time will be used to create insurance services for agricultural purposes. Table 3 shows the method of calculating the CDD index.

[12] Ibid, p. 139.

Table 3 Calculation of the CDD index

Reference temperature (A)	18°C	18°C	18°C	18°C	18°C	18°C	18°C	kumulativ
Maximum temperature	25°C	26°C	28°C	18°C	22°C	25°C	27°C	/
Minimum temperature	15°C	16°C	14°C	16°C	12°C	11°C	15°C	/
Average temperature (B)	20°C	21°C	22°C	17°C	17°C	18°C	21°C	/
CDD (BA)	2	3	4	0	0	0	3	12

Source: author's own presentation

IV. Other Weather Indices

In the past few decades, special attention has been dedicated to researching the phenomenon of drought, which affects a large number of countries and leaves catastrophe consequences. A comprehensive approach to the study of drought was developed in Brazil, where, in addition to the National Academy of Sciences, several national institutions deal with this phenomenon on a daily basis, including the National Institute for Space Research (INPE), the National Institute of Meteorology (INMET)) and the National Center for Monitoring and Early Warning of Natural Catastrophes.[13] The mentioned institutions dealt with drought assessment with the help of the standardized precipitation index (SPI index), presenting results that allow the use of information for forecasting and mitigating the negative effects.

The standardized precipitation index (SPI) proposed by the American scientist Thomas McKee corresponds to the number of standard deviations, where the observed amount of precipitation is out of the climatological average during a particular time span. To create the SPI , rainfall data sets for *m months* are prepared, whereby it is deemed that the most suitable observation period is not less than thirty years. Thereupon, averages for *i* months are created from the data sets, where *i* takes on the values of 3, 6, 12, 24 and 48 months. Each new data set of precipitation is compared to the previous period. A period of drought is confirmed when the value of the index is continuously less than -1. When the time scale is small (eg, 1, 2, or 3 months), the SPI often moves above or below zero, observing a drought meteorological regime. With an increase in the averaging scale (e.g. 12–24 months), the SPI reacts less to precipitation changes observing the drought hydrological regime. The obtained index values are comparable with series from other areas, however, a certain relationship can be established between the range of SPI values and the qualitative assessment of precipitation observed during a particular time

[13] In the first decades of this century, Brazil was hit by several catastrophic weather events caused by drought. The drought was in the period 2012–2016. It hit the territory inhabited by about 33.4 million people and caused damage of USD 30 billion. 17). Marengo J. A., at all, "Climatic characteristics of the 2010–2016 drought in the semiarid Northeast Brazil region", *Annals of the Brazilian Academy of Sciences* , 2018, p. in 1975

span. Columbia University's International Center for Climate and Society Research determined the most frequent relation between the index and precipitation, which we can see in the Table 4 below.

Table 4. Relation between SPI index values and climate categories

SPI values	Categories
SPI > 2	Extremely humid
1.50< SPI<1.99	Quite humid
1.00< SPI <1.49	Moderately humid
-0.99<SPI< 0.99	Almost normal
-1.00>SPI> – 1.49	Moderately dry
-1.50>SPI> – 1.99	Severely dry
SPI <-2.00	Extremely dry

Source: Brunini O., at all, "Coping Strategies with Agrometeorological Risk and Uncertainties for Drought Examples in Brazil", in Motha RP, Sivakumar M. V. K., Managing Weather and Climate Risks in Agriculture, Springer, Berlin Heidelberg, 2007, p. 286.

Empirical research has established that the probability distribution function of rainfall corresponds to the gamma distribution, [14] for which the following density function is adequate:

$$g(x) = \frac{1}{\beta^{a} G(\alpha)} x^{a-1} e^{\frac{-x}{\beta}}, \text{ for } x>0 \tag{4}$$

wherein

α – shape parameter,

β – size parameter,

x – amount of precipitation,

G(α) – gamma function defined by the expression

$$G(\alpha)=\int_0^{\infty} y^{\alpha-1} e^{-y} dy. \tag{5}$$

The probability density function of the gamma distribution gives different forms based on the variations of α. Values of this parameter below 1 show a strongly asymmetric distribution (exponential shape) with g(x) which is infinite when x reaches 0. When α=0, the function intercepts the vertical axis at β for x=0. An increase in the parameter decreases the asymmetric degree of the distribution. Values for α greater than 1 result in a density function to the right with a maximum value in

[14] McKee T. B., Doesken N. J., Kleist J., 1993.,„The relationship of drought frequency and duration to time scales", Eighth Conference on Applied Climatology, 17-22 January 1993, Anaheim, California, (24.01.2023) *http://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf.*

β* (α-1). An increase in the parameter β reduces the level of the density function and reduces the probability of the occurrence of a modal value. Similarly, as the density is compressed to the left (decreasing the level of β), the level of the function becomes larger and the possibility of the occurrence of a modal value increases.

Precisely because of this, the variations of α and β in the country show the areas with the highest degree of asymmetry in the temporal distribution of precipitation (irregularity of the amount of precipitation). Considering droughts, the irregularities associated with environmental conditions in each area, such areas are at the highest risk of becoming subject to meteorological droughts.[15]

One of the most significant steps in correctly assessing the occurrence of drought is the calculation of precipitations. Climatologically adequate conditions (**P**) can be understood as the amount of monthly precipitation required for a particular area in order for it to remain under normal climate conditions. That parameter was calculated and described by Wayne Palmer. To calculate the monthly anomalies in the water inflow (d), the precipitation observed in the month (P_i) is compared with the adequate climatological conditions **P** in the same period:

$$d = P_i - \mathbf{P} \tag{6}$$

Since Palmer developed a standardized index based on the comparison of data obtained from different locations in any period, its specific application when analyzing data at a specific location requires that it be standardized on a regional basis. To this end, Palmer developed a climatological categorization factor denoted by the letter K:

$$K = 17{,}67 \frac{K^{1}}{\sum_{i=1}^{12} DK^{1}} \tag{7}$$

wherein

$$K^{1} = 1{,}5 \log_{10}\left[\frac{T+2{,}8}{D}\right] + 0{,}5 \tag{8}$$

T – ratio of water consumption and supply in the region,
D – monthly average of absolute values for d.

Palmer suggested the following relationship of indices, rainfall and drought:

[15] Brunini O., at all, 2007, p. 287.

Table 5 Relationship between the Palmer index and drought categories

Palmer index	Categories
≥ 3.00	Extremely humid
2.00< a< 2.99	Severely humid
1.00 <a <1.99	Moderately humid
0.51< a< 0.99	Low humid
0.50 > a > -0.50	Close to normal
-0.51 >a> -0.99	The beginning of the drought
-1.00 >a >-1.99	Moderate drought
-2.00 >a>-2.99	Severe drought
≤-3.00	Extreme drought

Source: Brunini O., at all, 2007, p. 288.

In a number of countries, such as Australia, the decile method is used to assess the degree of drought. The decile method consists first of the organization in ascending order, and then of the classification of historical data on precipitation accumulated in a certain period of time, generally 1, 3, 6, 12 or more months, at 10 intervals of equal frequency. So the probability of occurrence in any interval is 10%. Those intervals are called deciles and are numbered from 1 to 10. *N* is the number of registered historical observations. The first decile contains of the smallest values for precipitations, where corresponds to an integer (*N*/10). The second decile contains the following values (&), where = (*N* /20) etc. After that, the category will correspond to each decile, that is, the descriptive concept of the amount of precipitation in which the deciles will be grouped. This means that more than one decile could be associated with the same category. If each category is marked with a particular colour, maps can be drawn showing the amount of precipitation, thus checking for each point the value of the amount of precipitation observed during a certain period and plotting the point on the map with the colour associated with the category. The methodology of using the classification of rainfall according to the decile method is shown in the Table 6 below.

Table 6 Classification according to the decile method

<table>
<tr><th rowspan="2">Decile</th><th>Originally posted classification</th><th>Classification adopted in Australia</th><th colspan="2">Classification adopted by INMET (Brazil)</th></tr>
<tr><th>Category</th><th>Category</th><th>Category</th><th>Index</th></tr>
<tr><td rowspan="2">1</td><td rowspan="3">Much below normal</td><td>The lowest</td><td rowspan="2">Extremely below normal</td><td rowspan="2">-3</td></tr>
<tr><td>Much below average</td></tr>
<tr><td>2</td><td rowspan="2">Below average</td><td>Below normal</td><td>-2</td></tr>
<tr><td>3</td><td rowspan="2">Below normal</td><td>Slightly below normal</td><td>-1</td></tr>
<tr><td>4</td><td rowspan="4">Average</td><td rowspan="4">Normal</td><td>0</td></tr>
<tr><td>5</td><td rowspan="2">Close to normal</td><td>1</td></tr>
<tr><td>6</td><td>2</td></tr>
<tr><td>7</td><td rowspan="2">Above normal</td><td>3</td></tr>
<tr><td>8</td><td rowspan="2">Above average</td><td>Slightly above average</td><td>1</td></tr>
<tr><td>9</td><td rowspan="3">Much above normal</td><td>Above average</td><td>2</td></tr>
<tr><td rowspan="2">10</td><td>Much above average</td><td rowspan="2">Extremely above average</td><td rowspan="2">3</td></tr>
<tr><td>The highest</td></tr>
</table>

Source: Brunini O., at all, 2007, p. 289.

As can be seen in Table 6, in addition to the general classification, the Australian Bureau of Meteorology and the National Institute of Meteorology of Brazil (INMET) have developed some modifications and adopted their own classifications, shown in the second and third columns of the table, which are linked to a numerical index with range between -3 and 3 for each category. Modelled after the decile method, the quartile method consists of classifying the accumulated amounts of precipitation during a particular period of time (time scale) *X* into five categories, which can be seen in Table 7 below:

Table 7 Classification of precipitations applying quantile method

Precipitation level	Associated probability	Categories (observed precipitation)
Quantile 1	15%	Very dry
Quantile 2	20%	Dry
Quantile 3	30%	Normal
Quantile 4	20%	Humid
Quantile 5	15%	Very humid

Source: Brunini O., at all, 2007, p. 290.

The first quantile, 0≤X≤Q_1, where Q_1 such that the probability is P(X≤Q_1)=0.15

The second quantile, Q_1 <X≤Q_2, where Q_2 is such that the probability is P (X≤Q_2)=0.35

The third quantile, Q_2<X≤$Q_{3,}$ where $Q_{3,}$ is such that the probability is P (X≤$Q_{3,}$)=0.65

The fourth quantile, $Q_{3,}$<X≤$Q_{4,}$ where is is such that the probability P (X≤ $Q_{4,}$)=0.85

The fifth quantile, X > Q_4.

As with the SPI index, to determine the value of Q_i, *i* =1,...,5, the probability model is adjusted (normal gamma distribution) by historical data in the observed period. *X* is the amount of precipitation for a certain period, while F(x) is the density function, which is fitted to the historical values for X, while it is fitted to the inverse F function, so that:

Q_1=F^1 (0.15), Q_2 = F^1(0.35), Q_3 = F^1(0.65) i Q_4 = F^1 (0.85).

Each of the five described quantiles is associated with a qualitative classification from Table 7. As with other models, the specified period is 1, 3, 6, 12 or more months.[16]

With the exception of the Palmer index, the essence of the methods described above is the same and their results will differ only in terms of the existence of certain variations in the categorization of the weather phenomenon, in this case drought. In order to identify and then determine as realistically as possible the cause-and-effect relation between the weather phenomenon and the particular damage caused, the existing, traditional meteorological indices have been supplemented. It is important to mention that the phenomenon of drought can be determined in relation to meteorological, hydrological, agronomic and socioeconomic aspects. However, from an agronomic point of view, any management and forecasting must be based on methods that include agronomy and agrometeorological knowledge. To this effect, composite weather indices were developed, such as evapotranspiration standardized index, humidity index, index of water influence on the crops and index of crops growth as a function of humidity.

IndexCo is the world's most eminent company that deals with the creation of indices for the needs of the insurance industry and the financial market in a broader sense. Guy Carpenter Catastrophe Index, which is owned by Index Co, is designed to measure the level of insured damage occurring from atmospheric hazards such as

[16] Brunini O., at all, 2007, p. 290.

hurricanes, tornadoes, storms, hail and freezing to U.S. homes. The index is expressed as a ratio of damage to value, that is, as a ratio of insured damages to insured value. The index is published for all 50 states and the District of Columbia, while Texas is published in a separate process. The index can be adjusted to almost any area in the US. It is calculated on a specific event basis and on an aggregate basis. In case of event-based calculations, the index measures the damage of the largest catastrophe weather event that hit a specific location in a specific time period. In the case of calculation on an aggregate basis, the index measures the total damage arising from a particular type of weather catastrophe in a certain time period.

The index is intended for the creation of insurance services for residential buildings, where it is important to note that these services cannot include protection against allied perils such as floods, wind, lightning or earthquakes. The most detailed and relevant reporting unit needed to create an index at the postcode level is a postcode or a group of postcodes composed so as to cover a larger geographic area and thus form a credible reporting area. The index can then be aggregated at any other higher level. For a zip code to qualify as a reporting unit, it must have at least 1,000 occupied housing units and at least four insurance companies covering the area and participating in the insurance of said housing units, each of which must provide data on at least ten homes with a minimum of $700,000 insured housing values. If it is necessary to create an index, and the postal code is not qualified as a reporting unit, in order to create an adequate index, the aforementioned postal code is grouped together with other postal codes until an area is created that can be qualified as a reporting unit. Once the reporting unit is defined, the index is calculated by adding up the LTV ratios (losses to value) of all insurance companies from the selected area and then such number is divided by the number of companies. The index is published for the next two semi-annual periods.

The RMS index compares the catastrophe model with relation to the potential exposure of an industry. When all the parameters of the catastrophe event are known after the catastrophe (such as central pressure, movement speed and maximum wind radius, etc.) they are entered into the catastrophe model to determine the loss generated by the model. Losses generated by the model for hazards such as hurricanes, typhoons, cyclones and earthquakes can be calculated for events occurring around the world. The losses generated by the models are divided by $100 million and rounded to the nearest whole number to obtain the index value. The index is available on both an event basis and an aggregate basis.

The occurrence threshold (Richter scale) for earthquakes varies from 5.0 to 7.0 by region. The event threshold for hurricanes is Saffir-Simpson Category 1 or above. Losses generated by the model can be reported at the postcode area level for various periods. Final index values are available 28 days after the event.

Every year, "Swiss Re", the Swiss reinsurance company, publishes the *Sigma magazine* dedicated to natural and man-made catastrophes. Based on the mentioned data, the sigma index was developed. It was not initially designed to be an index, however, as such it can be used in the financial market in derivatives transactions. Natural catastrophes include floods, storms, earthquakes (including seafloor earthquakes and tsunamis), droughts, wildfires (including heatstroke), cold, frost and others (including hail and avalanches). Man-made catastrophes include major fires, explosions, aviation catastrophes, ship catastrophes, road/rail catastrophes, mining accidents, building/bridge collapses and miscellaneous (including terrorism). The index is most often used for international securitization. The "Swiss Re" has published tables with heavy losses since 1970. Data sources are daily newspapers, Property Claims Service, periodical publications of primary insurance and reinsurance, professional publications as well as reports of primary insurance and reinsurance companies.

V. Conclusion

Understanding the complex nature of exposure and vulnerability is a prerequisite for determining how weather and climate events contribute to catastrophe occurrences, as well as for designing and implementing effective strategies for adaptation and catastrophe risk management. Previous experiences with climate extremes contribute to the understanding of effective catastrophe risk management and/or the adoption of approaches to manage those risks. The severity of impact of climate extremes much depends on the level of exposure and vulnerability to those extremes. Exposure and vulnerability trends are the main drivers of change when it comes to catastrophe risks. Understanding the complex nature of exposure and vulnerability is a prerequisite for determining how weather and climate events contribute to catastrophe occurrences and/or for developing and implementing effective strategies for adaptation and catastrophe risk management.

One of the most innovative responses to the ever-growing threat of climate risks are index insurance services. The prerequisite for their application is, it goes without saying, the possibility of modelling of a particular weather variable with indices. By sublimating the basic qualitative characteristics that indexes should have, potential contradictions can be observed, that is, mutually exclusive requirements. Clearly, it is difficult for any index to satisfy each and every characteristic, to the extent of its comparability. Therefore, a good index often involves a compromise between several different characteristics.

The lack of effective market mechanisms for protection against weather risks in Serbia will have to be compensated, first of all, if we consider the damage caused by floods. Although, technically observed, there are opportunities to create weather indices, above all temperature and precipitation, from a network of measuring stations of the Republic Hydrometeorological Institute, the Insurance Act does not provide for the existence of such type of insurance services. Based on the practical implementation of this model, primarily in Latin and North America, its numerous advantages and benefits can be clearly seen and they would have positive effects on the economy of Serbia.

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