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*Abstract

Part I Introduction

To this day we still struggle with cancer. Even with all our modern equipment and knowledge we have still not been able to tame this horrible disease.

Incidence is the increase in the rate of new occurrences. So if we were to analyze the amount of new HIV incidents over 10 years and we start with 20 incidents, then after 5 years we get 20 new incidents and then after 10 years, we get 30 new incidents. We now have a total of 75 new incidents since the start ($20 + 20 + 30$). Because we do not know when the 20 first incidents in the first 5 years happened, we assume they happened after 2,5 years (halfway to 5 years). So we will get $20 * 2,5$ and end up with 50 possible new cases. Do the same with the next 5 years and the next 30 new occurrences! The only exception to the previous calculation is that we know they happened somewhere between 5 and 10 years, so we go halfway, to 7,5 ($(5+10)/2 =$

- Disease disposition
 - What is a patient's risk of developing cancer in the future?
- Screening
 - Does earlier detection of patients with cancer decrease mortality?
- Diagnostic
 - Who has cancer? What is the grade of the cancer?
- Prognostic
 - What clinical outcome is most likely if therapy is not administered?
- Predictive
 - Which therapy is most appropriate?
- Monitoring
 - Was therapy effective? Did the patient's disease recur?
- Pharmacogenomic
 - What is the risk for adverse reaction to the prescribed therapeutic dose?

Characteristics for a good biomarker:

- Safe and easy to measure
- Cost efficient to follow up
- Modifiable with treatment
- Consistent across gender and ethnic groups

An example of a single molecule biomarker is the prostate specific antigen (PSA). This is a protein produced by the prostate gland in male humans. The identification of cancer with PSA is simple, the higher the level of PSA, measured in ng/mL (nanograms per milliliter), the higher is the chance of the patient having prostate cancer [1].

Today PSA is used for both identifying and evaluating the current stage of prostate cancer. This biomarker can be found by analyzing blood samples from patients, thus fulfilling some of the demands for a good biomarker, but not all of them. It is easy to measure and easy to acquire, but not reliable enough to be used as the only marker to identify and determine the stage

or remission of prostate cancer. The low grade of reliability comes from the fact that even though higher levels of PSA shows higher chance of having prostate cancer, prostate cancer is not the only reason to have elevated levels of PSA [1]. Namely inflammation and enlargement of the prostate. Though, a man with both of these cases may or may not develop prostate cancer.

So the conclusion for the PSA biomarker is that it is not reliable enough and are causing faulty treatment of prostate cancer that may not even exist. Because even if a patient has prostate cancer, it may not be harmful, promoting the case of not taking any action against it at all. So there is need for a new biomarker, or at least a better way to diagnose and predict the right treatment.

Next-generation sequencing Today, rapid analyzing of genes and proteins are made available through Next-Generation Sequencing (NGS)[2]. Networks offers us an informatics, algorithmic, visual and mathematical tool to study this bigger picture. This project will integrate the opportunity networks offer to discover new biomarkers in cancer. Through acquiring more data, faster than before, there now exists databases with much information that is easy to access. This makes room for building huge networks of proteins and genes, allowing for more extensively and thorough assays to be done. For example, what if something that is classified as a prostate cancer biomarker only is viable when proteins that has not been classified as a biomarker, also is present? Together they could represent a more appropriate *network biomarker*. The amount of data that can be analyzed also opens up for another more personalized approach to each cancer patient. Finding patient-specific biomarkers could make a huge impact on the quality of treatment [21]. Next generation of biomarkers The PSA biomarker is over 20 years old [17]. Through those years, it has been discovered other and better biomarkers for prostate cancer than PSA. Among those, PCA3, which is detectable through urine samples from patients. It also has the benefit of not being affected by the size of the prostate gland [18]. But still the results could be better. Therefore, it has been tried to combine these two biomarkers in order to see if it is beneficial to see the results from each biomarker in light of each other [22]. The results from these tests is that they complement each other to a level of significance that makes it compelling to analyze them both to diagnose prostate cancer. It is important to point out that even if these biomarkers are not the best at indicating if a patient has cancer or not, these biomarkers are good at indicating progression and recurrence of prostate cancer.

But all of this is based on single genes or proteins. What if we looked at whole networks as biomarkers?

Networks as a tool in cancer research Viewing the cell as a network of proteins and genes presents us with several assumptions to make. Firstly, there is no physical connection between the proteins and genes, which represents the nodes in the network. So a way of defining edges between nodes

has to be established. It exists several ways of doing this, but there has yet to be discovered a silver bullet of defining the edges.

Bayesian probability networks are one way of defining edges [19]. It is based on the probability that if a node A exists, then node B exists. That way it is possible to create networks based on the assumption that if node A exists, then node B is 80% likely to exist. Maybe node C and D have a 100% chance of existing if node B exists. These percentages represents how strong the edges between the nodes are, and makes it able to construct a directed acyclic graph, DAG for short. It is important to note that a true bayesian network can not be achieved through random observations. Rather should some constant value(s) be introduced to be able to really measure the effect of the other variables.

The way of defining edges in a network also determines what kind of information that is possible to get from it. The different bio-databases has different ways of calculating edges. Should the database alone define the edges? If the database supply weights in the edges and/or nodes, should it be used, changed or ignored? The final decision of how and in what way the edges should be defined has yet to come.

Network clustering: Toward network based biomarker discovery Networks is the pre-processing of single gene prioritization that is necessary in order to come to the next step, clustering of the network. Clustering is about making a hierarchical view of a network to be able to look at the bigger picture of the cell. The reason to group a network into clusters and rank them is that the edges we create represents different connections. They can represent function, probability of existence, interactions or contents of the cell [15]. The function of the cell is what Ranklust is after. There is several algorithms to create clusters, and all need to be heavily researched in order to find the best suiting one. The major differences on how these algorithms work is centered around how they handle vertices and edges. For example how the cluster is expanded, what density level it is aiming for, how robust the algorithm is towards incomplete networks. It is feasible if the cluster-making algorithm is easily, or even already implemented as an app in Cytoscape. ClusterMaker2 is such an app and will be considered [3]. But there is faster cluster-creating algorithms than those implemented in ClusterMaker2, namely the SPICi [20] algorithm. So a possible solution for Ranklust could be to implement the SPICi algorithm into the ClusterMaker2 app, in order to reuse most of the code that represents the GUI, single gene prioritization and network creation.

In addition to the cluster-creating algorithms, there is a need for cluster-ranking algorithms. They should be ranked in the order of being a biomarker for cancer. Cytoscape: An implementation to rank clusters Cytoscape is the open-source software platform the Ranklust app will be developed on. Its main purpose is to visualize molecular interaction networks and biological pathways. It is easy to integrate *Apps* and even combine multiple apps to

solve new problems, given that the source code of the apps is available or that it exists an easy way of piping results from one app to another.

The goal of Ranklust is to cluster the networks we get from single gene prioritization and rank them in order to identify network biomarkers. Apps taking care of making the networks already exists, but there still has to be made a decision about whether or not they could be modified in order to better support the clustering.

Which databases to use has to be considered. The reason to use databases is because they have information about how protein and genes form a network based on how they interact with eachother. The initial database candidates in Ranklust are iRefIndex [4], GeneMania [5] and STRING [6]. These databases all have in common that it exists Cytoscape apps made to use these databases. STRING however, does not have any repository available through the Cytoscape app store, so interacting with the database through a new app in Cytoscape without making new plugins may be difficult. On the other hand, both iRefIndex and GeneMania have their repositories easily available to the public together with decent documentation. However, the difference between them is what they contain information about. iRefIndex contains data about protein-protein interaction (PPI), while GeneMania contains data about genes. Since proteins come from genes, GeneMania can also give us some information about proteins. Differences between the two databases will be discussed in greater depth at a later stage. The open-source plugins in Cytoscape to communicate with the databases are iRefScape [7] for iRefIndex and GeneMANIA [8] for GeneMania.

Cytoscape is based on the Java programming language, which is a little bit untraditional for a software platform used to develop bioinformatics tools. The reason to choose Java above Python, Perl or other popular programming languages is simply because I am more versed in Java programming than any other language. Java is known for being this big bloated enterprise programming language, and Python as the fast and easy mockup tool to develop good programs fast. Python also has big biological computation libraries like *Biopython* [9], that makes it easy to build your own standalone apps. Though when used in a bigger environment as Cytoscape, Java shines, having sturdy packaging and modelling standards. The Cytoscape community is big, alive and has standards for how the architecture of apps should look like. The community promotes this through the use of the *OSGi* standard [10].

Developing OSGi software should promote modularization [11] of the code and increase the probability of the app being launched as an official Cytoscape app; in addition to provide other developers with the possibility of reusing my modules in their own apps. Also, it seems like Java 9 is aimed at making it easier to modularize apps along the lines of the OSGi standard, so it might be easier to refactor an application in the future from Java 8 to Java 9 when the architecture already is in place. There exists

several design patterns that could prove to be useful in the development of Ranklust. Another strategy to follow may not be a direct design pattern [12], but more of a collection of them, is the clean code principles by Robert C. Martin [13]. More thorough examination of these strategies will follow.

Prototyping of different parts of the app will be done in Python and the Galaxy environment [14]. Python is an easy language to prototype with, and Galaxy is an easy environment to test small scripts in. Galaxy also has great logging of previous experiments combined with settings, so recreating simulations and comparing results is easy to do and reliable. However, in my experience, Java comes up to par with Python in development speed once all of the boilerplate code is written and a good deployment tool is used. Therefore the Cytoscape platform is used for the final deployment of Ranklust.

Part II

Images testing...

Part III

The project

Part IV

Results

Part V

Analysis

Part VI

Conclusion

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Figure 1: Cancers Ranked by Number of Incident Cases in Both Sexes, Globally, by Development Status, and in the 50 Most Populous Countries, 2013

Region	Country	Breast cancer	Trachea, bronchus, and lung cancer	Colon and rectum cancer	Prostate cancer	Stomach cancer	Liver cancer	Cervical cancer	Non-Hodgkin lymphoma	Esophageal cancer	Leukemia	Lip and oral cavity cancer	Bladder cancer	Uterine cancer	Pancreatic cancer	Brain and nervous system cancer	Kidney cancer	Malignant skin melanoma	Ovarian cancer	Thyroid cancer	Gallbladder and biliary tract cancer	Larynx cancer	Other pharynx cancer	Multiple myeloma	Hodgkin lymphoma	Nasopharynx cancer	Testicular cancer	Mesothelioma	
Global		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
Developed		3	4	2	1	5	11	17	7	20	12	14	6	13	8	16	10	9	15	18	19	22	23	21	24	27	25	26	
Developing		1	2	4	6	3	5	7	11	8	10	9	16	13	14	12	20	23	18	19	17	21	25	24	22	26	27		
High-income Asia Pacific	Japan	4	2	1	6	3	5	17	10	11	13	14	9	18	7	22	12	23	15	16	8	21	20	19	27	26	25	24	
	South Korea	5	2	1	8	3	4	13	10	15	14	18	11	19	9	16	12	23	17	6	7	21	22	20	25	24	27	26	
High-income North America	Canada	4	3	2	1	12	18	20	5	19	10	14	6	8	11	13	9	7	15	17	21	22	23	16	24	27	25	26	
	United States	2	3	4	1	13	18	20	7	19	11	12	6	9	10	17	8	5	15	14	23	21	22	16	24	27	25	26	
Southern Latin America	Argentina ^a	1	4	3	2	5	18	6	8	14	12	16	10	7	9	19	11	15	17	21	13	20	25	23	24	26	22	27	
Western Europe	France	3	4	2	1	10	14	19	6	18	13	12	5	7	11	16	9	8	17	22	23	21	15	20	24	27	25	26	
	Germany	3	4	2	1	6	16	21	9	18	11	15	5	12	8	14	7	10	13	22	17	23	19	20	26	27	24	25	
	Italy	2	4	1	3	6	8	21	7	22	11	19	5	12	9	14	10	13	15	18	16	20	24	17	25	27	26	23	
	Spain	4	3	1	2	6	11	20	7	23	12	13	5	8	9	15	10	14	16	22	19	17	21	18	24	27	25	26	
	United Kingdom	4	3	2	1	7	18	19	6	12	11	17	5	14	9	15	10	8	13	24	23	20	22	16	26	27	25	21	
Central Asia	Uzbekistan ^a	1	3	8	11	2	9	4	12	5	6	10	20	13	16	7	17	18	19	24	21	14	23	25	15	26	22	27	
Central Europe	Poland	3	1	2	4	6	19	11	14	14	20	12	16	5	9	8	13	7	17	10	21	18	15	23	22	25	26	24	27
Eastern Europe	Russia	3	2	1	5	4	17	9	14	19	12	11	8	10	7	18	6	16	13	15	21	20	22	24	23	26	25	27	
	Ukraine	2	3	1	4	5	21	9	15	20	11	8	10	17	7	14	6	13	12	16	19	18	22	24	23	27	26	25	
Andean Latin America	Peru ^a	3	6	4	1	2	9	5	7	21	8	18	20	10	12	15	14	17	16	11	13	24	25	19	23	27	22	26	
Central Latin America	Colombia ^a	2	6	4	1	3	10	5	9	17	7	16	23	13	12	11	20	18	14	8	15	19	25	22	21	26	24	27	
	Mexico ^a	2	7	3	1	5	10	4	9	22	8	18	24	16	12	14	11	20	13	6	17	19	25	23	21	27	15	26	
	Venezuela ^a	2	4	5	1	6	13	3	7	19	8	16	22	10	11	17	12	20	15	9	18	14	25	21	23	26	24	27	
Tropical Latin America	Brazil ^a	2	4	3	1	5	17	6	11	14	8	10	21	16	12	7	18	13	20	9	22	15	19	23	24	26	25	27	
East Asia	China ^a	5	1	4	9	2	3	12	11	6	8	19	14	7	13	10	20	26	21	17	18	16	25	24	22	15	27	23	
	North Korea ^a	4	1	5	11	3	2	7	12	6	9	14	17	8	13	10	22	23	21	20	19	16	25	24	18	15	27	26	
Southeast Asia	Indonesia ^a	1	2	4	7	5	10	3	8	21	11	6	18	13	15	12	19	23	14	9	16	20	22	25	24	17	26	27	
	Malaysia ^a	1	2	3	4	7	6	10	5	19	8	14	15	12	17	18	16	22	11	9	23	20	21	25	24	13	26	27	
	Myanmar ^a	1	2	5	11	12	4	3	9	17	7	6	22	8	15	14	23	24	10	13	16	19	20	25	21	18	26	27	
	Philippines ^a	1	2	4	3	12	7	5	11	23	6	10	20	9	15	14	18	21	8	19	17	22	26	25	16	24	27		
	Thailand ^a	3	1	4	5	7	2	6	10	19	11	8	13	17	16	14	18	23	15	12	9	20	21	26	25	22	24	27	
	Vietnam ^a	4	2	5	12	3	1	8	6	10	11	7	18	13	17	9	21	25	20	14	19	15	16	26	24	22	23	27	
South Asia	Afghanistan ^a	3	2	8	10	1	9	4	12	17	5	14	11	13	18	6	20	23	22	16	21	15	25	24	7	19	26	27	
	Bangladesh ^a	3	4	7	11	6	2	8	5	10	9	1	19	17	22	14	23	24	12	26	18	15	13	25	20	16	21	27	
	India ^a	1	6	4	15	5	8	3	11	7	10	2	19	24	22	12	21	16	14	17	20	13	9	25	18	23	26	27	
	Nepal ^a	1	4	6	13	7	9	3	12	5	8	2	21	22	17	14	23	25	11	20	16	15	10	24	18	19	26	27	
	Pakistan ^a	1	3	6	8	13	12	15	5	4	7	2	9	17	24	14	22	25	11	18	20	10	16	23	19	21	26	27	
North Africa and Middle East	Algeria ^a	1	3	2	10	4	15	7	6	23	5	21	14	20	16	8	22	24	17	12	9	18	25	19	13	11	26	27	
	Egypt ^a	1	6	7	3	9	2	11	13	20	4	14	8	15	10	5	16	23	19	12	18	17	24	25	22	26	21	27	
	Iran ^a	2	5	6	3	1	9	15	10	4	7	14	12	24	17	8	18	21	19	13	16	11	26	23	20	25	22	27	
	Iraq ^a	1	2	5	8	6	7	10	11	19	3	15	14	9	12	4	16	26	17	13	20	18	24	23	21	25	22	27	
	Morocco ^a	1	2	6	3	5	9	4	10	20	8	13	15	11	12	7	21	23	17	16	14	19	25	26	18	22	24	27	
	Saudi Arabia ^a	1	4	2	6	9	3	16	5	17	8	13	14	22	11	7	15	26	18	10	12	19	21	23	24	20	27	26	
	Sudan ^a	1	2	4	5	3	8	11	9	15	6	14	10	18	17	7	19	22	20	12	21	16	26	24	13	23	25	27	
	Turkey ^a	2	1	3	4	5	13	18	7	24	6	20	10	11	9	8	16	22	14	12	19	15	27	21	23	25	17	26	
Central sub-Saharan Africa	Yemen ^a	1	2	5	8	3	9	6	10	19	4	15	11	12	18	7	22	23	20	13	16	17	26	24	20	14	21	25	27
	DRC ^{a,b}	1	7	5	3	4	6	2	9	8	11	10	16	17	15	12	19	14	10	12	13	19	22	17	25	24	20	14	26
Eastern sub-Saharan Africa	Ethiopia ^a	1	8	4	3	7	6	2	9	5	18	11	21	15	16	10	12	13	19	22	17	25	24	20	14	26	23	27	
	Kenya ^a	1	10	5	4	6	9	3	8	2	14	7	15	23	13	12	20	18	11	17	24	16	25	19	21	22	26	27	
	Mozambique ^a	2	7	4	1	5	6	3	8	10	14	11	19	18	16	9	13	15	20	25	17	24	23	21	12	26	22	27	
	Tanzania ^a	1	10	4	2	8	5	3	7	6	14	11	21	18	17	9	13	15	19	23	16	25	24	20	12	26	22	27	
Southern sub-Saharan Africa	Uganda ^a	3	9	6	1	8	7	2	4	5	12	11	16	15	19	21	18	20	10	13	25	24	22	23	14	17	26	27	
	South Africa ^a	2	4	3	1	10	11	6	7	5	13	8	15																

Figure 2: Cancers Ranked by Number of Deaths in Both Sexes, Globally, by Development Status, and in the 50 Most Populous Countries, 2013

Region	Country	Tracheal, bronchus, and lung cancer	Stomach cancer	Liver cancer	Colon and rectum cancer	Breast cancer	Esophageal cancer	Pancreatic cancer	Prostate cancer	Leukemia	Cervical cancer	Non-Hodgkin lymphoma	Brain and nervous system cancer	Bladder cancer	Ovarian cancer	Gallbladder and biliary tract cancer	Lip and oral cavity cancer	Kidney cancer	Larynx cancer	Multiple myeloma	Other pharynx cancer	Uterine cancer	Nasopharynx cancer	Malignant skin melanoma	Mesothelioma	Thyroid cancer	Hodgkin lymphoma	Testicular cancer
Global		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Developed		1	3	7	2	4	11	5	6	8	17	9	14	10	13	15	18	12	21	16	22	20	23	24	25	27		
Developing		1	3	2	4	6	5	9	12	8	7	11	10	14	15	16	13	18	17	22	19	21	20	24	26	23	25	27
High-income Asia Pacific	Japan	1	2	4	3	9	7	5	8	11	16	10	18	12	14	6	17	13	23	15	19	20	24	25	22	21	26	27
	South Korea	1	3	2	4	8	7	5	9	11	13	10	14	12	16	6	20	15	18	17	21	22	24	23	25	19	26	27
High-income North America	Canada	1	7	13	2	3	12	5	4	8	20	6	9	10	11	17	18	14	22	15	23	19	25	16	21	24	26	27
	United States	1	9	8	2	3	13	4	5	7	18	6	12	14	10	20	19	11	21	15	22	17	26	16	23	24	25	27
Southern Latin America	Argentina ^a	1	4	8	2	3	7	6	5	11	10	13	16	14	15	12	19	9	17	20	23	18	26	21	24	22	25	27
Western Europe	France	1	7	6	2	4	11	5	3	8	20	10	14	9	13	17	16	21	15	18	22	25	19	23	24	26	27	
	Germany	1	6	10	2	3	14	4	5	7	19	11	13	9	12	15	18	8	23	16	20	21	26	17	22	24	25	27
	Italy	1	3	6	2	4	16	5	7	9	22	10	12	8	13	14	18	11	20	15	23	21	26	17	19	24	25	27
	Spain	1	3	7	2	5	14	6	4	9	21	10	11	8	12	16	18	13	17	15	22	19	26	20	23	24	25	27
	United Kingdom	1	7	14	2	3	6	5	4	10	21	8	13	11	9	20	19	12	22	15	23	18	26	16	17	24	25	27
Central Asia	Uzbekistan ^a	2	1	5	7	4	3	10	18	6	9	11	8	16	15	17	12	14	13	24	20	19	23	21	27	26	22	25
Central Europe	Poland	1	3	12	2	4	16	5	6	11	14	15	8	7	9	13	18	10	17	21	22	19	25	20	26	23	24	27
Eastern Europe	Russia	1	3	7	2	4	13	5	6	10	12	16	11	14	9	18	15	8	17	22	21	19	25	20	26	23	24	27
	Ukraine	1	3	14	2	4	16	5	8	11	10	15	12	9	7	18	13	6	17	23	20	21	25	19	24	22	26	27
Andean Latin America	Peru ^a	2	1	6	3	7	17	8	4	9	5	10	12	16	14	11	20	13	22	18	23	15	27	19	24	21	25	26
Central Latin America	Colombia ^a	2	1	7	3	5	12	9	4	8	6	10	11	15	14	13	18	17	16	19	24	22	25	21	27	20	23	26
	Mexico ^a	1	2	3	5	6	15	8	4	9	7	10	13	17	12	14	19	11	16	18	26	22	27	23	25	20	21	24
	Venezuela ^a	1	2	7	4	5	13	8	3	9	6	10	14	17	11	16	19	12	15	18	23	20	25	21	27	22	24	26
Tropical Latin America	Brazil ^a	1	3	8	2	5	7	6	4	11	9	12	10	13	14	18	15	17	16	20	19	21	25	22	26	23	24	27
East Asia	China ^a	1	3	2	5	8	4	6	15	7	12	11	9	13	18	14	20	17	19	22	23	16	10	26	21	24	25	27
	North Korea ^a	1	3	2	4	7	5	10	20	6	9	12	8	11	16	14	19	18	17	22	24	15	13	26	25	23	21	27
Southeast Asia	Indonesia ^a	1	3	6	2	5	14	8	19	7	4	10	9	16	12	13	11	17	20	24	18	21	15	23	25	22	26	27
	Malaysia ^a	1	5	3	2	4	13	7	12	6	10	8	17	15	11	18	16	14	21	20	19	23	9	24	27	22	25	26
	Myanmar ^a	1	7	2	4	5	13	11	20	6	3	9	14	15	8	12	10	17	21	25	19	18	16	24	26	22	23	27
	Philippines ^a	1	6	2	4	3	16	8	11	5	7	10	12	19	9	15	13	17	22	23	21	20	14	24	27	18	25	26
	Thailand ^a	2	4	1	3	6	12	9	16	8	5	13	11	15	14	7	10	17	20	24	19	22	18	23	26	21	25	27
	Vietnam ^a	2	3	1	4	11	5	12	14	9	8	6	7	16	22	19	10	21	15	24	13	18	20	26	27	17	25	23
South Asia	Afghanistan ^a	2	1	5	7	3	12	13	14	4	6	10	9	8	18	17	20	16	11	24	23	21	19	26	25	22	15	27
	Bangladesh ^a	2	3	1	8	9	7	19	18	5	10	4	13	14	11	16	6	20	15	24	12	21	17	25	26	27	22	23
	India ^a	4	1	2	7	5	3	15	20	10	6	11	13	16	12	17	8	19	14	21	29	15	28	27	23	24	26	
	Nepal ^a	2	3	6	5	4	1	16	20	8	7	11	15	17	10	14	9	19	13	21	12	23	18	25	27	22	24	26
	Pakistan ^a	1	10	5	9	2	3	18	19	8	16	4	13	7	11	15	6	20	12	21	14	22	17	26	27	23	24	25
North Africa and Middle East	Algeria ^a	1	3	9	4	2	18	13	15	5	12	6	8	10	14	7	22	19	16	17	23	24	11	25	26	20	21	27
	Egypt ^a	2	7	1	8	3	11	9	10	5	14	12	4	6	17	16	18	13	15	23	21	20	27	24	19	22	26	27
	Iran ^a	3	1	9	5	8	2	12	7	4	17	14	6	10	16	13	18	15	11	20	24	26	19	22	27	21	23	25
	Iraq ^a	2	5	4	7	1	15	8	11	3	12	10	6	9	13	17	19	14	16	21	23	18	22	25	27	20	24	26
	Morocco ^a	1	3	5	4	2	15	9	6	10	7	11	8	12	14	13	19	17	16	21	23	18	20	25	26	21	22	27
	Saudi Arabia ^a	2	6	1	3	4	12	8	10	7	17	9	5	13	15	11	16	14	18	22	21	25	20	24	27	19	23	26
	Sudan ^a	1	2	6	4	3	12	11	10	5	13	9	7	8	16	15	18	17	14	22	24	23	19	25	27	20	21	26
	Turkey ^a	1	2	10	3	4	16	5	6	7	18	11	8	9	12	15	22	13	14	17	27	19	23	24	21	20	25	26
	Yemen ^a	1	2	6	5	3	13	12	11	9	10	4	10	9	7	8	16	14	18	17	23	24	20	19	25	26	21	22
Central sub-Saharan Africa	DRC ^{a,b}	6	2	5	4	3	7	11	9	10	1	8	14	12	17	13	15	16	18	21	22	20	24	23	27	25	19	26
Eastern sub-Saharan Africa	Ethiopia ^a	7	6	4	3	5	2	10	9	14	1	8	12	16	17	13	15	11	22	18	21	20	26	23	27	25	19	24
	Kenya ^a	8	4	5	6	3	1	9	11	14	2	7	15	13	10	19	12	18	16	17	22	25	20	24	27	23	21	26
	Mozambique ^a	7	3	4	1	5	9	12	6	13	2	8	11	15	18	14	16	10	21	19	20	22	26	23	25	27	17	24
	Tanzania ^a	8	6	2	3	4	5	13	9	12	1	7	10	16	17	14	15	11	22	19	20	21	25	23	26	27	18	24
	Uganda ^a	9	8	4	6	7	2	13	5	11	1	3	20	12	10	24	16	15	21	18	17	23	14	25	27	19	22	26
Southern sub-Saharan Africa	South Africa ^a	1	9	8	3	5	2	7	4	11	6	10	17	14	12	21	13	16	10</									