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Investigation of Simultaneous Occurrence Probabilities of Some Dangerous and Spontaneous Meteorological Phenomena for Various Physical and Geographical Conditions of Georgia Using Multiplication and Addition Theorems of Probabilities

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A B S T R A C T

The occurrence probabilities of some independent dangerous and spontaneous meteorological phenomena complexes for different physical and geographical conditions of Georgia have been estimated using multiplication and addition probability theorems. The complex of precipitation -strong wind events occurs on the Colchis Lowland on average every 20 days in December and January, on the Eastern Georgia plains once per year in May, on the Likhi ridge every 5-7 days during whole year.The occurrence of intensive precipitation-strong wind complex is possible in Western Georgia 1 time per decade, in Eastern Georgia - 1 time in 25 years and in the highland zone of the Greater Caucasus approximately 9-10 times in every 25years and on Likhi Ridge once per month. The occurrence of the hail-strong wind complex is possible on average every 50 and 20 years (warm period of year) in the South Georgian Highlands and in Eastern Georgia respectively. The fog-strong wind complex in Greater Caucasus high-mountain zone in May can be realized on average every decade and on the Likhi Ridge every 3-5 days.

Keywords: Probability, Meteorological phenomena, Complex of events, Climatic conditions, Dangerous weather, Precipitations.

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Introduction

Dangerous and spontaneous meteorological phenomena, such as extreme temperature, rainfall, hail, blizzard, fog, strong and hurricane winds, etc., create emergency situations, causing damages and even human victims.

Natural weather phenomena, as the result of modern anthropogenic impact have been significantly intensified and often have catastrophic character. The intensification of natural meteorological phenomena has affected ecosystems and economy of Georgia, as it is evidenced by the impact of global warming on the regional climate, and even on the landscape structure [1-3].

Investigations of some dangerous and spontaneous weather phenomena over Georgian territory were initiated by one of the author of this article in the late 70th- at the beginning of 80th of last century. In the result of these studies the main features of the statistical structure of cloudiness, thunderstorm processes, abundant and intense rainfall, strong surface winds, the probabilistic

characteristics of fogs, including hazardous fogs [4, 5], extreme anomalies of mean monthly air temperature [6], frosts [7], hurricane winds [8] and other spontaneous meteorological phenomena [1, 9] were revealed [10-14].

Thus, for present a rather rich literature has been collected that characterize geography, structure and dynamics of individual spontaneous meteorological phenomena on the territory of Georgia. However, sometimes some events attack simultaneously, overlapping each other and thereby aggravate situation. For example, increased wind during shower, fog with snow, hurricane with hail, etc. To reduce the negative consequences of complex of these phenomena, one must know their probabilistic characteristics for the given locality.

These phenomena are independent from each other; therefore the probabilities of their joint occurrence can be determined using the multiplication and addition theorems of probabilities [15].

In this paper, the occurrence probability of some independent dangerous and spontaneous meteorological phenomena complexes for various physical and geographical conditions of Georgia has been estimated using multiplication and addition theorems.

2. Study Area

Georgia is characterized by exceptional variety of physical-geographical and climatic conditions [1, 16]. Its territory combines high-mountain, middle-mountain, hilly, low-flat, flat and plateau-like reliefs. The location of some lowlands don't exceed sea level, and individual mountain peaks ranges exceed 5000 m height.

In the northern part of the territory in the direction from the north-west to the south-east there extends the Main Caucasian Ridge. In the southern part, almost parallel to the Main Caucasus Ridge, there extends the South Georgian Highlands, which is part of the Lesser Caucasus. The main Caucasian ridge is connected to the South Georgian mountain range by the Likhi Ridge, which divides Georgia into two climatic regions: the West, with humid subtropical climate and the East, with moderately dry continental climate. Between the Great Caucasus and the South Georgian upland there is a tectonic depression, which is represented by lowlands, river valleys, plains and plateaus: the Black Sea coast, the Colchis Lowland, the Imereti highlands, East Georgia plains, the Alazani Valley.

3. Data and methods

According to the basic provisions of the probability theory [15], the probability of the set of independent events A and B, can be calculated using multiplication theorem of probabilities:

$$P(AB)=P(A)P(B), \qquad (1)$$

and the probability of realization of one of the events is determined by the addition theorem of probabilities

$$P(A+B)=P(A)+P(B)- P(AB), \qquad (2)$$

where P(A) –probability of A event, P(B) – probability of B event, if we consider the complete system of events A_i, where i = 1,2,3, ... n.

If it is known that there has been occurred event B, then the probability of event A is calculated in accordance with the Byes theorem:

$$P(A/B)=[P(Ai)P(B)]/ P(Ai)P(B). \qquad (3)$$

P(A/B) – is called conditional probability.

In our case, two opposite events are considered: A_1 - the existence of specific meteorological phenomenon (precipitation, hail, fog, strong and hurricane winds, etc.) and A_2 - the absence of the same phenomenon. The sum of the probabilities of these phenomena equals to 1, so they form a complete system of events.

To study pattern of precipitation-strong wind complex probabilities based on the mean annual data and construct corresponding map, the observation materials of 16 meteorological stations were used and for complex probabilities of phenomena characteristic for the regions monthly data were used. Also the resources of scientific- application handbook were used as initial data [17].

In presented research 7 posts were chosen considering Georgian physical-geographical conditions: seaside resort Batumi (2m) characterizing Georgian Black Sea coastline, Samtredia (28m) located in central part of Colchis Lowland, Tbilisi (403m) typical for eastern lowland part of Georgia, Telavi (550-900m) located at north-eastern slope of Gombori Ridge characterizing foothill and low mountain zone of eastern Georgia, Akhalkalaki (1716m) characterizing the climatic conditions of the South Georgian Highland and Kazbegi (3600m) characterizing high mountain zone of Great Caucasus and Mta-Sabueti (1242m) located on climate separating Likhi Ridge.

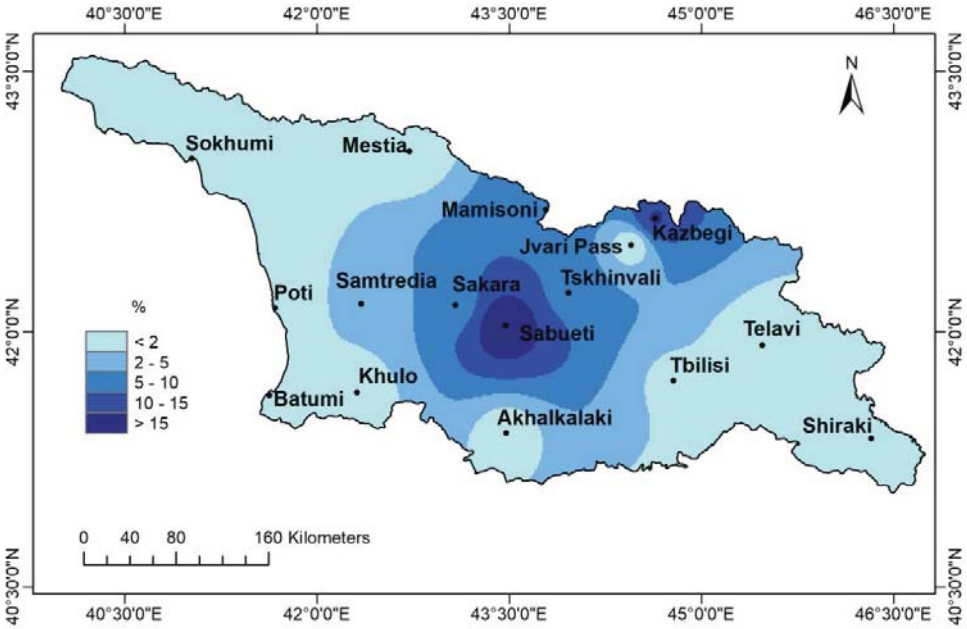


Fig. 1. *The distribution probability (%) of precipitation-strong wind complex mean annual probability*

4. Discussion

The map of precipitation-strong wind complex mean annual distribution probability, calculated according to the equation (1) has been presented on Fig.1.

From the map it follows that the greatest probability of the complex as a whole (15-20%) per year is recorded on the Likhi Ridge (about 70 days per year). On the eastern part of the southern slope of the Greater Caucasus, the probability of the same complex is 10-15% (35-50 days). At the Black Sea coastline the occurrence probability of the complex is 2%, and in most of the Southern Georgia Highland and the plains of Eastern Georgia it does not exceed 1%, which corresponds to 7 and 4 days. Obviously during year the occurrence of both individual meteorological phenomena, as well as their complexes, changes significantly.

For example in the Table 1 there are presented values of empirical occurrence probabilities of some typical and dangerous meteorological phenomena for Telavi: hail, fog, strong wind, precipitation and intense precipitation. The wind is strong when its speed exceeds 15 m / sec, and precipitation is considered to be intense when their daily amount exceeds 20 mm.

From Table 1 it follows that for Telavi the most presumable phenomena are fog and precipitation, including intense precipitation. The probability of fog in winter months increases to 17-23%, which amounts 5-7 days, and the probability of precipitation month dependence varies between 7-10%. The occurrence probability of other dangerous meteorological phenomena is low, even if they cause significant damages.

Table 1. *Empirical occurrence probabilities of some dangerous meteorological phenomena (%) Telavi*

Event	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Hail	0	0	0.07	1.3	2.7	2	0.3	0.7	0.3	0.3	0.07	0
Fog	20	17	20	10	3	3	2	2	3	10	13	23
Strong wind	3	4	5	3	2	2	0.7	1	2.3	5	2.3	2.7
Precipitation	10	7	10	10	10	10	10	10	7	7	10	7
Intense precipitation	0.3	1.3	1.3	3	7	7	3	3	3	3	3	1.3

Table 2. *Probabilities of the most dangerous meteorological phenomena (%) combinations (Telavi)*

Months	Precipitation-fog			Intense precipitation-strong wind			Hail-strong wind		
	P(AB)	P(A+B)	P(A/B)	P(AB)	P(A+B)	P(A/B)	P(AB)	P(A+B)	P(A/B)
1	2	28	10	0.009	3	0.3	0	3	0
2	1	12	6	0.052	5	1	0	4	0
3	2	28	10	0.065	6	1	0.0035	5	0.12
4	1	19	9	0.09	6	3	0.039	4	2
5	0.3	13	10	0.14	9	7	0.054	5	3
6	0.3	13	10	0.14	9	7	0.04	4	2
7	0.2	12	10	0.021	4	0.3	0.002	4	0.2
8	0.2	12	10	0.04	4	0.4	0.007	1	0.7
9	0.2	9	7	0.069	3	0.3	0.0069	2	0.3
10	0.6	16	6	0.15	8	3	0.015	3	0.3
11	1	22	8	0.069	5	0.3	0.0161	5	0.8
12	2	28	10	0.025	4	1	0	2	0

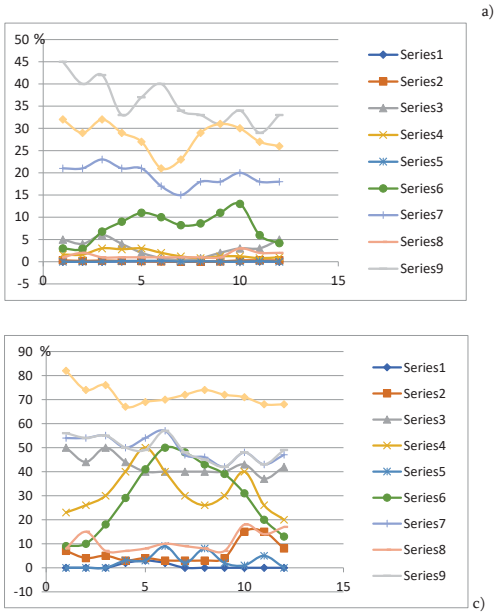
In Table 2 there are presented the probabilities of the most dangerous phenomena combinations: precipitation-fog, intense precipitation-strong wind, and hail-strong wind by months, calculated by equations (1, 2, 3) based on table 1 data.

From Table 2 it follows that the occurrence probability of the precipitation-fog event complex P (AB) in winter months, as well as in the beginning of spring and at the end of autumn is 1-2%, and in summer months decreases to 0.2%. The occurrence probability of one of the events P (A + B) (precipitation or fog) is much bigger and amounts to 9-28%, the maximum in December, January and March and the minimum in September. While considering fog, the probability of precipitation P (A/B) increases, making 6-8% in fall and at the end of winter, and 9-10% for all rest months.

It also follows from Table 2 that the occurrence probabilities of complex precipitation-strong wind and hail-strong P (AB) are very low. The probability of one of the events of the complexes P (A + B) is 3-9% in the first case and 1-5% in the second one. During strong winds period the probability of intense precipitation and hail P (A/B) increases and amounts to 0.3% in May.

Figure 2 shows the annual course of the most dangerous probability combinations of meteorological phenomena for different physical-geographical conditions of Georgia.

Locations and phenomena combinations: 1-Telavi (hail-strong wind); 2-Batumi (heavy precipitation-strong wind); 3- Samtredia (precipitation - strong wind); 4- Tbilisi (precipitation - strong wind); 5- Akhalkalaki (hail-strong wind); 6- Kazbegi (fog-strong wind); 7-Mta-Sabueti (precipitation-strong wind); 8-Mta-Sabueti (heavy precipitation-strong wind); 9-Mta-Sabueti (precipitation-fog); 10-Mta-Sabueti (fog-strong wind). On Fig. 1a) curves 1 and 5 coincide.



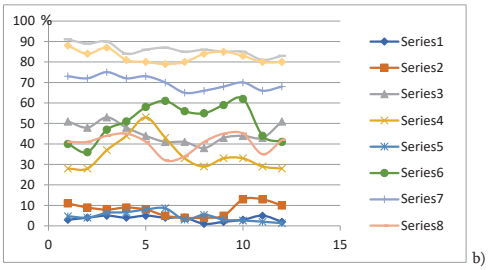


Fig. 2. *The annual course of probability combinations of the most dangerous meteorological phenomena for different physical-geographical conditions of Georgia: a) the probability of simultaneous occurrence of independent events, b) the occurrence probability of one of the events, c) occurrence probability of complex in case if one of the event has been occurred.*

As follows from Fig. 2 the annual course of occurrence probability of various variants of meteorological phenomena complexes depends essentially on the physical and geographical conditions of the location. For example, the probability of simultaneous occurrence of strong wind and precipitation on the Colchis Lowland (Samtredia) fluctuates on average from 0.4 to 5% during the year, the minimum in May and maximum in December and January, while on East Georgia plains (Tbilisi) probability of the same complex is 1-3%, the minimum in August and November, and maximum in May. The occurrence probability of precipitation-strong wind complex on the Likhi Ridge (Mta-Sabueti) makes 15-23%, the minimum in July and the maximum in March. Consequently, precipitation-strong wind complex occurs on the Colchis Lowland on average every 20 days on December-January, on Eastern Georgia plains in May per year only once, and on the Likhi Ridge every 5-7 days. The occurrence probability of one of the phenomena from the precipitation- strong wind complex in the Colchis Lowland during the year fluctuates between 38-51%, the minimum in August, and the maximum in December-January, and on the Eastern Georgia plains is 28-53%, the minimum in January -February, and the maximum in May, and at Likhi Ridge ranges between 65-75%. When one of the events from the precipitation-strong wind complex occurs, the probability of its second component occurrence during the year on the Colchis Lowland ranges from 37 to 50%, the minimum in November and July, and the maximum in December-January and March, and on the East Georgia plains the probability of the corresponding event is 20-40%, the minimum in December, August and November, and the maximum in March and May, and on the Likhi Ridge ranges between 42-55% minimum in September, the maximum in March.

Precipitation-strong wind complex is characterized by a small probability on the Black Sea coast (Batumi), which frequently is the most dangerously coincided with a storm. The probability of this complex during year ranges from 0.03% (July-August), - 0.3% (January), the probability of this complex in Eastern Georgia is even less, and on the Likhi Ridge it ranges between 1-3%, the maximum in October . Thus, this complex can be realized on the Black Sea coast on average 1 time per decade, and on the Likhi ridge - 1 time per month. The occurrence probability of one of the phenomena complex is 4-13% on the Black Sea coast, a minimum in July-August and maximum in October-November, and the occurrence probability of the complex, with the onset of one of the events, ranges from 3% (summer July-September) up to 15% (October-November January); For the Likhi Ridge, respectively 32-45%, the minimum in June and the maximum in April, September-October, and 7-18%, the minimum in March-April, September and the maximum in December.

Very rarely there is hail-strong winds complex, which on 19.07.2017 in Telavi has catastrophic nature and caused significant material damages. The maximum probability of this complex at foothill and lowland zones of East Georgia (Telavi) is 0.04-0.06% (April-June), and at the South Georgia Highlands (Akhalkalaki) - 0.16-0.17% (May June). This means that the complex hail-strong wind for the indicated months occurs on average 1 time in 50 years and for 20 years, respectively for Eastern Georgia and the South Georgian Highlands. The occurrence probability of one of the complex's events throughout the year varies from 1% in August to 5% in March and May and in the South Georgian Highlands from 1% in December to 8-9% in May-June. The probability of the complex significantly increases when one of the events has been already occurred and reaches 3-9% (May-June) respectively.

Unlike the considered meteorological phenomena complex, the fog-strong wind complex has been characterized by significant probability in mountains. The occurrence probability of this complex of phenomena on the Likhi Ridge (Mta-Sabueti) varies within the limits of 21% (June) - 32% (January, March), and on the Caucasus (Kazbegi) - within 3% (January-February) - 11% (May). Thus, this complex can be realized, respectively, on average 3-5 days and every ten days. The likelihood of realizing one of the phenomena of the same complex is 79-88% at Likhi Ridge, and on Caucasus -36-62%, and the occurring probability of the complex upon realizing one of the events varies, respectively, from 67% (April) to 82% (January) and from 9% (January) to 50% (June).

On the climate separating Likhi Ridge there is also high probability of precipitation-fog complex -29-45%, the minimum on November and maximum on January. This complex is happening every 2-3 days. The probability of one of the phenomena of the complex during the year fluctuates within 81-91%, the minimum also in November and the maximum in January, and occurrence probability of

the complex at the onset of one of the events varies within 42% (September, October) - 56% (January).

5. Conclusion

The simultaneous occurrence probability of strong wind and precipitation on the Colchis Lowland varies from 0.4 to 5% during the year, and on Eastern Georgia plains it is 1-3%, and on the Likhi Ridge it is 15-23%. The occurrence probability of one of these phenomena is 38-51% in the Colchis Lowland, and in Eastern Georgia it is 28-53%, and in the Likhi Ridge ranges between 65-75%. In case of one of the events, the occurrence probability of the second component of the complex is 37-50% in the Colchis Lowland, while in East Georgia it is 20-40%, and in the Likhi Ridge ranges between 42-55%.

The occurrence probability of the complex of intense precipitation-strong wind fluctuates throughout the year on the Black Sea coast and the Colchis Lowland within 0.03% -0.3%, and on the Likhi Ridge it is 1-3%. The occurrence probability of one of the phenomena of the complex is 4-13% on the Black Sea coast, a minimum in July-August and maximum in October-November, and the occurrence probability of the complex, with the onset of one of the events, ranges from 3% (summer July-September) , up to 15% (October-November January). For the Likhi Ridge it is respectively, 32-45%, the minimum in June and the maximum in April, September-October, and 7-18%, the minimum in March-April, September and the maximum in December.

The maximum occurrence probability of complex hail-strong wind in the foothill and lowland zone of Eastern Georgia is 0.04-0.06% (April-June), and in the South Georgian Highlands - 0.16-0.17% (May June). The occurrence probability of one of the complex's events throughout the year varies from 1% in August to 5% in March and May in the South Georgian Highlands from 1% in December to 8-9% in (May, June). The occurrence probability of the same complex, when one of the events has been happened, reaches 3-9% (May-June).

The complex fog-strong wind is characterized by significant probability in the mountains. The occurrence probability of this phenomena complex on the Likhi Ridge ranges from 21% to 32%, while for the Caucasus (Kazbegi) ranges from 3% to 11%. The likelihood of happening one of the phenomena of the same complex is 79-88% in the Likhi Ridge, and in the Caucasus -36-62%, and the probability of happening the complex in the case when one of the event has been already occurred varied respectively from 67% (April) to 82% (January) and from 9% (January) to 50% (June).

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